

Application for s75W Modification 1 to
MP 10_0046 – Preliminary Works
Project

APPENDIX

A

Seedsman Geotechnical Report, 2011



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GUJARAT NRE NO 1 COLLIERY

MANAGEMENT OF SUBSIDENCE RISKS
ASSOCIATED WITH WONGAWILLI SEAM EXTRACTION
WITH PARTICULAR FOCUS ON WONGAWILLI EAST – AREA 2

SMP AREA 2.docx

JULY 2011



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Thursday, 23 February 2012

Ref: SMP AREA 2.docx

Dr C Harvey
Mining Superintendent
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Dear Chris,

Re: Subsidence associated with Wongawilli extraction at NRE No 1 colliery

We are pleased to submit this report on the possible subsidence deformations that will be associated with the extraction of the Wongawilli Seam under existing Bulli and in some areas existing Balgownie extraction.

Please contact the undersigned if you require further information.



EXECUTIVE SUMMARY

It is proposed to extract Wongawilli Seam coal by longwall methods in the eastern and western areas of the NRE No 1 Colliery lease. The extracted thickness will be approximately 2.7m to 3.2m and typical depths are 300m and 500m respectively.

For both the Wongawilli East and Wongawilli West areas the Bulli Seam, and in some areas the Balgownie Seam, have already been extracted by either longwall or pillar extraction techniques. As a result there are a number of constraints and assumptions that are fundamental to the subsidence predictions and these will require ongoing review and assessment to support the subsidence predictions for the proposed Wongawilli seam extraction.

There are a number of features which can be considered to be of special significance – Illawarra Escarpment, Mount Ousley Road, Cataract Reservoir, and fourth order streams. In addition there are a number of environmentally and ecologically significant areas.

A hierarchy of risk management strategies have applied to the mining proposals.

Elimination – Longwall extraction is not to be conducted under or in close proximity to the identified features of special significance.

Substitution – Narrow longwall blocks (nominally 150m) with wide chain pillars are proposed for the Wongawilli East area so that the coal within the Cataract Reservoir Notification Area can be extracted. This strategy reduces prediction uncertainty in areas where both the overlying seams have been extracted. The use of narrow panels was not economic for the western area and here the longwall faces are proposed to be nominally 380m wide.

Because of the need to progressively validate model assumptions that underpin the prediction of subsidence with multiple seam extraction and the resultant subsidence impacts, engineering and administrative controls are proposed to manage the mining. These controls will need to be developed progressively as monitoring data are collected and prediction models refined. A modified type of a Subsidence Management Plan (SMP) will need to be formulated to manage this.

The report examines the proposed layouts that seek to include these risk management strategies. The mine design approach has been to reduce exposure of mining-related impacts to key surface features while recognising that the majority of the surface can be safely subsided even if the prediction uncertainties are high.

The associated first workings in the Bulli and Wongawilli Seams required to access the proposed extraction areas will not result in any surface subsidence greater than 20mm and hence associated deformations (tilts or strains) will not be measureable..



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- C. Failure Mode and Effects Analysis



GLOSSARY

Term	Definition
Goaf	The rock above an extraction panel that was intentionally left to collapse
Upsidence	Vertical subsidence movements that are less than the local trend of deformations.
Smax	The maximum vertical subsidence recorded
W	Width of an extraction pane
Pw	Width of the chain pillar between extraction panels
H	Depth of the coal seam
T	Thickness of coal extracted
Face	Extraction panel
Angle of draw	Angle from the vertical between the edge of the extraction to a selected deformation at the surface - often the locus of points with vertical subsidence less than 20mm
K1, K2, K3	Parameters that relate maximum strains or tilt to Smax and H.
w	width of pillars
h	height of pillars
Influence angle	Parameter used in the influence function method. Approximately, but not equal to, the compliment of the angle of draw.
Sag, panel sag	The deflection of the surface above an extraction panel between 2 chain pillars
Pillar compression	Deflection of the surface above a chain pillar
Tributary area loading	Way of estimating the load on pillars based on the assumption that each pillar carries is share of the full overburden.
Incremental profile method	Confidential method for predicting subsidence based on fitting curves to subsidence profiles
Influence function method	Method of creating subsidence surfaces assuming a mathematical function describes the shape



1 INTRODUCTION

1.1 MINING PROPOSAL

The mining proposal is to conduct longwall extraction in the economic working section at the base of the Wongawilli Seam in both the Wongawilli East and Wongawilli West areas. The Wongawilli East area lies astride Mount Ousley Road and is crossed by the down-stream end of Cataract Creek. The western side of Area 2 lies within the NSW Dams Safety Committee Notification Area for the Cataract Reservoir (Figure 1)¹. At the current market conditions (August 2011), it is understood Area 1 is not being considered for extraction. The topographic relief is in the order of 60m and the crest of the Illawarra Escarpment is approximately 1 km to the east of Mount Ousley Road in this area.

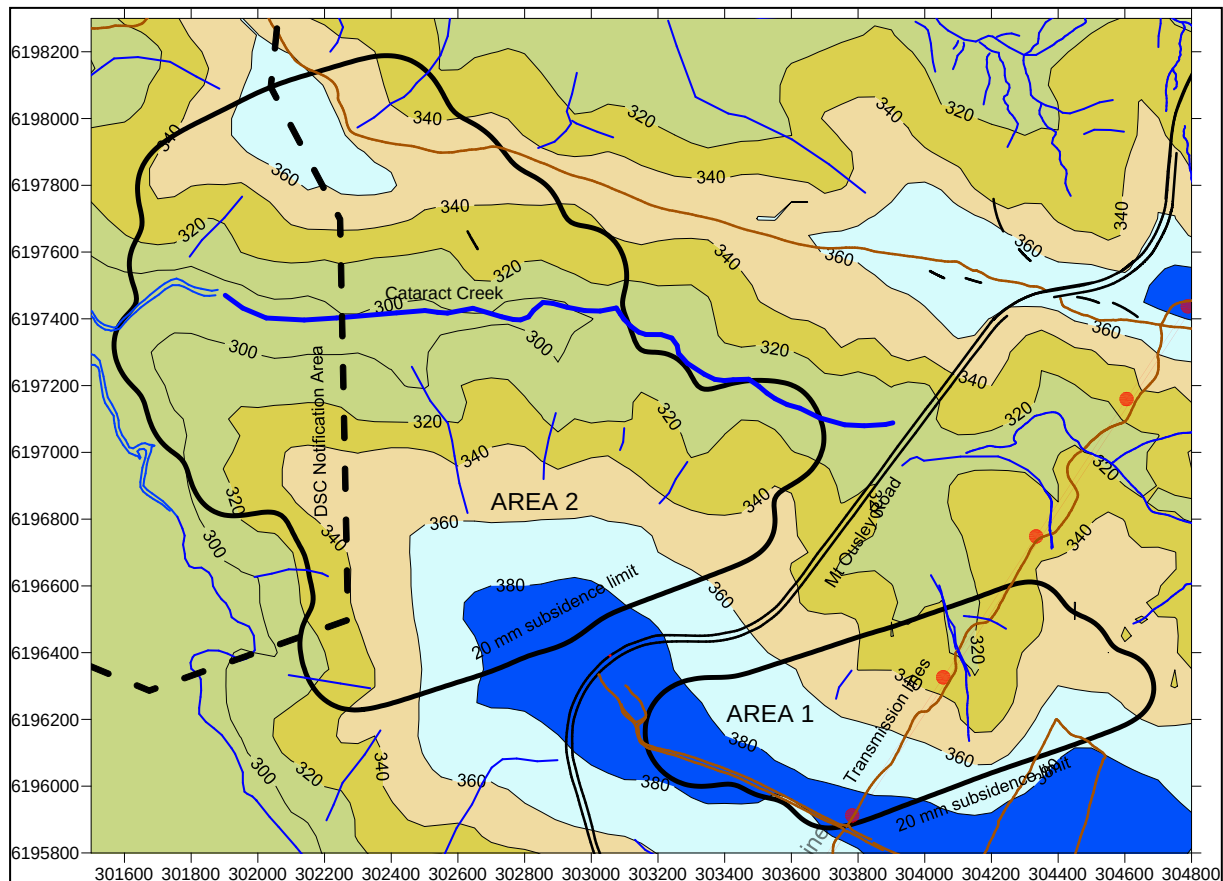


Figure 1 Topography and potential footprint for longwall extraction in the Wongawilli East area

The Wongawilli West area lies to the west of Cataract Reservoir and partially within the same Notification Area for Cataract Reservoir (Figure 2). The area is crossed by fire trials and drained by two 3rd order streams. Topographic relief is in the order of 40-50m.

¹ Figure 1 and other figures in this report includes reference to potential footprints for longwall panels (20mm of vertical subsidence) that have been developed based on the assessments in this report.

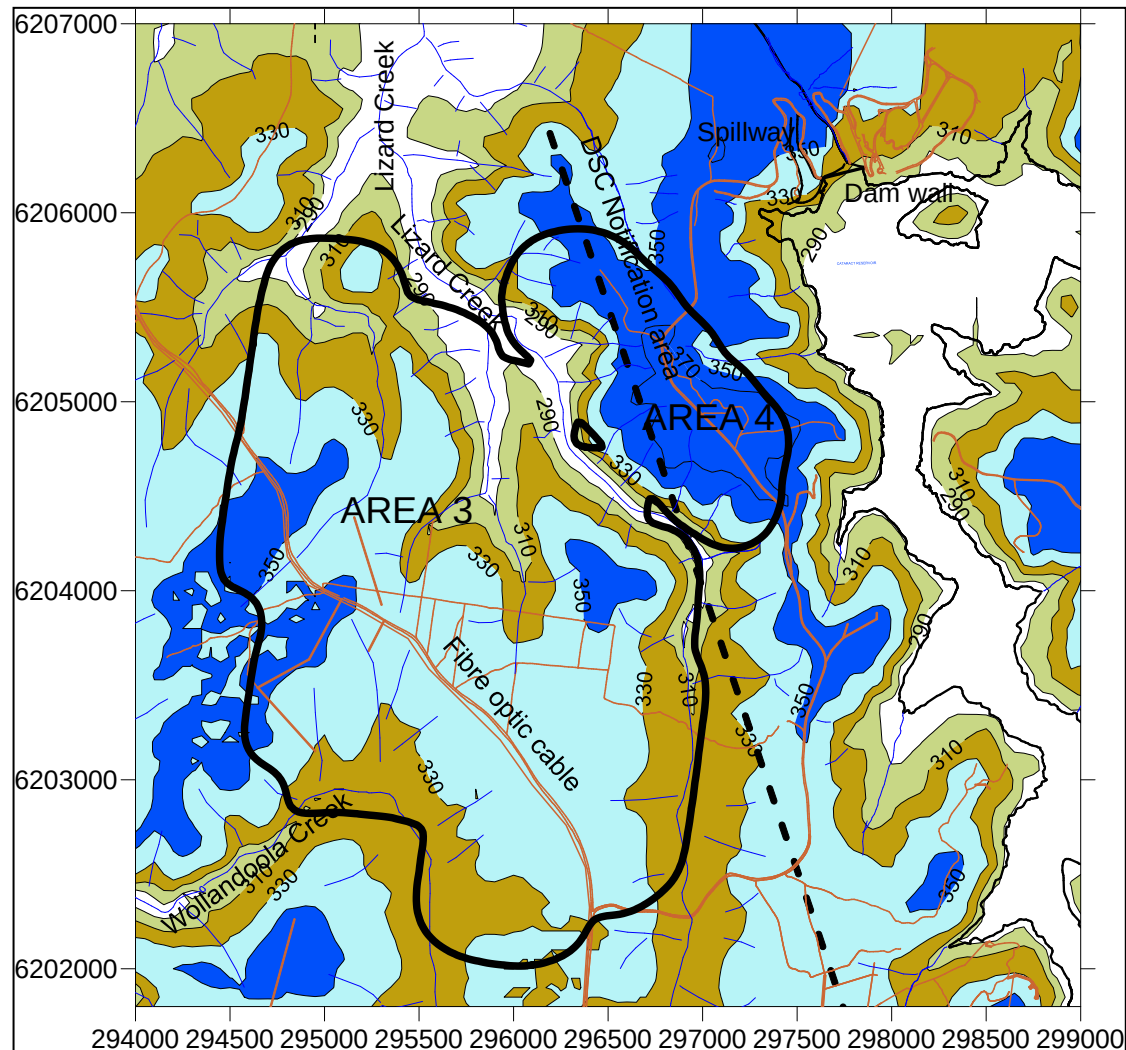


Figure 2 Topography and potential footprint for longwall extraction in the Wongawilli West area

In both areas identified for longwall extraction, there are overlying workings in the Bulli Seam and there are additional Balgownie Seam workings in the Wongawilli East area. The Bulli workings date from early last century, and the Balgownie workings, which were longwalls, date from the late 1970s.

Both areas have a number of surface constraints and these have required special consideration. The focus of mine planning has been to eliminate the subsidence impacts (both actual and perceived) as much as possible, consistent with business requirements. Several specific mining options have been considered for subsidence assessment over the last 12 months and options that were rejected are outlined in Appendix A.

This report outlines how the major subsidence risks have been eliminated by the mine layout and in the case of Wongawilli West and alternative mining system substituted in the plan. The report then examines the engineering and administrative controls that are required to manage the remaining risks.

The use of key subsidence assumptions will need to be tested by ongoing review and validation in order to overcome potential prediction uncertainties associated with multiple seam extraction such that coal extraction can be optimised. It is anticipated that the progressive extraction of longwall panels



will provide key information which will be used to determine how the mine planning should be optimised to economically extract coal to the required constraints.

1.2 OPERATIONAL LAYOUT CONSTRAINTS

Not only subsidence prediction but also underground operations in multiple seam layouts are subject to various design constraints that are additional to those normally encountered for single seams. Many of these extra constraints are related to the lack of multiple seam mining experience in Australia and hence available data to confirm prediction models and parameters. Multiple seams layouts are currently being proposed for several Hunter Valley operations but these are modern layouts where the seams are planned together: these layouts are parallel and staggered (Table 1).

Table 1 Multiple seam longwall definitions

	Definition	Aspects
Parallel	Gate roads in different seams are parallel	Ideal feature as no need to manage different stress fields under or above pillars
Non-parallel	Gate roads in different seams are not parallel	Often a legacy from much earlier mining, or if earlier mining was no longwall. Stress footprint means more emphasis needed on alignment of subsequent longwalls with respect to the cleat and joint fields.
Parallel Staggered	Gateroads are located under the goaf of the overlying seams	Ideally, subsequent gateroads subtend more than 45° to earlier pillars.
Parallel Superimposed (= stacked)	Gateroads are located under the gateroads of the overlying seam	Gateroad driveage conditions will be very difficult.

For all the proposed NRE No 1 areas, the extraction of seams will be in a descending order. For Wongawilli East, the layout is non-parallel because the Bulli Seam was based on pillar extraction and hence has no dominant orientation, and the Balgownie orientation is assessed to be inappropriate for the Wongawilli Seam as it would place the longwall face parallel to the regional joint and cleat structure and result in unsafe mining conditions.

For Wongawilli West, the opportunity has been taken to adopt a parallel staggered layout which is assessed to have the lowest mining risk. It should be noted that the decisions on the orientation and layout have primarily been developed to support safe mining operations. The need to manage subsidence impacts then followed.

1.3 SEEDSMAN GEOTECHNICS PTY LTD

Seedsman Geotechnics Pty Ltd (SGPL) was established in 1998 by Dr Ross Seedsman who is a mine geotechnical engineer with over 30 years experience. Since 1998 Dr Seedsman has consulted to the various operators of the current Gujarat NRE lease and was the key advisor to the widening of the longwall panels under Cataract Reservoir. Whilst the details of some of this work have been published, it is not referenced in any of the recent subsidence inquiries and PACs. Dr Seedsman has been at the forefront of the development of a more analytical approach to subsidence and the use of influence functions to visualise the subsidence bowls – all of which has been published in local and international conferences but once again not referenced in any of the recent inquiries or PACs. A CV and listing of subsidence publications are attached as an appendix.



2 SITE CONSTRAINTS

It is understood that others have prepared detailed reports on the topography, geomorphology, aboriginal and European heritage, and a variety of ecological issues. Based on discussions with you and your consultants, it is understood that there are a number of surface features that can be considered to have “Special Significance Status” and hence require separate consideration. There are other features for which the subsidence impacts can be managed during operations in an SMP context.

2.1 SITES OF SPECIAL SIGNIFICANCE

A - Mount Ousley Road is the major access to Wollongong. It is understood that this road was realigned sometime after the Balgownie extraction as it lies directly above a Balgownie Seam chain pillar and over Bulli Seam extracted areas. Discussions with the Road and Traffic Authority and a review of literature indicate that the limiting subsidence deformation for road pavements is strain (such that the pavement does not crack).

B – Cataract Dam wall and spillway The NSW Dam Safety Committee (DSC) recognises that far-field horizontal movements were induced by previous mining at South Bulli Colliery within about 620m of the spillway. They have set a 1km line within their Notification Area whereby they pay greater attention to mining. Given the state of the art in terms of far-field movements and the ability to validate any predictive model, it has been decided that their 1km line should form a boundary to longwall extraction.

C - Stored water and Notification Area of Cataract Reservoir Previous operators on the mining lease (Austen and Butta, Allied Mining) successfully extracted narrow longwalls in the Bulli Seam below the stored water adjacent to the Wongawilli West area. Economic longwall extraction in the Wongawilli Seam in this area would require undermining the Bulli Seam chain pillars which would then be associated with an unacceptable risk to the stored water both from a mining safety and a water supply perspective. No additional longwalling below the Cataract Reservoir in the Western Area is proposed. In the Wongawilli East area there has been no longwall extraction of the upper seams inside the Notification Area. Wongawilli coal in the eastern area is considered a mining target with a layout that produces vertical subsidence similar to or less than those from the western area.

D – Illawarra Escarpment The elevation at the lip of the escarpment is approximately 320m AHD. The land slopes steeply from the top of the escarpment to the Russell Vale Site offices, which are at approximately 140m AHD. From here the terrain slopes relatively gently to the east. Vertical faces of Bulgo Sandstone are exposed in the upper portions of the escarpment.

E – Fourth order streams The lower reaches of Cataract Creek and Lizard Creek are indicated to be 4th order streams.

2.2 SIGNIFICANT NATURAL FEATURES

The majority of the ground surface area above the proposed mining areas is on a westerly dipping plateau to the west of the escarpment. There are no significant cliff lines above the proposed mining areas.



F – Third order streams All three named creeks (Cataract, Lizard, Wollandoola) have already been undermined. Inspections of the 3 creeks have identified mining impacts (cracking of bars, localised loss of surface water flows) in only Lizard Creek. There are no flows of water into mine that can be related to drainage of any of these creeks. Recognising the current community sensitivities to mining near creeks, NRE have made the decision not to extract wide longwalls under named 3rd order streams – the use of narrow longwalls will be discussed later in this report. The selection of a stand-off distance is discussed later in this report.

G – Upland swamps Contiguous networks of intact upland swamps, including the Wollandoola Creek swamp cluster are present in both the Wongawilli East and Wongawilli West areas (Figure 3). The swamps have been noted by others to be in good condition in the upper regions of Wollandoola Creek and Lizard Creek, and were observed to provide habitat for a number of threatened species listed under the TSC Act. In some parts of the study area sections of swamps were observed to be very dry, with evidence of scouring and erosion in some areas as a result of decreased water availability for reasons that were not determined.

H - Transitional Shale Forests. Open Blue Gum and Stringy Bark forests are present above Area 3 in Wongawilli West area (Figure 4). In the study area the understorey composition indicates a history of disturbance including fire.

2.3 OTHER FEATURES

I Heritage sites

There are a large number of aboriginal heritage sites in the overall lease area, and some of them are within the expected subsidence footprint.

J Telstra cable

There is a fibre optic cable located alongside one of the fire trails in Area 3 above the Wongawilli West area. The proposed mining in V Mains (subject of an earlier SMP submission) will occur under this fibre optic cable as well.

K Transmission lines

TransGrid owns/maintains the 330kV & 132kV power lines, and Integral owns/maintains the 33kV power line, both of which run in a NE/SW direction above Area 1 Wonga East.

2.4 PROPOSED RISK MANAGEMENT

The entire surface could be considered as a risk management zone of one type or another; partly because of the sites of special significance and other features, and partly because of the additional uncertainties of multiple seam subsidence which will be discussed later.

The hierarchy of risk management controls involves elimination, substitution, engineering, and administration. Whilst these have been developed in an occupational health and safety context, they can be applied equally to environmental risks in longwall mining.

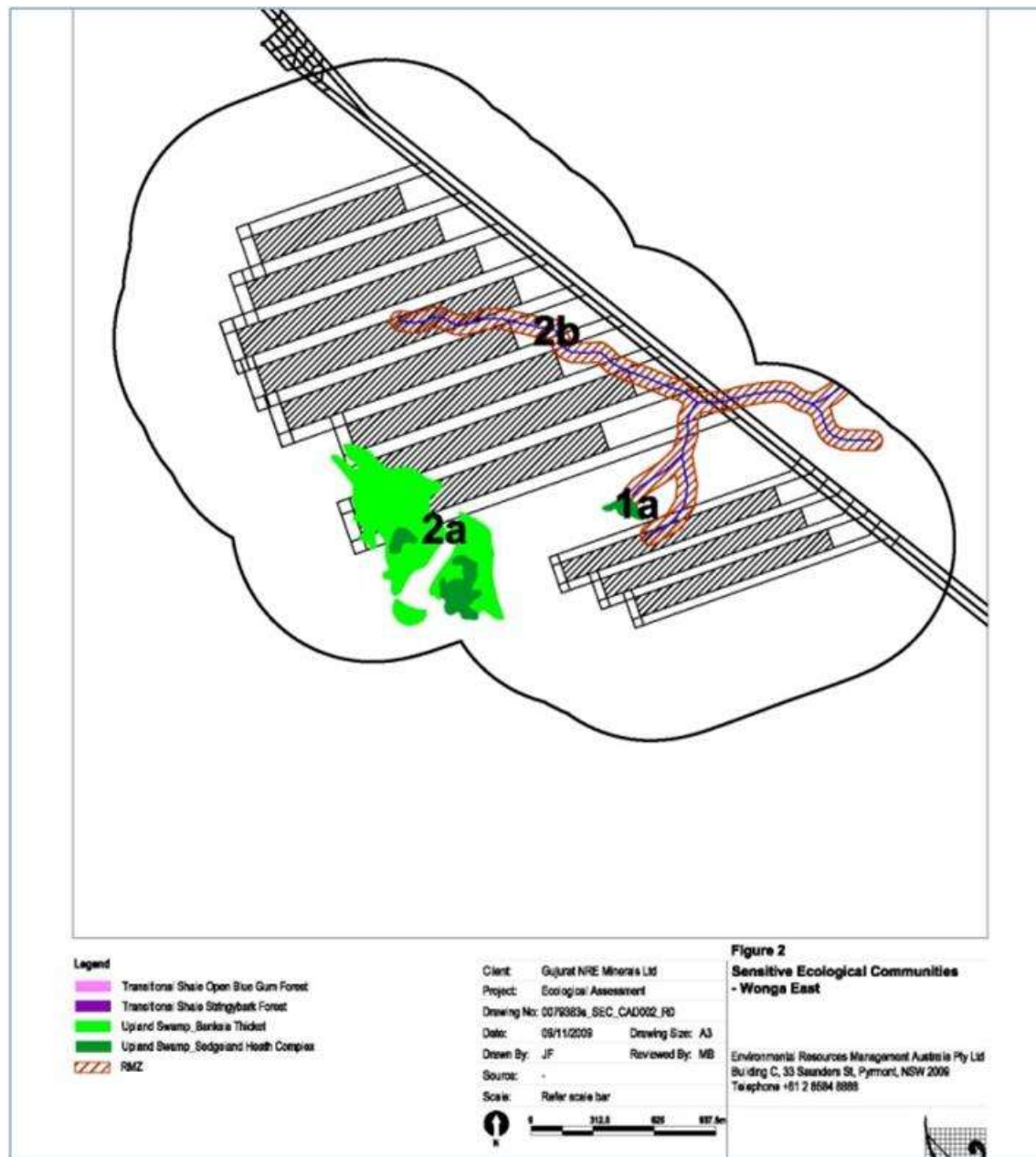


Figure 3 Ecological significant features identified by ERM in Wongawilli East area

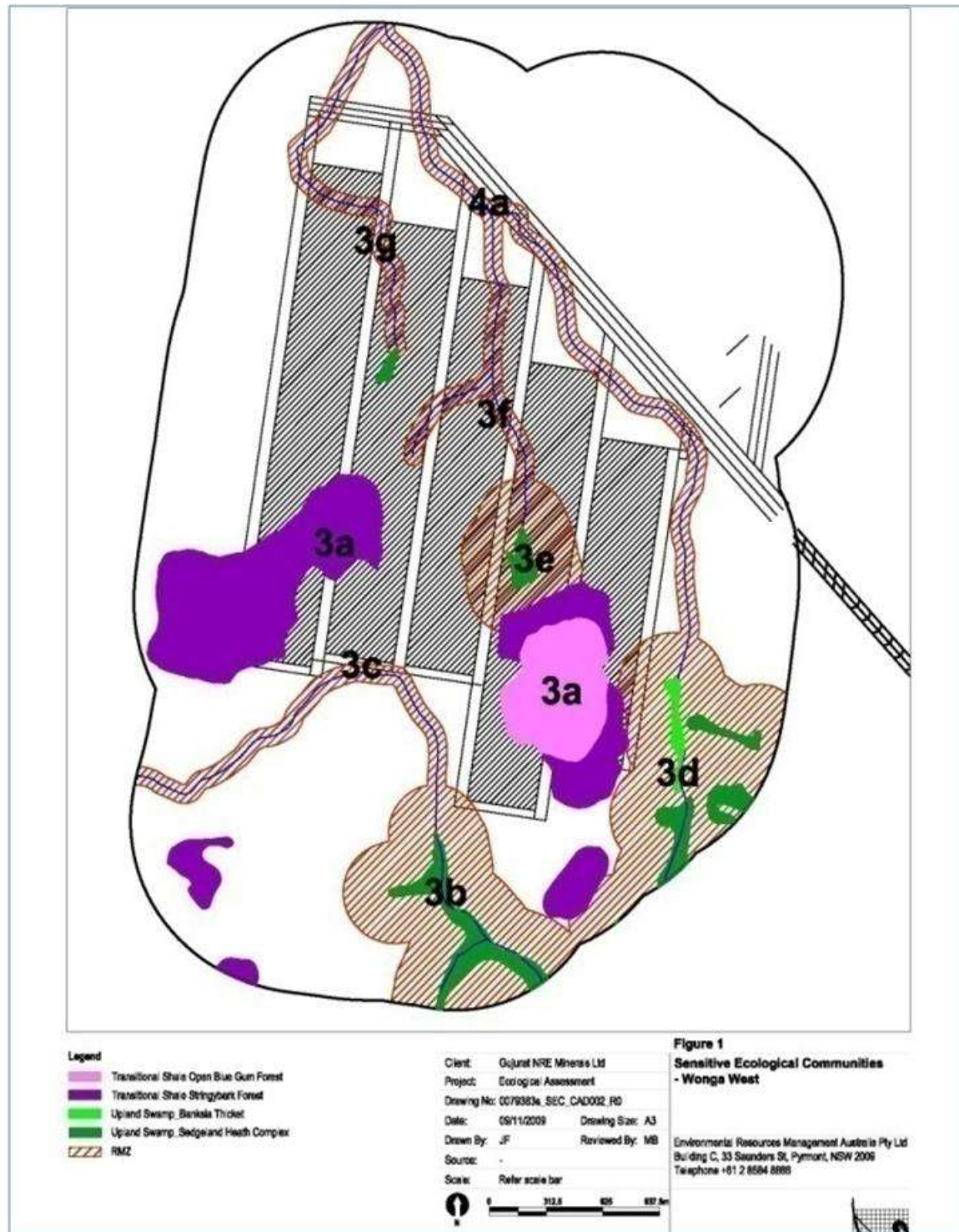


Figure 4 Ecological significant features identified by ERM in Wongawilli West area.

For Mount Ousley Road, Cataract Dam Wall, fourth order streams, and the Illawarra Escarpment, the adopted control should be elimination. No longwall extraction should be conducted under or near these features. By adopting elimination, the risks associated with prediction uncertainty are removed by the fact that the deformations, if any, will be negligible.



In the longwall mining context, substitution can be viewed in terms of narrower longwall faces than the current standards of 250m to 400m, combined with wider chain pillars. The economics of longwall mining leads to as wide a face as possible. The use of narrow longwalls is not economic in the Wongawilli West area because their width would need to be as little as 40m-50m to prevent the mobilisation of the Bulli Seam. In the Wongawilli East area, 150m wide longwall panels and wide pillars could allow access to coal in the Notification Area and under Cataract Creek. Compared to elimination, there are some prediction uncertainties but these are small given the demonstrated outcomes with the narrow longwall panels already present under Cataract Reservoir.

For the other features, engineering and administrative controls can be used to modify panel widths and stand-off distances once better site specific data is available on which to make decisions.

Elsewhere, the risk management approach would be based on the acceptance that any consequences of subsidence will be acceptable in terms of no identified hazard or a hazard that applies to only a small proportion of the total population.

Clearly, the validity of this risk management strategy depends in part on the robustness of the predictions of subsidence deformations. To better understand the potential limitations of this approach, a risk workshop was convened with other subsidence engineers – Mr Arthur Waddington of MSEC and Dr Ken Mills of SCT (Appendix C). These experts developed a ranking system based on the likelihood the subsidence predictions would be found to be too low, and whether the consequences of such an under-prediction would be material to the implementation of the engineering and administrative controls. The nature of the task meant that quantification of the prediction risk was not possible. The highest rankings, which were low-to-medium, related to the severity of any outcomes:

- Illawarra Escarpment – there was a request to update and “endorse” plans of the Bulli Seam workings. A registered colliery surveyor has since provided the new plans used in this report.
- Mount Ousley Road – discussion with the RTA are well advanced and they and their subsidence/geotechnical consultants are satisfied with the management plan that is being developed. The expert panel dismissed pillar run as a hazard.
- Cataract Dam wall and spillway – the panel noted it was the role of the DSC to determine this
- Stored water and the DSC Notification Area – the panel requested specific analysis of the chain pillars to be used in the substitution strategy in Wonga East.
- Fourth order streams – the panel suggested that estimates of closure and upsidence given by the MSEC plots should be doubled.
- Shallow ground water systems – no definite conclusion was made regarding the assessment there will be no loss of surface water to the mine. This issue is addressed more fully later in this report.

3 GEOTECHNICAL AND HYDROGEOLOGICAL CONDITIONS

3.1 SEAM GEOMETRY

Extraction thickness in the Wongawilli Seam will range between 2.7m and 3.2m depending on the specific coal quality and market process at the time of extraction. Depth to the floor of the Wongawilli Seam is shown in Figures 5 and 6. In the Wongawilli East area the depth ranges from 280 m in Cataract Creek to 340m to the south. In the Wongawilli West area, the depths to the Wongawilli Seam are much greater – 440m to 500m.



The overburden sequence is typical of the Southern Coalfield and includes the Bulgo and Hawkesbury Sandstones (Figure 7). In the Wongawilli East area, the Hawkesbury Sandstone is about 40m thick, and in the Wongawilli West area this unit will be thicker – say in the order of 160m. The Bulgo Sandstone is about 140m thick. The Wongawilli Seam lies approximately 45m below the Bulli Seam and 38m below the Balgownie Seam (Figure 8).

Whilst the Wongawilli Seam is often referred to as being in the order of 10m thick, in NRE No 1 Colliery the upper portion of the seam is mostly stone (Figure 8). In detail, the Wongawilli Seam is better considered to be in the order of 3m thick with some coal horizons in the immediate roof. The Wongawilli Sandstone Band is well developed in both areas – it is noted that this is a local term only as the band is in fact a tuffaceous unit.

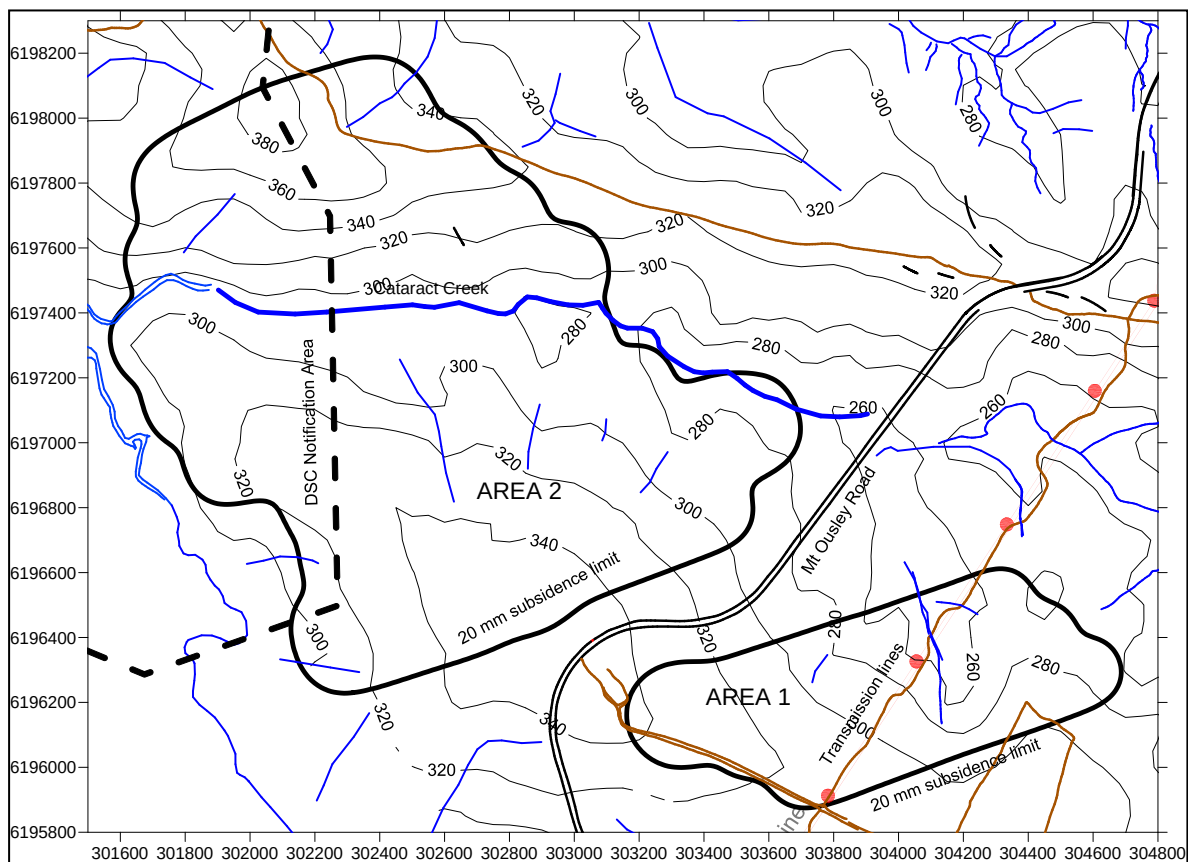


Figure 5 Depth to Wongawilli Seam and indicative subsidence footprint – Wongawilli East

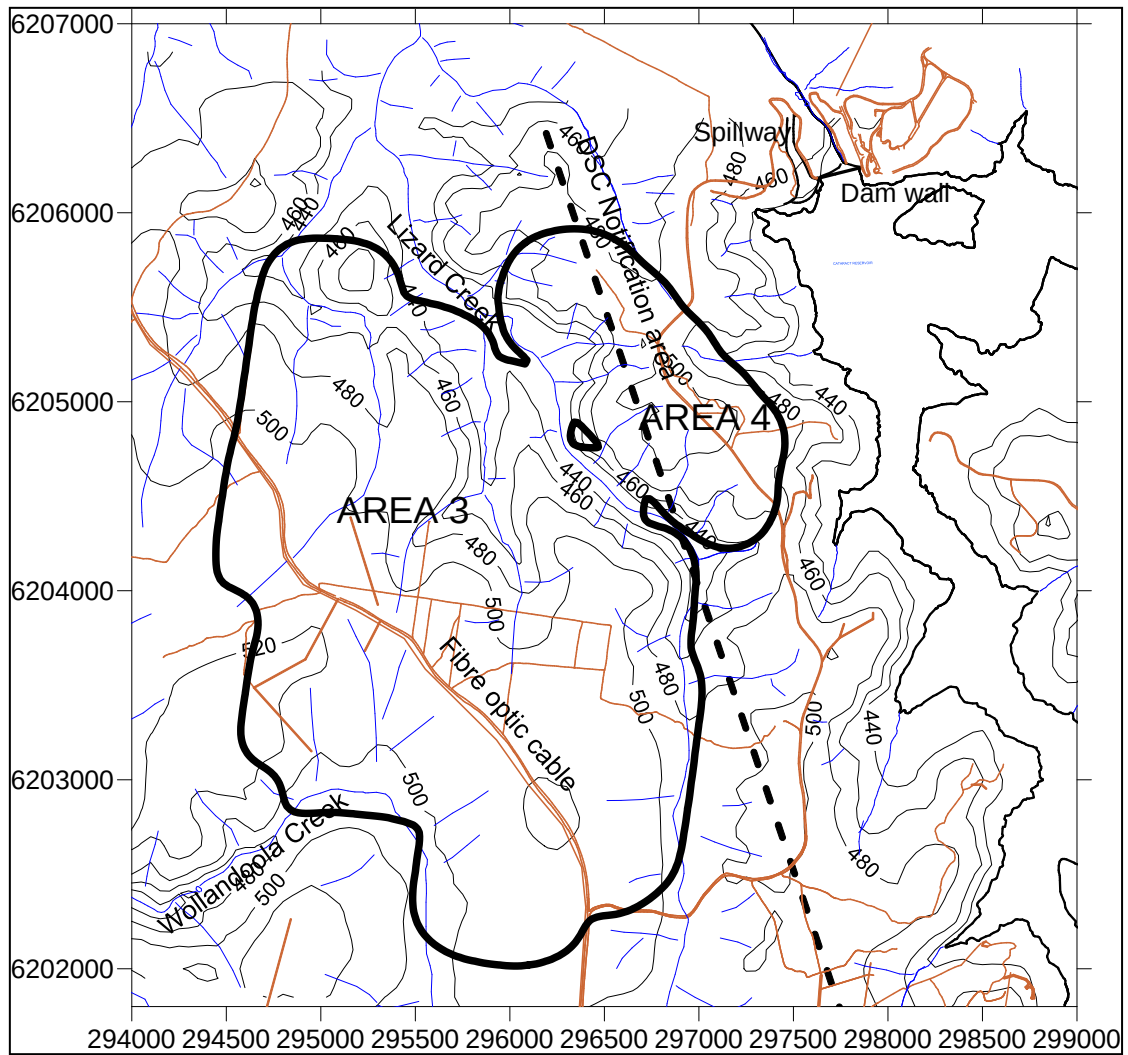


Figure 6 Depth to Wongawilli Seam and indicative subsidence footprint – Wongawilli West

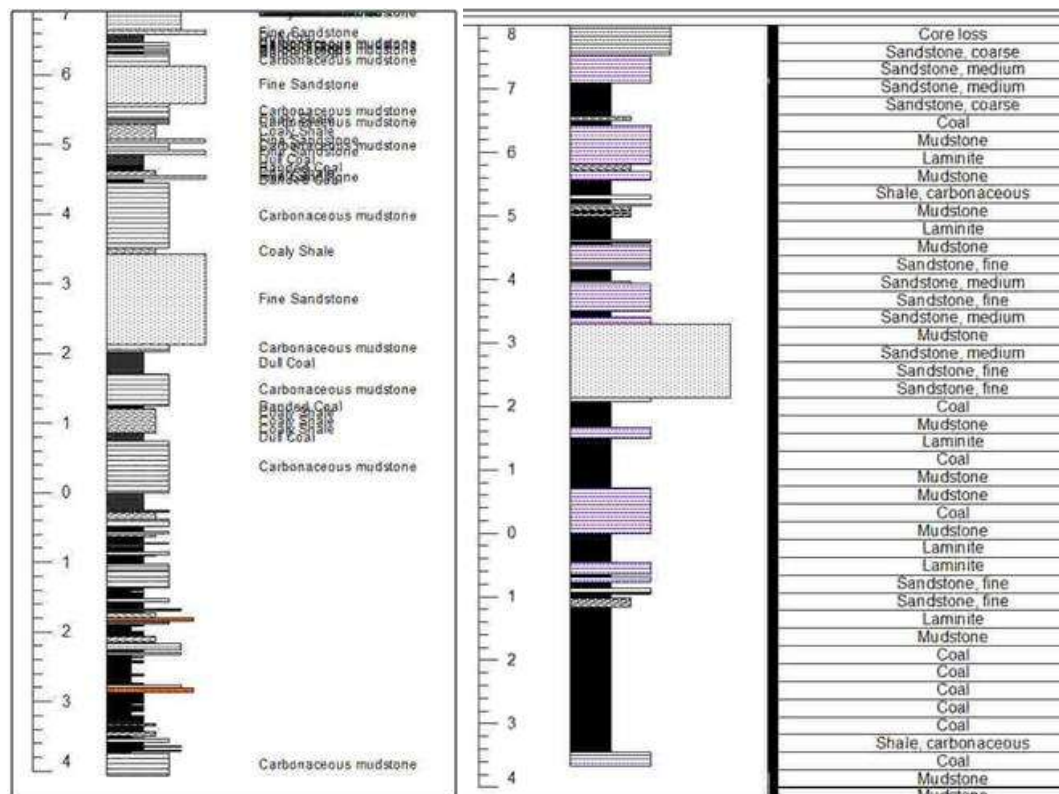


Figure 8 Detail of the Wongawilli Seam – West and East areas

3.2 PREVIOUS MINING

3.2.1 Wongawilli East extraction

Details of the Bulli and Balgownie Seam extraction are shown generally in Figures 9 and 10. The Bulli Seam mining was conducted in the early parts of the last century, at least 70-80 years ago. The layouts are chaotic compared to modern practice but it is possible to interpret some general trends. Roadways were probably driven at 16 ft width (5m) with pillars about 25m wide. In some cases the plan shows that the pillars were then split diagonally. There are a number of wider areas (between 190m and 490m in width) that are shown as extraction goaf. Because of the safety concerns with accessing old workings, the accuracy of the mine plans cannot be verified. We are not aware of any remote sensing technology that could be used over the full areas. It is noted that Dr Seedsman was involved with the mining of the Balgownie seam in the immediately adjacent area and the ground conditions encountered well matched the recorded mine workings in the overlying Bulli Seam.

The Balgownie longwalls were extracted in the 1970s and 1980s. There is a very high confidence in the accuracy of these plans as the gate road locations are still accessible. There is some published information on this mining and there are still records available at the mine. The Balgownie Seam in this area was about 1.35m thick; the mining height may have been slightly greater. Panel widths ranged from 144m to 186m and the pillar widths were initially 25m increasing to 40m. The depth of cover was about 280m - 290m. Close inspection of Figure 10 shows where the face was relocated around a northwest trending structure - a hard dyke.

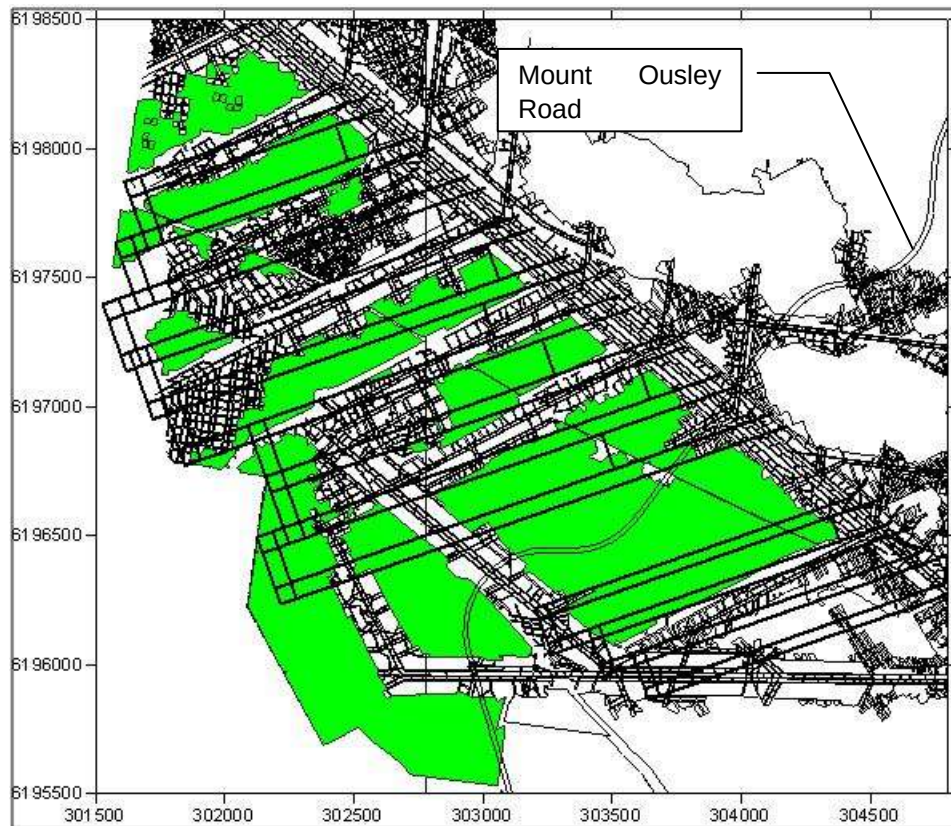


Figure 9 Bulli Seam workings in Wongawilli East area (green areas show pillar extraction, heavy black lines are proposed Wongawilli longwalls)

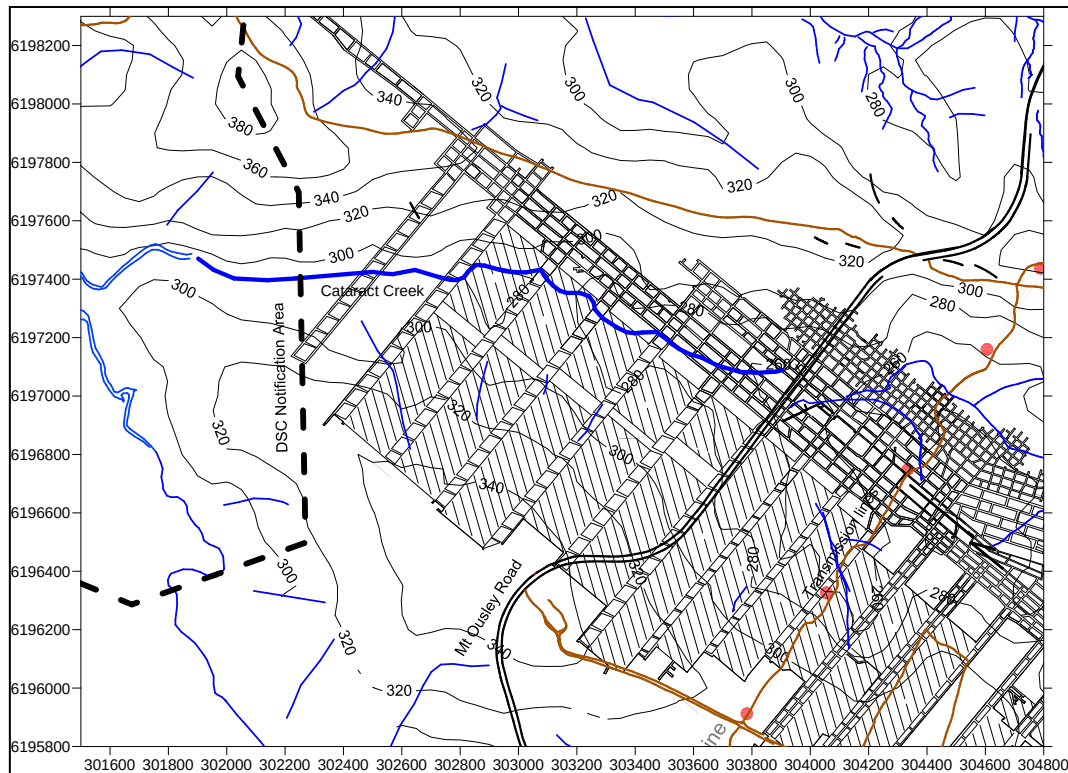


Figure 10 Balgownie Seam workings in Wongawilli East area



There has been some Balgownie Seam longwall extraction and Bulli Seam pillar extraction under Cataract Creek (Figure 11). In this area Cataract Creek is a 4th order stream. Whilst the mining was conducted a long time ago, there are no records of adverse or benign impacts on the creek.

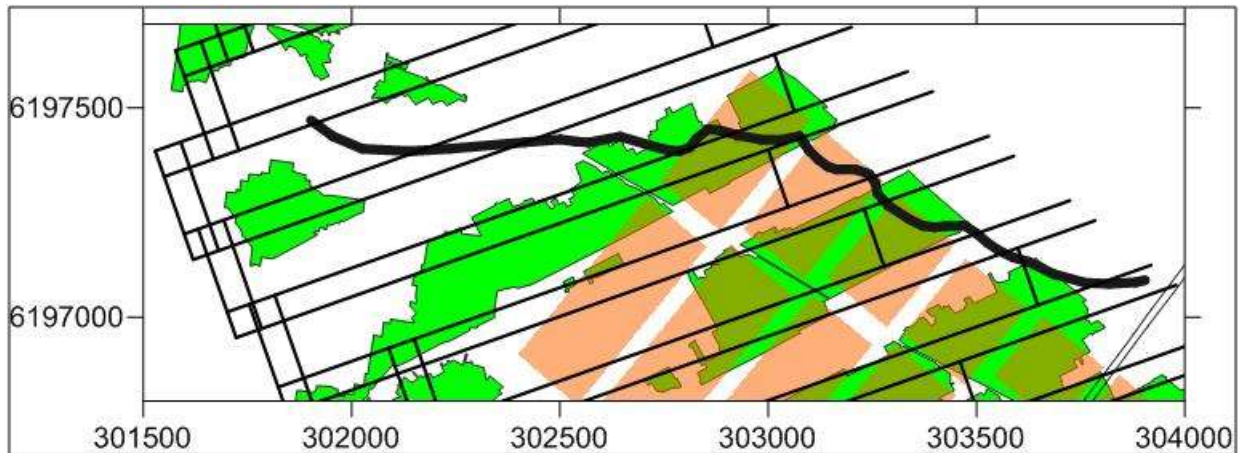


Figure 11 Details of previous extraction panels under Cataract Creek (green – Bulli seam goafs, Orange – Balgownie Seam goafs, black outline – Wongawilli proposal)

3.2.2 Wongawilli West extraction

The Bulli Seam has been extracted by longwall methods in the Wongawilli West area (Figure 12). The north/south aligned panels (200 and 300 series) are of interest in this report. These panels were extracted in the 1980 and 1990s and there is a large amount of information available. This portion of the mine is still largely accessible.

The panel widths were 142m initially and then increased to 188m. Pillar widths were initially 19m increasing to 35m, with some experiments with wider ones at 51m. The depth of cover ranged between 400m and 450m and the seam thickness was typically 2.5m

It is noteworthy that longwall extraction was conducted under the third order portions of Lizard Creek, Wollandoola Creek and other unnamed creeks with no apparent adverse impacts observed and reported at the time. Recent inspections have revealed that there is some cracking of rock layers in Lizard Creek and localised diversion of water to underflow beneath the creek bed; water quality leaving the lease area is still high (Geoterra – personal communication).

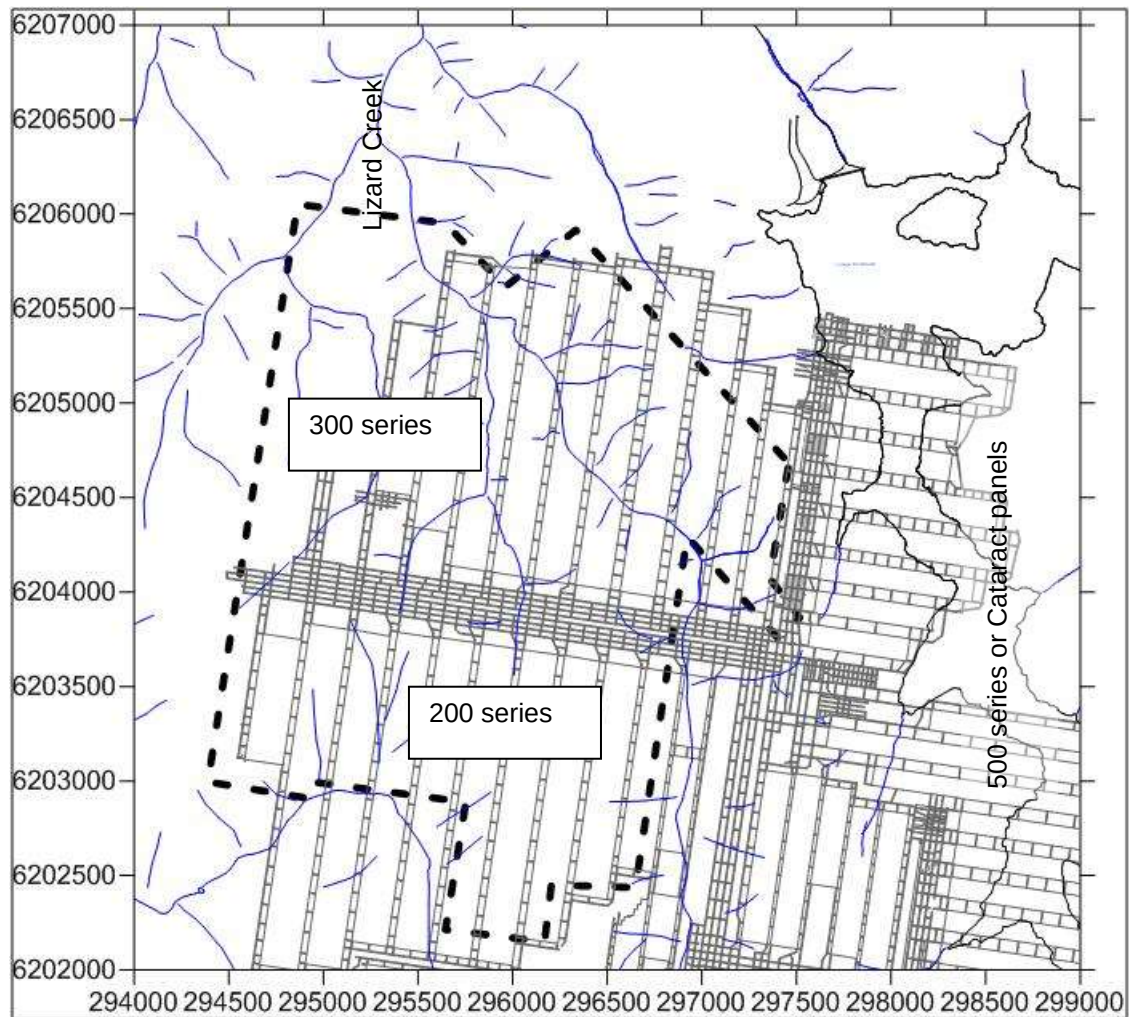


Figure 12 Bulli seam workings – Wongawilli West area

3.3 HYDROGEOLOGY

General aspects of the groundwater regime include:

- Unconsolidated material in the regional drainage recharged by rainfall
- Localised perched aquifers in the Hawkesbury Sandstone recharged by rainfall
- Regional fractured rock aquifer in the Hawkesbury Sandstone with a base level controlled by the streams and stored water.

Rainfall runoff is rapid where outcrop occurs or where the regolith is thin. The Hawkesbury Sandstone areas are unlikely to accommodate substantive groundwater recharge or to contribute significantly to stream base flow unless substantial secondary permeability and porosity is developed in fractures (Geoterra – personal communication).

The deeper sandstones and the coal seams are also aquifers that are regarded as of no significance to the surface ecosystems.



Detailed monitoring of the longwalls under Cataract Reservoir under the auspices of the DSC has shown that there is no induced water inflow to the mine. Piezometers installed in the Bulgo Sandstone showed a rapid temporary loss of head and then a recovery over about 3-5 years consistent with stress-driven changes in storativity in the Bulgo Sandstone. This behaviour suggests no fracture connection to the underground workings, and this is supported by microseismic studies connected at this site² and also at the adjacent Appin Colliery.

4 SUBSIDENCE HISTORY

4.1 PREVIOUS WONGAWILLI EAST SUBSIDENCE

There was subsidence monitoring of the Balgownie Seam extraction with centrelines down each panel and a number of cross lines. Through the use of 3 cross lines, full coverage across the panels was achieved (Figure 13). The general subsidence pattern was for about 0.55m of subsidence above the chain pillars and additional sag between the pillars of 0.2m to 0.8m. A maximum subsidence of 1.4m was measured. A maximum of 3mm/m strain was measured above large Bulli pillars and a maximum of about 6mm/m above Bulli extracted areas. Tilts ranged up to 20mm/m.

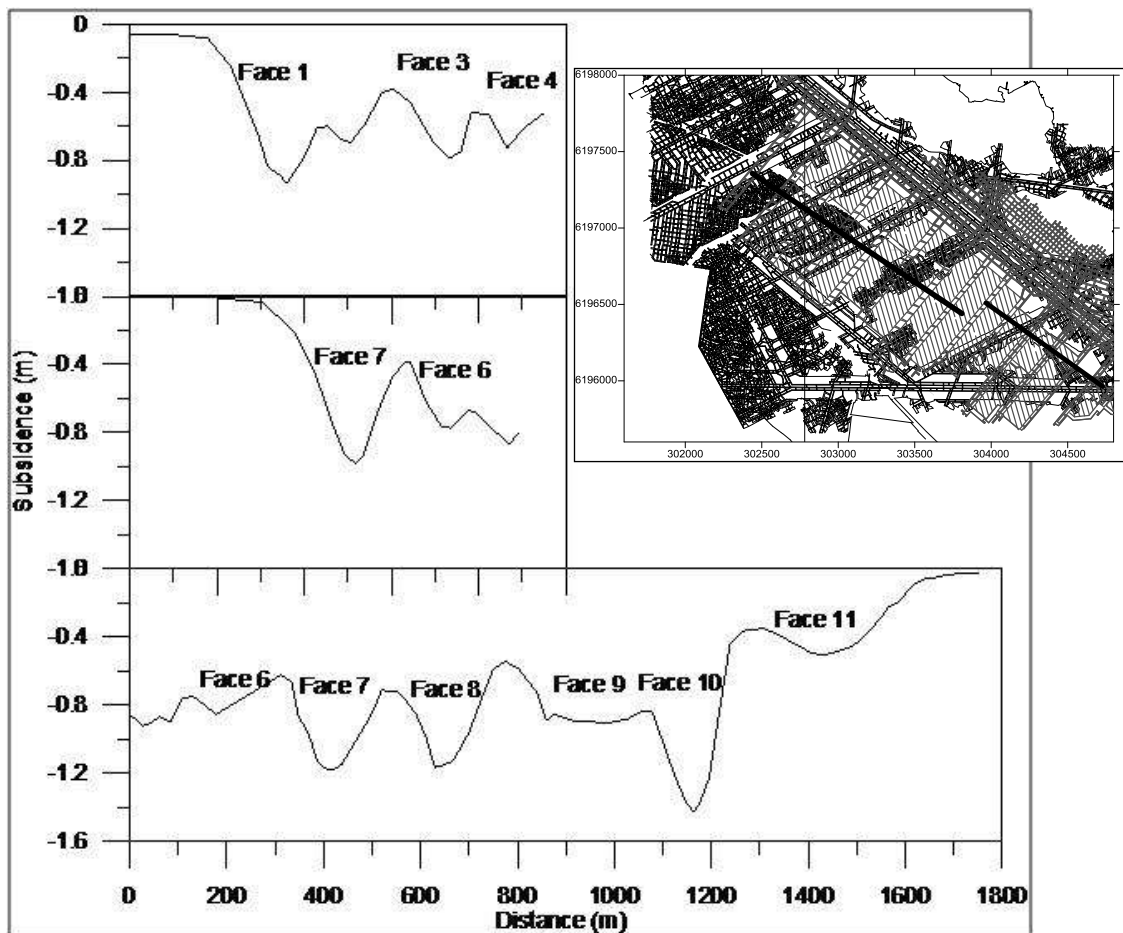


Figure 13 Balgownie longwall cross line subsidence data

² Seedsman R.W. and Kerr G 2001 Coal extraction beneath cataract reservoir: Mining at Bellambi West from 1998 to 2001. 5th Triennial Conference Proceedings. Mine Subsidence Technological Society. /



Figures 14 and 15 present the subsidence results during Balgownie Seam extraction along the length of Faces 6 and 7. It is noted that the age of these drawings is such that they were drawn in feet and inches (1 foot = 304.8mm).

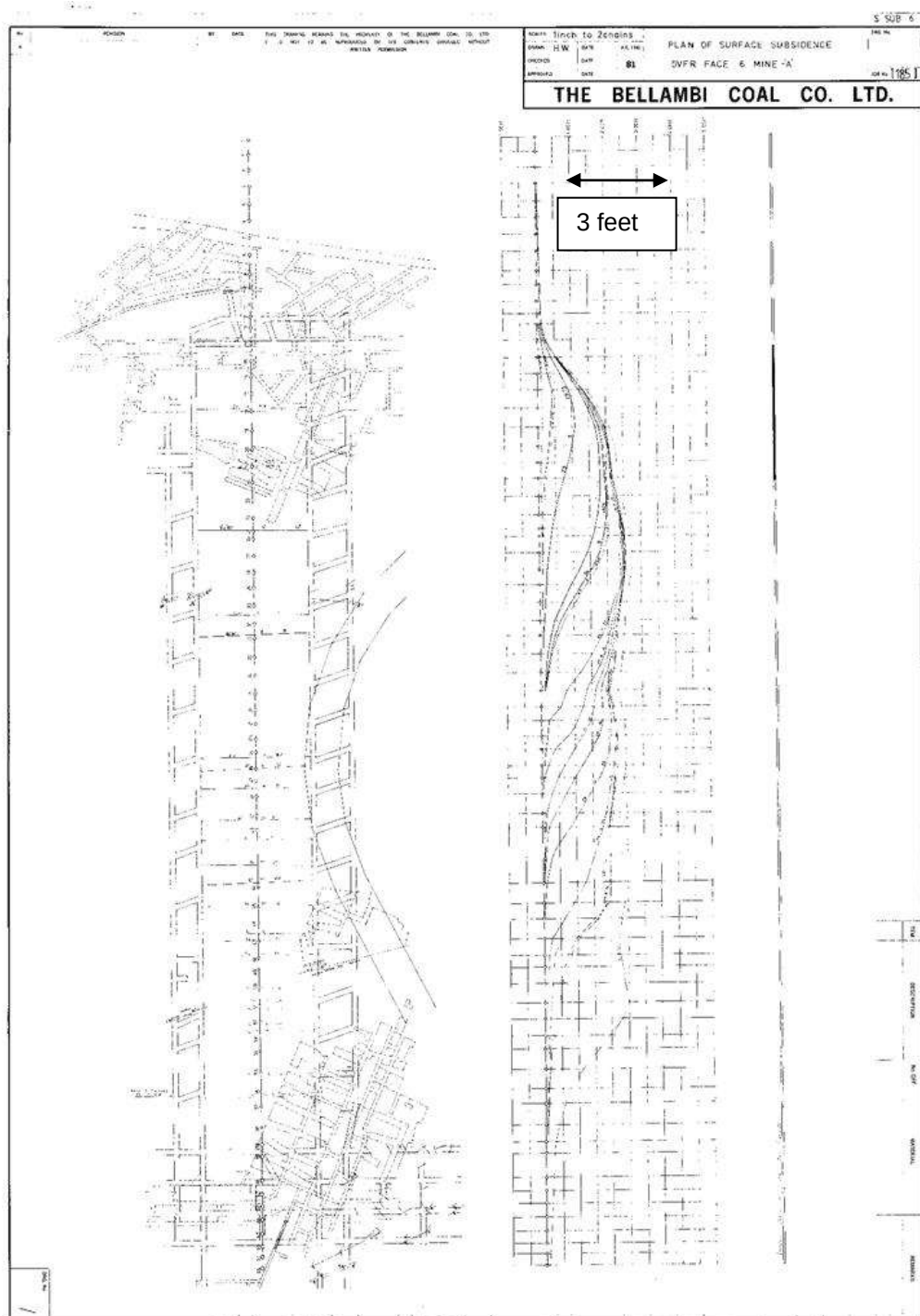


Figure 14 Subsidence along the centreline of Face 6.

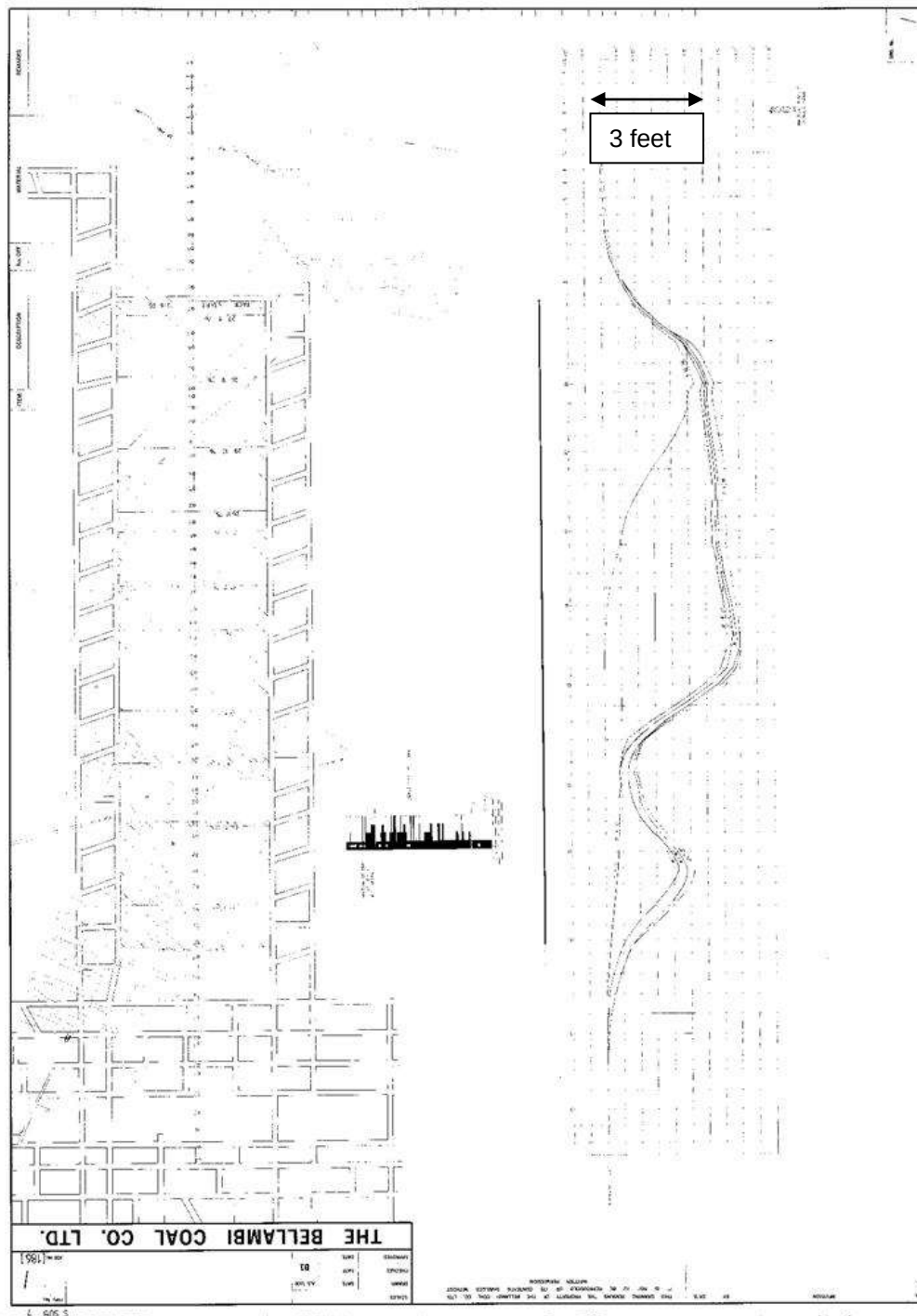


Figure 15 Subsidence along the centreline of Face 7

4.1.1 Vertical movements

When both the centreline and cross line data are examined in detail, there is a distinct difference in the behaviour of the overburden where the Bulli Seam is shown to have been extracted compared to where there are large pillars and barriers in the Bulli Seam. The maximum vertical subsidence that develops in the former case varies between 0.8m and 1.3m (average 1.1m) and in the latter case



0.6m to 0.8m, averaging 0.76m. The vertical subsidence above the pillars averages about 0.55m with little difference with different pillar widths (Figure 16a).

For the case of the broad areas of Bulli first workings, the sag above the Balgownie longwalls between Balgownie Seam pillars is about 0.2m (Figure 16b). This compares well with a fractured rock beam calculation (Figure 17) whereby voids of 150m to 190m widths would induce centreline deflections within the Bulgo Sandstone of about 100mm - 200mm.

Interestingly, the Bulli extraction areas had widths of up to 490m and Figure 17 suggests that these should have caused the collapse of the overburden as failure is indicated at 320m span. The vertical subsidence in these areas is greater and reflects about 80% of the extracted Balgownie thickness. This apparent lack of bulking is considered reasonable once it is recognised that there is only the thin interseam of about 6m - 8m to the Bulli that is available for bulking

Above Face 10, the area where subsidence was the greatest, and approaches if not exceeds the Balgownie extraction thickness, the mine plan shows very small pillars and possibly extracted pillars in a panel that is 188m wide – it is possible that this is the only area where there was delayed caving of the Bulli Seam.

Figure 18 provides a simple cartoon that seeks to provide an explanation for the 3 different subsidence outcomes.

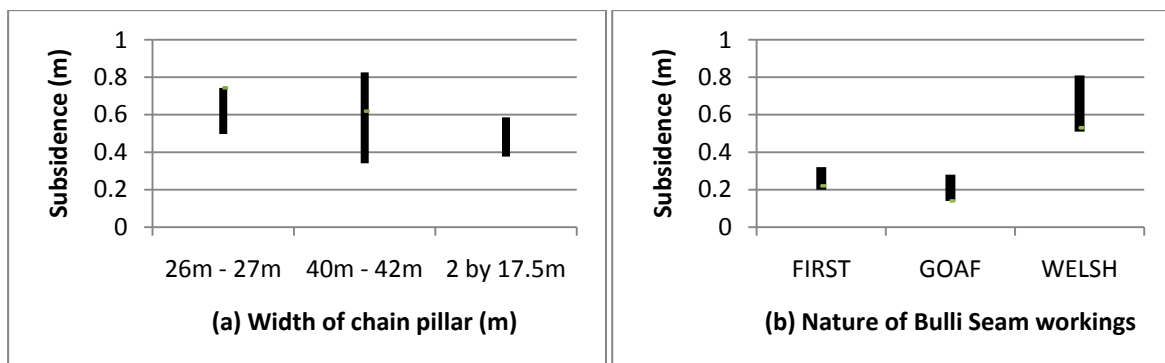


Figure 16 Pillar compression and sag data from Balgownie longwalls

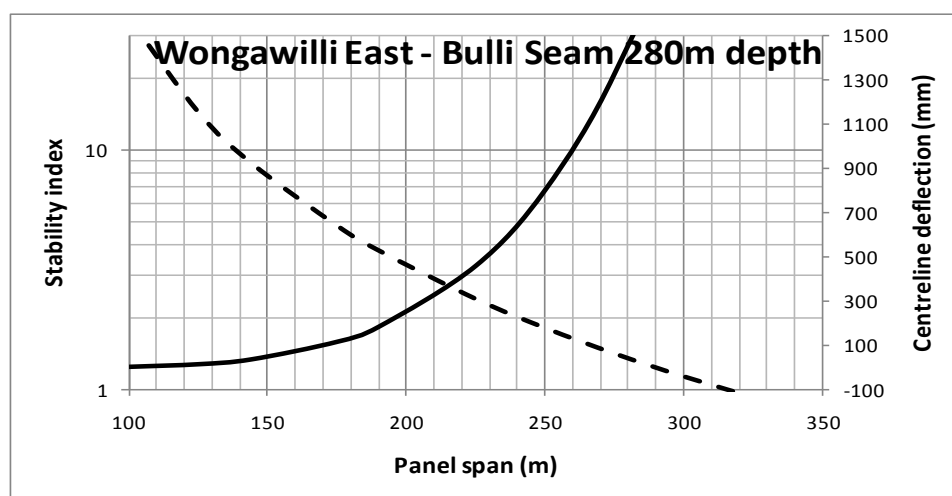


Figure 17 Fractured rock beam analysis for the Wongawilli East area (dashed line – stability, solid line – deflection).

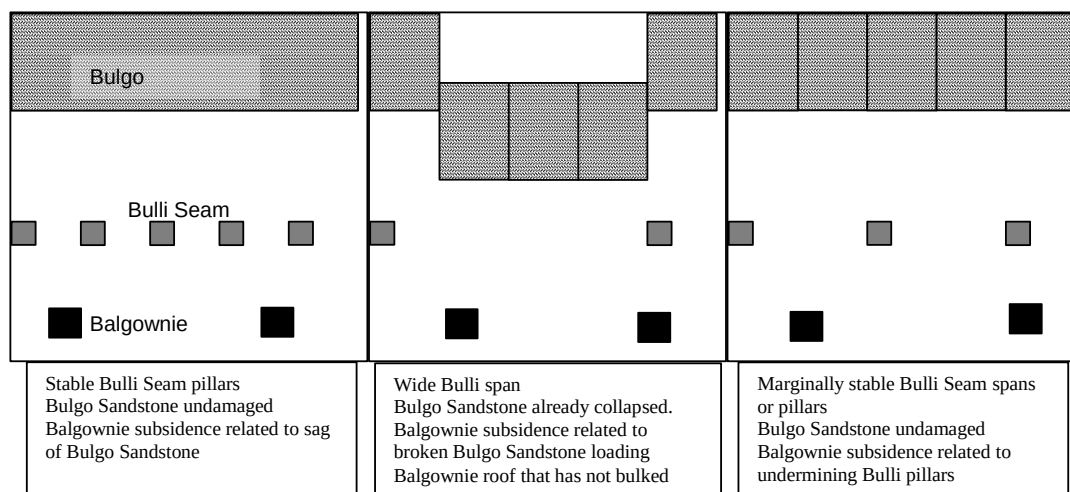


Figure 18 Cartoon explaining different Balgownie subsidence outcomes

4.1.2 Shape of profiles

An angle of draw to negligible vertical subsidence is indicated to be 5° - 34° (Table 2), which is consistent with other mines in the Southern Coalfield. The goaf-edge subsidence is also consistent with the regional patterns. The subsidence data are conclusive in demonstrating Face 6 and Face 7 did not induce a pillar run in the adjacent Bulli Seam pillars that lay within 6-8m of the extraction – this is a key piece of data to consider when assessing the onset of a pillar run induced by a deeper seam.

Table 2 Details of Balgownie subsidence near Mount Ousley Road

Parameter	Face 6	Face 7
Width	142	192
Width/Depth	0.5	0.68
Maximum subsidence	840mm	1200mm
Sag	150mm	500mm
Sag/Thickness	0.11	0.38
Pillar compression	750mm	750mm
Distance to negligible vertical subsidence	22m, 187m	97m, 83m
Angle of draw to negligible vertical subsidence	5° , 34°	19° , 17°
Goaf edge subsidence	228mm, 228mm	228mm, 76mm
Goaf edge subsidence/maximum subsidence	0.27, 0.27	0.19, 0.06

4.1.3 Maximum tilts and strains

Maximum tilts can be measured off the crossline data from along the centrelines (Table 3). For the centreline data, the maximum vertical subsidence corresponds to the value applying in the immediate vicinity and for the cross line data the quoted subsidence is the calculated sag. Whilst there is a general trend of increasing tilt with increasing subsidence, there is not a strong liner relationship (Figure 19).



Table 3 Maximum tilt and strain data from the Balgownie subsidence surveys

Centreline data			Crossline data		
Face	Smax(metres)	Tilt max (mm/m)	Face	Smax	Tilt max (mm/m)
1	1.14	11	1	0.51	8.6
1	0.91	7.9	2	0.20	4.7
2	0.99	10.3	3	0.32	9.8
3	0.91	6	4	0.22	4.6
3	1.30	15.9	6	0.23	6.5
4	1.10	10	7	0.72	7.85
4	1.10	7	6	0.14	2.2
5	0.84	7.3	7	0.53	9.2
5	0.91	8.7	8	0.54	9.6
6	0.76	6.3	9	0.22	8.4
6	0.82	6	10	0.81	18.5
7	0.79	8.5	11	0.28	4.3
7	0.91	15.1			
8	0.80	9.2			
8	1.00	7.2			
9	0.85	15.4			
9	1.15	11.1			
10	0.85	7.7			
10	1.40	4.2			
11	1.30	17.3			
11	0.80	5.8			

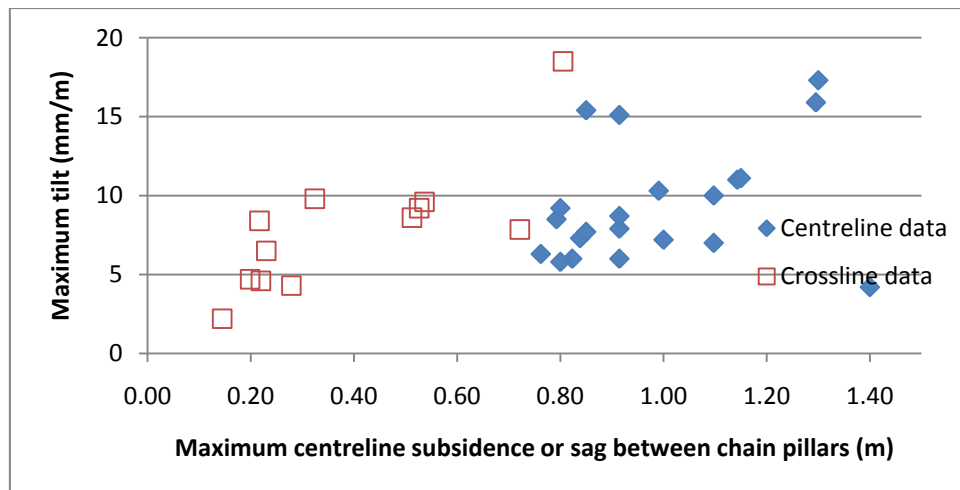


Figure 19 Maximum tilt and associated maximum vertical subsidence from Balgownie surveys

The corresponding K3 values³ for the cross line data plot above the Southern Coalfield guideline⁴ and off-scale (Figure 20).

³ $K_n = \max * H / S_{\max}$, where max = maximum value of tensile strain (n=1), compressive strain (n=2), and tilt (n=3).

⁴ Holla, L. & Barclay, E. 2000. Mine Subsidence in the Southern Coalfield, NSW, Australia. NSW Department of Mineral Resources.

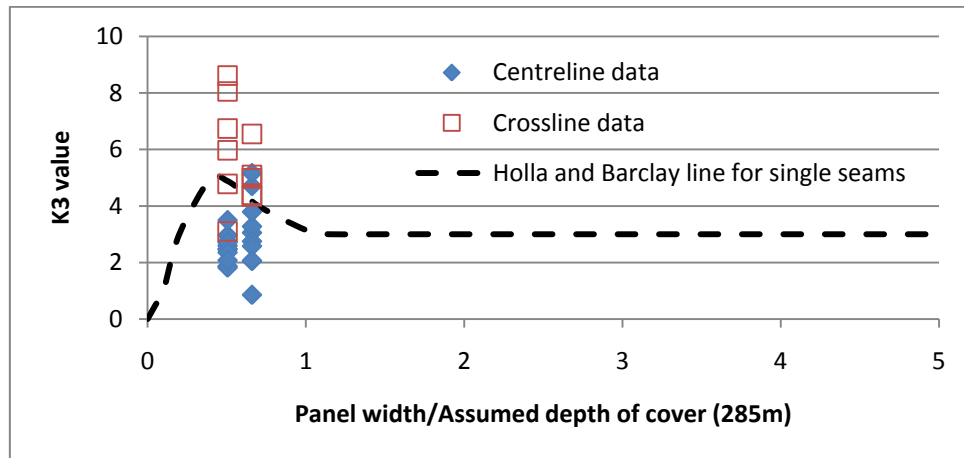


Figure 20 K3 values and panel width/panel depth ratio

Strains were measured only along the centreline of Face 11. At the inbye end of the face, the maximum subsidence was about 0.9m and the maximum strains were 3mm/m both tensile and compressive. The K1 and K2 values are 1.0. At the outbye end, the maximum subsidence was about 1.3m and the maximum strains were 9mm/m tension and 13mm/m compression. The K1 and K2 values are 2.0 and 2.9. Three of these points plot well with respect to the guidelines (Figure 21) and the compressive strains for the inbye end plot above the line.

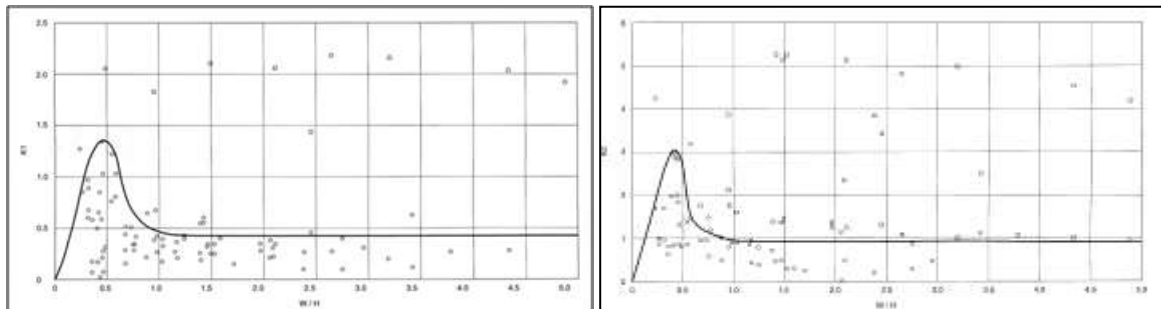


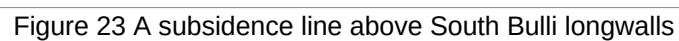
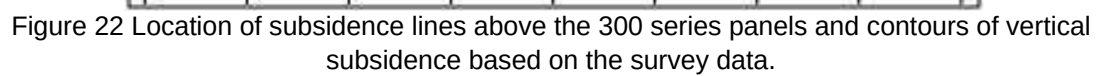
Figure 21 Holla and Barclay single seam guidelines for K1 and K2.

4.2 PREVIOUS WONGAWILLI WEST SUBSIDENCE

4.2.1 300 series longwalls

Because of the interest of the NSW Dams Safety Committee the first four longwalls in the 300 series area were extensively monitored (Figure 22). Typical data from one of the crosslines (Figure 23) shows the pattern of sag above the panels between the chain pillars together with even greater deformation above the chain pillars. The vertical subsidence was about 1m, the maximum tilts were about 4.5 mm/m and the maximum strains about 1.5mm/m. The magnitude of the sag matches that predicted from fractured rock theory and the subsidence above the pillars is well predicted with elastic compression concepts for the roof and floor once the yield of the chain pillars is included. The impact of the wider 51m pillars can be seen in the crossline data.

The available subsidence data has been manipulated to give an indicative contour plan of the vertical subsidence across the first 4 panels (Figure 22). The data was also processed in SDPS to allow a visualisation of the likely subsidence across the full western area (Figure 24).



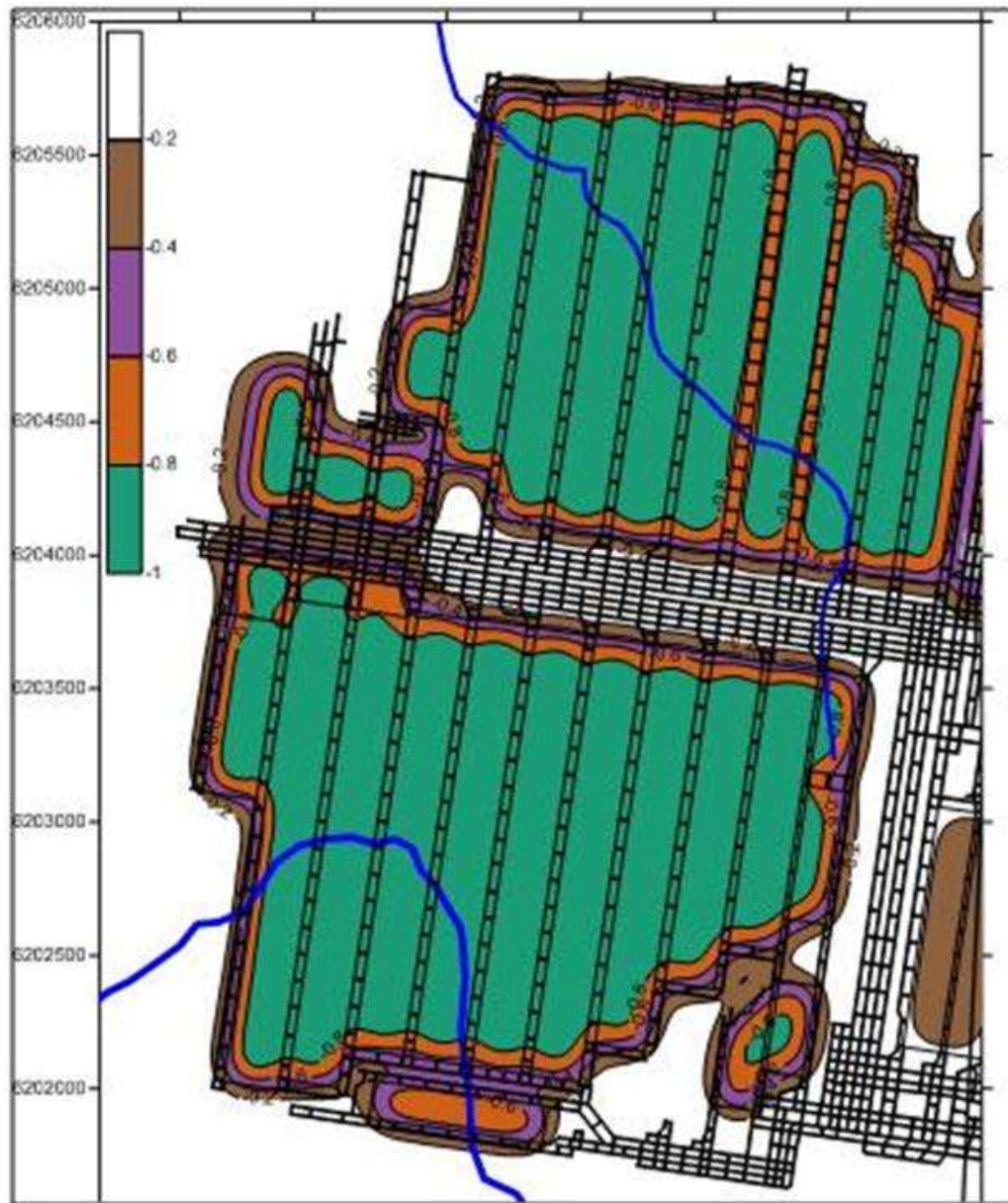


Figure 24 Visualisation of subsidence after Bulli Seam extraction

4.2.2 500 series longwalls – Cataract Panels

The original layout for the 500 series panels directly under the stored waters of Cataract Reservoir involved 110m - 120m wide panels and 60m pillars, and from 1998 the panel widths were increased to 150m and the pillars to 65m. For the first of the widest 150m wide panels, which was the only one that could be surveyed, the maximum vertical subsidence was approximately 300mm combining 240mm of pillar compression and approximately 60mm of sag (Figure 25). The maximum tensile strains are of 0.5mm/m, maximum compressive strains of 0.9mm/m, and maximum tilts of 1.1 mm/m. No valley closure across the arm of the reservoir was measured and no cracking of the rock outcrops was observed. Over the earlier 110m - 120m wide panels, the maximum vertical subsidence was 202mm with tensile strains less than 0.2 mm/m and compressive strains less than 0.4 mm/m.

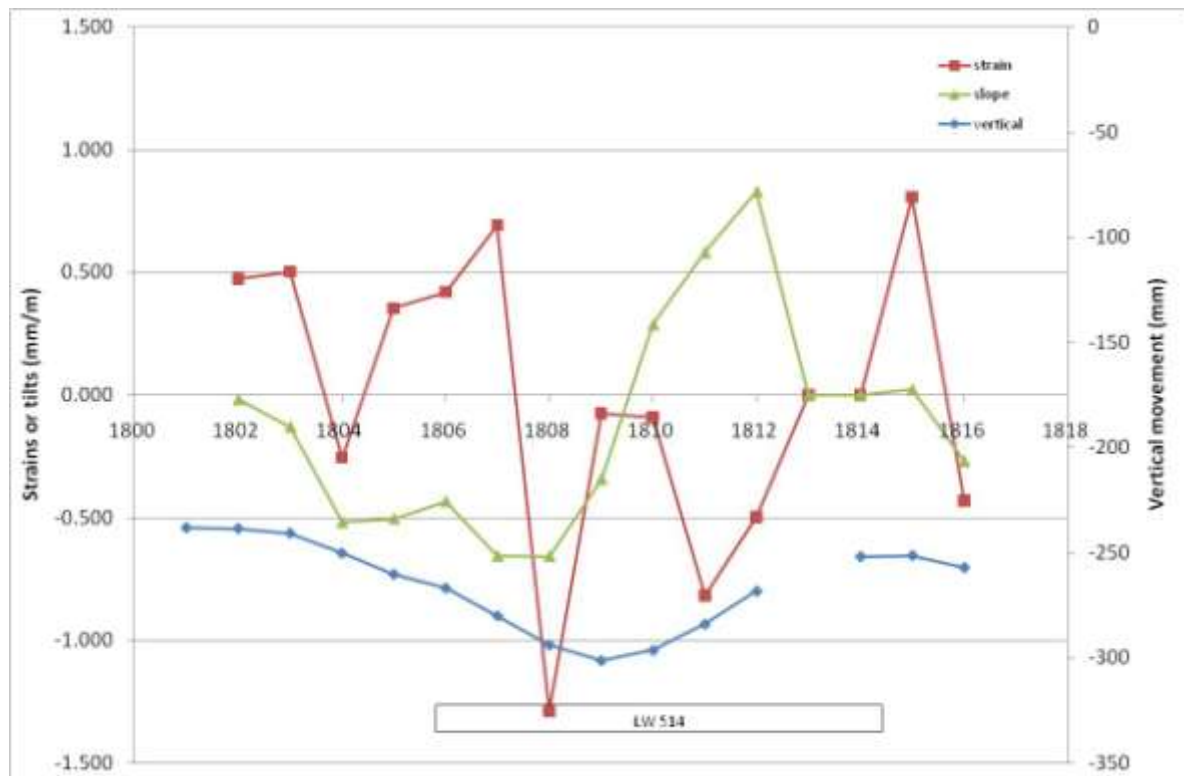


Figure 25 Subsidence above LW514 under Cataract Reservoir

More details are given in Seedsman and Kerr (op cit) which presents a summary of the monitoring of microseismic emissions and microstrain within the rock mass, far field movements, and the development of pillar subsidence and panel sag.

5 SUBSIDENCE PREDICTIONS

5.1 CONVENTIONAL AND NON-CONVENTIONAL SUBSIDENCE

Conventional subsidence has been defined by Southern Coalfields Inquiry⁵ (SCI) as:

The conventional or general model of surface subsidence, which finds worldwide acceptance, is based on assuming the following site conditions:

- ☐ *the surface topography is relatively flat;*
- ☐ *the seam is level;*
- ☐ *the surrounding rock mass is relatively uniform and free of major geological disturbances or dissimilarities;*
- ☐ *the surrounding rock mass does not contain any extremely strong or extremely weak strata; and*
- ☐ *the mine workings are laid out on a regular pattern.*

⁵ Southern Coalfields Inquiry (2008). NSW Department of Planning.



The behaviour of a single, or isolated, excavation provides the basis for the conventional model of subsidence behaviour.”

By default, all other subsidence must be defined as non-conventional. The SCI recognised that ‘nonconventional subsidence’ term was somewhat of a misnomer but decided to maintain the term for the sake of simplicity.

On the basis of the SCI definition, all subsidence above the proposed Wongawilli longwalls will be non-conventional. This is because the conditions that are being considered include:

- Multiple seams are to be extracted,
- The panels in the previously mined seams are not isolated
- The proposed panels are not isolated,
- The chain pillars are designed to yield or fail,
- An irregular topographic surface is present,
- The Bulgo Sandstone is known to be an extremely strong/spanning unit,
- The mine workings in the Wongawilli East area are not on a regular pattern.

The Bulgo Sandstone is known to be a spanning unit over Bulli Seam longwall panels with widths of at least 200m to 250m. This can be readily seen in the Holla and Barclay curves and has also been shown from microseismic studies. In addition, upsidence of plateau ground (not valleys) associated with massive units has been recorded on the NRE lease adjacent to Cordeaux Colliery.

Almost all longwall layouts in the Southern Coalfield have employed pillar designs whereby the chain pillars are designed to yield or fail. The consequence of this is a subsidence pattern whereby the majority of the subsidence develops above the chain pillars and there is a minor increase above the longwall voids (see Figure 22 for an example).

The Southern Coalfield is characterised by a rugged or undulating topography. Down-hill movement in steep topography is the same phenomenon as valley closure. The dominant mechanism is likely to be simple shear translation along flat-lying bedding surfaces that daylight in the sides of any low points in the topography. Uplift (upsidence) can develop if the translation is along a surface that is just below the base of the surface relief.

5.2 PREDICTING SUBSIDENCE DEFORMATIONS

5.2.1 Predicting vertical subsidence

In all methods, the prediction process starts with an estimate of vertical subsidence – either as a few discrete points or as profiles or surfaces. For profiles and surfaces, differentiation gives tilts and curvatures. Empirical relationship then used to give strains.

For single seams, vertical subsidence can be predicted by a number of methods:

- Upper-bound values from a data base – The various reports by Holla provide some of the details of the database and a transparent presentation of the recommended design lines. The design lines are drawn towards predicting the maximum deformations.
- Incremental profile method – This is a proprietary method developed by MSEC. The database has not been published and there is no publication of any details of the design lines.



It can only be used by MSEC and is not subject to peer review. Despite this lack of transparency, it is the method advocated by several government agencies.

- Application of geotechnical engineering principles to the estimation of subsidence above pillars and sag between pillars – see the published papers by Seedsman.
- Direct application of precedent practice from nearby identical layouts.

For multiple seams, the prediction of the vertical subsidence is more problematic – see Section 5.4 later in this report.

5.2.2 Predicting the shape of the bowl

The prediction of the shape of the subsidence bowl is more complex. In the Holla method, a number of estimates of key shape parameters are available and a smooth line is then drawn:

- Location of the inflexion point
- Maximum tilt – K3 values
- Maximum strain – K1 and K2 values
- Vertical subsidence at the goaf edge,
- Extent of subsidence bowl

It is not known how the shape of the subsidence bowls is determined in the incremental profile method.

In the influence function method, international experience in many coal fields has shown that a Gaussian function fits the subsidence well and this has been confirmed in Australian coalfields⁶. As implemented in SDPS⁷, determining the shape of the subsidence bowl with the influence function method requires:

- Location of the inflexion point (as presented in the Holla methods)
- Maximum tilt via the influence angle (tangent of the influence angle is equivalent to K3 in the Holla methods)
- Strain coefficient – empirically derived 0.35 in USA, often 0.20 in Australia.

For multiple seams, there is no database of inflexion point locations, K3 values or strain coefficients. The approach adopted in this report has been to determine appropriate values from a back analysis of the Balgownie subsidence results.

5.2.3 Predicting strains

The recent Bulli Seam PAC claims there are theoretical problems in the way subsidence strain is calculated, and there is reference to the well-acknowledged problem of assuming continuum behaviour for jointed rock. The academic validity of these comments is accepted, but this does not negate the need for the practical application of the engineering concepts.

One of the major problems with predicting strains is related to the fact that much of the data is at magnitudes approaching the resolution of the survey tools. This means there is a large degree of “noise” in the data (the cloud of points near the origin in Figure 25). A statistical line of best fit is close to

⁶ Byrnes, R. Case studies in the application of influence functions to visualising surface subsidence. Coal 2003 4th Australasian Coal Operator's Conference, Wollongong, 2003.

⁷ www.carlsonsw.com

meaningless in low strain range – but this is not material as any associated impacts or consequences are non-existent. At higher strain values, the spread of the data is consistent with other subsidence relationships.

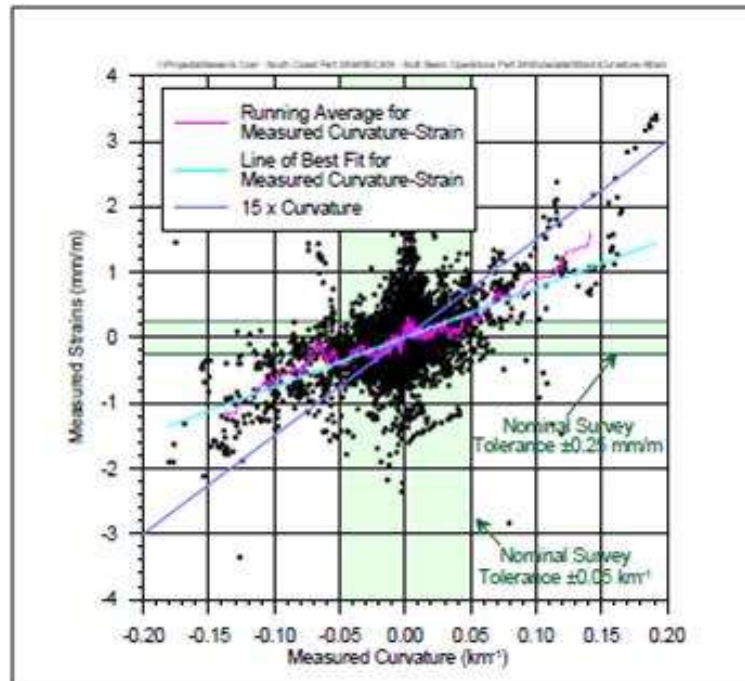


Figure 26 Cross plot of curvature and strain

For strains, SDPS determines the curvature and applies an empirically derived coefficient. For this report, we have obtained a suitable value from the back analysis of the Balgownie subsidence.

5.3 ACCURACY, UNCERTAINTY AND PREDICTION

In interactions with the various government agencies over the last 3 years, it has become apparent there is a serious disconnect between their expectation of “accuracy” and the practice of geotechnical engineering in general and specifically subsidence engineering.

In their correct application, the term accuracy relates to a measurement – how close is the measurement to the actual dimension, and precision relates to the reproducibility of the measurement.

In all geotechnical engineering, including subsidence engineering, the requirement is to achieve an acceptable outcome. Achieving a predicted deformation makes the engineering venture easier, but geotechnical engineers realise that this is not always achievable and that risk management is always required. Risk management can include the strategies outlined earlier or can be as simple as assuming a worst case forecast or a percentage of the forecast.

By definition, a worst-case prediction cannot be considered absolutely reliable as there will be many circumstances where the prediction is in excess of what is subsequently measured. Importantly, there must be a fundamental concern if a worst-case prediction is subsequently found to be lower than what is measured. Both the Holla and MSEC methods claim to be biased towards “worst case” but there are now numerous examples where they have significantly under-predicted.



The current perceptions of the uncertainties with subsidence predictions relate to single seam operations where there is a large experience base. There is a very small experience base with multiple seams so precedent practice cannot be used.

The approach adopted in this report is to consider the engineering mechanics and to apply that knowledge with our broad rock mechanics experience to produce a set of estimates for the various deformations. We will keep the concepts as simple as possible so the uncertainties can be readily identified. This will allow appropriate “uncertainty factors” to be applied when conducting risk assessments on the impact to features which are to be undermined. Adaptive management based on monitoring deformations above the early longwalls will then be incorporated as soon as possible.

5.4 VERTICAL SUBSIDENCE ABOVE MULTIPLE SEAM EXTRACTION

Li et al⁸ has begun the important task of collating information on the subsidence developed above multiple seam longwalls. Their 2010 paper presents an abbreviated database of five studies of mostly shallow cases of longwall mining under previous longwalls. No information is provided on tilts and strains, nor on the geological conditions in the overburdens. Only one of the case studies is from a depth comparable to those under consideration in this report. Two are from mines where the panels were stacked, and two are from situations where there is no survey data provided for the upper walls.

Only the case study from Liddell (Figure 27) is relevant to the proposed layouts at NRE No1, in as much as it has the lower longwall passing under both longwall extraction and pillars. The analogy is not strong but is discussed below because it demonstrates an alternative explanation of the data. Based on the data provided in Li et al, Longwall 1 extracted the 2.40m thick Upper Liddell Seam at 160m depth and Longwall 3 extracted the 2.0m thick Middle Liddell Seam at 200m depth. The Liddell Seams are known to split and merge extensively so it is possible that the quoted thicknesses do not reflect what was actually mined. In contrast to what is stated in the paper, the geology is also complicated with the presence of thickly to massively bedded sandstone units above the Upper Liddell and between the Upper Liddell and Middle Liddell Seams.

The subsidence due solely to the lower seam (Middle Liddell) extraction is that developed above the pillars (Figure 28) and is 1.52m to 1.9m, whilst the subsidence for the thicker shallower seam was less at 1.43m. This appears to be anomalous and suggests the extraction thicknesses are incorrect, the upper seam subsidence was not complete (the upper seam panel was sub critical), or there is survey variability. The latter is assessed to be likely contributor as the LW1 centreline data shows a fluctuation between 1.25m and 1.6m – this is typical of all centreline data.

⁸ Li , G., Stuart, P., and Paquet, R. A case study on multi-seam subsidence with specific reference to longwall mining under existing longwall goaf. 7th Triennial Conference Mine Subsidence Technological Society.

Li , G., Stuart, P., Paquet, R., and Ramage, R. A case study on mine subsidence due to multi-seam longwall extraction. 2nd Australasian Ground Control in Mining Conference, Sydney. 23-24 November.

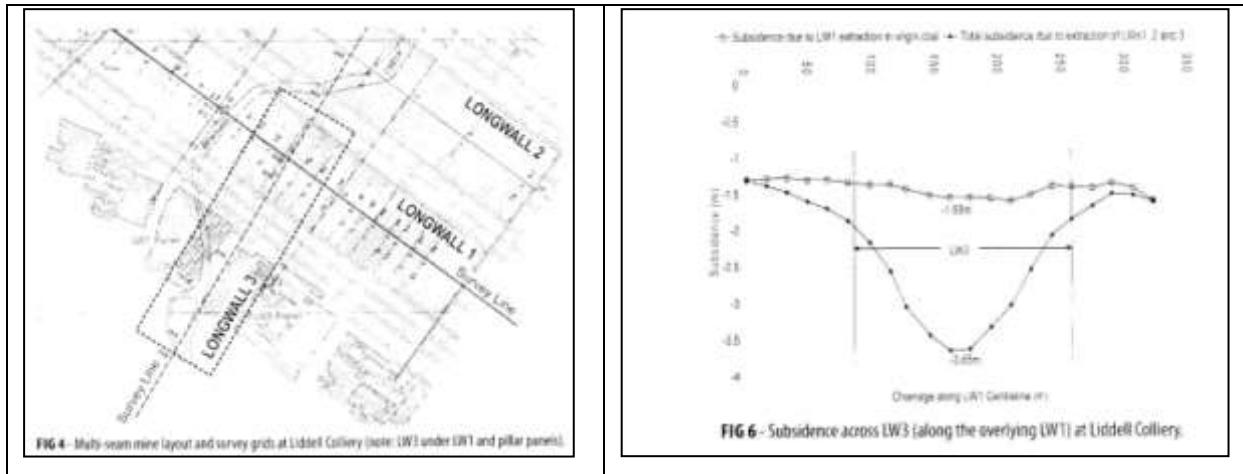


Figure 27 Location plan and subsidence results along centreline of Longwall 1

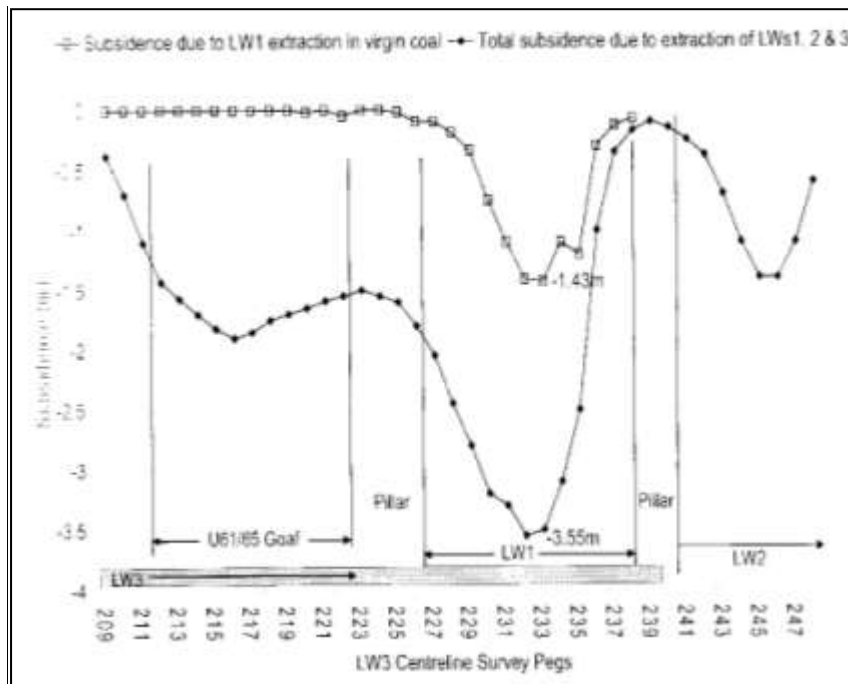


Figure 28 Vertical subsidence along the centreline of Longwall 3.

In Figure 29, the LW3 centreline data has been manipulated to show the subsidence generated by the extraction of LW3 only. The subsidence above the pillar was 1.52m, and above the barrier pillar between the two pillar extraction goafs the subsidence is greater at about 1.9m. The incremental subsidence at the centreline of the LW1 goaf is approximately 2.15m and the maximum (2.5m) can be seen to have shifted away from the centreline.

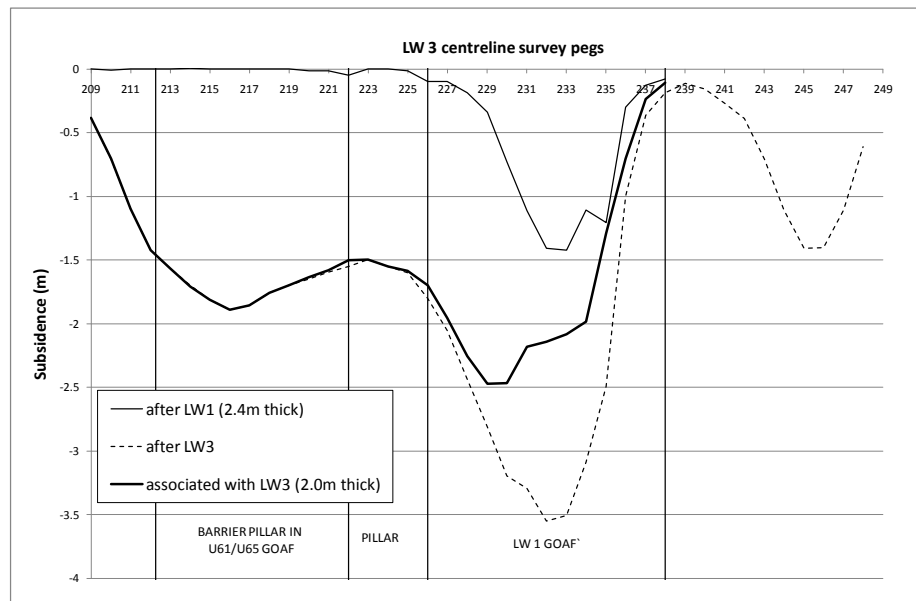


Figure 29 Manipulation of LW3 centreline data

The subsidence factor for the upper seam is reported to be 65% but for the lower seam the subsidence factor is at least 76% (or it could be higher if the barrier pillar data is considered valid). The difference in these values is not consistent with the caving fracturing models discussed by the authors. It is likely the problem lies with the normalising to seam thickness. The extraction thickness may have been greater than the coal thickness – this could have been the case if the longwall face supports could not operate within the thinner lower seam. Further analysis along the lines of normalising to extraction thickness is futile if the extraction thickness cannot be verified.

An alternative is to consider the absolute subsidence data in Figure 29. Based on LW3 centreline, the maximum subsidence associated with the lower seam with no overlying goafs is 1.9m, and with overlying goaf is 2.1m (along centreline). The difference is 0.2m, which is within the variation that is recorded along all centreline surveys.

To date, Li et al have not given appropriate attention to the influence of the thickness of the interburden as discussed as early as 1987⁹. The majority of the bulking that occurs in a longwall goaf develops in the caving zone (Figure 30). If this caved zone from the lower seam intersects the overlying seam the thickness of the caved zone and hence the amount of bulking will be reduced. On this basis, if the interburden is very thin the amount of bulking supplied by the interburden is small and the total subsidence for the lower extraction will approach 100% of the extracted thickness. If the interburden is thick (in excess of the normal thickness of the caved zone - say 10 times the seam thickness), the lower seam bulking will fully develop and the total subsidence for the lower seam extraction will tend towards the value for a single seam (say 65%).

⁹ Van der Merwe, J.N. 1987. A study of the effects of mining relatively shallow overlying longwall panels with staggered inter-panel pillars at Sigma Colliery, South Africa. In *Engineering geology of underground movements*, Proceedings of the 23rd Annual conference of the Engineering Group of the Geological Society, Nottingham.

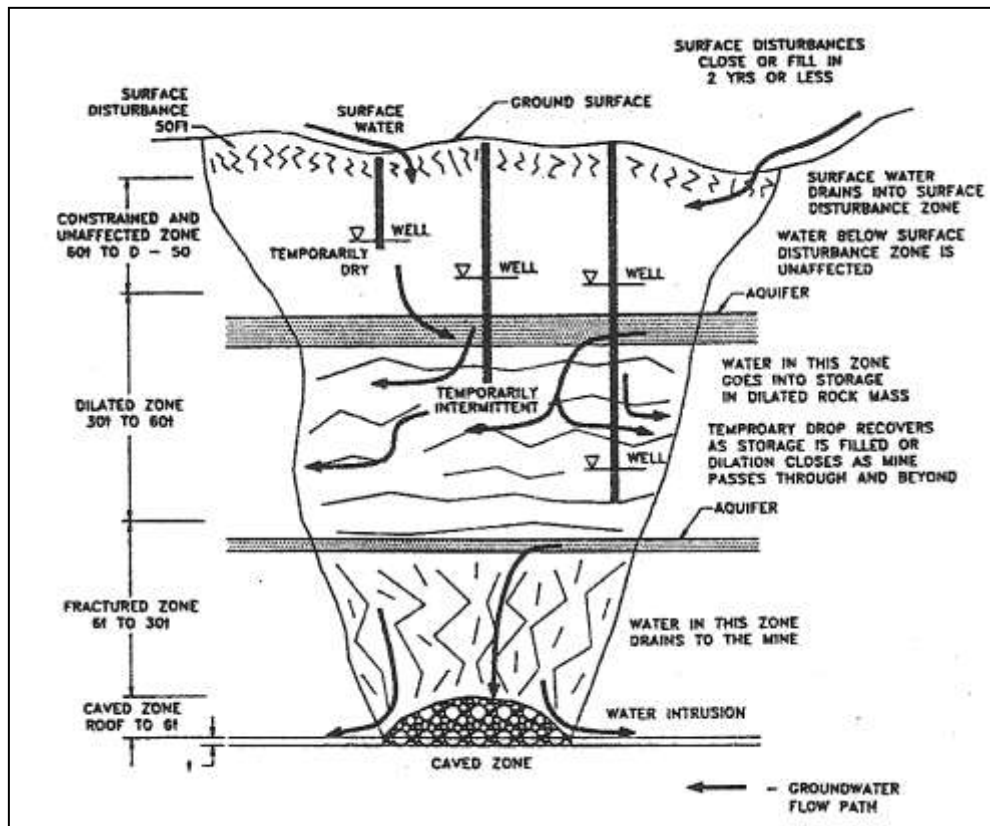


Figure 30 A model for fracturing above a longwall panel¹⁰

The 2010 paper also make reference to a “new” case study which did not fit their conclusions – “... where longwall mining under existing longwall goafs caused reduced vertical subsidence (i.e. currently $a_2=75$ per cent, rather than 100 per cent”. This case study is however not included in the present case studies).

Li et al does not give any information or guidance on the likely tilts and strains associated with the staggered multiple seam extraction. Estimation of tilts and strains will be discussed in later sections on the visualisation of subsidence.

Given our alternative analyses, the apparent availability of other information which is not consistent with the Li et al model and the lack of guidelines for the selection of shape parameters, there is no rigorous basis for using the Li et al recommendations at this time. We are not willing to comply with the direction of the Sydney Catchment Authority to use the Li et al method.

The approach adopted in this report is to assume that the vertical subsidence will be the sum of the subsidence associated with the Wongawilli Seam plus any residual subsidence that may develop in the upper seam.

For Wongawilli East this means:

- A nominal 300mm for the narrow Wongawilli longwall panels
- Plus the impact of the collapse of small Bulli Seam pillars

¹⁰ Bai, M and Kendorski F.S. 1995. Chinese and North American High Extraction Undergoround Coal Mining Strata behaviour and Water Protection Experience and Guidelines. 14th Conference on Ground Control in Mining. 209-217.



For Wongawilli West this means:

- 65% of Wongawilli extraction
- Plus collapse of the overburden above Bulli Seam longwall panels so that the residual of 65% develops for that seam.

As will be discussed later, these estimates provide the base case for risk assessments. As required in the earlier SMP process, the estimates can be increased by nominated percentages to address prediction uncertainty.

5.5 PREDICTIONS OF VERTICAL SUBSIDENCE FOR WONGAWILLI EAST AND WONGAWILLI WEST

5.5.1 Wonga East

The basic geometric parameters for Wonga East area are:

- Depths – 280m to 340m
- Extraction – 2.7m to 3.2m – assume 2.8m average
- Panel width – 150.5m rib to rib
- Pillar width – 59.5m rib to rib

The Wonga East area is complex with a variety of overburden conditions including:

- First working Bulli Seam workings with pillars greater than 15m in width with no Balgownie Seam longwall panels
- First working Bulli Seam workings with pillars greater than 15m in width with Balgownie Seam longwall panels
- Bulli Seam pillar extraction goafs with no Balgownie Seam longwall panels
- Bulli Seam pillar extraction goafs with Balgownie Seam longwall panels
- Bulli Seam pillars with widths less than 15m with no Balgownie Seam longwall panels
- Bulli Seam pillars with widths less than 15m with Balgownie Seam longwall panels

Subsidence in the Southern Coalfield is controlled in part by the spanning capability of very thick to massive units within the Bulgo Sandstone. This capability may be destroyed by wide extraction panels formed by:

- Wide pillar extraction panels in the Bulli Seam
- Balgownie longwalls inducing wider spans by undermining Bulli Seam barriers.
- Wongawilli panels inducing wider spans by undermining Balgownie Seam chain pillars.

There is only the Balgownie longwall empirical database on which to determine maximum vertical subsidence, and no information for multiple seams involving the Wongawilli Seam. A large degree of judgement has been used to decide on maximum vertical subsidence outcomes for the various layouts that are proposed.

For the Wongawilli East area, the model for subsidence history proposes the Balgownie longwalls collapsed much of the overburden sequence (Table 4). This has the advantage of limiting the onset of any delayed subsidence in areas distant from the proposed Wongawilli extraction, but this also means that there is no spanning capacity left within the Bulgo Sandstone directly above the proposed extraction.



In areas where there has been no Balgownie extraction and only Bulli first workings, the proposed narrow longwalls with wide pillars, as used in the Cataract 500 series area, will result in subsidence similar to that developed under Cataract Reservoir.

The other input parameters for the influence function visualisation of subsidence are:

- Inflexion point located directly above the rib line. This tends to maximise the lateral extent of the subsidence bowl and is consistent with the Balgownie back analysis and also international experience with multiple seam extraction.
- Influence angle of 76° ($\tan B=4.0$). This value was selected to give maximum tilts similar to those measured in the Balgownie subsidence data. This is a relatively high value and results in steeper sides to the subsidence bowl.
- Strain coefficient of 0.35. This value selected to give similar maximum compressive and tensile strains similar to those recorded in the Balgownie data.

Table 4 Model for subsidence in the Wongawilli East area

Bulli Seam condition	Subsidence after Bulli Seam	Potential to have been remobilised by Balgownie longwalls	Maximum subsidence after Balgownie Seam	Potential to remobilise by narrow Wongawilli panels	Maximum additional subsidence induced by Wongawilli panels
Large stable pillars (> 15m wide)	None	No	760mm	No	300
Wide full extraction areas	60% of 2.5m, complete	No	1080mm	No	300
Narrow (less than 200m wide) extraction areas or small pillars (< 15m wide)	300mm	Yes	1300mm	Yes	large

5.5.2 Wongawilli West

The basic geometric parameters for Wonga West area are:

- Depths – 440m to 500m
- Extraction – 2.7m to 3.2m – assume 3.2m average
- Panel width – 388m rib to rib
- Pillar width – 59.5m rib to rib

For the Wongawilli West area, the geometric situation is simpler with only the Bulli Seam already extracted. Referring back to Figures 23 and 24, it can be appreciated that the maximum vertical subsidence recorded to date is about 1.0m which is less than the 1.6m (65% of 2.5 implied by Holla and Barclay) interpreted to be the maximum possible in conventional subsidence theory. It is proposed the difference is related to the spanning capacity of the Bulgo Sandstone across the panels which are less than 188m wide, and that this spanning may be destroyed with wider panels. The wider panels that are required for the Wongawilli extraction may destroy this spanning ability.



Referring to Figure 31, Table 5 outlines the possible subsidence history of various points.

- A. Above Bulli extraction panel, and above Wongawilli pillar. Subsidence of about 1.0m already developed due to compression of Bulli pillar system and sag of the Bulgo Sandstone. Additional subsidence related to the compression of the Wongawilli pillar system and “collapse” of the Bulgo Sandstone.
- B. Above Bulli Seam pillar and above Wongawilli panel. Subsidence of about 0.8m already developed due to compression of Bulli pillar system. Wide Wongawilli panel leads to subsidence of 65% of 3.2m extraction thickness or 2.08m.
- C. Above Bulli and Wongawilli goafs. Subsidence of about 1.0m already and possibly an additional 2.55m during Wongawilli extraction.

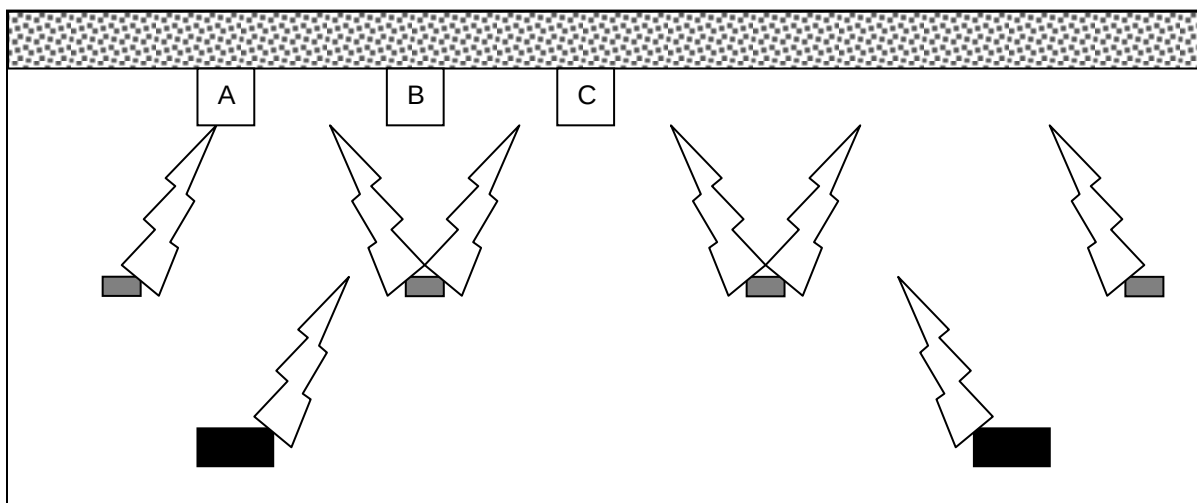


Figure 31 Cartoon showing relative location of 3 surface points above Bulli and Wongawilli Seam longwall panels

Table 5 Summary of possible maximum subsidence values for Wongawilli West

	Previous Bulli Seam	Bulli residual potential	Wongawilli Seam only	Mining proposal	Combined
A	1.0 m	0.6 m	0.8 m	1.4 m	2.4 m
B	0.8 m	0.0	1.95 m	1.95 m	2.75 m
C	1.0 m	0.6 m	1.95 m	2.55 m	3.55 m

5.6 THE LATERAL EXTENT OF SUBSIDENCE

Recognising the uncertainties in subsidence prediction and the need to apply risk management strategies, one of the key parameters is the lateral extent of subsidence deformations above unmined coal.

Holla and Barclay (op cit) state that for single seam operations in the Southern Coalfield the average angle of draw from the goaf edge to a vertical subsidence of 20mm is 29°, with 70% of the survey less than 35°. There are vertical movements outside the angle of draw but they are assessed to be related to survey precision. In this definition, there is no judgment made as to whether the 20mm threshold represents the onset of unacceptable deformation.

There is no data base for the angle of draw for multiple seams. From a consideration of the mechanics of broken overburden, the angle of draw in multiple seams should tend to be lower

Over the last 15-20 years, much focus has been applied to horizontal movements, and particularly those that have been measured outside the 35° angle of draw for vertical subsidence. A surprising and disappointing aspect of the studies has been the failure to acknowledge the precision of the surveys (20mm¹¹). Once this consideration is included, the available data (Figure 32) indicate no movements at 1900m from the goaf edge (10 sites, 28 data sets, range of topographic and geological conditions). The Kay et al (2007) paper also notes that “the magnitude of far-field movement reduces as the subsidence produced by the longwall reduces, which is expected.”. There is no database of horizontal movements associated with multiple seam extraction.

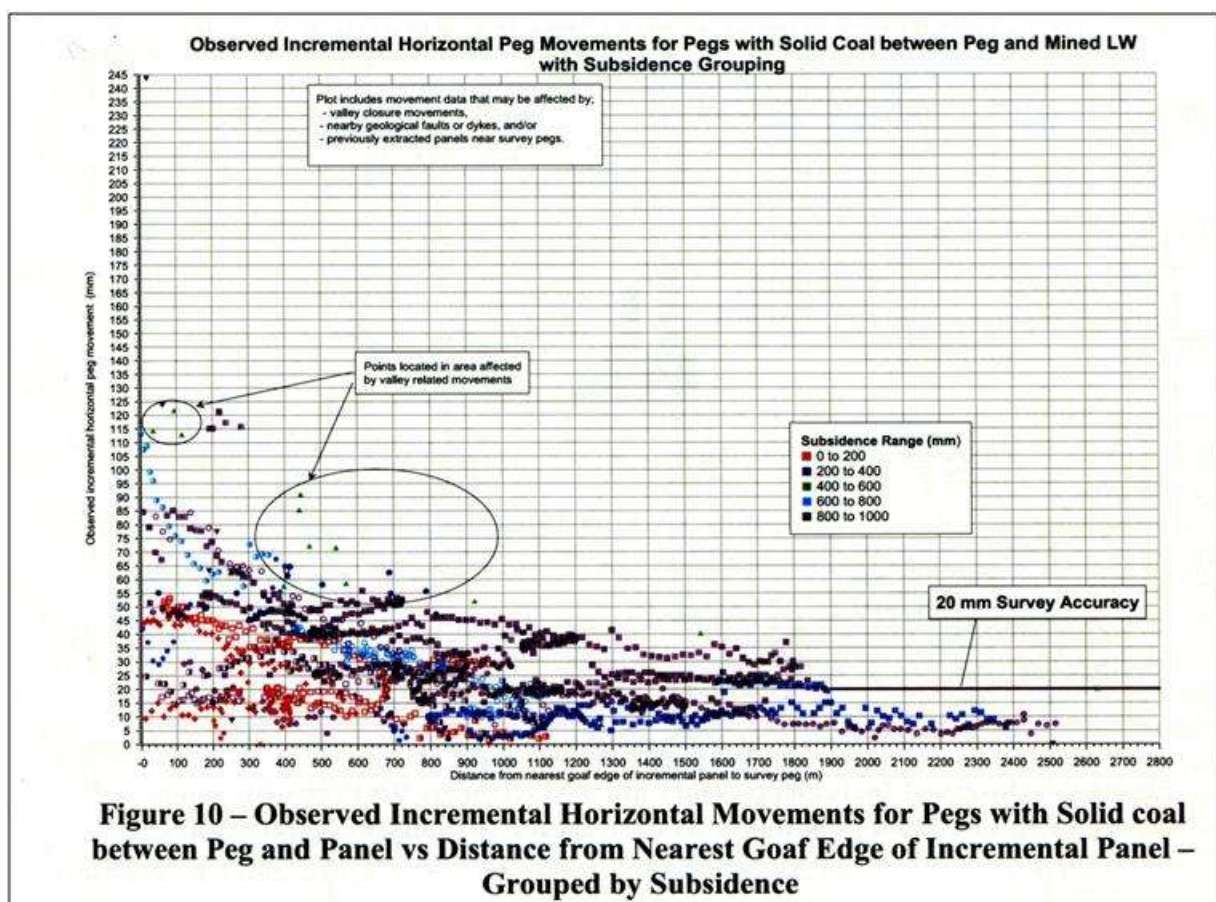


Figure 32 Horizontal movements above solid coal associated with single seam extraction (reproduced from Kay et al. 2007)

5.7 THE PILLAR RUN HAZARD IN WONGAWILLI EAST

5.7.1 Background

Government agencies have raised concerns about the potential for a pillar run. The term “pillar run” is often used but is not formally defined. Current usage seems to be an emotional term for any

¹¹ Kay, D.J., DeBono, P.L., & Pinkster, H. 2007. Probabilistic approach to predicting far field horizontal movements during mining. Proceedings 7th Triennial Conference on Mine Subsidence: A Community Issue.



unexpected and rapid failure of a large number of pillars. In the following, the term “pillar run” will be used to describe the rapid collapse of a large number of pillars. This distinguishes a run from another poorly defined term – a “pillar creep” – which is a slow convergence of the roadway over a large area.

There is no record of the Balgownie longwalls when extracted 6-8m below the Bulli seam inducing a pillar run. Given the imagined severity of such an event it is unlikely that it went unreported. In fact, inspection of the subsidence data shows the Balgownie panel edges deform in the same way as isolated Bulli Seam longwall panels which indicates that the Bulli Seam pillars immediately adjacent to the Balgownie goaf edges did not fail. If they did not fail here, there could not be a subsequent failure further away from the abutment stress peaks.

In the international technical literature, there is no record of a pillar run induced by mining in a lower seam

It can be argued pillar runs did occur prior to the 1960 collapse of Coalbrook in South Africa in 1960 that initiated detailed research into pillars. There have been examples of isolated pillar failures since the introduction of the pillar design methods, but SGPL is not aware of a pillar run. In South Africa, the more recent failures have been at shallow depth, with slender pillars and a particularly weak coal seam. In Australia, the pillar failures that were included in the UniNSW database were either formed prior to the introduction of the pillar design methodology or can be tracked to inappropriate implementation of the design methodology. There has been no pillar run in Australia that has been discussed in the engineering literature.

To generate a pillar run, a wide area of undersized pillars is required such that loads can be transferred to adjacent undersized pillars which then subsequently fail. At Wongawilli East, we would be dealing with a different mechanism of pillar failure compared to a standard “pillar run”. What is apparently being invoked is that by withdrawing the foundation to pillars, load is transferred to other pillars that have not been undermined and these then subsequently fail. Some key challenges to this proposed mechanism are required.

Firstly, the only way pillar loads can be increased in this geometry is for the overburden to arch from the undermined location. If the previous mining caused full subsidence and “broke” the overburden sequence, arching is not possible and hence loads cannot be transferred

Secondly, there is no case study of a subsidence-induced pillar run. Recent Newstan longwalls extracted directly under standing pillars in Awaba Colliery and did not induce a pillar run. There was extensive monitoring to examine this perceived hazard. The lack of a pillar run associated with the Balgownie longwalls has already been discussed.

5.7.2 What is an undersized pillar?

“Undersized” implies a pillar that fails to perform to requirements. The coal pillar failure database does not provide a definition of “failure” – it is assessed failure relates to underground operational issues, particularly workplace safety, and was originally designed to include cases of the failure of a large number of pillars in a panel and to specifically to exclude cases where the floor fails.

The interpretation of the pillar failure database is purely empirical/statistical: there has been no attempt to establish the engineering mechanisms. There were only 61 failed pillars in the Australian/South African database used in the UNSW method (16 Australian cases) and these limited numbers mean care is needed when quoting probabilities of failure. The probabilities quoted (up to 1:1,000,000) relate to an assumed normal distribution and particularly an assumption that there is no error in the

estimate of the pillar load. There is little value in pursuing statistical stability in the Mount Ousley Road case because there is a very high level of uncertainty in the estimate of pillar loads.

A major problem in the statistical analysis is the lack of any valid recorded case for failure of pillars with width/height greater than 4.3. A 2006 review of South African data¹² made a number of key observations:

- The database excludes floor failure,
- There were 27 failures in the 1967 database and there is 75 in the 2006 database,
- Most of the failures have occurred at less than 100m depth,
- There are none with w/h greater than 4.3.

A recent paper by Galvin¹³ includes a discussion of the only two cases of “failed” pillars where the w/h ratio is greater than 5.0. One of these cases is Crandal Canyon, and the other is an unpublished, confidential, and destroyed case study. The detailed nature of the Crandal Canyon pillar deformations are not known – the fatalities could have been due to rib spall/failure while the pillars were still load-bearing. The unpublished case study is apparently based on the interpretation of remote instrumentation and there is much confusion about the geometries that applied – in 1996, the depth was reported to be 170m but in 2010 the depth was reported as 300m. More recently, the UniNSW has stated this site is not the instrumented site and is likely to be from the Great Northern Seam with a very weak tuffaceous unit in the floor - a coal seam where floor failures are very common. Until the details are published and subject to standard peer review, the stance taken in this report is that there are no failures at a w/h ratio greater than 4.3. Unfortunately, in November 2010, Prof Galvin, on behalf of the UniNSW, announced that the database, which was confidential, had been destroyed according to UniNSW commitments and protocols. There are now substantial dangers in using the UniNSW methods.

An alternative approach is to seek to understand the kinematics of pillar behaviour. The published pillar database has no failed pillar with a width to height ratio of greater than 4.3 and this value is equivalent to a 13° friction angle if the failure mode is considered to be shear through the pillar (Figure 43). It is possible that the shape limit of failed pillars is ultimately controlled by shear.

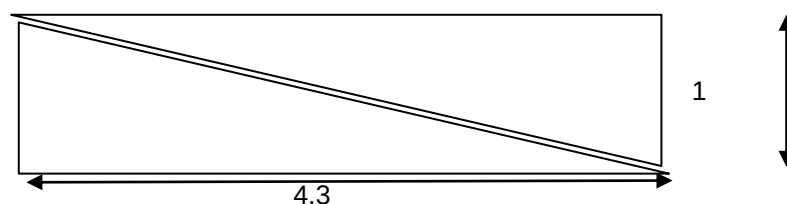


Figure 33 A 4.3:1 W/H ratio is equivalent to an included angle of 13°

The roof and floor of the Bulli and Balgownie Seams in this area of the mine are of rock strength and there is no hazard associated with low strength roof and floor materials such as would negate the use of the coal pillar strength approach.

Given the failure database, the presumed floor strengths, and the considerations of aspect ratios, it is assessed that a pillar with a w/h ratio of 6 (indicating a friction angle of 10° degrees) represents an appropriately conservative definition of a barrier to the progress of pillar failure. It is stressed that this does not mean that squatter pillars do not deform. They certainly will deform, and the level of

¹² Van der Merwe, 2006. South African coal pillar database. J South African Institute of Mining and Metallurgy, 106, 116-127.

¹³ Galvin, J.M. 2010. International Conference on Ground Control in Mining: Pillar design workshop.



deformation may or may not be interpreted as failure depending on the allowable deformations that have been defined. The possible deformations are implicitly discussed later in this report.

5.7.3 Analysis of layout

Recognising the way loads are redistributed between pillars of different stiffness, there is no value in determining the stability of small pillars because it is not possible to determine their loading. A more appropriate approach is to assess the stability of the large pillars and determine if they can carry the loads without failing. As discussed above, we have chosen a w/h ratio of 6:1 as the aspect ratio where the pillar has a very high strength and can be considered to be a barrier to progressive failure. On this basis, pillars in the Bulli Seam (2.4m seam height) more than 15m wide and in the Balgownie Seam (1.3m seam height) more than 8m wide will act as blocks to the progression of subsidence.

In addition, caving and hence subsidence deformation cannot extend through existing goafs. On this basis, the presence of goafs will also represent a block to subsidence progression. Figures 34 and 35 show the location of the blocking pillars and blocking goafs to subsidence progression. It can be seen that there is no un-blocked connection between the proposed Wongawilli panels and Mount Ousley Road.

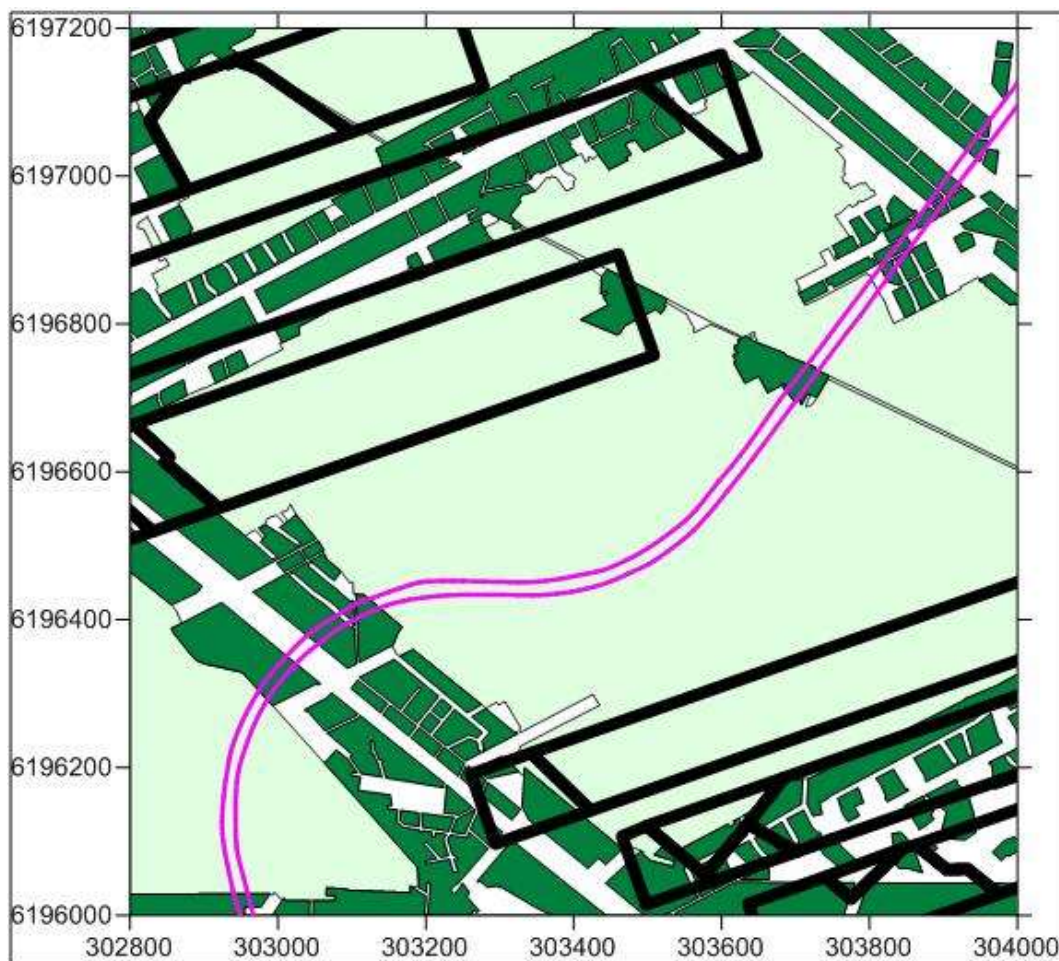


Figure 34 Blocking pillars and goafs in the Bulli Seam (dark green – pillar, light green – goaf)

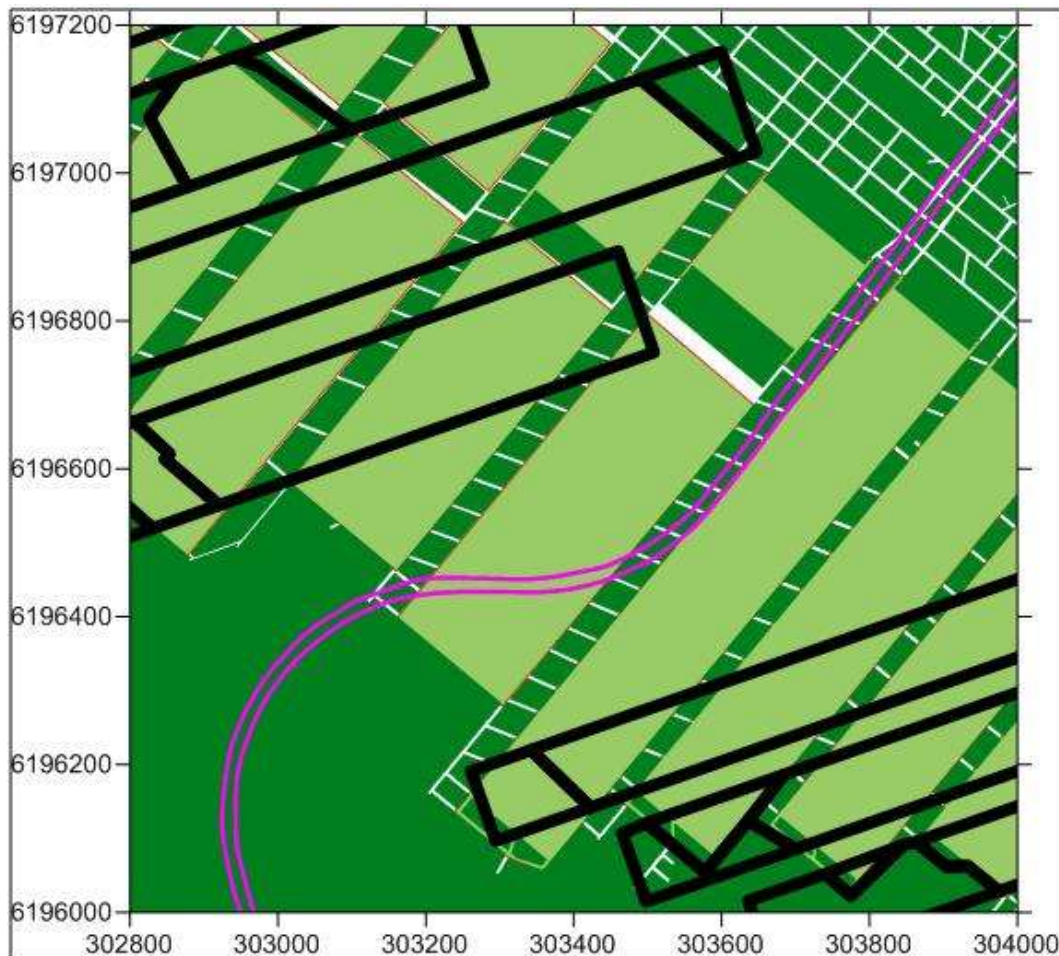


Figure 35 Blocking pillars and goafs in the Balgownie Seam (dark green – pillar, light green – goaf)

The other consideration is what may happen in the areas shown as white, particularly in Figure 34. By definition, these are areas where small pillars (less than 6:1 ratio) are present. Because of their smaller w/h ratio, these small pillars will have a lower stiffness than the adjacent large pillars and hence will not be exposed to the full overburden load. It is not possible to readily quantify the load reduction but it could be in the order of 30%-50% of tributary area. Even if such smaller pillars were to fail, the extent of any roof collapse would be limited to the approximately the width of the resultant span – a maximum height of approximately 40m (compared with a depth of about 300m). These collapses, should they develop, would not adversely impact on the road.

Accepting that a pillar run - a rapid progression - is not credible, there remains a concern about a creep. It is SGPL's view this is not possible as there is no way by which pillar stresses can increase on the pillars under the road as they are surrounded by goaf material or too far distant along the line of pillars. The deformations that could be associated with a creep are addressed indirectly in Section 7 of this report.

5.8 UPSIDENCE AND VALLEY CLOSURE

The reference in Footnote 11 notes that there is inadequate understanding to relate the extent of horizontal movement to the vertical subsidence recorded above the extraction panel. Conventional subsidence theory would propose that the horizontal movements will decrease with distance from the

edge of extraction. A corollary of this is that the surface would be under tension and that topographic features would tend to expand. This overall trend is apparent in Figure 32, but is contradicted by the measurements of valley closure and upsidence (both of which indicate compressive stresses).

Valley closure relates to the convergence of the 2 sides of a valley, upsidence is the amount by which the local subsidence is less than the wider trend. Figure 36 indicates that valley closure has been measured¹⁴ within about 700m in-line of extraction or about a 45° draw angle to the side. At the position of presumed negligible vertical subsidence (35° draw angle or say 300m) the range of horizontal movement is less than 20mm to 150mm or 70mm respectively.

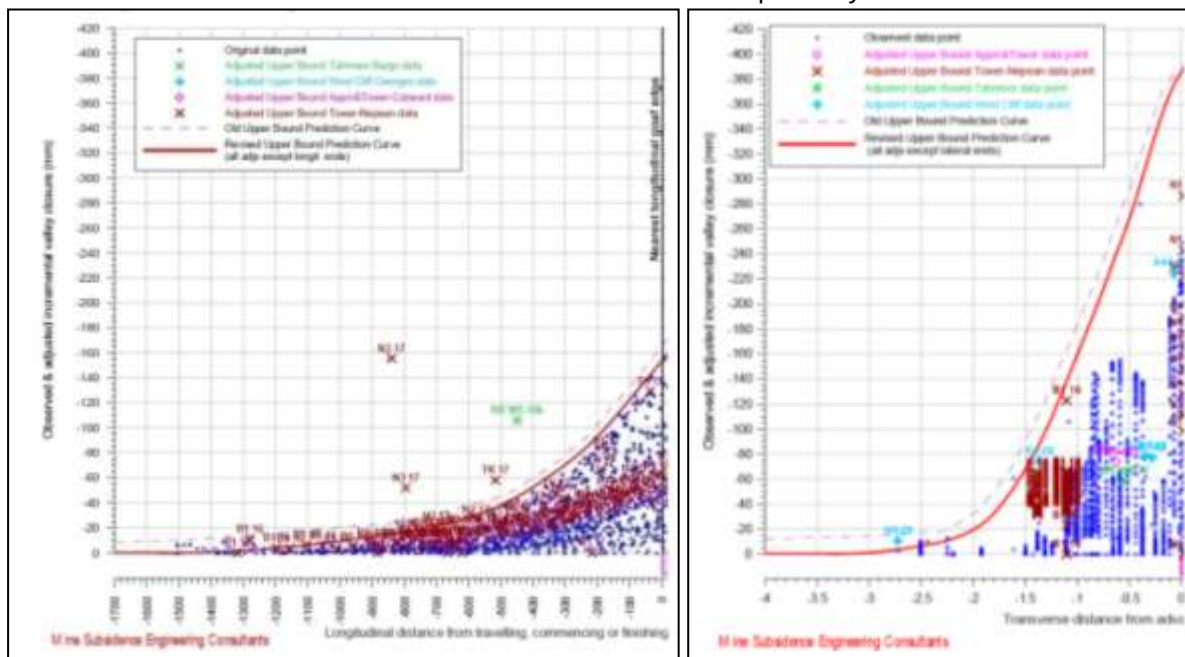


Figure 36 Closure data (reproduced from MSEC, 2008)

For upsidence, the range of values at the negligible vertical subsidence limit are less than 20mm to a maximum of 60mm (Figure 37).

The mechanisms for valley closure and upsidence are not fully understood and are hence not amenable to an analytical engineering prediction. The raw data is not available in the public domain and only modified incremental data is presented. Extrapolation to multiple seams is fraught with problems. The author has been working on this subject and has developed several concepts including the key aspect that there will be no closure or upsidence if there are no spanning units, or if shear plane is either above or well below the base of the valley.

¹⁴ MSEC (Mining Subsidence Engineering Consultants), 2008. The prediction of subsidence parameters and the assessment of mine subsidence impacts on natural features and surface infrastructure resulting from the proposed extraction of Longwalls 20 to 44 at Metropolitan Colliery in support of a Part 3a Application. Report Number MSEC285 to Helensburgh Coal Pty Ltd.

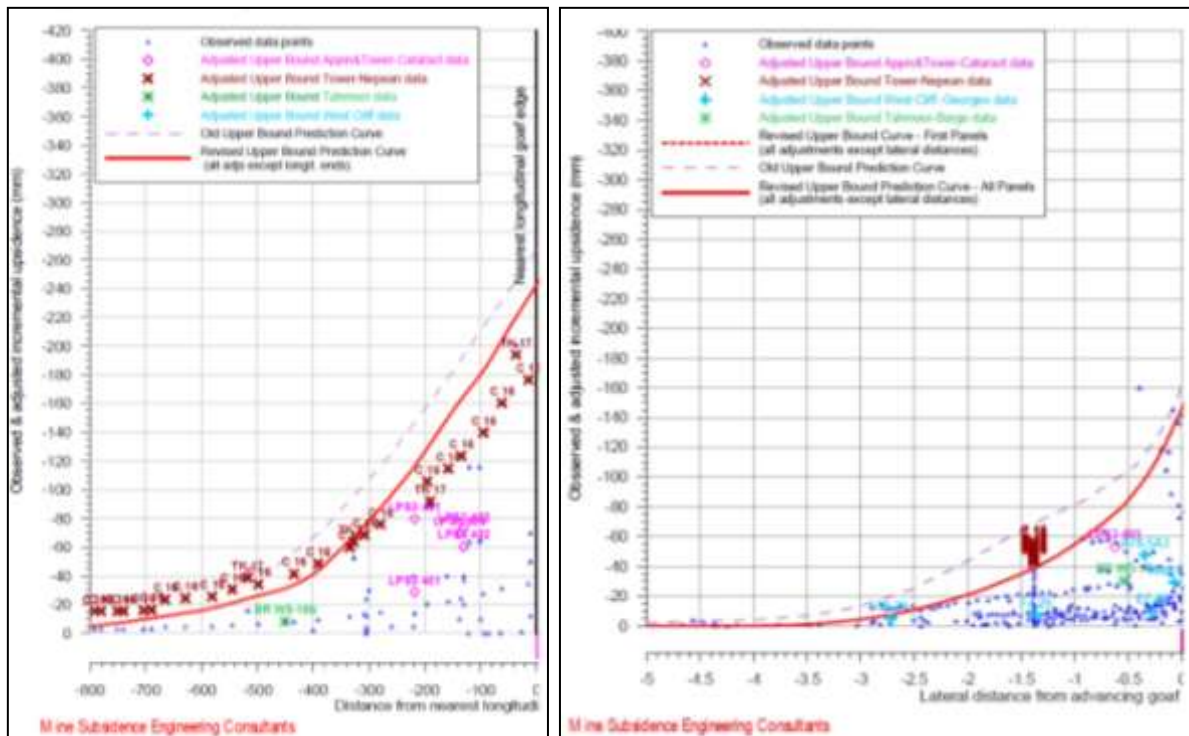


Figure 37 Upsidence data (reproduced from MSEC, 2008)

5.9 PREDICTION OF SUBSURFACE SUBSIDENCE EFFECTS

Any aquifers located within or intersected by mining-induced fracturing will undergo a change in permeability and the potential for localised drainage into the mine workings. If the fractured zone extends to the surface, there is a possibility for a interconnection between the surface and the mined seam.

5.9.1 Geometric models

The standard hydrogeological model (Figure 30) proposes caving and fracturing zones with their dimensions, which are derived empirically, related to the seam thickness. This normalisation process is anomalous in the context of the conventional model for subsidence whereby panel width is an important parameter. The ratios quoted in Figure 30 may be applicable only for the panel widths in the data base – and this parameter is not provided in the literature. An alternative approach is to consider the fracturing height in the context of the collapsing rock mass encountering a bridging or spanning unit.

It has been established from microseismic studies that the Bulgo Sandstone contains a bridging unit. Further evidence of spanning can be derived from an interpretation of the subsidence data for isolated panels which has subsidence of less than 10% of seam thickness (say 250mm) for width/depth ratios of 0.44 (say 205m panel at 470m depth).

5.9.2 Geotechnical models

Analyses of spanning units can be conducted using well-established concepts that are widely applied to mining (and civil engineering) designs. An important aspect of the analysis is the deflection that is

associated with the onset of failure. The following paragraphs speculate on an implication to fracturing and transmissivity.

The use of voussoir beam mechanics for this mining application is assessed to be valid, even though there is a view amongst the government regulators this is not the case because the method is used in civil engineering. The original voussoir beam work by Evans in 1941 was published in the Transactions of the Institution of Mining and Metallurgy, as was the update by Beer and Meek in 1982. From the 1985 first edition of the standard text “Rock Mechanics for Underground Mining” by Brady and Brown has included a full chapter dedicated to the approach. The more recent improvements have been published in the International Journal of Rock Mechanics and Mining Sciences. Seedsman Geotechnics Pty Ltd has been at the forefront of applying these concepts in their research into longwall strata behaviour and we have made some significant progress.

There is a need to consider the failure state of beams where the deflection is limited to a set amount. There may be situations where a stress-based analysis indicates a beam may fail, but such failure is prevented by the restraint offered by the bulking zone. There are major implications of this in the context of fracturing – if the beam fails it can be assumed to be fractured and have high vertical transmissivity, whereas if the beam is thick enough, the required deflection is prevented, the unit may become constrained with no change in transmissivity (in fact transmissivity may be decreased due to increased stresses compressing the pore space).

As outlined in FMEA report, there was no conclusive outcome of the considerations about potential water loss to the mine. The SGPL position is based on the mechanics of beam deflection and failure such that there is inadequate room for the Bulgo Sandstone beams to have deflected enough to cause through-going failure. Without such failure, there would be no transmissive fractures and hence no significant change in vertical transmissivity.

Figure 38 outlines a conceptual model for rock breakage and spanning in the Bulgo Sandstone above longwalls. An important aspect of this model is that a voussoir beam may “sit down” on top of the goaf material before it reaches the deflection that is associated with fracturing. This means that that a voussoir beam analysis needs to consider both the stability (onset of compressive failure) and the available deflection when assessing the possibility onset of collapse.

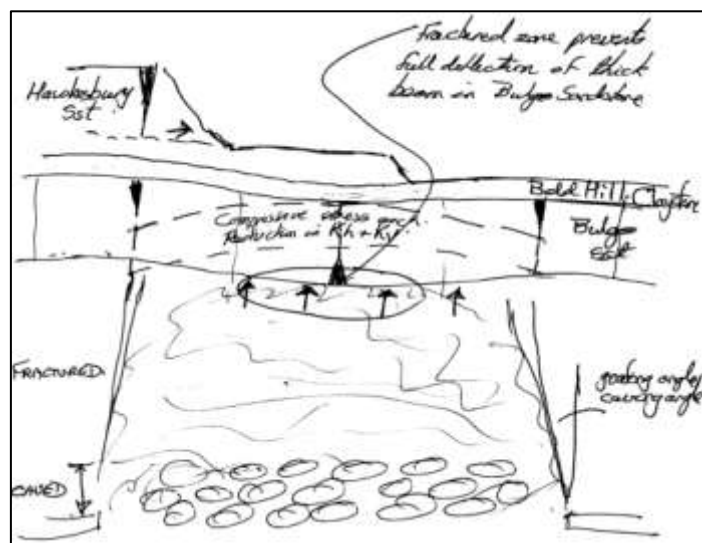


Figure 38 Collapse of a voussoir beam in the Bulgo Sandstone is prevented by bulking in the underlying goaf.

Figure 39 presents an analysis of the stability and deflection of various thickness of Bulgo Sandstone. For a 300m wide panel, a 50m thick units is required and compressive failure of the beam can only develop if the deflections are in excess of 1800mm. One aspect of this model is that incorporates both seam thickness (bulking reduces the available deflections) and panel width – the two issues the Bulli Seam PAC was recently grappling with.

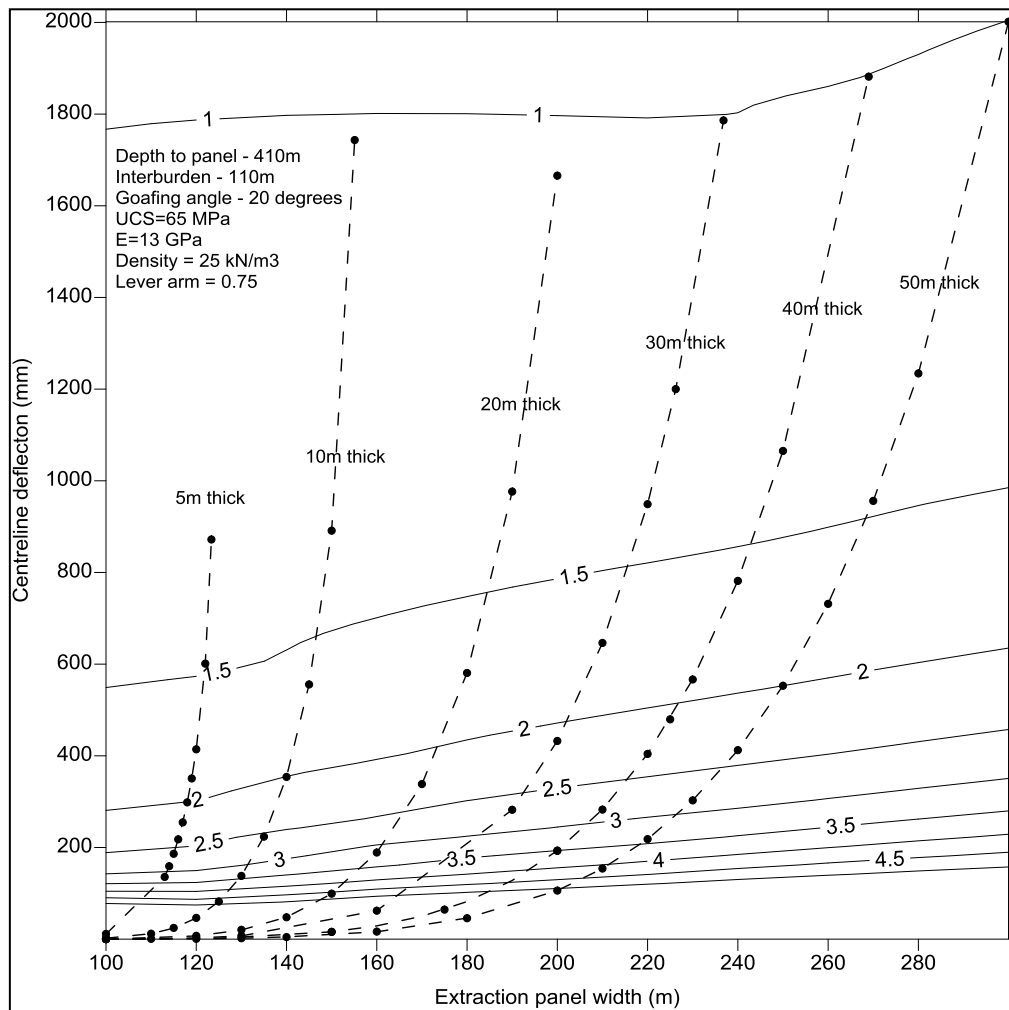


Figure 39 Stability and required deflection field for voussoir beam in the Bulgo Sandstone

The model may be considered too simplistic until reference is made to the recent ACARP research conducted by CSIRO¹⁵. Their extensometry data from Westcliff colliery reveals a 56m thick unit at the top of the Bulgo Sandstone (G5) that has deflected approximately 700mm (Figure 40).

¹⁵ Shen, B., Alehossien, H., Poulsen, B., and Waddington, A. 2010. Subsidence control using coal washery waste. ACARP C 16023.

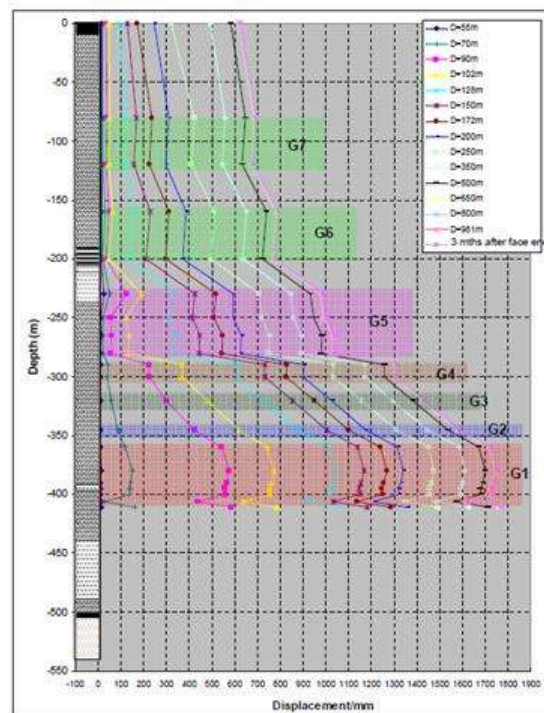


Figure 40 Westcliff extensometer data

In summary, there is a body of rock mechanics theory, supported by monitoring data, that suggests that cracking to the surface will not develop.

5.9.1 Other approaches

An alternative approach to assessing water inflow has been investigated using numerical models calibrated to empirical relationships from the British Coalfield¹⁶. For the postulated maximum vertical subsidence of 2.4-3.5m at 500m depth, Figure 43 indicates no water inflow issues.

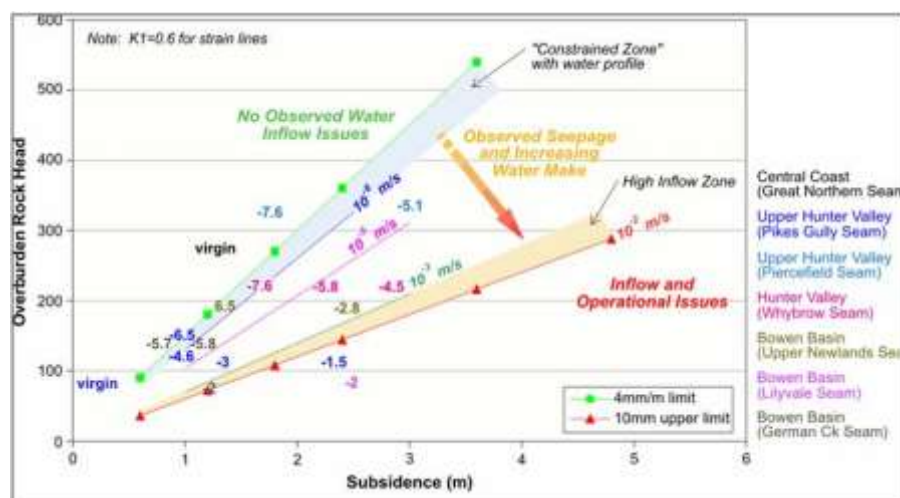


Figure 41 Average overburden conductivity characteristics relative to subsidence and depth criteria (reproduced from Gale, 2008)

¹⁶ Gale, W. 2008. ACARP Report C13013: Aquifer Inflow Prediction and Water Barrier Design for Longwall Panels

6 SUBSIDENCE RISK MANAGEMENT

Subsidence risks exist because the reliability of the predictions is uncertain and because the consequences of under-predictions may be unacceptable. An appropriate approach to manage the range of risks is to apply of the standard hierarchy of risk controls of elimination, substitution, engineering and administration.

On a local scale, prediction uncertainties can be eliminated by not extracting under or near the surface feature. The prediction uncertainties can be reduced by either substituting a mine layout with narrow panels and wide pillars such that there is confidence that the Bulgo Sandstone remains intact, or to have very wide panels so that the Bulgo Sandstone is definitely broken. The latter reduces the prediction uncertainties but could introduce a wide range of consequences that are deemed unacceptable.

6.1 ELIMINATION AS A CONTROL

6.1.1 Mount Ousley Road

Mount Ousley Road is the major road access between Wollongong and the South Coast and Sydney. In the some parts of the area of interest, Mount Ousley Road lies directly above a chain pillar in the Balgownie Seam (Figure 42). In terms of the Bulli Seam, the road lies partly above a wide extraction area and partly above first working pillars.

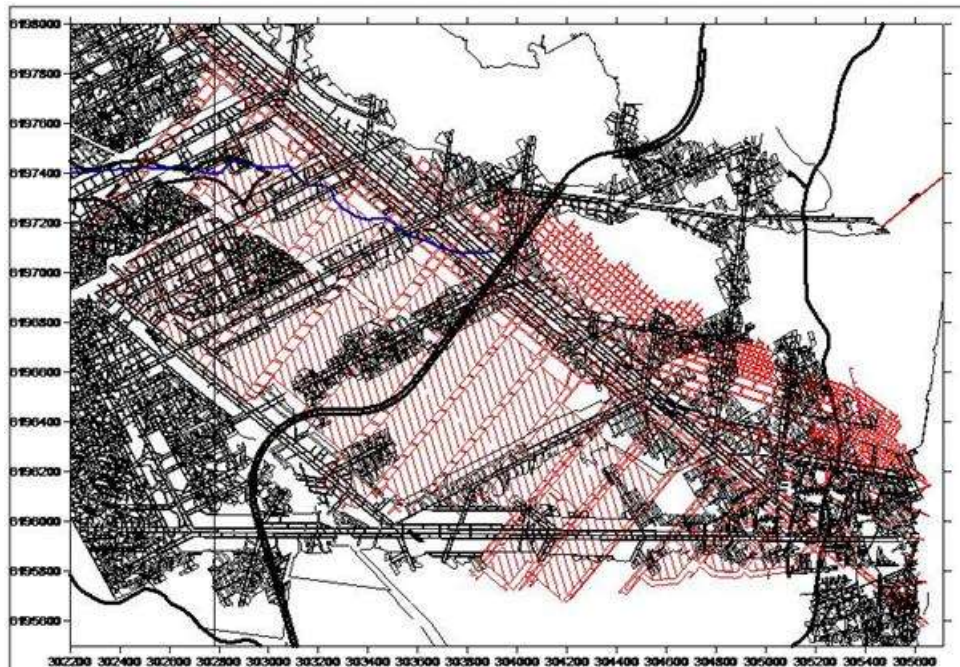


Figure 42 Mount Ousley Road and existing Bulli and Balgownie Seam workings

The Bulli and Balgownie extraction will have broken the Bulgo Sandstone and it assessed that there is no subsidence potential left in these 2 seams. This is particularly the case for Faces 6 and 7 adjacent to the road. This means that should subsidence develop distant from the road, it can not run through the pre-broken ground. Because of the pre-broken nature of the overburden, any Wongawilli longwall



extraction directly under the road (even at comparatively narrow widths) will produce large vertical subsidence, and high localised tilts and strains. One rejected mining layout considered longwall extraction under the road (see Appendix B).

A longwall elimination zone under and within 100m of the road is recommended where the road is above Bulli Seam extraction (Figure 43). For areas where the standing pillars in the Bulli Seam are indicated, engineering controls based on monitoring should be used to locate the finish line of the longwall panels.

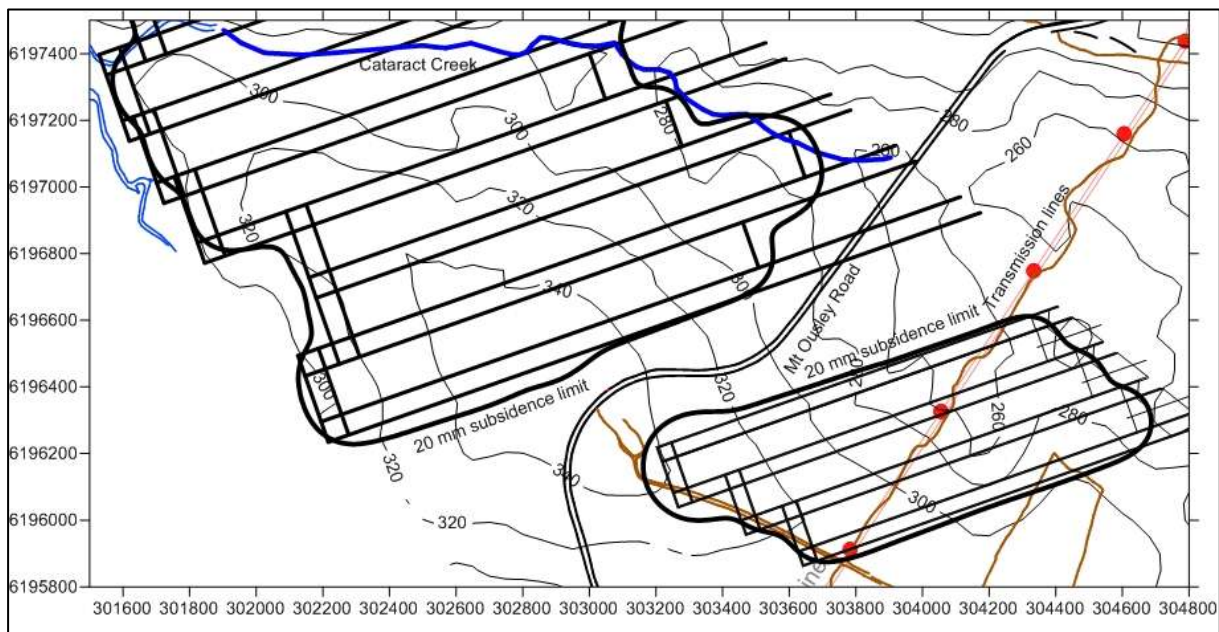


Figure 43 Proposed footprints for Wongawilli East with respect to Mount Ousley Road & Cataract Creek

6.1.2 Illawarra Escarpment

Based on the understanding of coal quality, the eastern end of the proposed extraction footprint is located 700m from the crest of the Illawarra Escarpment as defined as 340m ASL (Figure 44). The depth of cover to the Wongawilli Seam at this location is 260m, such that the angle of draw to the escarpment is 70°.

By reference to Figure 32, and anticipating the vertical subsidence predictions, the maximum expected horizontal movement at the crest of the escarpment would be in the order of 35mm. Better information is available from the monitoring of the 500 series panels where the maximum vertical subsidence was in the order of 250mm. In this case, at 700m distance, the horizontal movements were measured to be 20mm, and strains were less than 0.2 millistrain (Figure 45). Figure 45a highlights the difference between the horizontal movements with nominally 250mm subsidence (500 series and Station Y) and 1000mm (304 panel).

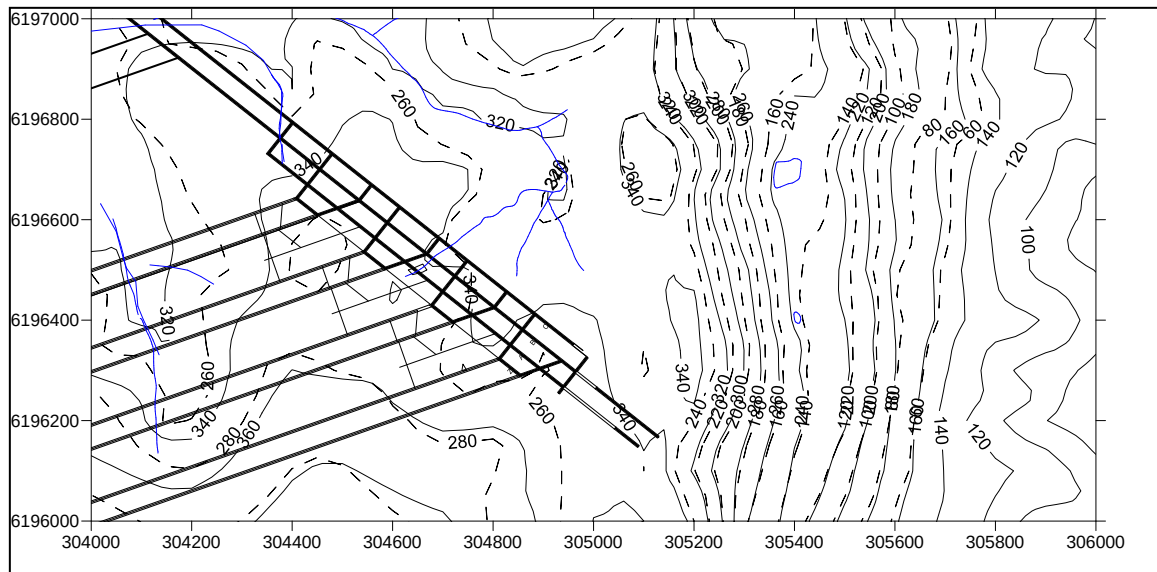


Figure 44 Location of possible extraction footprint in relation to escarpment

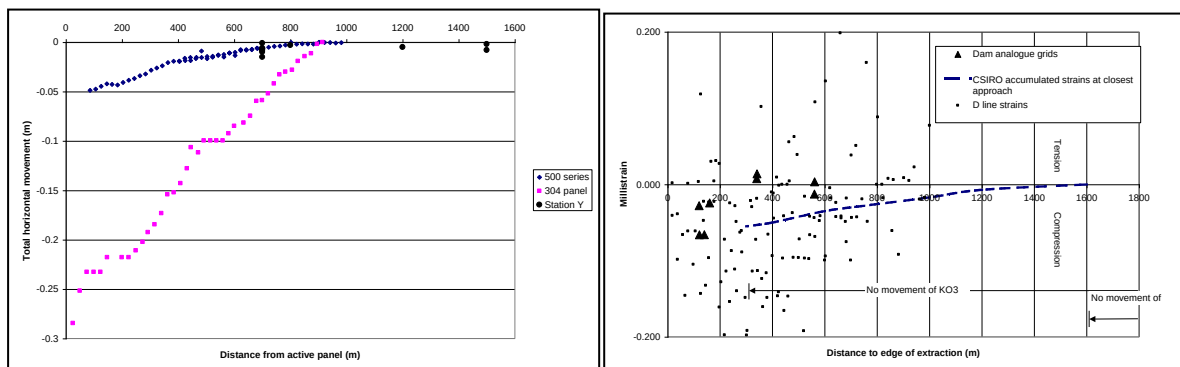


Figure 45 Horizontal movements associated with low levels of vertical subsidence in the 500 series panels

6.1.3 Cataract Reservoir

For the western area, the longwall extraction of Wongawilli Seam coal under the 500 series Bulli Seam longwalls directly under the stored waters would result in subsidence levels well beyond the current precedents. No such extraction is proposed for the western area.

Based on earlier dealings with the NSW Dams Safety Committee during the mining of the 500 series longwalls, a 1km distance from the spillway was set as a threshold for more detailed studies. The sequencing of the longwalls in the western area will not allow progressive collection of information so it is recommended that longwall extraction be eliminated inside this 1km limit (Figure 46).

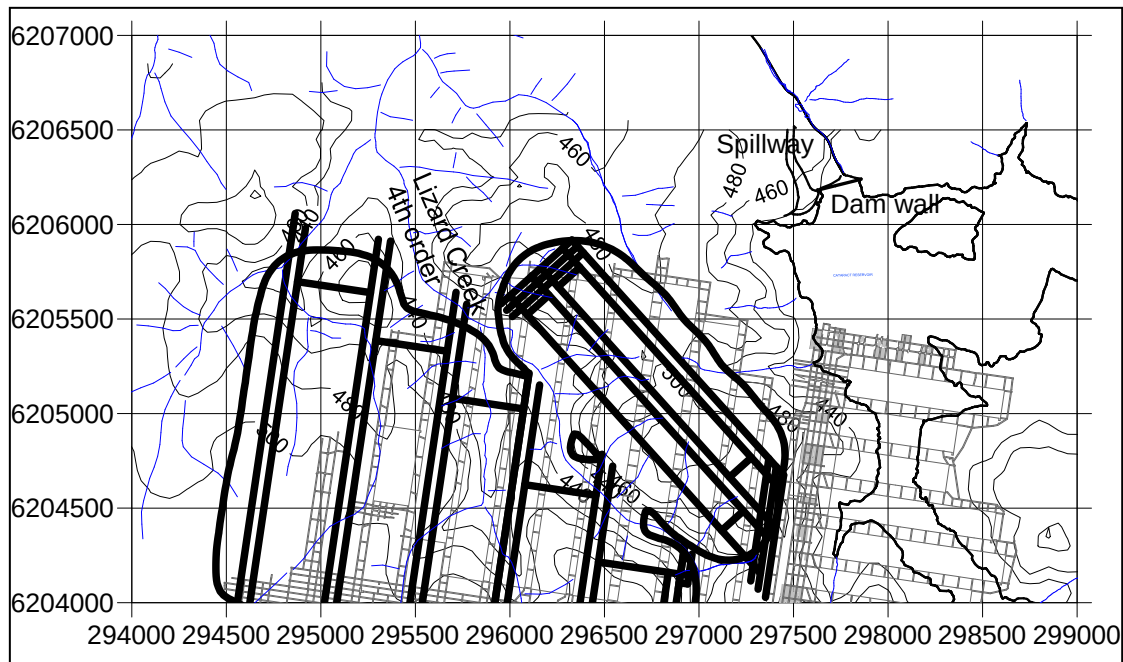


Figure 46 Extraction foot print for Wongawilli West area near Cataract dam

6.1.4 Fourth order Lizard Creek

Reflecting community concerns about mining near and under rivers, wide longwall extraction should be eliminated within a 200m offset from the centreline of the Lizard Creek. As will be outlined below, substitution with narrow layouts would be an alternative strategy.

6.2 SUBSTITUTION AS A CONTROL

The key to a substitution strategy is to reduce vertical subsidence but substituting narrow longwalls/wide pillars for wide longwalls/narrow pillars.

Longwalls in the Southern Coalfield have gradually increased in width such that the width at Appin, Westcliff and Dendrobium is in the order of 300m. Metropolitan Colliery utilises narrower panels (maximum of 163m). The maximum subsidence above these layouts is in the order of 1.2m to 1.4m, mainly reflecting the decision to have yielding chain pillars in order to maximise coal recovery.

The longwalling under Cataract Reservoir (op cit) substituted yielding pillars with large, very stable pillars and also used relatively narrow longwall panels. For the longwall panels closer the dam wall (LW514 onwards), the layout was based on 150m wide panels and 65m wide pillars. The maximum subsidence was 240mm and this involved 180mm above the chain pillars and 60mm of sag above the extraction. Compared to the Metropolitan outcome, the impact of wide pillars is highlighted.

The use of a layout with comparatively wide chain pillars provides a way of managing some of the subsidence risks at Wongawilli East. The elimination of the option of longwalling under Mount Ousley Road, together with operational considerations about panel alignment, requires a south-westerly orientation of the panels. With this orientation, the economic demands for longer panels require extraction within the DSC Notification Area and under the full supply level of Cataract Reservoir.



The DSC approved the 150m/65m panel and pillar layout and hence are familiar with the design concepts applied. The Wongawilli East area is shallower than the LW514 area and the application of the design to the deeper Wongawilli Seam is appropriate. A step-change in the geometry would require several years of monitoring data and analysis. A wide chain pillar layout also provides a way to consider extraction of coal under Cataract Creek in the Wongawilli East area. It is noted that there has been no Bulli or Balgownie pillar extraction in the Notification Area or directly under most of Cataract Creek – there are first workings.

6.3 ENGINEERING AND ADMINISTRATIVE CONTROLS

For longwalls, the principal engineering control is the ability to change the location of the start and finish lines of each panel. Administrative controls are incorporated in the various management plans required by the regulator.

The many uncertainties with the subsidence prediction in the multiple seam layouts required in the 2 areas means that it is not appropriate to seek to quantify the subsidence deformations at this time.

There will be a need to closely monitor the subsidence that develops as the walls are extracted and use this data to refine the controls.

7 SUBSIDENCE WITHIN THE WONGAWILLI EAST FOOTPRINT

This section presents a subsidence prediction and visualisation based on a very large degree of judgement in the absence of calibration/validation data. It is presented as an example of how subsidence management can be implemented and to provide indicative subsidence parameters for environmental assessments.

7.1 ELIMINATION AND SUBSTITUTION CONTROLS

The longwall footprint has been defined within an area more than 700m from the Illawarra Escarpment. It is assessed that the Bulli goafs and small Bulli pillars below Mount Ousley Road are fully collapsed and this means that the risk of a subsidence run under the road is eliminated. There is no longwall mining in the Wongawilli seam proposed within at least 100m of Mount Ousley Road.

Narrow longwalls are proposed for the Wongawilli Seam to allow longwall extraction within the Notification Area where there has been no secondary extraction of either the Bulli or Balgownie Seams. A consequence of this decision is that low levels of subsidence will develop in other areas where there are no Balgownie longwalls and large Bulli pillars.

7.2 LAYOUT OPTION

The layout under investigation involves 150m wide panels with 65m pillars inside the footprint defined by the elimination controls.

Based on previous dealings with the NSW Dams Safety Committee, their starting position is based on the Reynolds Recommendations, which were never formally adopted by the NSW Government. These guidelines involved a panel width no more than 1/3 depth and a pillar width no less than 1/5 depth (or more than 15 times the seam thickness). At Bellambi West, and directly under the stored



water, the panels were increased to 150m width and the pillars increased in width to 65m to maintain the same factor of safety (approximately 5.2). The minimum depth of cover was 310m to 410m.

For the Wongawilli East area, the depths to the Wongawilli Seam area are 300m to 340m, the proposed panels are 150 wide and the pillars are 60m wide. The start lines for the panels are offset 110m from the maximum stored water level. In the following calculations, the gateroad height is assumed to be 3.0m, with sensitivities determined at 3.2m or 3.5m. Table 6 shows that the factors of safety are in the range of 3.3 to 5.4.

As a frame of reference, long term stability is conventionally defined as a factor of safety of 2.11 for the squat equation if the pillar stresses are known with a high level of confidence. A threshold value for chain pillars and chain pillar loading has not been established. For the Bellambi West mining directly under the stored water values of 5.2 were accepted. It is assessed that the values in Table 6 are suitable for the mining which is not under the stored water and is offset by 110m.

With regards to the pillar loadings in the overlying seams, it is not possible to accurately model the complex and possibly temporal changes in pillars stresses in the Bulli and Balgownie Seams. This is one of the reasons why we have avoided making detailed subsidence predictions and adopted the risk management approach of elimination in key areas.

Table 6 Pillar stability calculations

Goaf angle	21					
Loading factor	2					
Depth (m)	310			340		
Pillar stress (MPa)	20.6			23.2		
Height (m)	3.0	3.2	3.5	3.0	3.2	3.5
Width/height ratio	20	18.7	17.1	20	18.7	17.1
Squat effective (MPa)	111.4	95.3	77	111.4	95.3	77
Linear, minimum width (MPa)	48.6	45.8	42.3	48.6	45.8	42.3
Factor of safety - squat	5.4	4.6	3.7	4.8	4.1	3.3
Factor of safety - linear	2.4	2.2	2.1	2.1	2.0	1.8

7.3 SUBSIDENCE VISUALISATION

7.3.1 Base case

A subsidence bowl has been determined using SDPS and shape parameters $\tan B = 4.0$, and strain coefficient of 0.35 (Figure 47). The statistical distributions of tilts and strains are shown graphically in Figure 48. The maximum tilts are 18 mm/m and the range of strains are from -14 mm/m to 16mm/m.

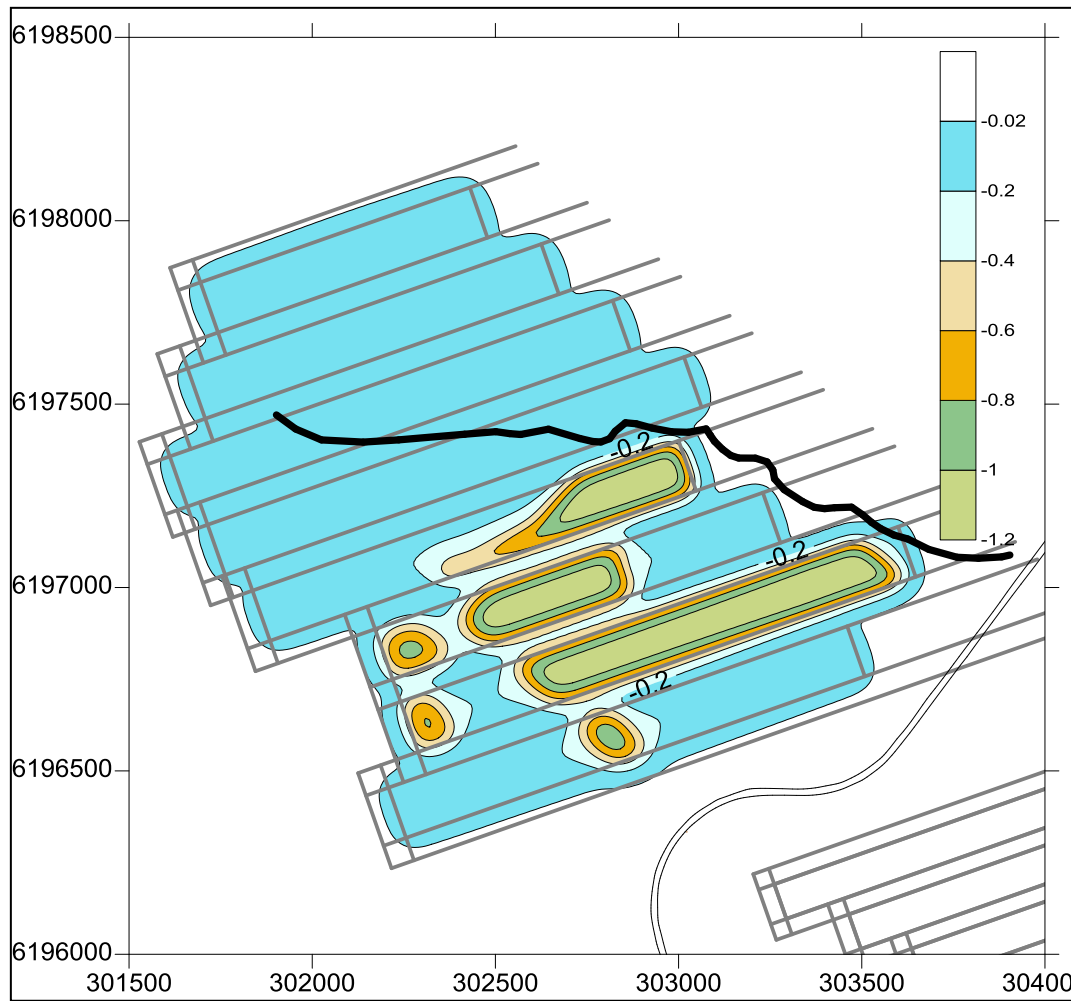


Figure 47 Vertical subsidence above Wongawilli East option

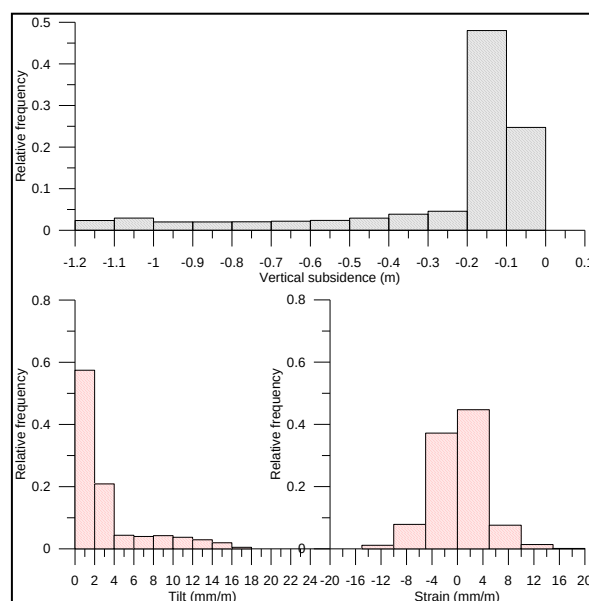


Figure 48 Histogram on the non-zero subsidence parameters for Wongawilli East



7.4 OTHER DEFORMATIONS

For the 150m panel/60m pillar layout used at Bellambi West, the vertical subsidence was measured to be in the order of 200mm-250mm with no valley closure across the arms of Cataract reservoir. On this basis, no “regular” valley closure and associated upsidence has been predicted for Wongawilli East.

The prediction of closure and upsidence in Cataract Creek relies on the prediction of vertical subsidence shown in Figure 2. The 1000mm of subsidence above longwalls 5 and 6 (Figure 47) is based on the worse case assumption that the Bulli pillars will collapse. This is an extreme assumption, because the subsidence data indicate that they did not collapse when undermined by the Balgownie longwalls.

Given the distance from Cataract Creek and the low levels of subsidence, a value of 50mm of closure is an appropriate value to use to identify any hazards in this creek.

7.5 SITES OF SPECIAL SIGNIFICANCE

7.5.1 Mount Ousley Road

As mentioned earlier, Mount Ousley Road is positioned on a chain pillar between two Balgownie longwall panels (Faces 6 and 7).

Both these centrelines show subsidence in excess of 3ft after the extraction of the Balgownie Seam. Given the seam thickness was in the order of 4ft, there is a very high degree of confidence that the overburden above both these faces has fully collapsed. A corollary of this is this collapsed zone provides a “barrier” to any lateral progression of subsidence that may induced by any mechanism in the immediate vicinity. Therefore, the prediction is that no significant deformations will be imposed on Mount Ousley Road.

Recognising the distance from the longwalls and its location, the Picton Road bridge over Mount Ousley Road is not exposed to mining-induced movements. The bridge is approximately 840m distant from the closest longwall extraction and the bridge itself is located on the southern side of a valley and does not span the valley.

7.5.2 Cataract Creek

There has been no pillar extraction of the Bulli and Balgownie Seam under about half the length of this creek and in this area the proposed narrow longwalls and wide chain pillars will not destabilise the Bulli pillars. In areas where there has been earlier extraction, it is proposed that the Wongawilli Seam longwalls will be cut short. The result of these strategies is a vertical subsidence less than about 200mm (Figure 49).

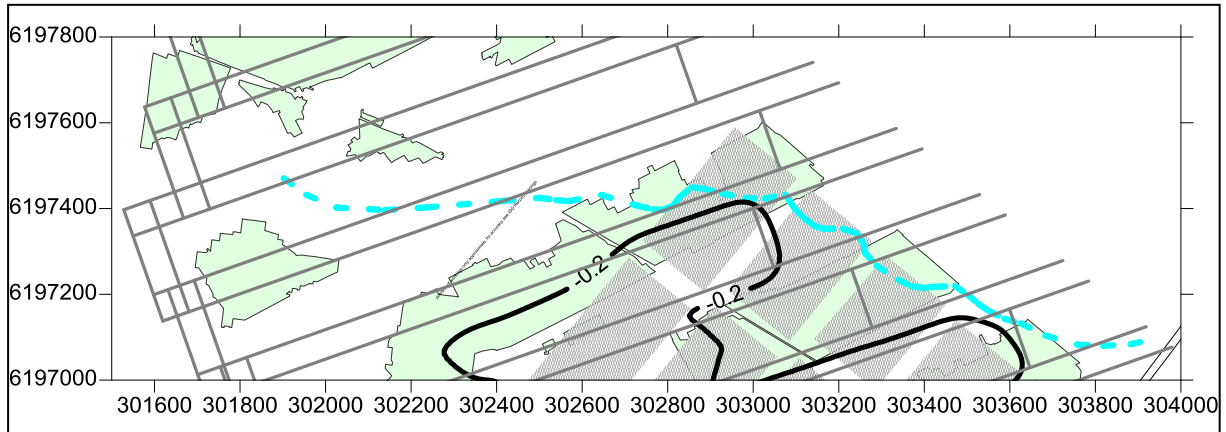


Figure 49 Details of the vertical subsidence (200mm contour), Bulli goafs (green) and Balgonwie goafs (hatched)

7.6 SIGNIFICANT NATURAL FEATURES

Figure 50 shows the subsidence footprint with respect to sensitive ecological communities in the Wonga East Area 2.

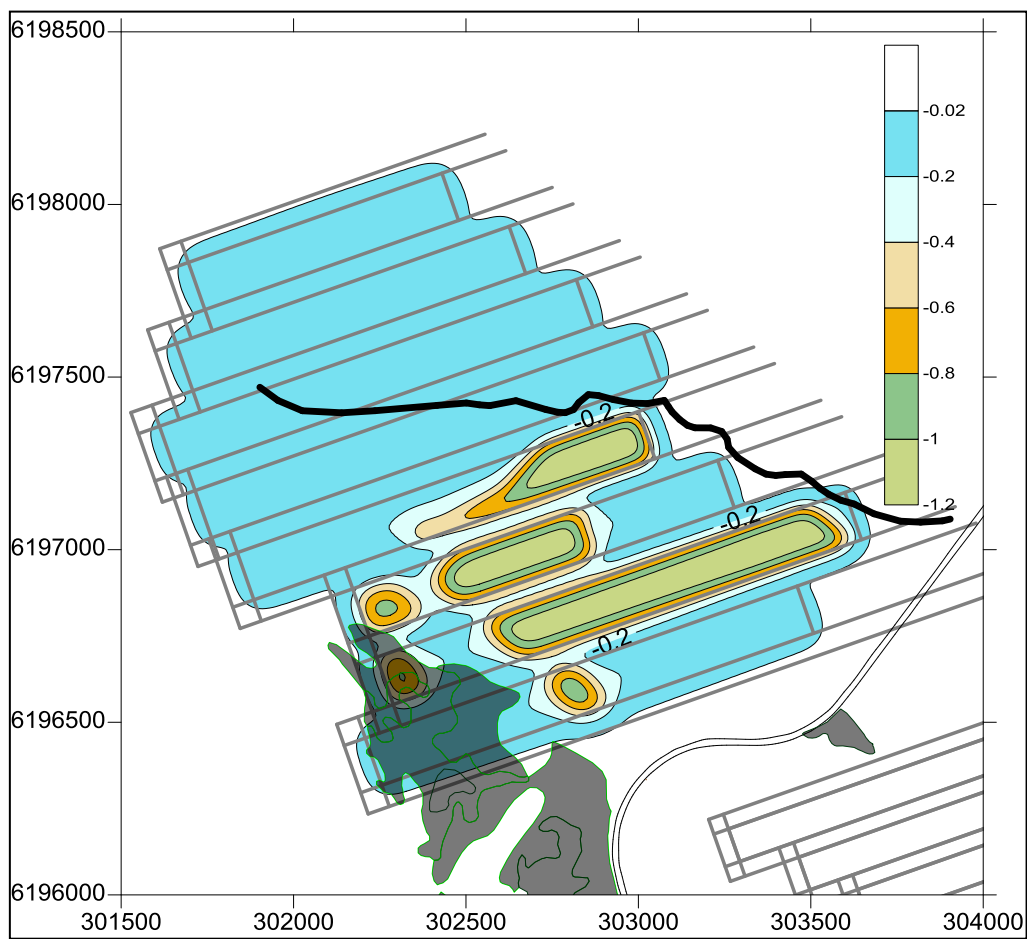


Figure 50 Significant features at Wonga East



8 SUBSIDENCE WITHIN THE WONGAWILLI WEST FOOTPRINT

8.1 ELIMINATION AND SUBSTITUTION CONTROLS

No longwall extraction is planned within 1 km from the spillway and dam wall of Cataract Reservoir or directly under the named 3rd or all 4th order creeks. A longwall is proposed under an un-named 3rd order creek

The possibility of narrowing the extraction under the creeks was examined. The geotechnical limitations on where to place the gateroads meant that the option resulted in panels being uneconomic.

8.2 LAYOUT OPTION

The mine plan locates the main headings in close proximity and aligned with Lizard Creek and then extracts wide longwalls to the south with a parallel and staggered layout (Figure 51).

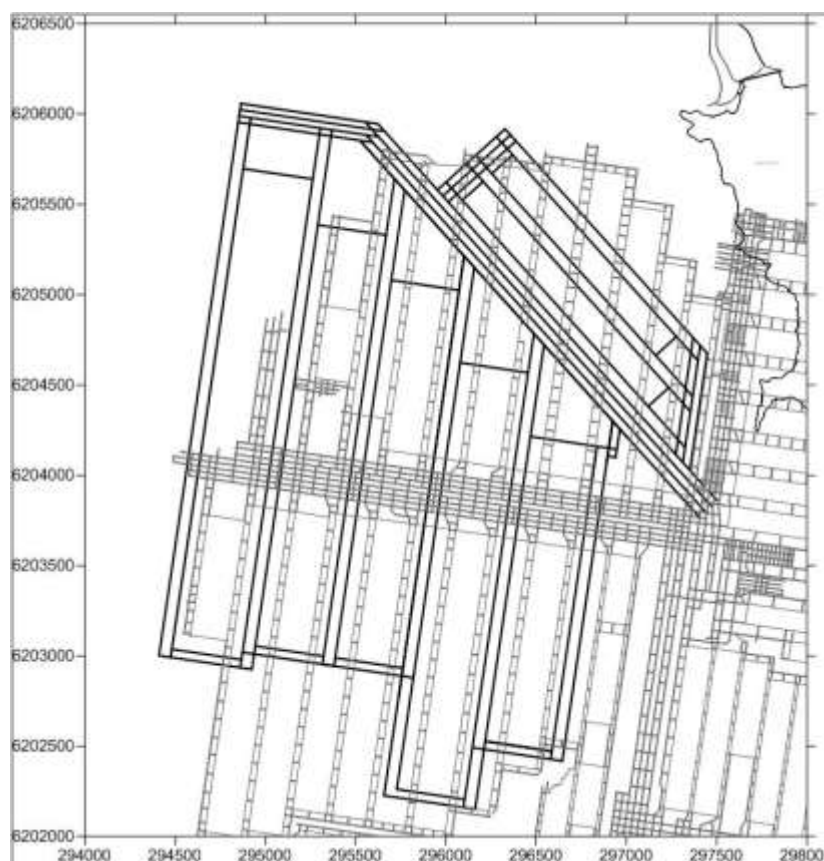


Figure 51 Current option being considered for Wongawilli West

8.3 SUBSIDENCE VISUALISATION

A visualisation of the subsidence bowls associated with just the Wongawilli Seam extraction is shown in Figure 52, and the combination of Bulli and Wongawilli Seams in Figure 53. Histograms of vertical movement and tilts are presented in Figure 54.

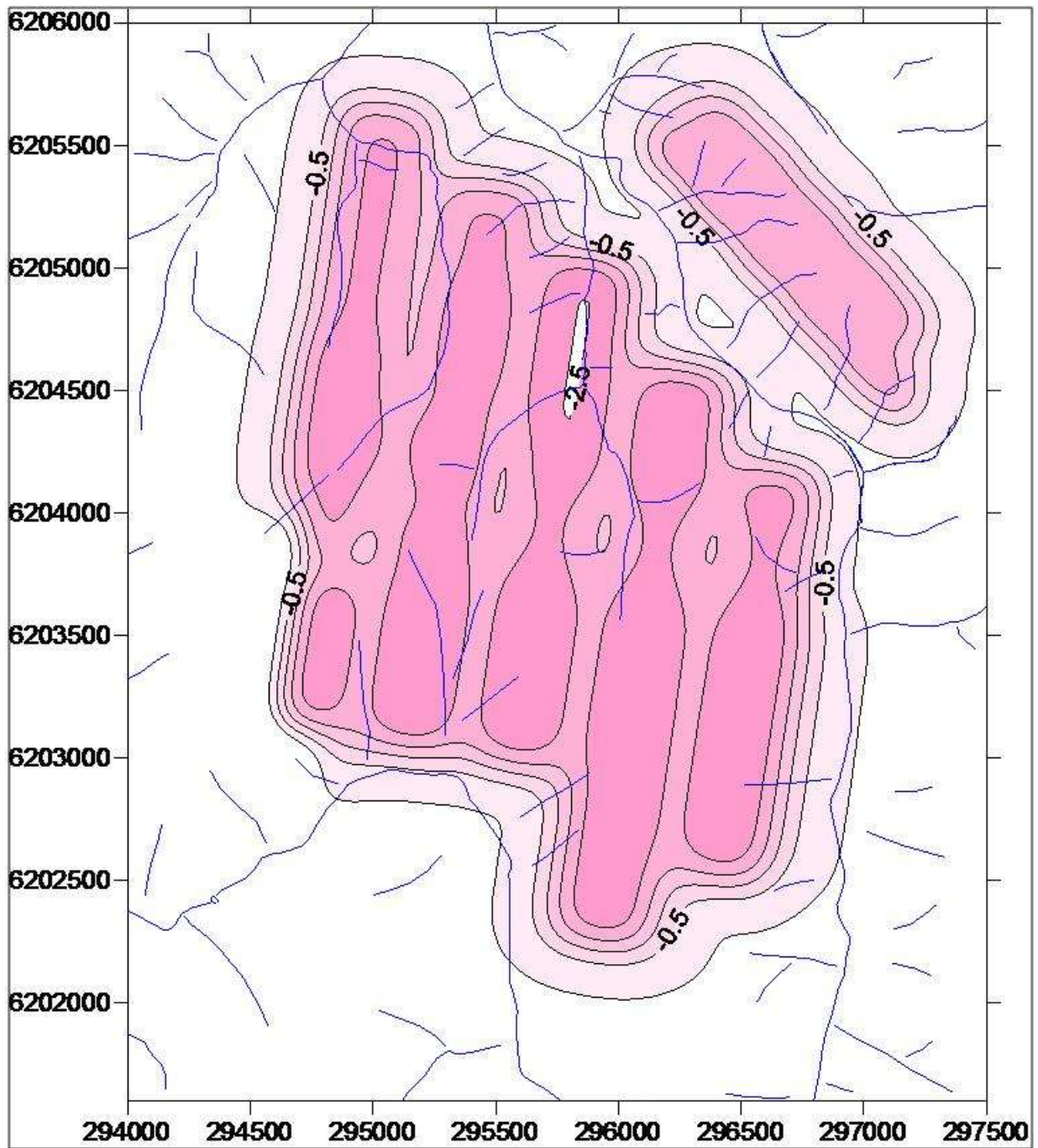


Figure 52 Possible vertical subsidence above the proposed Wongawilli West layout

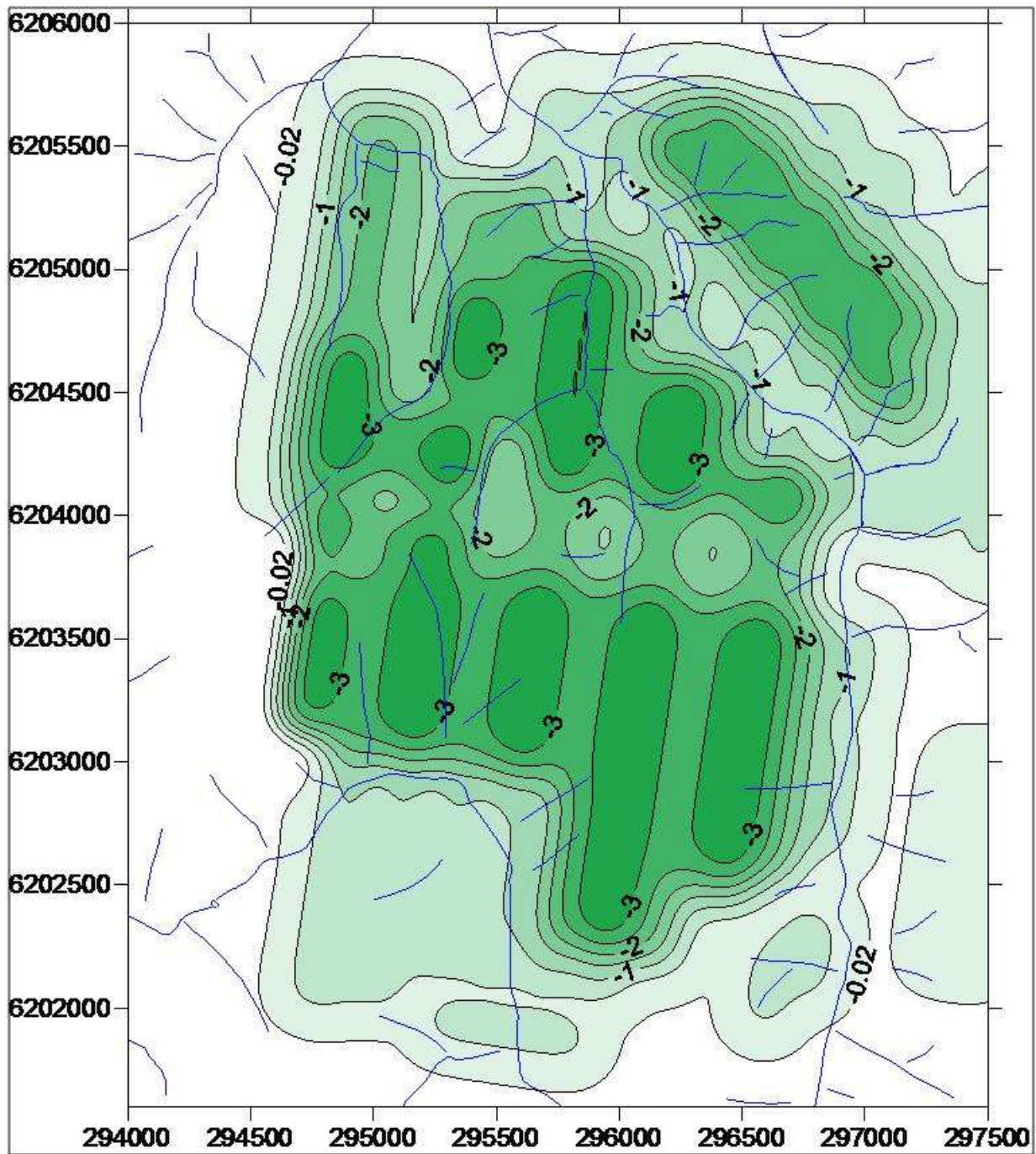


Figure 53 Combined Bulli and Wongawilli vertical subsidence for Wongawilli West

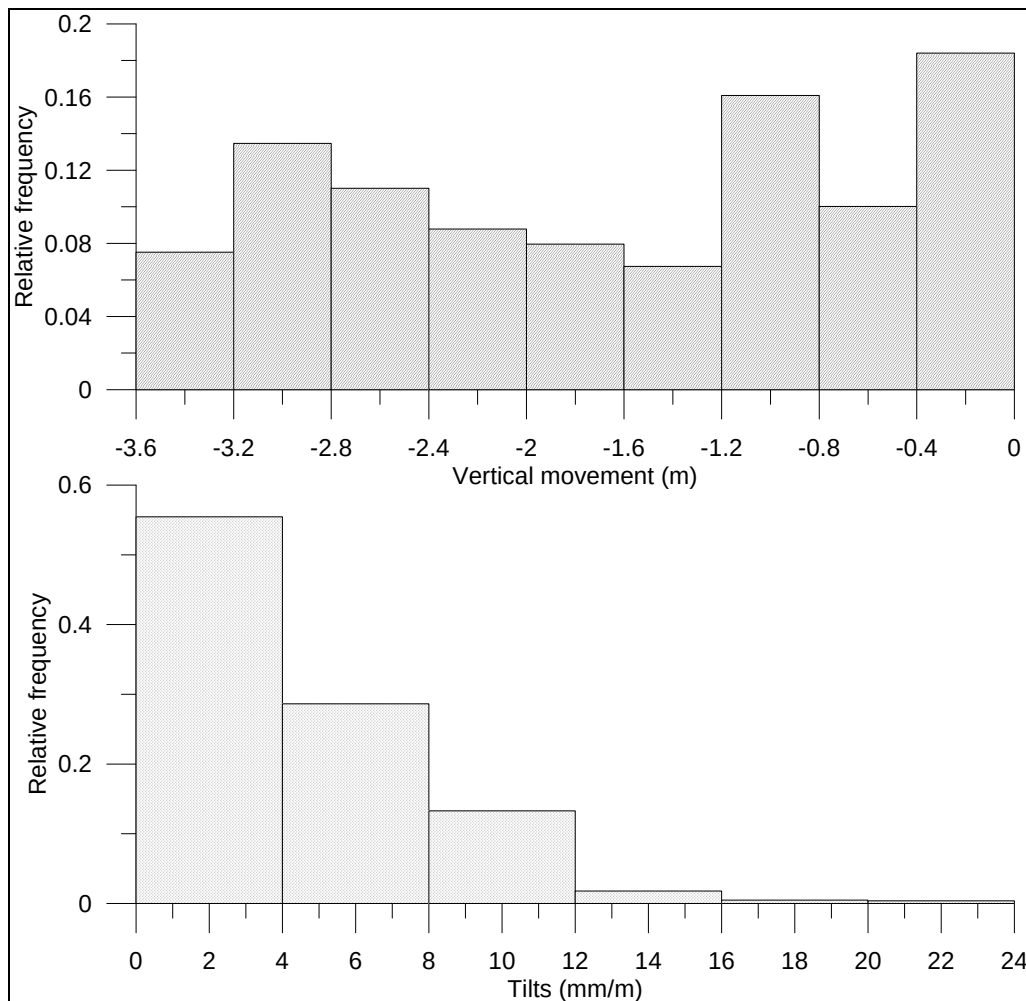


Figure 54 Statistics of vertical movements and tilts induced by both seam

8.4 OTHER DEFORMATIONS

The available prediction method for closure and upsidence is based on single seam extraction with wide panels and small pillars and does not provide a system for dealing with multiple seams – such a layout was not envisaged when the system was developed. Detailed reference to the available method would be misleading and give any prediction more credence than can be justified. It is noted that subsidence associated with the proposed mining will be less adverse than that already imposed on the Lizard Creek by the Bulli extraction.

Because of the decision to eliminate longwall extraction under named 3rd order creeks, the systematic strains in these creeks can only be tensile. Because of block rotations above the longwall extraction panels there may be some compressive strains transferred to the creeks. Valley closures of about 100mm and upsidence of about 60mm should be anticipated. The comment by the FMEA review was that it would be good practice to double these estimates in the context of an impact risk assessment.

8.5 SITES OF SPECIAL SIGNIFICANCE

Longwall extraction has been eliminated from the area of the dam wall and the DSC notification area.

8.6 SIGNIFICANT NATURAL FEATURES

Figure 24 shows the likely subsidence that has already been imposed onto the third order Lizard and Wollandoola Creeks by the Bulli Seam longwalls. Up to 1m of vertical subsidence is predicted to have occurred based on survey data above some of the 300 series walls. Also shown in Figure 55 are the significant natural features discussed in Section 2. Based on the survey conducted in 2009, there are several upland swamps and transitional shale forests above the already subsided areas.



Figure 55 Compilation of subsidence and surface aspects of Area 3 in Wongawilli West (shaded contours – Bulli Seam subsidence, black line – 20mm and 100mm of Wongawilli subsidence, green areas – swamps, purple/pink – transitional forests)



It is understood there is evidence of likely mining-induced enhancement of underflow along significant portions and that water quality in Lizard Creek downstream of mining area is of very high quality (Geoterra – personal communication).

It is assessed that the creek systems have a degree of “robustness” and that the previous mining has not caused significant damage even on a local scale. On this basis it is assessed that the 125m offset from the 3rd order creeks to the first longwall panel in Area 3 will minimise or possibly remove any additional impacts. With vertical subsidence less than about 100mm, it is assessed that there will be no significant change in gradients so no pooling or flow reversals.

8.6.1 Lizard Creek

There is a portion of the creek that currently has subsidence deformations in excess of 100mm, with associated higher tilts and strains. If subsequent predictions, to be made once validation data are available, give high values as that are determined to be unacceptable, the location of the finish line of the relevant longwall could be adjusted.

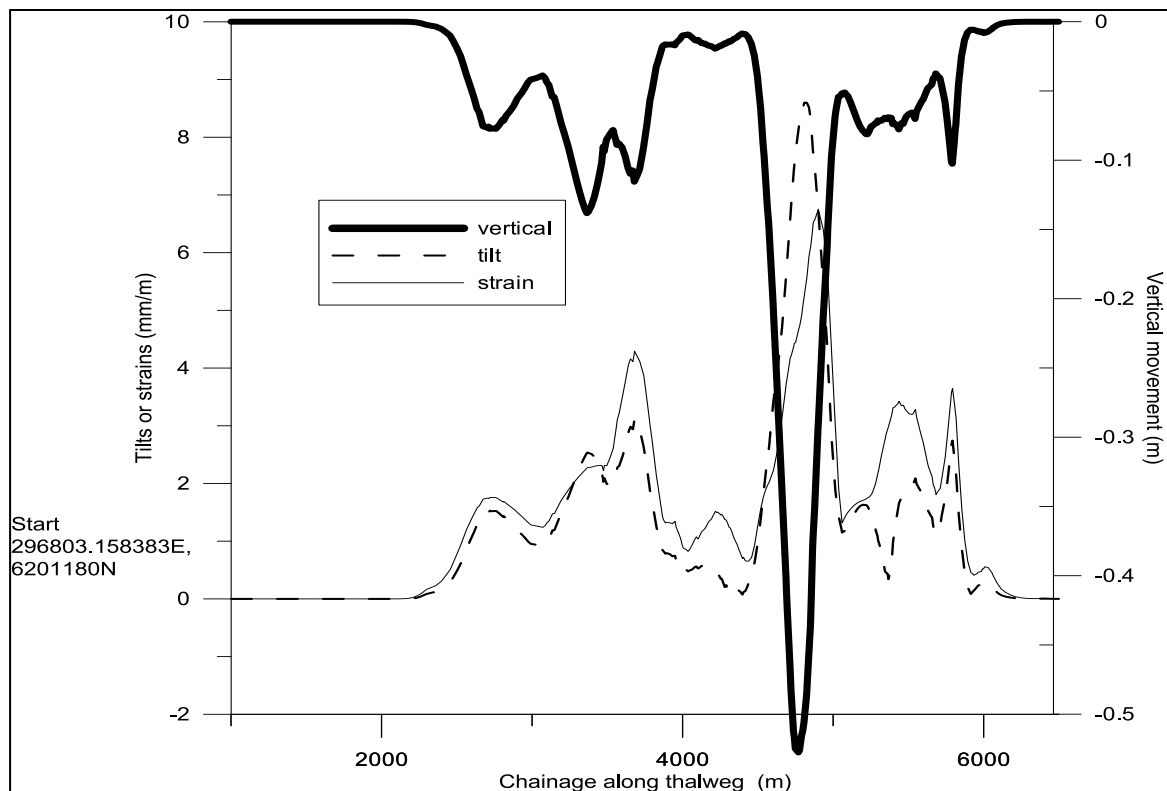


Figure 56 Visualised subsidence parameters along the thalweg of Lizard Creek



APPENDICES

- A. SEEDSMAN GEOTECHNICS
- B. REJECTED MINE LAYOUTS
- C. FMECA



APPENDIX A - CV

ROSS SEEDSMAN

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MINE GEOTECHNICAL ENGINEER

Specialist geotechnical advice to mining companies from operations to board level. Demonstrated success in introducing rigorous engineering analyses to mining operations and planning. Track record of applying specialist skills to achieve productivity improvements and environmental outcomes. Commitment to the transfer of knowledge and experience to the wider industry through publications, conferences and workshops.

- Ground control in coal mines
- Mine subsidence
- Feasibility and planning studies
- Due diligence studies
- Slope stability in coal and metal mines
- Site investigations
- Rock mechanics research
- Training and lecturing

Professional Experience

DIRECTOR
SEEDSMAN GEOTECHNICS PTY LTD – 1998 TO PRESENT
Wollongong, NSW

Specialist geotechnical advice within an informal network of like-minded professionals. Training and mentoring of site geotechnical engineers. Support to projects involving changes in roadway development systems and roof support. Subsidence engineering to exploit geotechnical conditions in the overburden. Slope stability in steeply dipping seams and low strength materials. Industry-funded research into subsidence and roof/rib support. Due diligence studies. Clients in Australia, Columbia, Canada, Mongolia, Iran, Kazakhstan, Congo and Mauritania.

Selected projects:

- ✓ Redesign of longwall layout to accommodate tight environmental constraints.
- ✓ New models for the behaviour of coal roof in roadway development.
- ✓ Industry funded research to document analytical approach to specifying ground support.
- ✓ Independent geotechnical peer reviewer for major international mining house.
- ✓ Invited by European Bank for Reconstruction and Development to present keynote lecture on roof support in Astana.



- ✓ Invited by SME to author chapter on rock mechanics for Mining Engineering Handbook.

MANAGER - MINING
COFFEY PARTNERS INTERNATIONAL – 1993 to 1997
Sydney, NSW

Principal and then Manager. Initially appointed to grow the underground mining sector. Rebuilt the group to include 8 engineers and geologists working in both surface and underground mines in Australia, Indonesia and the Philippines. Personal involvement in projects such as design and construction monitoring of a 120m deep, 1.2km long river diversion around a gold mine in Indonesia, assessment of water inflows into longwall mines, and subsidence impacts on rivers.

MANAGER – GEOTECHNICAL ENGINEERING
AUSTRALIAN COAL INDUSTRY RESEARCH LABORATORIES - 1988 to 1992
Wollongong, NSW

Initially appointed to manage the rock testing laboratory. In last 2 years managed a group of 12-15 geologists, geophysicists and mining engineers. Conducted and managed a number of major research projects and numerous consulting commissions, including thick seam longwalling, better subsidence prediction, geotechnical feasibility studies for new longwall projects.

EXPERIMENTAL OFFICER
CSIRO DIVISION OF GEOMECHANICS – 1978 to 1987
Brisbane, Queensland

Research into the behavior of clay-rich rocks in the mining environment. Re-analysis of spoil pile failures in the Bowen Basin. Application of soil mechanics to floor heave and roof support in the presence of clay-rich tuffaceous rocks.

Education & Credentials

Bachelor of Science, Geology, 1974, University of Melbourne
Master of Science, Sedimentology, 1978, University of Melbourne
Doctor of Philosophy, Civil Engineering, 1988, University of Queensland,

Certified Professional Geotechnical (Mining) – AusIMM
Registered Professional Engineer – Queensland
Member – Australasian Institute of Mining and Metallurgy
Member – Australian Geomechanics Society



Paper by Dr Seedsman on coal mine subsidence

Calibrated parameters for the prediction of subsidence at Mandalong Mine. Coal 2010 - 10th Australasian Coal Operators' Conference, Wollongong, February 2010.

Techniques to Predict and Measure Subsidence and Its Impacts on the Groundwater Regime above Shallow Longwalls. ACARP Report C13009.

Designing a longwall layout in the face of stringent subsidence constraints – the Mandalong Experience. Mine Subsidence Technological Society, 7th Triennial Conference Proceedings, Wollongong – November 2007

Numerical modelling of mining induced subsidence. Keilich, W, Seedsman, R.W. and Aziz, N. Coal 2006 - 7th Australasian Coal Operators' Conference, Wollongong, 2006

An analytical subsidence prediction method to maximise underground coal extraction under tight environmental constraints. 2nd International Conference on "Advances in Mineral resources management and Environmental Geotechnology" Hania, Crete – 2006.

Back Analysis of Sub-Critical Subsidence Events In the Newcastle Coalfield Using Voussoir Beam Concepts. Mine Subsidence Technological Society, 6th Triennial Conference Proceedings, Maitland – August 2004.

A review of methods to determine panel and pillar dimensions to limit subsidence to a specified impact. Coal 2004 - 5th Australasian Coal Operator's Conference, Wollongong, 2003.

Case studies in the application of influence functions to visualising surface subsidence. Coal 2003 4th Australasian Coal Operator's Conference, Wollongong, 2003.

Coal extraction beneath Cataract Reservoir: Mining at Bellambi West from 1998 to 2001. *in* Coal Mine Subsidence 2001 – Current Practice and Issues. Mine Subsidence Technology Society, 5th Triennial Conference Proceedings, Maitland – August 2001.

Sensitive infrastructure and horizontal ground movements at Newstan Colliery. *in* Coal Mine Subsidence 2001 – Current Practice and Issues. Mine Subsidence Technology Society, 5th Triennial Conference Proceedings, Maitland – August 2001.

The ground – more than a surface to build on. *in* Buildings and Structures subject to ground movement. Mine Subsidence Technology Society, 4th Triennial Conference Proceedings, Maitland – July 1998.



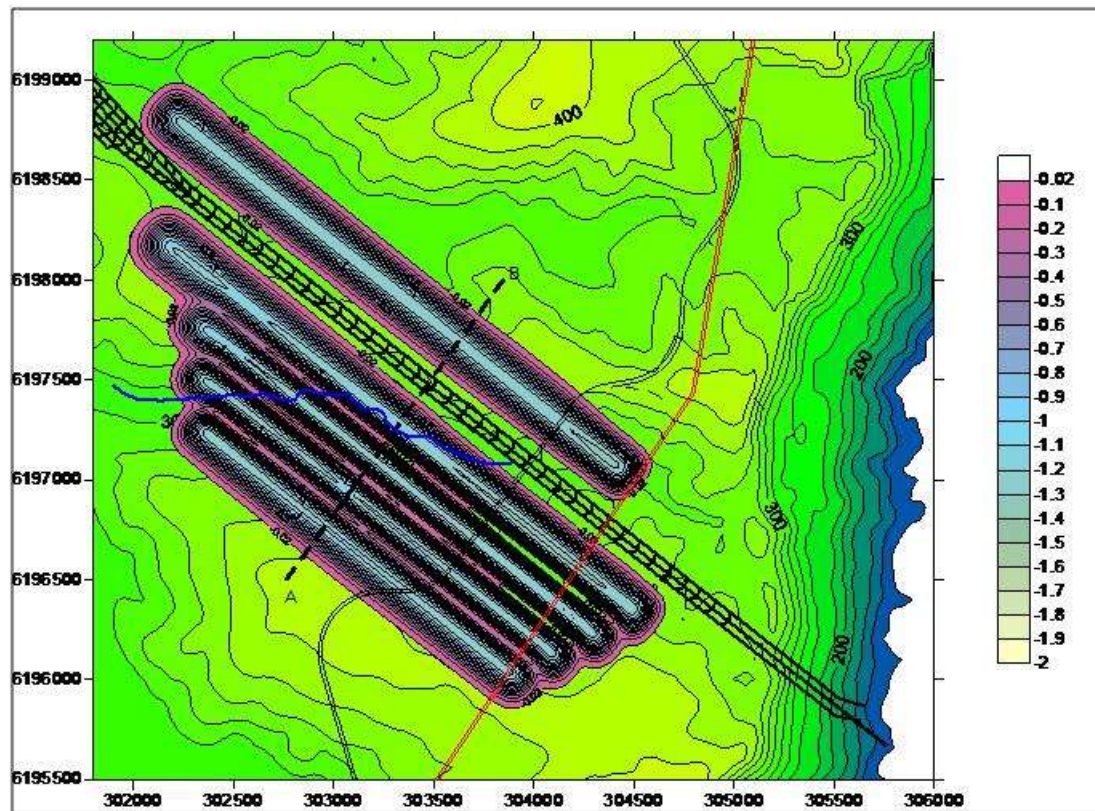
APPENDIX B

REJECTED OPTIONS

Wongawilli East

This option involved long panels aligned parallel to the Wonga Mains. Both wide (250m) and narrow (150m) options were examined. This option had high coal recoveries and high rates of investment return. Predicted strains under Mount Ousley Road were in the order of 8-10 mm/m and discussions with RTA indicate a very strong reluctance to consider this.

Elimination of longwall extraction under Mount Ousley Road was adopted and layouts aligned north east investigated

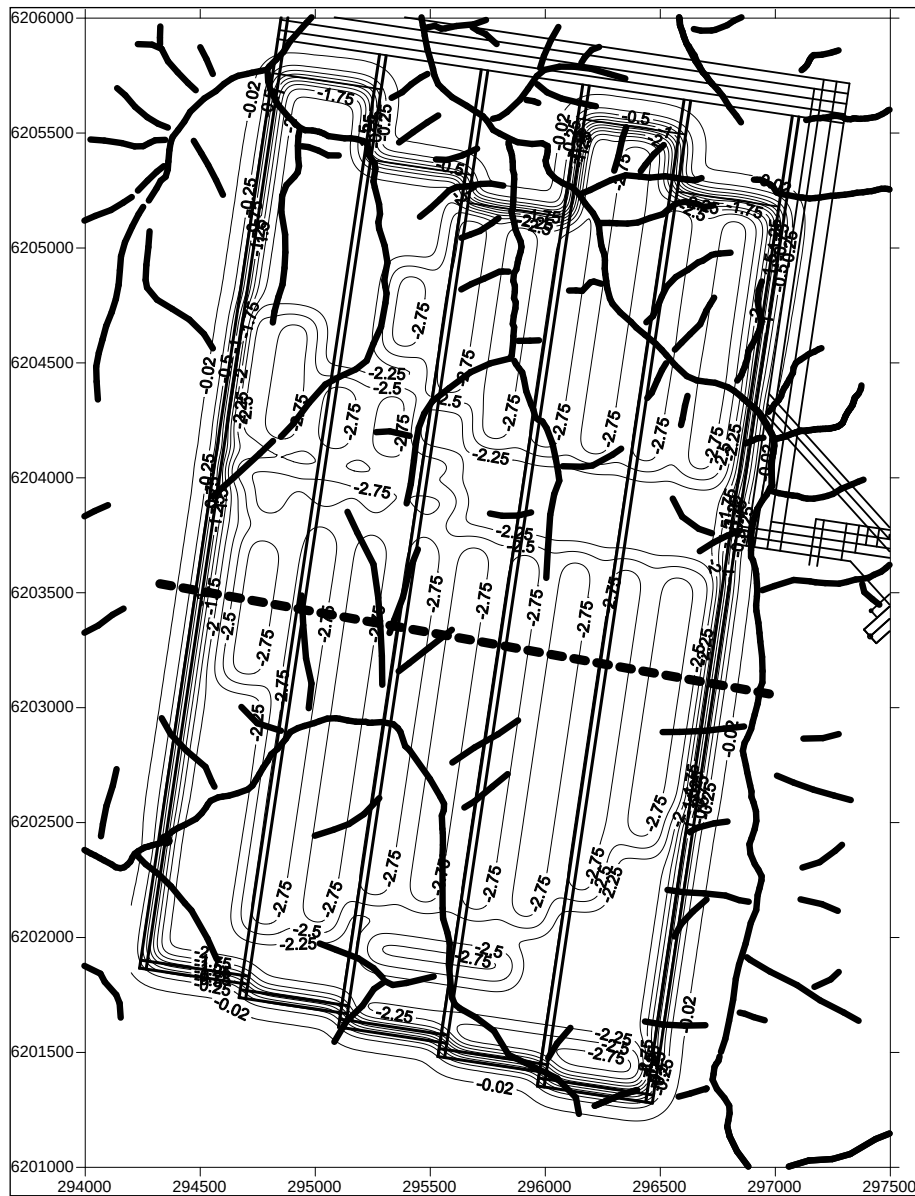


Vertical subsidence patterns in the Wongawilli East area for the rejected layout



Wongawilli West

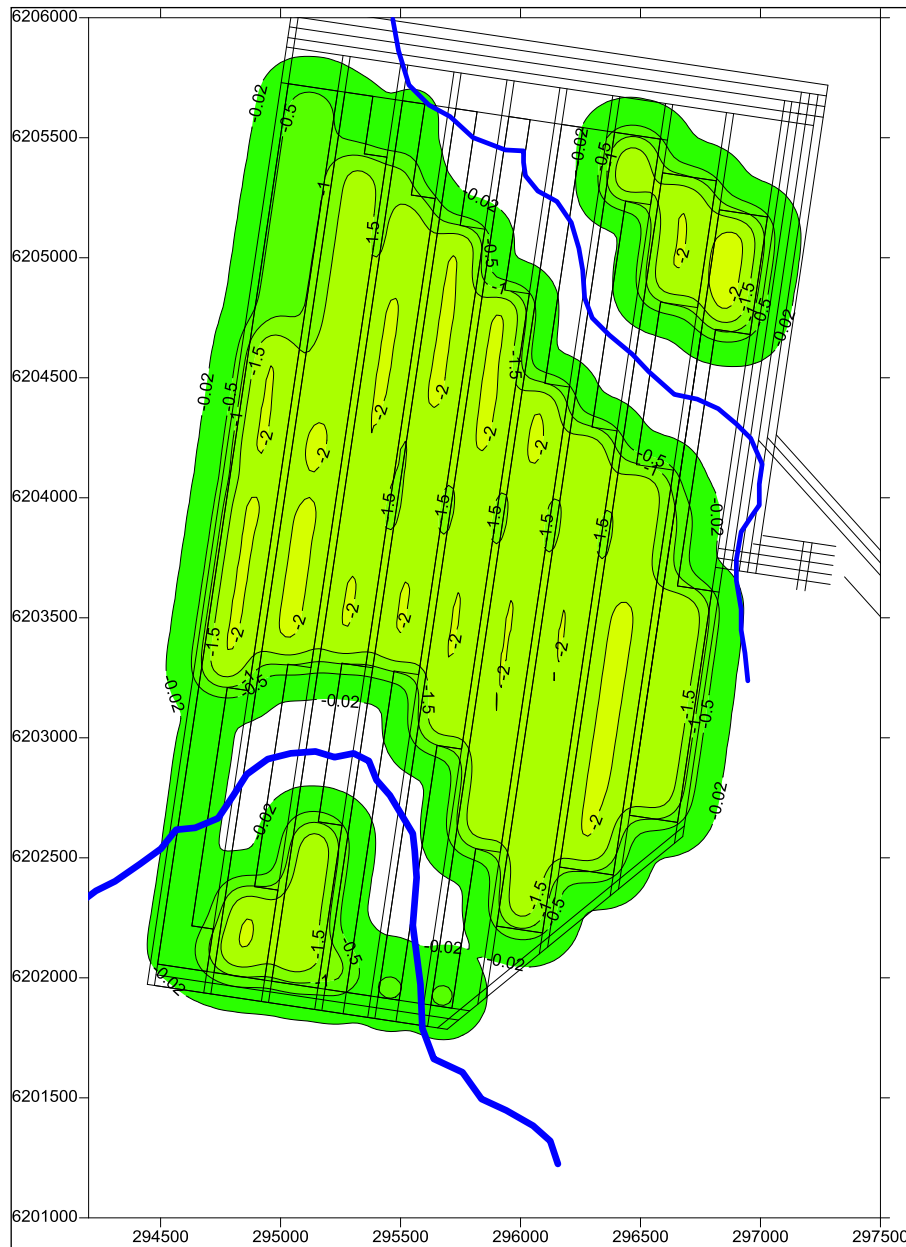
This option involved wide panels taking all of the assessable coal outside of 4th order streams. The layout was rejected due to hazards of up to 3m of subsidence under the 3rd order creeks – Lizard/Wollandoola Creeks.



Vertical subsidence patterns for the rejected wide longwall layout in Wongawilli West (subsidence after both seams)

Wongawilli West

This utilised a staggered layout with panel widths in the Wongawill Seam set by the Bulli Seam layout, and narrowing these even more to pass under the 3rd order creeks. The layout was assessed to be uneconomic and a number of practical mining limitations with respect to ventilation were identified.



Vertical subsidence patterns with the narrow Wongawilli layout.



APPENDIX C

OLSEN ENVIRONMENTAL CONSULTING PTY LIMITED

DRAFT

NRE No. 1 Colliery
Wongawilli Longwalls
Risk Associated With Subsidence
Prediction Methodology

Failure Mode and Effects Analysis Report

April 2010





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NEW SOUTH WALES**

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OEC File Reference: P84/2308



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3. OUTCOMES, FINDINGS AND RECOMMENDATIONS	5



**FINAL DRAFT Failure Mode and Effects Analysis Report
NRE No 1 Colliery Wongawilli Longwalls
Risk Associated With Subsidence Prediction Methodology
April 2010**

1. INTRODUCTION

Gujarat NRE FCGL Ltd (NRE) own and operate the NRE No 1 Colliery at Russell Vale and are planning to continue to operate the colliery. NRE are required to obtain a valid development approval for the Colliery in accordance with the Environmental Planning and Assessment Act 1979 (EP&A Act). This requires the preparation of an Environmental Assessment under the provisions of Part 3A of the EP&A Act. NRE have commissioned Environmental Resources Management (ERM) to prepare an Environmental Assessment.

Part of the mining development of the continued operations of the colliery includes a proposal to mine Wongawilli coal from areas identified as:

- Wongawilli East Areas 1 and 2, and
- Wongawilli West Areas 3 and 4.

The proposed mining will be undertaken in the Wongawilli Seam. The subsidence prediction methodology is described in a report prepared by Seedsman Geotechnics Pty Ltd, "Gujarat No 1 Colliery Management of Subsidence Risks Associated with Wongawilli Seam Extraction" dated March 2010.

In the areas of interest see areas the Bulli Seam and in some places, the Balgownie Seam have already been extracted either by longwall or pillar extraction techniques. As a result there are a number of constraints and assumptions that are fundamental to the subsidence predictions and these will require ongoing review and assessment to support the subsidence predictions for the proposed Wongawilli Seam extraction.

Seedsman has recommended a hierarchy of risk management strategies be applied to the mining proposals.

The hierarchy of risk management controls is:

- Elimination,
- Substitution,
- Engineering, and,
- Administration.

NRE commissioned Olsen Environmental Consulting Pty Limited (OEC) to facilitate a Failure Mode and Effects Analysis (FMEA) of the risks associated with the subsidence prediction methodology. The primary objectives of the FMEA were to:

- Confirm that the risk management approach adopted by Seedsman was robust and acceptable given the specific circumstances of the proposed activity, and,
- Identify any factors or components that were either inadequately addressed or that had not as yet been considered.

Actions determined during the FMEA would assist development of engineering and administration approaches to risk management that could be implemented to ensure appropriate management of subsidence impacts on the environment. Only some of these



**FINAL DRAFT Failure Mode and Effects Analysis Report
NRE No 1 Colliery Wongawilli Longwalls
Risk Associated With Subsidence Prediction Methodology
April 2010**

controls would be able to be developed prior to mining commencing, with some being progressively developed as monitoring data is collected and prediction models refined.

2. FMEA METHODOLOGY

Failure Mode Risk and Effect Analysis (FMEA) is a recognized methodology described in the NSW Department of Primary Industries document MDG 1010, "Risk Management Handbook for the Mining Industry". It is most applicable when only one type of impact is being considered (eg environmental impact or subsidence impacts) and is therefore suitable for this exercise.

FMEA aims to identify the nature of failures which can occur in a system;

- By identifying the components or subsystems,
- Considering for each the full range of possible failure types, and,
- The effect on the system of each type of failure. In this FMEA, the effect on the system would be additional deformation resulting from a failure to accurately predict subsidence parameters.

Further insight into the consequence of the failure modes was achieved by determining a likely Exposure as a result of risk associated with subsidence prediction. Exposure was determined by assigning a rating to both the likelihood of additional deformation and the severity of the potential outcome of any additional deformation. This enabled the risks to be ranked, and was achieved utilising the assessment matrix shown in Table 1.

The ranking in the Likelihood column also reflects a measure of confidence in the data available to estimate the subsidence predictions. A Low level of confidence in the data results in a High likelihood rating and a High level of confidence results in a Low likelihood rating.

It is important to appreciate that this FMEA addresses the subsidence methodology risk and not the environmental impact outcomes of that subsidence. NRE conducted an additional Failure Mode and Effects Analysis which specifically addressed the likely environmental impacts of mine subsidence. This other FMEA was undertaken by a range of appropriate environmental experts and addressed issues including flora, fauna, archaeology, surface water, groundwater and surface features. The outcomes of this other FMEA are documented in a report titled "NRE No 1 Colliery Wongawilli East and West Mining Areas Failure Mode and Effects Analysis report" dated December 2009 and prepared by Olsen Consulting Group.

Table 1. Risk Assessment Matrix.

LIKELIHOOD	SEVERITY (OF ADDITIONAL DEFORMATION)		
	Low	Medium	High
High	Medium Risk	Medium-High Risk	High Risk
Medium	Low-medium Risk	Medium Risk	Medium-High Risk
Low	Low Risk	Low-medium Risk	Medium Risk



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The steps in the FMEA were to:

Step 1. Define the scope of the study.

Step 2. Decide the level of analysis. In this analysis the main areas potentially subject to subsidence impacts were regarded as the elements. For each of these elements a variety of potential failure modes were identified.

The Main Elements and a list of Possible Failure Types for the FMEA were prepared by NRE, Seedsman and OEC prior to the meeting. It was not intended to be an exclusive list but was generated to provide guidance on the distinction between elements and failure types in the FMEA process. Opportunity was provided for modifications, deletions and additions during the FMEA meeting and the eventual list is as follows:

1. Illawarra Escarpment

Unacceptable impact on the Illawarra Escarpment.

2. Mount Ousley Road

Unacceptable subsidence effects on Mount Ousley Road as a result of mine subsidence.

3. Cataract Dam Wall and Spillway

Unacceptable impacts on Cataract Dam Wall and Spillway as a result of mine subsidence.

4. Cataract Dam Stored Water and DSC Notification Area

Unacceptable impacts on stored water and DSC Notification Area as a result of mining-induced subsidence.

5. Fourth Order Streams

Unacceptable impacts on Lizard Creek due to mine subsidence.

Unacceptable impacts on Cataract River and Cataract Creek due to mine subsidence.

6. High Significance Features

Unacceptable impacts on High Significance Features due to mine subsidence.

7. Groundwater System

Unacceptable impacts on groundwater system due to mine subsidence

Step 3. For all the potential failure modes, the effect on the system as a whole and the relative importance of those effects was determined by the subsidence experts present in the FMEA meeting. The objective was to identify subsidence prediction or management risks that had been overlooked or that were still significant subsequent to ameliorative action. There was additional discussion subsequent to the meeting to clarify some matters.

Step 4. A Exposure rating was determined for each failure mode utilising the Assessment Matrix shown in Table 1.



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Step 5. Agreed additional actions that would enhance the robustness of the mine subsidence assessment were developed and documented.

Part of Step 2 included discussion among the participants to identify any subsidence aspects that had not been listed for discussion during the FMEA. This was also repeated at the conclusion of the FMEA. All participants in the FMEA were satisfied that all potential predictable effects had been addressed.



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Table 2 identifies the participants in the FMEA and their area of expertise.

Table 2. FEMA Participants.

Participant	Organisation	Area of Expertise
Dr Chris Harvey	NRE	Mining Engineering and Environment
Danyil Skora	NRE	Environment
Ken Mills	SCT Operations	Geotechnical Engineering and Mine Subsidence
Arthur Waddington	MSEC	Geotechnical Engineering and Mine Subsidence
David Olsen	OEC	Risk Assessment and Environment
Ross Seedsman	Seedsman Geotechnics	Geotechnical Engineering and Mine Subsidence

3. OUTCOMES, FINDINGS AND RECOMMENDATIONS

During and immediately following the FMEA meeting a worksheet was completed for each identified Possible Failure Types. A complete set of worksheets is included in **Appendix I**.

The Worksheets identify the following:

- Element,
- Possible Failure Type,
- Effect on System of that Failure Type,
- Expert Panel Comments,
- Agreed Additional Actions, and,
- Criticality Analysis.



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APPENDIX

FAILURE MODE AND EFFECT ANALYSIS

MEETING WORKSHEETS



FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Actions	Exposure
1. Illawarra Escarpment	1.1 Unacceptable impact on the Bawarra Escarpment. The eastern end of the proposed extraction footprint is located 300m from the crest of the Bawarra Escarpment (BME).	1.1.1 Proposal to leave 700m standoff considered to be inadequate to confidently predict negligible impacts.	Standoff distance of 700m considered appropriate.	Check actual standoff distance on current plans and adjust mine plan to accommodate the correct stand-off distance. Check standoff distances and associated data with Dendrobium for comparison.	Unlikely: Low Severity: Low LOW
		1.1.2 Lack of geological data limits confidence in ability to define acceptable/whistleblower standoff distance.	Geological data not limiting.	N/A	Unlikely: Low Severity: Low LOW
		1.1.3 Adverse impact on escarpment face due to land instability resulting from subsidence.	Strong induced movements, if any, would be small horizontal displacements. These would not destabilise the escarpment.	N/A	Unlikely: Low Severity: Low LOW
		1.1.4 Available mining history information not adequate to determine whether selected standoff distance is appropriate to avoid impacts.	Historical mining data adequate.	N/A	Unlikely: Low Severity: Low LOW
		1.1.5 Initiation of pillar run may adversely affect subsidence predictions.	Plans to ensure available plans are accurate. Previous extraction close to the escarpment will also reduce risk.	URE to ensure the most accurate plans are obtained and utilized.	Unlikely: Low Severity: Medium LOW-MEDIUM

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
2. Mount Ousley Road	2.1 Unacceptable subsidence effects on Mount Ousley Road as a result of mine subsidence. Current proposed Mount Ousley Road is located within the proposed extraction footprint and near the BME. Selected road is a 2-lane road with a 10m wide shoulder. The road is recommended where the road is close to the BME. For areas where the road is further from the BME, engineering controls are proposed to ensure the road is constructed to the appropriate standards.	2.1.1 Proposal to leave 700m standoff distance away of BME is considered inadequate to confidently predict negligible impacts.	700m standoff distance is considered appropriate. A 10m wide shoulder is proposed. Engineering controls will be implemented in consultation with URE.	The assessment of the road is based on the 10m wide shoulder. The assessment of the road is based on the 10m wide shoulder. The assessment of the road is based on the 10m wide shoulder.	Unlikely: Low Severity: Medium LOW-MEDIUM
		2.1.2 Proposal to leave 700m standoff distance away of BME is considered inadequate to confidently predict negligible impacts.	700m standoff distance is considered appropriate. A 10m wide shoulder is proposed. Engineering controls will be implemented in consultation with URE.	The assessment of the road is based on the 10m wide shoulder. The assessment of the road is based on the 10m wide shoulder. The assessment of the road is based on the 10m wide shoulder.	Unlikely: Low Severity: Medium LOW-MEDIUM
		2.1.3 The proposed analysis of monitoring data and definition of triggering data is inadequate to ensure acceptable engineering controls.	Monitoring data will be used to ensure the road is constructed to the appropriate standards.	N/A	Unlikely: Low Severity: Low LOW
		2.1.4 Lack of geology data limits confidence in ability to define acceptable/whistleblower standoff distance.	Geological data adequate.	N/A	Unlikely: Low Severity: Low LOW
		2.1.5 Available mining history information not adequate to determine whether selected standoff distance is appropriate to avoid impacts.	Available mining history is adequate.	N/A	Unlikely: Low Severity: Low LOW
		2.1.6 Initiation of pillar running may adversely affect subsidence predictions.	Plans to ensure available plans are accurate. Previous extraction close to the escarpment will also reduce risk.	URE to ensure the most accurate plans are obtained and utilized.	Unlikely: Low Severity: Medium LOW-MEDIUM
		2.1.7 Lack of knowledge of BME and surrounding terrain.	Although standoff distance is considered to be sufficient, the BME and surrounding terrain are not fully understood. The BME and surrounding terrain are not fully understood.	Check BME data and surrounding terrain. Check BME data and surrounding terrain. Check BME data and surrounding terrain.	Unlikely: Low Severity: Medium LOW-MEDIUM
		2.1.8 Lack of knowledge of BME and surrounding terrain.	Although standoff distance is considered to be sufficient, the BME and surrounding terrain are not fully understood. The BME and surrounding terrain are not fully understood.	Check BME data and surrounding terrain. Check BME data and surrounding terrain. Check BME data and surrounding terrain.	Unlikely: Low Severity: Medium LOW-MEDIUM



FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
3. Cataract Dam Wall and Spillway	3.1 Unacceptable impacts on Cataract Dam Wall and Spillway as a result of mine subsidence. It has been decided that the DSC 1km boundary will form a boundary to longwall extraction.	3.1.1 Adverse effects on structures because DSC 1km standoff not adequate to confidently predict negligible subsidence impacts.	The 1km standoff under the current mining layout is acceptable. The Expert Panel noted that it is ultimately subject to DSC approval.	Ongoing monitoring will supplement validation data.	Likelihood: Low Severity: Medium LOW-MEDIUM
		3.1.2 Lack of geological data limits confidence in ability to define acceptable/suitable standoff distance.	Geological data adequate.	Nil	Likelihood: Low Severity: Low LOW
		3.1.3 Initiation of pillar run may adversely affect subsidence predictions.	There is no precedent for a 'pillar run' in a longwall chain pillar layout. The width to height ratio of the chain pillars mitigates against a run. It is valid to assume it will not occur.	Nil	Likelihood: Low Severity: Low LOW
		3.1.4 Inadequate knowledge of SCA structures limits ability to determine subsidence effects.		Structures currently monitored by SCA. Management Plan will be developed with DSC before mining in general area of structures commences.	Likelihood: Low Severity: Low LOW

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
4. Cataract Dam Stored Water and DSC Notification Area	4.1 Unacceptable impacts on stored water and DSC Notification Area as a result of mining-induced subsidence. Narrow longwalls have been extracted from the Bulli Seam in Wongawilli West area. Consequently, additional longwall extraction is not proposed here. Within the DSC notification area , there has been no previous longwall extraction in the Wongawilli East area and narrow longwalls are now proposed. Proposed layouts should produce vertical subsidence similar to or less than those already experienced in the '500 series' panels.	4.1.1 Lack of geological data limits confidence in ability to predict subsidence characteristics.	Geological data adequate (but see agreed action column). Mining in Notification Area will be subject to DSC approval.	Undertake further assessment of loading estimates for chain pillars in Bulli Seam within the DSC Notification Area in Wongawilli east area .	Likelihood: Low Severity: Medium LOW-MEDIUM
		4.1.2 Available mining history information not adequate to determine whether selected standoff distance or extraction proposal is appropriate to avoid impacts.	Available mining history is adequate for current predictions.	Nil	Likelihood: Low Severity: Low LOW
		4.1.3 Time between analysis of monitoring data and definition of fracturing line is inadequate to implement appropriate engineering controls.	Adequate time available to respond to monitoring data.	Nil	Likelihood: Low Severity: Low LOW



FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
5. Fourth Order Streams	5.1 Unacceptable impacts on Lizard Creek due to active subsidence. The lower reaches of Lizard Creek are predicted to contain a 4th order stream. Longwall extraction will not cause surface subsidence that from the north of Lizard Creek.	5.1.1 Available mining history information not adequate to determine whether selected extraction proposal is appropriate to avoid impacts.	• Mining history data from adjacent mines can be applied. • The 20th quarter 2011 Lizard Creek streamflow data indicates a further monitoring reduction as appropriate to allow appropriate risk rating to be applied.	• Conduct an appropriate assessment and a forecast of third order stream flow. • If appropriate, develop a management plan for the impacted stream to ensure appropriate water management in the event of stream failure of Lizard Creek.	Unlikely Low Severity, Medium LOW MEDIUM
		5.1.2 Time between analysis of monitoring data and definition of working face is inadequate to implement appropriate engineering controls.	• Adequate time available to respond to monitoring data.		Unlikely Low Severity, Low LOW
	5.2 Unacceptable impacts on O'Connell River and O'Connell Creek due to active subsidence. The lower reaches of O'Connell Creek are predicted to contain a 4th order stream.	5.2.1 Lack of geological data limits confidence in ability to predict subsidence characteristics.	• Geological data adequate for prediction.		Unlikely Low Severity, Low LOW
		5.2.2 Available mining history information not adequate to determine whether selected extraction proposal is appropriate to avoid impacts.	• Mining history data adequate for assessment.		Unlikely Low Severity, Low LOW
		5.2.3 Time between analysis of monitoring data and definition of working face is inadequate to implement appropriate engineering controls.	• Adequate time available to respond to monitoring data.		Unlikely Low Severity, Low LOW
		5.2.4 Reference greater than 100m distance between O'Connell Creek and Lizard Creek.	• This information provides a forecast of data obtained from the 100m of targeted extraction.	• Assess the subsidence of the water flow in the 100m of the prediction of up to 100m subsidence adjacent to the second stage. This mine should be appropriately monitored to ensure subsidence is not a problem.	Unlikely Low Severity, Low LOW

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
6. High Significance Features	6.1 Unacceptable impacts on High Significance Features due to mine subsidence. High Significance Features include: 1. Third Order Streams O'Connell Creek, Lizard Creek, Willendoot Creek and some unnamed creeks have already been undermined. NRE have made the decision to not extract wide longwall under named 3rd order creeks. 2. Upward Swamps Contiguous networks of intact upland swamps are present in both the Wongawilli East and Wongawilli West areas. 3. Transitional Shale Forests Open Blue Gum and Stringybark forests are present above area 2 in the Wongawilli West area. 4. Heritage Sites Some archaeological sites present. 5. Telstra Cable There is a fibre optic cable located alongside one of the fire trails in area 2 above the Wongawilli West area. 6. Transmission Lines and Towers 7. Fire Trails	6.1.1 Available mining history information not adequate to determine whether selected extraction proposal is appropriate to avoid significant impacts.	Adequate mining history available for risk assessment purposes. High Significance Features will be subject to various Management Plans determined prior to mining. Panel noted Lizard Creek and Willendoot Creek will not be undermined despite the presence of good coal reserves.	Nil	Unlikely Low Severity, Low LOW
		6.1.2 Time between analysis of monitoring data and definition of working face is inadequate to implement appropriate engineering controls.	Adequate time available to respond to monitoring data.	Nil	Unlikely Low Severity, Low LOW
		6.1.3 Lack of geological data limits confidence in ability to predict subsidence characteristics.	Geological data adequate for assessment purposes.	Nil	Unlikely Low Severity, Low LOW



FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
7. Shallow Groundwater System	7.1 Unacceptable impacts on groundwater systems due to mine subsidence. Analyses indicate no significant change in fracture flow from surface to coal seam.	7.1.1 Inadequate knowledge of geological and groundwater related structures to determine subsidence effects.	Groundwater impacts have been addressed in a manner that is acceptable. Monitoring programs will provide data as mining progresses.	Nil	Likelihood Low Severity Low LOW
		7.1.2 Loss of surface runoff to the mine workings.	Not likely, although wider longwall panels and multiple seams mean that large degree of interpretation of empirical database is required	Review risk assessment with external consultants as appropriate	Likelihood Low Severity Medium LOW-MEDIUM
		7.1.3 Lack of geological data limits confidence in ability to define acceptable/suitable standoff distance.	Geological data adequate.	Nil	Likelihood Low Severity Low LOW
		7.1.4 Available mining history information not adequate to determine whether selected standoff distance or extraction proposal is appropriate to avoid impacts.	Mining history adequate.	Nil	Likelihood Low Severity Low LOW
		7.1.5 Inflation of pillar run may adversely affect subsidence predictions.	Given pillar shape and distribution with respect to mined and unmined areas, pillar run is unlikely to occur. It is valid to assume it will not occur.	Nil	Likelihood Low Severity Low LOW