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West Wallsend Colliery

Additional Mine Subsidence Impact Assessment of the Steep Slopes and Cliffs above the Proposed Longwall Panels LW38 to 50 at West Wallsend Colliery

Report No. WWD-012/7

Date: 12 September 2011

12 September, 2011

Mr Mark Robinson
Environment and Community Co-ordinator
West Wallsend Colliery
The Broadway
Killingworth NSW 2278

Report No. WWD-012/7

Dear Mark,

Subject: Additional Mine Subsidence Impact Assessment for the Steep Slopes and Cliffs above the Proposed Longwall Panels LW38 to 50 at West Wallsend Colliery

This report has been prepared as an addendum to the Mine Subsidence Impact Assessment Report (DgS Report No. WWD-012/1 dated 15/03/2010) that was prepared for an EIS Submission to the Department of Planning (DoP).

The report provides further information on the condition of the steep slopes and cliffs above the proposed mining area within the Western Domain of West Wallsend Colliery and has been peer reviewed by Mr Mark Delaney of Newcastle Geotech Pty Ltd.

Subsidence effect contours for three proposed cliff and steep slope mitigation options (No.s 3 to 5) have also been included for subsidence impact control purposes along visible ridges of the Sugarloaf Range.

Please contact the undersigned if you have any questions regarding this matter.

For and on behalf of
Ditton Geotechnical Services Pty Ltd

Steven Ditton
Principal Engineer

Executive Summary

This report provides a detailed assessment of the likely and credible worst-case impact of the proposed 178.6 m wide longwall panels LWs 38 to 50 at West Wallsend Colliery (WWC) on the steep slopes and cliffs along the Sugarloaf Range within the study area.

The Sugarloaf Range exists within the western area of the proposed mine site and rises from RL 60 to 80 along its' eastern foot slopes to RL 200 to 360 m (AHD) along north-south striking ridge crests.

It is understood that the DII (Department Industry and Investment) are concerned that any instability along the ridge lines during mining will be visible over 2 to 30 km away on the F3 Freeway and from the townships of West Wallsend, Lake Macquarie, Newcastle and Stockton to the east and Mulbring to the west. Based on fieldwork to-date, the existing condition of the cliff lines and steep slopes cannot be seen with the naked eye from any of the above locations due to the dense tree coverage and vegetation present. However, the impacts of any instability along the upper level cliffs and steep slopes may become visible if large-scale slope or tree felling was to occur.

There are six multi-terraced cliff lines and steep slopes that have been identified within the Western Domain. The cliffs and slopes will be subsided by the proposed longwalls 40 to 43 and 47 to 50 at West Wallsend Colliery. Representative cliff and slope sections have been mapped for the purposes of impact management assessment.

The total length of steep slope that will be subsided is estimated to be 13.9 km with gradients ranging from (18^o to 45^o). Based on the definitions of cliff lines at other NSW mine sites, there are approximately 1.7 km of discontinuous, single and multi-tiered cliff faces with heights ranging from 10 m to 25 m with average slopes ranging from 50^o to 70^o. The multi-terraced cliff faces have two to five tiers with individual cliff faces ranging in height from 3 m to 11 m. The slopes on the cliff tiers range from 45^o to 80^o and are typically 65^o.

Minor cliffs (< 10 m high) and rock outcrops (< 5 m high) are common along the rest of the steep slopes.

The cliff faces are predominately conglomerate and quartz-lithic sandstone of the Triassic Narrabeen Group (Munmorah Conglomerate and Tuggerah Formations). Interbedded sandstones and mudstones (shale) form the steep talus slopes, which have undercut the sandstone cliff line to produce overhangs in places. Persistent widely spaced vertical jointing parallel and perpendicular to the cliff faces is the primary mechanism for natural rock fall roll out and talus slope development along the cliff lines.

The bedding dip is approximately 3^o to the south and south east and considered favourable for slope stability along the upper level eastern and western cliffs and steep talus slopes (No.s 1, 2 and 4). The upper level cliffs and slopes are likely to be subsided by 0.1 m to 1.4 m after extraction of the proposed mining layout. The tilts are estimated to range from 10 to 30 mm/m and tensile strains are likely to range between 5 mm/m and 10 mm/m.

The lower level cliffs and steep slopes (No. 3, 5 and 6) along the eastern and southern foot slopes of the Sugarloaf range may be subject to subsidence ranging from 0.1 to 2.5 m, tilt of 6 to 70 mm/m and tensile strain of 2 to 20 mm/m.

Surface cracks ranging from 100 mm to 350 mm width may develop on the upper slopes (No. 1, 2 and 4) with cracks ranging from 50 mm to 700 mm estimated for the lower slopes (No. 3, 5 and 6).

The predicted tilting, bending and cracking along the cliff lines > 10 m high may generate rock falls and release boulders that may subsequently roll down the steep talus slopes. Based on the data base of NSW cliff lines and in particular, the cliff lines and steep slopes above Dendrobium Mine in the Southern Coalfield, it is estimated that the proposed longwalls may cause rock falls along 13% to 23% of the 1.7 km of cliff lines. Approximately 10% of the impacted length is likely to be the result of natural instability (and is included in the 23%).

The development of deep cracks on the steep slopes and behind minor cliffs and cliffs are likely to result in the lowering of the Factors of Safety against deep-seated sliding from > 3 (after mining) to between 1.2 and 1.5 if the cracks fill with water during wet weather. It is considered that a minimum long-term design FoS for the post-mining slopes should not be < 1.5 for an extreme range of weather conditions (excluding earthquakes).

If the cracks are not repaired with grout, the development of perched water table conditions in the steep slopes could cause softening on mudstone/claystone beds and result in a large-scale land slip after mine subsidence is completed. Durable gravel backfill may be used to backfill cracks on accessible slopes provided the top 300 mm is backfilled with clay fill, bentonite or low strength grout.

Significant longitudinal tensile cracks that occur on the steep slopes > 26.5^{o} should probably be grouted at this stage for planning purposes, however, confirmation of necessary crack repairs on all of the Western Domain slopes should be assessed, based on inspection by a suitably qualified geotechnical engineer.

Surface and subsurface monitoring of piezometric levels and shear displacements within the steep slopes will also be required during and up to 2 years after mining (and possibly longer if slope creeps have developed). It is not considered necessary to grout transient tensile cracks generally, unless there is significant long-term slope stability concerns identified after mine subsidence has fully developed.

Approximately 600 m of terraced cliff line 10 to 25 m high along Steep Slope No. 1 forms a ridge along the Sugarloaf Range that is likely to be visible to the west of Newcastle and Lake Macquarie communities. Approximately 260 m of the east facing Steep Slope No. 1 is > 20 m.

Another similar length (700 m) of terraced cliff line > 10 m high exists along Steep Slope No. 2, and is located > 100 m further down slope of the upper cliff line. Slope No. 2 may just be visible from the communities to the north-east and east.

Approximately 2 km of the ridge line (Steep Slope No. 4) along the western side of the proposed longwall mining area has steep talus slopes and minor cliffs (< 10 m high) that are likely to be visible from the village of Mulbring.

All other cliffs (> 10 m high) on the site (a length of approximately 400 m above LWs 41 and 42) are not visible from these communities, and they can only be accessed (and viewed) with difficulty from the Great Northern Walk, Mount Sugarloaf Road and several mountain bike tracks and fire trails. Impacts to the cliff lines and steep slopes therefore presently represent a public safety hazard.

Five subsidence control and impact mitigation options have been developed for reducing the predicted 'High' overall mining impacts along cliffs above Steep Slope No.s 1 and 2 to either 'Moderate', 'Low' or 'Very Low' Overall Impact.

The predicted subsidence effects (U95%Confidence Limit values) along the first 700 m of cliff and Slope No. 1 and 2 for each control option are summarised in the following table:

Option	**Steep Slope No.**	**Subsidence (m)**		**Tilt (mm/m)**		**Tensile Strain (mm/m)**		**Crack Width (mm)**	
		Cliff	**Slope**	**Cliff**	**Slope**	**Cliff**	**Slope**	**Cliff**	**Slope**
1	1	0.2-0.6	0.6	4-5	9	2-5	5	40-50	90
	2	0.2-0.8	1.0	9	20	2-5	8	90	200
2	1	0.2	0.2	4	4	2	2	40	40
	2	0.2	1.4	4	20	2	5	4	200
3	1	0	0	0	0	0	0	40	40
	2	0.2	1.4	4	20	2	4	40	200
4	1	0.2	4	4	2	4	2	40	40
	2	0.2	4	20	2	4	4	40	200
5	1	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0

The estimated FoS values for the cliffs and Steep Slopes No. 1 and 2 for the first four slope impact mitigation options proposed have been increased to > 1.5 to give a 'low' potential for deep seated sliding after mining is completed. In-filling cracks with low-strength grout on steep slopes will further increase the FoS > 4 for these options. Option 5 will probably not result in cracking or require grouting of the first 700 m sections of Steep Slopes No. 1 and 2.

The subsidence control measures suggested herein should also reduce mining impacts to 3% or less for the Steep Slope No.s 1 and 2 cliffs and from 4 to 8% for all cliffs > 10 m high on site generally (excluding natural instability effects).

A summary of the existing cliffs and slopes after mining and proposed subsidence control measures are presented in the table below:

Steep Slope and Cliff Instability Summary for the Proposed Post-Longwall Impact Mitigation Options

Case	Steep Slope No	Cliff Height (m)	Cliff >10m High Length (m)	Deep Cliff Sliding FoS Dry	Deep Cliff Sliding FoS Wet	Steep Slope Length (m)	Deep Steep Slope Sliding FoS Dry	Deep Steep Slope Sliding FoS Wet	Cliff# Line Damage %	Cliff# Line Damage (m)	Overall Cliff# Impact Rating
Current	1	3-25	600	3.46	**1.28**	2200	3.46	**1.48**	9-19	54 - 114	**High**
	2	3-20	900	3.06	**1.25**	2200	3.06	**1.38**	14-24	98 - 168	Mod
	3	2-18	200	2.89	**1.20**	2600	2.89	**1.32**	17-27	34 - 54	Mod
	4	5	0	3.70	1.66	2000	3.70	1.67	9-19	0	Mod
	5	3-15	0	3.25	**1.29**	1900	3.25	**1.49**	14-24	0	Mod
	6	3-9	0	2.18	**1.22**	3000	2.18	**1.48**	17-27	0	Mod
Option 1 (700m of LW43 excluded)	1	15-25	500	4.75	1.69	0	4.75	1.79	3-8	15 - 40	Low
	1	15-25	100	4.67	1.50	800	4.36	1.69	4-14	4 - 14	Mod
	2	10-20	700	4.36	1.59	800	4.36	1.78	4-14	8 - 28	Mod
	2	10-20	200	3.06	**1.25**	1400	3.06	**1.38**	14-24	70 - 120	Mod
Option 2 (700m of LW42 Excluded)	1	15-25	600	4.75	1.52	700	4.75	1.77	3-8	18 - 48	Low
	2	10-20	700	4.75	1.68	1700	4.75	1.87	3-8	18 - 48	Low
	2	10-20	200	3.06	**1.25**	500	3.06	**1.38**	14-24	14 - 24	Mod
Option 3 (700m of LW42&43 Excluded)	1	15-25	600	-	-	800	-	-	-	-	V. Low
	2	10-20	700	4.75	1.68	1200	4.75	1.87	3-8	18 - 48	Low
	2	10-20	200	3.06	**1.25**	1000	3.06	**1.38**	14-24	14 - 24	Mod
Option 4 (700m of Subcritical LW42&43)	1	15-25	600	4.75	1.52	800	4.75	1.77	3-8	18 - 48	Low
	2	10-20	700	4.75	1.52	1200	4.75	1.77	3-8	18 - 56	Low
	2	10-20	200	3.06	**1.25**	1000	3.06	**1.38**	14-24	14 - 24	Mod
Option 5 (700m of LW41to43 Excluded)	1	15-25	600	-	-	800	-	-	-	-	V. Low
	2	10-20	700	-	-	1200	-	-	-	-	V. Low
	2	10-20	200	3.06	**1.25**	1000	3.06	**1.38**	14-24	14 - 24	Mod

- Only cliffs and terraces > 10 m in height with slopes >50^{o} are included in rock fall impact assessment.
Bold - Predicted FoS < Long-term Design FoS (see **Section 6.1**). Shaded - Slopes &/or cliffs considered visible from off-site communities (2 to 30 km away).

The estimated FoS values for the cliffs along Steep Slope No. 1 and 2 for the four slope impact mitigation options proposed have been increased to > 1.5 in the north western ridge area prior to grouting, to give a 'low' potential for deep seated sliding after mining is completed. In-filling cracks with low-strength grout (2 - 5 MPa UCS) in the vicinity of the cliff lines will further increase the FoS > 4.

The first four subsidence control and impact mitigation options have been developed for reducing the predicted 'High' Overall Mining impacts along Steep Slope No.s 1 and 2 to either 'Moderate' or 'Low' Impact. A fifth subsidence control option will further reduce the instability risk to 'Very Low'.

The estimated FoS values for the cliffs and steep slopes along Steep Slope No.s 1 and 2 for the first four slope impact mitigation options proposed, have been increased to > 1.5 to give a 'low' potential for deep seated sliding after mining is completed. In-filling cracks with low-strength grout in the vicinity of the cliff lines will further increase the FoS > 4. The fifth option will not subside Steep Slopes 1 and 2 and is therefore unlikely to require grouting.

The subsidence control measures suggested herein should also reduce mining impacts to 3% or less for the cliffs along Steep Slope No.s 1 and 2, and from 4 to 8% for all cliffs > 10 m high on site generally (excluding natural instability).

The proposed grouting of deep cracks is intended to reduce surface runoff inflows into the slopes from concentrating at a given location and minimise the potential for perched water table conditions to develop and result in deep-seated sliding. The possible opening of existing joints or bedding may increase surface runoff into the slope, but the overall effect will be countered by the slopes ability to drain more freely. The slopes will also be monitored and inspected on a regular basis during mine subsidence development, and the need for additional grouting will be made.

Preliminary discussions with DII and mine representatives indicate that Options 3 to 5 are likely to be the primary candidates for the controlling impacts to the cliff terraces along the crests of Steep Slopes No. 1 and 2 to acceptable levels. It should be noted that the likelihood of impact to Cliff No. 1 is considered to be the primary point of reference in the Overall Impact Ratings, which have also considered the potential for impacts to develop due to undermining the lower level cliffs and slopes (i.e. Cliff No.s 2 and 3).

Option 3 and 4 are assessed to have a 'Low' Overall Impact of the two cliff terraces No.s 1 and 2; however, cliff terrace No.2 is more likely to be affected than Cliff Terrace No. 1, due to the possibility that cracking on the steep slopes above LW41 could lead to further upslope instability to develop in the vicinity of Cliff Terrace No. 2. It is considered very unlikely that deep seated sliding will develop in the vicinity of Cliff Terrace No. 1 due to favourability of the bedding dip. As a precautionary measure, this option will therefore require any deep cracking on the slopes below Cliff Terrace No. 1 to be repaired promptly.

Option 5 is assessed to have a 'Very Low' Overall impact because the slopes below Cliff Terrace No. 2 will not be subsided or cracked. This Option is therefore unlikely to require any grouting on the slopes below the 'High' Risk Zone of Cliff Terrace No 1.

The proposed mining layout amendments should enable appropriate subsidence management plans to be implemented without significant risk to the safety of public and mining personnel, cliff line aesthetics, or damage to existing infrastructure (i.e. Gencom Towers).

On-going monitoring and review of the effectiveness of the methodology used and management plans developed from it will be required as mining progresses. The impact review process may also indicate that some further subsidence control zone restrictions may be required after each longwall panel is completed, and if predicted impacts are higher than anticipated. It is recommended that impacted slopes should be monitored for a minimum of 2 and maximum of 5 years after mining has been completed.

The longwall mining layout and subsidence impact management measures proposed in this report is similar to that of the Dendrobium Mine and their Corrective Management Actions for undermining steep slopes and cliffs in the vicinity of the Cataract Reservoir. The same approach has been applied to the Metropolitan Mine longwalls beneath the Waratah Rivulet.

The **ACARP, 2002** cliff impact assessment model has been applied to the abovementioned mine site impact data and indicates that the predicted impact model outcomes for West Wallsend Colliery are likely to be conservative.

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1.0 Introduction

This report provides a detailed assessment of the likely and credible worst-case impact of the proposed 178.6 m wide longwall panels LWs 38 to 50 at West Wallsend Colliery (WWC) on the steep slopes and cliffs along the Sugarloaf Range within the study area.

The Sugarloaf Range exists within the western area of the proposed mine site and rises from RL 60 to 80 along its' eastern foot slopes to RL 200 to 360 m (AHD) along north-south striking ridge crests. The ridges dominate the western horizon of the greater Newcastle and Lake Macquarie communities. The proposed longwall layout and known surface features are shown in **Figure 1**.

It is understood that the DII (Department Industry and Investment) are concerned that any instability along the ridge lines during mining will be visible over 2 to 30 km away on the F3 Freeway and from the townships of West Wallsend, Lake Macquarie, Newcastle and Stockton to the east and Mulbring to the west. Based on fieldwork to-date, the existing condition of the cliff lines and steep slopes cannot be seen with the naked eye from any of the above locations due to the dense tree coverage and vegetation present. However, the impacts of any instability along the upper level cliffs may become visible if large scale slope or tree felling was to occur.

The focus of this study will be to assess subsidence impacts to the cliffs and steep slopes and determine how the impacts to the cliffs are likely to be made 'tolerable' and manageable in regards to stakeholder expectations. The above approach is considered reasonable based on approved subsidence impact management plans developed for cliffs and steep slopes at several other operating longwall mines in NSW (namely Dendrobium, Metropolitan and Baal Bone Mines).

Further risk management studies and subsequent mine layout refinements are likely to be required where the predicted subsidence impacts to the cliffs and slopes are unlikely to provide acceptable outcomes to stakeholders.

The general condition of the cliffs and slopes were presented in summarised format in the mine subsidence impact assessment prepared by **DgS, 2010**. Further details and discussions of the current condition of the cliffs and slopes and the proposed mining impacts have been provided in this report for risk assessment purposes.

2.0 Scope of Work

The work completed in this study has included:

- A review of the Project Approval for the Metropolitan Mine in 2009 (Department of Planning) for sub-critical longwall panels 16 - 30 beneath the Waratah Rivulet in the Southern NSW Coalfield.
- A review of Metropolitan Mine's cliff and steep slope impacts due to LWs 1 - 15 in the Southern NSW Coalfield.
- A review of Dendrobium Mine's Area 2 SMP and cliff and steep slope impacts due to LWs 1 and 2.
- A review of Baal Bone Mine's cliff and steep slope impacts due to LWs 1 - 23 in the Western Coalfield.
- A review of the Commission of Enquiry Report, 1993 for the proposed Airly underground Coal Mine (Total and Partial Pillar Extraction) in the Western NSW Coalfield.
- A summary of surface inspection results for the typical cliff lines and steep slope conditions present in September 2008 and May 2011.
- A review of the predicted subsidence effects on the cliffs and steep slopes above LWs 40 to 43 and LWs 47 to 50 in the Western Domain. LW 38 has already been extracted and LW39 is nearing completion. First workings development of LWs 40 and 41 gate roads is currently underway.
- A review of the **ACARP, 2002** holistic subsidence impact assessment results of the cliffs and slopes that was prepared for the current EIS Submission.
- Recommendations for subsidence impact management using mine planning and/or mitigation/hazard control techniques for LWs 40 to 43 and 47 to 50 in the Western Domain.

Subsidence predictions presented in **DgS, 2010** have been referred to for the purposes of this study.

The details of the landform surveys undertaken to date within the proposed longwall mining area known as the Western Domain are presented in **Appendix A** and summarised in **Section 4.0**.

3.0 Review Summaries

3.1 Definition of Steep Slopes and Cliffs

The definitions of a cliff and steep slopes that were defined in the recent Project Approval for the Metropolitan Mine (Southern NSW Coalfield) in 2009 (Department of Planning) are given below:

"Cliff" - A continuous rock face (>20 m in length), including overhangs, having a minimum height of 10 m and slope > 66^o.

"Steep Slope" - An area of land having a natural gradient ranging between 33^o and 66^o.

A similar set of definitions was defined for the cliffs and steep slopes at the Dendrobium Mine (Southern NSW Coalfield) as follows:

"Cliff" - A continuous rock face (>20 m in length) having a minimum height of 10 m and slope > 63.4^o.

"Minor Cliff" - A discontinuous rock face (<20 m in length) having heights of < 15 m, and slopes > 63.4^o.

"Rock Outcrops" – A rock face with a minimum height of 5 m and slope > 63.4^o.

"Steep Slope" - An area of land having a natural gradient ranging between 18^o and 63^o.

The above definitions are also generally consistent with the slope descriptions provided below in the Landslide Risk Management Guidelines prepared by the Australian Geomechanics Society (**AGS, 2007**):

"Cliff" - Slope appears vertical and ranges between 64^o and 84^o. *Note: No minimum height is specified.*

"Extreme Slope" - Need rope access to climb slope and ranges between 45^o and 64^o.

"Very Steep Slope" - Can only climb slope by clutching at vegetation, rocks etc and ranges between 27^o and 45^o.

"Steep Slope" - Walkable with effort and ranges between 18^o and 27^o.

"Moderate Slope" - Walkable and ranges between 10^o and 18^o.

"Gentle Slope" - Easy Walking and ranges between 0^o and 10^o.

For the purposes of maintaining consistency between the impact assessment methodology used on cliffs and slopes in different coal fields, the definition of a cliff should reflect whether mine subsidence impacts can cause significant changes to the characteristics or morphology of the landscape.

For example, a continuous cliff face with a height of 10 m (or more) with overhang features present, is more likely to have a greater impact on the characteristics of a ridgeline if the overhangs collapse, compared to a discontinuous cliff face with a height of < 10 m. In other words, there will be a point where the low height, discontinuous cliff is really just a rocky slope and instability along the rock face will probably not result in a permanent change to the landscape (although a public safety and temporary environmental impact hazard may still exist). The focus of the mine subsidence impact assessment would therefore be given to the steep slopes, if they are not cliffs by definition.

Based on precedents applied in other coal fields with similar mining and steep surface conditions, the definitions in **Table 1** have been adopted in this report.

Table 1 - Definitions of Cliffs and Steep Slopes for the Western Domain

Surface Feature	Definition by Geometry	Impacts of Concern due to Subsidence Effects
Cliff	ontinuous rock face (>20 m in length) having a height >10 m and slope > 63.4° (2V:1H).	Tilting and cracking resulting in collapse of overhangs, wedge & toppling failures; rock fall roll outs, felling trees and public safety hazards. Permanent Landscape changes.
Minor Cliff	Either (i) A continuous rock face (> 20 m in length) having heights between 5 and 10 m and slope > 63.4° (2V:1H) or (ii) a discontinuous rock face (< 20 m in length) with heights between 10 m and 20 m.	Tilting and cracking resulting in collapse of overhangs, wedge & toppling failures; rock fall roll outs, felling trees and public safety hazards. Temporary landscape changes.
Cliff Terrace	A combination of two to five minor cliffs in close proximity that have resulted in a 'stepped' surface profile. The average slope between upper and lower cliffs ranges between 50° and 60° with a total cliff height of between 10 and 25 m.	Tilting and cracking resulting in collapse of overhangs, wedge & toppling failures; rock fall roll outs, felling trees and public safety hazards. Temporary to Permanent Landscape changes.
Rock Outcrop	A discontinuous rock face (< 20 m in length) having heights < 5 m and slope > 63.4° (2V:1H).	Tilting and cracking resulting in collapse of overhangs, wedge & toppling failures; rock fall roll outs, felling trees and public safety hazards. Temporary landscape changes.
Very Steep Slopes*	An area of land having a natural gradient ranging between 45° and 63° (1V:1H to 2V:1H).	Tilting and cracking resulting in landslip failures; felling trees and public safety hazards. Permanent to temporary landscape changes.
Steep Slopes+	An area of land having a natural gradient ranging between 18.4° and 45° (1V:3H to 1V:1H).	Tilting and cracking resulting in landslip failures; felling trees and public safety hazards. Permanent to temporary landscape changes.

* - Very steep slopes are generally located within cliff line terraces. + - Steep slopes generally exist below the cliff terraces, minor cliffs and rock outcrops and extend for 100 m or more.

3.2 Summary of Commission of Inquiry on Mounts Airly and Genowlan due to Underground Coal Mining

Initial feedback from the DoP and DII regarding second workings mining beneath steep slopes and cliffs, was that the proposal should consider the findings of the Airly Commission of Inquiry. Other EISs prepared for the Metropolitan Coal Project and Baal Bone Coal mine were also suggested and will be discussed later.

The proposed underground pillar extraction coal mine by Novacoal Australia Pty Ltd was subject to a Commission of Inquiry (CoI) to the Department of Environment and Planning in 1993.

It was proposed to undertake total pillar extraction mining beneath sensitive rock formations (pagodas and beehives) and >20 m high sandstone cliffs of considerable scenic, aesthetic and scientific value to the general community. Parts of the proposed mining area belong to the 'Gardens of Stone' that conservation groups consider should be rezoned into the Wollembi National Park. The above features were also assessed to have significant ecological and aboriginal and European heritage value.

It was assessed that the cliffs and rock formations of significance should not be irreversibly damaged by cracking or destabilised by subsidence, tilt and strain. Likely damage from 1.7 m to 1.8 m of subsidence was considered to be unacceptable due to the associated tilting, cracking and/or rock falls.

The outcomes of the CoI was to grant conditional development consent for first workings only inside of identified EPZs or Environmental Protection Zones, with second workings allowed outside of these zones. It was indicated that partial pillar extraction would be considered within EPZs if it could be demonstrated (by the Mine) that monitoring and management of impact to DPI (formerly DMR) requirements could be achieved.

Surface features within the EPZ's included the following:

- Internal and external cliffs with heights of 20 m or above.
- Significant rock features such as 'pagodas' and 'beehives' of any height.

It was indicated that a detailed landform survey showing locations and conditions of all ≥20 m high cliffs and significant rock features would need to be completed within 12 months of Development Consent being granted.

Overall, it is assessed that the Airly CoI report is not directly applicable to the Western Domain due to the following factors:

(i) The cliffs and pagodas in the Blue Mountains have a much higher aesthetic quality than the Sugarloaf range cliffs and slopes.

(ii) The impacts of second workings (i.e. longwalls) with similar mining geometry and surface topography have been managed successfully at the Dendrobium Mine (which had significantly higher cliffs of between 20 and 30 m and slopes of a similar gradient to the Sugar Loaf Range).

(iii) None of the individual cliffs in the Western Domain have a height in excess of 20 m.

However, despite the significant topographical differences between the two areas, it is concluded that the management of subsidence impacts due to the proposed second workings beneath the Sugarloaf Range, will require a robust management plan that has demonstrable effectiveness in regards to controlling visible short term and long term impacts to within acceptable limits.

At this stage it is assumed that the acceptable limits will not include large-scale landslip or tree felling that will be noticeable to the nearby communities.

3.3 Impact Management Controls for Cliffs and Steep Slopes

The assessment of the subsidence impacts along a cliff face or steep mining will require a system to assess and define the observed impacts. The assessed impact category will then initiate an appropriate management response that has been pre-determined through consultation with relevant stakeholders.

A summary of the Dendrobium Mine's Landscape Impact Assessment Trigger Levels (Area 2 SMP Application) are presented in **Table A**. The plan categorises impacts to cliffs, minor cliffs and rock outcrops of between 5 m and 30 m high and steep slopes > 18^o.

Table A - Definition of Steep Slopes and Cliffs Impacts and Management Action Response Plan for Dendrobium Mine

Impact Scale*	Impact Description	Response Type	Response Timing	Monitoring Required
Minor Impact	Rock fall at a cliff site, where the cliff is mostly intact, and there has been significant ground disturbance, which should naturally stabilise in the near future.	N/A	N/A	Standard Monitoring
	Minor surface movement or rock displacement with negligible soil surface exposed			
	A small crack at the surface, which should not result in any significant erosion or further ground movement			
Moderate Impact	Rock fall or overhang collapse at a cliff site, where the characteristics (e.g. morphology) of the cliff have changed, and there has been significant ground disturbance.	Consider Standard CMA Options	Short Term**	Monitor monthly until stabilised
	Surface movement or rock displacement that has been exposed significant areas of soil.			
	A crack at the surface, which could result in significant erosion or movement of the surface.			
Severe Impact	Major cliff collapse or rock fall, where the characteristics (e.g. morphology) of the cliff have changed significantly, and there has been significant ground disturbance which is not likely to naturally stabilise in the medium to long term.	Consider Standard CMA Options	As Soon As Practicable **	Monitor until stabilised, with the frequency and type of monitoring set specifically to meet the CMA
	Mass movement resulting in large areas of soil exposure with potential for further movement.			
	A large crack at the surface which has resulted in significant erosion or is likely to cause mass movement of the surface.			

* - In this context, "impact" refers to a change in the site characteristics caused by mining induced subsidence.
** - Where sites are still in a highly dynamic state and further mass movement is likely, intermediate remedial measures will be implemented with final measures to be implemented at an appropriate time in the future, when further movement is unlikely to occur.

Post-mining reporting in the Annual Environmental Monitoring Report (AEMR) for Area 1 (LWs 1-2) has identified that impact to cliffs and steep slopes subject to subsidence of 0.34 to 1.3 m, tilts from 15 to 30 mm/m, compressive strains up to 11 mm/m and tensile strains up to 5 mm/m, has resulted in ‘Minor’ to ‘Moderate’ impacts as defined in **Table A**.

The impacts to the cliffs included eight isolated rock falls and steep talus soil slope cracking. Some minor tree felling and erosion of exposed soils also occurred. Corrective Management Actions (CMAs) included erosion and sediment transport controls being implemented below cliff lines with rock falls. Cracks in steep slopes were repaired with crushed and screened (free draining) sandstone gravel. It is noted that similar subsidence effects and impacts have occurred above LW3 in Area 2 at Dendrobium Mine and the necessary CMA's have been implemented.

It is considered that the measured subsidence effects and approach taken by Dendrobium Mine to manage the impacts to the steep slopes and cliff lines from longwall mining have merit in regards to developing cliff and steep slope impact management plans at West Wallsend Colliery.

4.0 Description of Steep Slopes and Cliffs at the West Wallsend Mine

4.1 Geological Setting

The geology of the Sugarloaf Range within the study area has been identified on the DMR 1:100,000 Geological Map for Newcastle.

The map indicates that the elevated ridges are located within the Clifton Sub-Group of the Permian Narrabeen Group. The lithology consists of sandstone, siltstone, claystone and conglomerate beds.

The Munmorah Conglomerate Formation is likely to outcrop along the lower ridge slopes with upper level slopes having exposures of sandstone, siltstone, shale (mudstone) and claystone associated with the Tuggerah Formation and possibly the Patonga Claystone and Terrigal Formations.

The eastern low lying portion of the site is situated within the Permian Newcastle Coal Measures with sandstone, siltstone, claystone (tuff), conglomerate and sub-cropping coal seams (Wallarah, Great Northern, Fassifern and Pilot Seams) of the Moon-Island Beach and Boolaroo Sub-Groups.

Quaternary Alluvium exists along the creeks and watercourses associated with Cockle Creek, Diega Creek and Ryhope Creek.

4.2 Geomorphology

Erskine and Fityus, 1998 note that the geology of the region is dominated by resistant sandstones with occasional claystones and shales. Much of the sandstone is quartzose, relatively thickly bedded and often it erodes at a faster rate than it can weather and accumulate to form soils. Where beds of quartz sandstone become thicker, they form cliff lines and structural benches. These often contain thin shaley units which lie at the base of the cliffs, or coincide with the benches.

A landform evolution model, similar to that for the conglomerate landforms in the coal measures has been postulated for Narrabeen Group sandstones, however rather than the sandstone blocks sliding on the underlying shales (as occurs in the Newcastle Coal Measures), the shales are exposed to erosion, and are eroded preferentially, under-cutting the sandstone cliffs and causing blocks to topple (rotate) away from the receding cliff lines.

As the shales in the Triassic rocks are typically less expansive and less dispersive than the siltstones and tuffs of the Permian coal measures, they are more resistant to weathering, and so, the rate of undercutting of sandstone units is slower. Where the proportion of finer sediments is greater, slope stability conditions similar to those of the coal measures prevail.

4.3 Fieldwork

A Principal Geotechnical Engineer inspected the steep slopes in the study area over two periods from 17th to 19th September, 2008 and 17th to 19th May, 2011. The condition of the slopes was mapped using a Suunto Clinometer, 60 m tape, geological hammer and hand-held GPS unit (Garmin GPS 60). Digital photographs of the cliffs, cliff heights, slopes, jointing and cliff line crest locations were recorded with the GPS unit.

The slopes and cliff lines were mapped at 15 locations during the fieldwork (M1-M15) and considered to be representative of the six steep slopes and associated cliff lines present within the study area. The location of the mapped slopes and cliffs are shown in **Figures 2a** and **2b**.

Aerial Laser scanning and aerial photography was also used to model the pre and post mining landscape. The slope gradients derived from the scanning provide a higher level of accuracy than orthophoto maps provide, however, slopes in excess of 64° on individual cliff faces tend to be averaged out over distances of 10 m or more. Despite this, the location of cliff line terraces are clearly definable on the site and are noted where average slope gradients exceed 45°.

The mapping details and photographs of the cliffs and slopes are presented in **Appendix A**.

4.4 Steep Slope and Cliff Condition Summary

The Western Domain longwall panels are overlain by areas of steep, rocky slopes (18° to 45°) with shallow residual soil cover (< 1 m thick). The steep slopes are located to the north and south of the Great North Walk and east and west of Mount Sugarloaf Road (which follow ridge and spur crests), see **Figures 2a** and **2b**.

The near surface strata on the steeper slopes generally consist of blocky, thickly bedded sandstone and conglomerate beds of medium to high strength (UCS ranges from 30 to 70 MPa). Weak, interbedded, poorly cemented silty sandstone and claystone / mudstone units are present between the stronger units, and have eroded more rapidly. This has resulted in terraced cliff line development with the strata bedding generally dipping towards the south to south east between 1° and 3°.

There are approximately six steep slopes with ‘minor’ to ‘terraced’ cliff lines ranging from 2 to 25 m high. The cliff faces are sub-rounded to sheer, with faces sloping at 65° to 80°. Very steep slopes of between 40° and 45° were noted between some of the terraced cliff areas. Definitions of the cliff line and steep slope types present on the site are provided in **Table 1** (**Section 3.1**).

The six steep slopes and cliff lines identified and mapped within the study area have been defined in terms of their aspect on the ridge and cover depth above the proposed longwalls in the West Borehole Seam:

- Steep Slope 1 - Upper North Eastern Terrace (cover depths range from 220 to 300 m);
- Steep Slope 2 - Middle North Eastern Terrace (cover depths range from 160 to 200 m);
- Steep Slope 3 - Lower North Eastern Terrace (cover depths range from 120 to 140 m);
- Steep Slope 4 - Upper Western Terrace (cover depths range from 220 to 260 m);
- Steep Slope 5 - Upper South Eastern Terrace (cover depths range from 160 to 200 m);
- Steep Slope 6 - Lower South Eastern Terrace (cover depths range from 80 to 140 m).

The location of the steep slope and cliff terraces (and surface developments) are shown in **Figures 2a** and **2b** with surface level and WBH Seam cover depth contours respectively. The locations of the assessed cliff types are shown in **Figure 2c**.

Exploration boreholes and surface mapping have been applied to identify the lithological profiles for the cliff lines. The location of the available boreholes (which generally included geophysical logs) are shown in **Figure 3a**. The top of Great Northern Seam Level Isopachs are given in **Figure 3b** to indicate general bedding dip over the study area.

The cliff faces are joint controlled by persistent, sub-vertical and orthogonal joint sets spaced between 1 m and 10 m. The joints strike sub-parallel and normal (perpendicular) to the faces (NW/SE, NE/SW and E/W), with many open joints and detached blocks observed along the cliff crests. Occasional mid-angled joints dipping out of slope at 55^o towards the north were also noted. Tree-root wedging is a significant factor in the opening and detachment of blocks along the cliff faces.

The cliff lines are generally considered to be discontinuous with cliff sections ranging between 5 and 30 m in length along the crests. Extremely weathered sections of the cliffs have left 1 m to 15 m gaps between the cliff face sections, allowing persons to walk (with difficulty) down the steep to very steep slopes to the front of the cliff faces.

Well-developed talus slopes with sandstone and conglomerate boulders from 0.5 m to 5 m diameter exist beneath the cliff lines. The talus slopes range in height (i.e. change in vertical elevation between toe and crest) from 13 m to 80 m and have gradients ranging from 10^o to 38^o. The lithology of the slopes comprises interbedded sandstone and mudstone or shale of the Narrabeen Group. There are several concave and convex breaks in slope due to transitioning of sandstone dominant to claystone dominant lithologies.

Some sandstone boulders between 0.5 m and 1.5 m diameter have rolled for distances of up to 100 m downhill of the cliff line crests. The boulders appear to have been stopped by tree impacts on the densely timbered slopes or at breaks in slope. There were several large, fallen trees on the slopes that may have been impacted by boulders or were blown down due to the shallow soil profile (and root system).

Lithological profiles through the eastern slopes near the existing Gencom Communications Towers (CT1 and CT2) are presented in **Figures 4** and **5** respectively. The sections (No. 1 and 2) are located at M12 and M11 as shown in **Figures 2a** and **2b**, and represent the highest and steepest slopes within the study area.

Vegetation on the cliff faces and the slopes above, on and below the cliffs have dense stands of trees (say 1 tree/25 m^2) with lantana, shrubs and ferns. The trees are predominately eucalyptus species and have an average lower trunk diameter of approximately 0.2 m (with a range of 0.1 m to 0.5 m).

Naturally incised, drainage gullies and ephemeral watercourses have developed along the cliff lines at approximately 200 m to 300 m spacing. Sandy sediments have accumulated at breaks in slope along exposed rocky, ephemeral creek beds. Open joints along the cliff lines are being infilled by slopewash sediments or provide pathways for surface runoff to drain further down slope. The watercourses typically run perpendicular to the surface contours and no evidence of radial drainage along the contours (that is indicative of slope instability) was observed.

There is no evidence of previous natural landslip or slides of the steep slopes except for the cliff fall debris (i.e. talus) already mentioned. Based on the surface observations, it is considered that the groundwater table is probably located below the cliff lines and slopes, however, perched water tables or piezometric heads may develop in open, clay infilled joints on a temporary basis after prolonged rainfall events.

The upper ridge crests along the Sugarloaf Range may be seen from a distances of 2 to 30 km away from communities, rural-residential areas and unsealed / sealed roads. The cliffs and slopes themselves are difficult to see due to the dense tree coverage. The middle and lower cliff lines are more difficult to see than the upper cliffs due to the dense vegetation on the slopes and surface topography blocking clear sight lines.

Bush walkers, mountain bike riders and 4W-Drivers currently have access to the steep slopes and cliffs, but all are generally hard to see (or walk on) from established access roads and tracks between the cliff lines and along ridges, due to dense vegetation and steepness of the topography. Access tracks exist between the Upper and Middle Northern Eastern cliff lines (Steep Slope No.s 1 and 2) and several ridges in the southern area of the Western Domain. The communications towers CT1 and CT2 are 100 m to 200 m west of the eastern cliff lines and are unlikely to be impacted by cliff instability.

A summary of each of the steep slopes and associated cliff lines are given in **Table 2** in accordance with the cliff line and steep slope definitions given in **Table 1** (see **Section 3.2**).

It should be noted that the majority of the individual cliffs in the Western Domain are < 10 m high and therefore fit the 'minor cliff' definition. However, as the combined height of the cliffs in close proximity to each other (i.e. the terraces) form a very steep slope with a height > 10 m and a slope angle between 50^o and 60^o, it is assessed that the terraces will behave like a cliff in regards to their potential for rock falls and roll outs during mine subsidence development.

Approximately 260 m of cliff terrace along Steep Slope No. 1 is > 20 m high above LWs 41 and 42.

It is also considered that subsiding the 'minor cliffs' and ‘terraces’ are unlikely to generate many rock falls due to the inherent flexibility that these cliffs, due to their height and discontinuous length. It is also considered unlikely that permanent landscape changing rock falls will occur if they do produce rock fall roll outs at a given location.

The minor cliffs and rock outcrops (which have overall heights < 10 m) have therefore been discounted when assessing the percentage of cliff line damage due to the proposed mining layouts in **Section 7.0**.

Table 2 - Steep Slope and Cliff Line Condition Summary

Steep Slope No.	Mapping Lines	Cliff Details					Talus Slope Details					Combined Cliff & Talus Slope	
		Overall Height (m)	Slope (o)	Cliff Type	Lithology	UCS* (MPa)	Height (m)	Slope (o)	Lithology	Soil Thick-ness (m)	Down Slope Length (m)	Total Cliff Length# (m)	Total Slope Length# (m)
1	M11	*8 - 15*	65	2 Cliff Terrace - Minor Cliff	Int. Sast & SiSast	15 - 70	33	36 - 10	Int. Sast & Muds (Shale)	<1	243	200	400
	M12	*20 - 25*	53	5 Cliff Terrace		15 - 70	78	35 - 10		<1	190	400	400
	M7	2 - 4	70	Rock Outcrops		15 - 60	80	20 - 25		<1	200	0	700
	M14	1.5 - 3	65	Rock Outcrops		40 - 60	60	36 - 38		<1	100	0	700
2	M11	11-*15*	60	3 Cliff Terrace - Minor Cliffs	Int. Cong & Sast	40 - 70	21	21-29	Int. Sast & Muds (Shale)	<1	100	300	800
	M12	*15 - 20*	54	3 Cliff Terrace - Minor Cliffs		40 - 70	40	19 - 27		<1	100	400	1100
	M5	10 - 16	65	Cliff		40 - 60	40	20 - 25		<1	100	200	200
	M4	1 - 3	65	Minor Cliffs		40 - 60	60	25 - 35		<1	100	0	100
3	M11	1 - 3	45-60	Rock Outcrops	Int. Cong & Sast	40 - 60	12	13-37	Int. Sast & Muds (Shale)	1.0^	123	0	2000
	M4	*15 - 18*	50	4 Cliff Terrace - Minor Cliffs		40 - 70	13	10 - 15		<3	50	200	300
	M2	1.5 - 2	65	Outcrops		30 - 60	20	22 - 25		<2	30	0	300

Table 2 (Cont...) - Steep Slope and Cliff Line Condition Summary

Steep Slope No.	**Mapping Lines**	**Cliff Details**					**Talus Slope Details**					**Combined Cliffs + Steep Talus Slopes**	
		Height (m)	**Slope (o)**	**Cliff Type**	**Lithology**	**UCS* (MPa)**	**Height (m)**	**Slope (o)**	**Lithology**	**Soil Thick-ness (m)**	**Down Slope Length (m)**	**Total Cliff Length# (m)**	**Total Slope Length# (m)**
4	M13	3-5	65	Rock Outcrops - Minor Cliff	Int. Cong & Sast	40 - 70	26	16 - 25	Int. Sast & Muds	<2	200	0	2000
5	M3	3 - 6	65	Minor Cliff - Rock Outcrops	Int. Cong & Sast	15 - 60	25	25 - 30	Int. Sast & Muds (Shale)	<2	50	0	400
	M6	3	65	Rock Outcrops		15 - 60	40	20 - 25		<2	100	0	500
	M15	*5 - 9*	60	Minor Cliff		40 - 60	40	15 - 25		<2	100	0	1000
6	M1	1-3	65	Rock Outcrops	Int. Cong & Sast	15 - 60	17	20	Int. Sast & Muds (Shale)	1.2^	50	0	600
	M8	0 - 3	-	Nil – Rock Outcrops		15 - 60	20 - 40	19 - 23		<2	200	0	1200
	M9	5 - 9	65	Minor Cliff – Rock Outcrops		30 - 60	17	15 - 20		<2	50	0	800
	M10	4 - 6	65	Minor Cliff		20 - 60	10	15 - 20		<2	30	0	400
Min	M1	1.5	39			15	12	10		1	30	0	100
Max	M12	25	70			70	80	38		3	243	400	2000
											Total	**1700**	**13,900**

Italics - terraced or benched cliff slope with 2 to 5 minor cliffs with heights generally <10 m & typically 3 to 7 m. Cliffs have slopes ranging from 65^o to 80^o with rounded crests ranging from 45^o to 60^o. Underlined - average slope of terraced cliffs.
Lithology Key: Cong = conglomerate; Sast = Sandstone; Muds = Mudstone; Int = interbedded. # - Distance along cliff line or slope crest.
* - Unconfined compressive strength estimated from fieldwork guideline AS1726-1993. ^ - Soil/rock profile observed in subsidence crack above LW39.

5.0 Subsidence Effect and Impact Parameter Predictions

Predictions of credible worst-case (U95%CL) subsidence contours, principal tilt, horizontal displacements and strain have been previously presented in **DgS, 2010** for the proposed longwall panels (LWs 38 to 43 and 47 to 50) using SDPS software, Version 5.5R (09/05/07). The SDPS model was calibrated to predicted subsidence profiles derived with the modified **ACARP, 2003** empirical model. The U95%CL subsidence, tilt and strain contours are presented in **Figures 6** to **8** with the locations of steep slopes (>25^{o}) and terraced cliff lines.

The worst-case subsidence predictions for the proposed longwall panels range between 0.6 m and 2.5 m for the given cover depths above the workings of 100 m to 320 m. Worst-case tilts are estimated to range from 6 mm/m to 70 mm/m with tensile/compressive strains ranging from 2 mm/m to 25 mm/m.

The key impacts of the predicted subsidence effects will be caused by tilting, bending and cracking of the steep slopes and cliff lines above the extracted longwall panels. Based on recent observations of two subsidence cracks above the recently extracted areas of LW39, it is assessed that crack widths on subsided slopes are likely to be larger than in relatively flat terrain.

Previous DgS reports of crack width estimation above the Western Domain longwalls (LW38 and 39) have been based on the predicted strains multiplied by 10 m (an empirical factor based on distance between survey pegs). However, it is apparent from the measured crack widths that they are strongly influenced by the tilting of surface ridges as well, see **Table 3**.

Table 3 - Measured Crack Widths v. Predicted Subsidence Effects Above Steep Slopes

LW	Location	Cover H (m)	Measured Crack Width (mm)	Crack Depth z (m)	Ridge Slope (o)	Predicted U95%CL Tensile Strain (mm/m)	Predicted Crack Width from Strain (mm)	Predicted U95%CL Tilt (mm/m)	Predicted Crack Width from Tilt & Strain (mm)
38	Ridge at end of panel	140	300	n/m	10 - 15	6 - 8	**60 - 80**	26 - 39	**260 - 390**
39	Ridge at 900 m from start	110	600	2.3	15 - 20	10 - 14	**100 - 140**	35 - 52	**350 - 520**
39	Ridge 2.3km from start	110	*430*	2.3 - 5.9	10 - 15	10 - 14	**100 - 140**	35 - 52	**350 - 520**
39	Valley Floor	110	3 cracks 25,40,40 @ 1-3 m spacing	1.0	2 - 5	10 - 14	**100 - 140**	35 - 52	**N/A**

* - Steep slope crack widths = 10 x (Predicted U95%CL Tilt); *italics* - transient crack.

Based on the above review, it is now considered appropriate to estimate cracks on the steep slopes and cliff lines using the predicted tilts multiplied by 10.

The cracks on the steep slopes are likely to develop along the high rib-side of the longwall blocks and in the vicinity of the peak tensile strains. The tensile strain profile is likely to migrate towards the high side ribs and may occur outside the limits of extraction (refer to **DgS, 2010** for further details). Compressive strain effects such as shear failures and 'hump' development may occur along the low rib-side of the longwalls. Transient cracking across and behind the longwall face may occur periodically after each goaf fall in the workings.

A summary of the subsidence effect parameters and estimated crack widths for the steep slopes and cliffs are presented in **Table 4**.

Table 4 - Predicted Range of Subsidence Effects on Steep Slopes and Cliff Lines

Steep Slope No.	Map Line No.	Cliff Height (m)	LWs	Cover Depth (m)	Subsidence S_{max} (m) (U95%CL)	Tilt T_{max} (m/mm) (U95%CL)	Compress Strain E_{max} (m/mm) (U95%CL)	Tensile Strain E_{max} (m/mm) (U95%CL)	Crack Width* (mm) (U95%CL)
1	M11	15	42	200-280	0.6 - 1.0	15 - 25	3 - 5	2 - 4	150-200
	M12	25	42	235-320	0.6 - 1.0	10 - 15	3 - 5	2 - 4	100-150
	M7	4	42-43	200-280	0.6 - 1.4	10 - 15	3 - 5	2 - 4	100-150
	M14	3	43-47	240-300	0.6 - 1.4	10 - 15	3 - 5	2 - 4	100-150
2	M11	15	41-42	160-180	0.6 - 1.6	20 - 30	7 - 10	3 - 5	200-300
	M12	20	41-42	160-220	0.6 - 2.0	20 - 35	7 - 10	3 - 5	200-350
	M5	16	42	160-180	0.6 - 1.4	20 - 35	6 - 9	3 - 5	200-350
	M4	3	42	160-180	0.2 - 1.4	15 - 35	6 - 9	5 - 5	150-350
3	M11	3	40-41	140-160	1.5 - 2.2	30 - 40	7 - 13	5 - 20	300-400
	M4	18	40-41	100-140	0.1 - 2.2	30 - 40	9 - 14	6 - 20	300-400
	M2	2	39-40	120-140	2.0 - 2.2	30 - 40	9 - 14	6 - 9	400-600
4	M13	5	47-48	220-260	0.6 - 1.4	5 - 20	3 - 6	2 - 4	50-200
5	M3	6	42	120-180	0.2 - 1.6	20 - 30	6 - 10	4 - 7	200-300
	M6	3	43-47	140-200	0.2 - 1.4	5 - 30	4 - 9	3 - 6	50-300
	M15	15	47-49	150-200	0.2 - 1.8	5 - 30	3 - 9	2 - 5	50-300
6	M1	3	39-40	120-150	0.2 - 2.4	40 - 60	9 - 15	7 - 12	400-600
	M8	0	40-42	100-140	0.6 - 2.5	40 - 70	6 - 24	5 - 20	400-700
	M9	10	47-48	100-120	0.1 - 1.8	50 - 70	8 - 24	6 - 20	500-700
	M10	6	49-50	120-140	0.1 - 1.2	40 - 60	6 - 15	5 - 10	400-600

* - crack widths assume a single crack may develop along the upslope rib side of the given longwall beneath steep slopes > 25^{o}. The crack depth is estimated to range between 6 and 20 m on the steep slopes.

A review of measured subsidence effect data for LW38 (refer to **DgS, 2011a**) indicates that the predicted subsidence, tilt and strain values presented in this study are conservative.

Predicted U95%CL Subsidence profiles were produced for the LW41 to 42 SMP Report (refer to **DgS, 2011**) through the steep slopes east of the Gencom communications towers, CT1 and CT2, and are re-presented here in **Figures 9a** and **9b** with the measured subsidence profile for LW38 (LW39 LIDAR data is still pending).

The subsidence effect predictions have been used to define the input parameters required for the cliff damage impact assessment discussed in the **Section 6.5**.

6.0 General Slope Instability Assessment

6.1 Steep Rock Slopes

The proposed longwalls will cause subsidence, tilting and bending of the surface supporting the cliffs and slopes. The subsidence effects are likely to result in an increase in down slope forces acting on the cliffs and slopes, and possibly a reduction in resisting forces due to crack development.

By adopting the predictions of principal tilt and strain shown in **Figures 7** and **8**, the 10^o to 38^o talus slopes in the middle to upper slopes (No. 1, 2 and 4) may be subject to tilts of 5 to 35 mm/m and tensile strains of 2 to 5 mm/m. The lower slopes (No. 3, 5 and 6) may be subject to tilts of 5 to 70 mm/m and tensile strains of 2 to 20 mm/m.

Based on the predicted tilts, surface cracks ranging from 50 mm to 350 mm width may occur on the upper slopes (No. 1, 2 and 4) with crack widths ranging from 50 mm to 700 mm estimated for the lower slopes (No. 3, 5 and 6). The crack depths are likely to range between 5 and 10 m (as has been measured on the steep slopes above LW39) but could reach 20 m at some locations.

The stability of the 25 to 38 degree slopes below the cliff lines in the study area have been assessed for large-scale block sliding on claystone beds in wet (saturated) and dry conditions before and after the effects of longwall mining. The potential for shallow translational sliding in surface soils have been assessed in **Section 6.1.3**.

The factor of safety (FoS) for large scale block translational sliding of interbedded sandstone and shale strata units has been calculated using a simple force balance model defined in **Hoek, 2000** and shown in **Figure 10a**. The weight force of a unit width of a dry and wet cracked slope with perched water present (in the cracks) acting down the slope and the frictional resistance against sliding has been calculated as follows:

$W = (d_r g)h^2 ((1-(z/h)^2)\cot(a) - \cot(b))$ = weight of rock slope block with density (d_r), gravity constant (g), depth (h), crack depth (z), bedding or failure plane slope (a) and surface slope (b).

$z = H (1-\sqrt{\cot(b)\tan(a)})$ = maximum tension crack depth for the minimum FoS of the given rock slope geometry.

$U_1 = d_w g z_w^2/2$ = driving force of water (with density d_w) filled crack of depth z_w on the slope block.

$U_2 = d_w g z_w X/2$ = driving force of water (with density d_w) filled crack of depth z_w along the base distance X the slope block.

$X = (H-z)/\sin(a)$ = base length of sliding rock block

$T = W[\sin(a)+\alpha\cos(a)] + U_1\cos(a)$ = driving force of rock block (W), water filled crack (U_1)

and horizontal earthquake acceleration (α) along potential failure plane. *Note - α = 0.08 g was assumed.*

$S = cX + [W(\cos(a)-\alpha\sin(a))-U_2-U_1\sin(a)]\tan(p)$ = rock block sliding resistance along potential failure plane with drained cohesion, c and drained friction angle, p.

FoS = S/T = factor of safety against sliding.

The above theory indicates that the stability of the steep slopes will be most sensitive to (i) the shear strength properties of mudstone beds, (ii) bedding or failure plane slope (iii) surface slope and (iv) water filled cracks.

Based on reference to **Fell, 1995**, conservative drained Mohr-Coulomb residual shear strength parameters of cohesion, c=0 and friction angle, phi=15^o were assumed for a softened mudstone or claystone bed in the Narrabeen Group that has been exposed to a water filled crack caused by mine subsidence.

Note: Residual strength implies lower bound shear strength has developed on a claystone bedding plane due to initial softening caused by water ingress, and the magnitude of bedding plane shear / horizontal strain and tilt (associated with subsidence) was sufficient to develop residual strength properties.

This is a conservative assumption, as the residual shear strength along bedding planes generally needs to occur over a significant area of a weaker bed to induce large-scale instability (eg Teralba Conglomerate block-sliding over claystone beds in the Lake Macquarie area). The subsidence induced residual shear strength parameters that could develop along claystone beds are more likely to be stepped up through the profile, rather than forming laterally extensive residual strength zones along individual bedding planes.

This could explain why there are very few cases of deep-seated landslips that have been the direct result of mine subsidence impact.

The potential or likelihood of slope failure may then be considered based on reference to **Luo and Peng, 1999,** which provides the following assessment of 'sliding potential' categories for the predicted FoS values:

FoS > 1.5	'Low Potential' for slope failure
1.2< FoS > 1.5	'Medium Potential' for slope failure
FoS < 1.2	'High Potential' for slope failure

The above values are consistent to values often used to design cuttings and fill embankments in civil works, with long and short-term stability criteria set at 1.5 and 1.2 to 1.3 for average and lower bound peak material strengths respectively (refer to **Leventhal and Stone, 1995**).

A minimum FoS of 1.2 may be adopted for a softened mudstone or claystone unit with residual strength properties that may develop after being exposed to a water filled crack for several weeks. A FoS as low as 1.0 may also be acceptable for short-term adverse loading conditions due to water filled cracks and earthquakes occurring simultaneously (which is a very unlikely scenario).

The stability assessment was completed for the six steep slopes mapped (see **Appendix B** for details) and the outcomes are summarised in **Table 5**. Details of the stability analysis are presented in **Appendix B**.

The slopes in the Western Domain in their current, pre-mining condition are assessed to have a 'Low' sliding potential over an extreme range of climatic conditions (i.e. Dry to Saturated) with an FoS range of 1.81 to 5.11. This is confirmed by the absence of slope features that are indicative of existing or past slope instability.

If the steep slopes (No. 1 to 6) are subjected to the worst-case tilts after mining, the FoS against sliding is estimated to range from 2.18 to 3.97 for dry, cracked conditions and from 1.32 to 1.74 for saturated conditions with water filled cracks. The potentially visible slopes (No.1 and 2) have estimated cracked and wet FoS values predicted to range between 1.46 and 1.62.

The subsided slopes are therefore assessed to have 'Low' to 'Medium' sliding potential during worst-case conditions with unrepaired cracks. The stability of the slopes with water filled cracks may be marginal in the event of the design earthquake (or from vibrations due to underground goafing).

Another important factor is the alignment of the tensile cracking in relation to the slope crests. Cracks that are sub-parallel to the slope crests will have a greater potential impact on slope instability than cracks which are perpendicular to the slope crests. The stability analysis has assumed that the cracks are longitudinal and continuous along the length of the slope.

Based on the proposed layout, it has been assumed that the transient cracking that occurs behind the longwall face will be perpendicular or at a high angle to the slope crests for the east and west facing cliffs and slopes, whereas the final, longitudinal cracks above the longwall panels will be sub-parallel to the eastern cliffs and slopes (No. 1 to 4). The opposite will apply to the south and north facing cliffs and slopes generally (No.s 5 and 6).

The potential for slope instability to develop will be minimised if significant longitudinal cracks can be grouted in a timely manner (ie. in weeks rather than months after occurrence).

Table 5 - Summary of Instability Assessment of the Steep Slopes in the Western Domain

Pre-mining Conditions										Post-Mining Conditions for Current Longwall Layout				
Steep Slope No.	**Map Lines**	**LWs**	**Cover Depth (m)**	**Slope Height (m)**	**Initial Bed Dip (o)**	**Initial Talus Slope (o)**	**Min Dry FoS**	**Min Wet FoS + WFC**	**Min Wet FoS +WFC +EQ**	**Tilt (m/mm) (U95%CL)**	**Post Mining Bed Dip (o)**	**Min Dry FoS**	**Min Wet FoS + WFC**	**Min Wet FoS +WFQ +EQ**
1	M11	42-43	200-280	57	3	36	5.11	1.84	1.09	15 - 25	4.4	3.46	**1.48**	**0.95**
	M12	42-43	235-320	78	3	35	5.11	1.85	1.09	10 - 15	3.9	3.97	1.62	1.00
	M7	42-43	200-280	80	3	25	5.11	2.00	1.14	10 - 15	3.9	3.97	1.74	1.05
	M14	43-47	240-300	60	3	38	5.11	1.81	1.08	10 - 15	3.9	3.97	1.58	**0.99**
2	M11	41-42	140-180	38	3	29	5.11	1.94	1.12	20 - 30	4.7	3.25	1.50	**0.95**
	M12	41-42	160-220	40	3	19	5.11	2.10	1.18	20 - 35	5.0	3.06	**1.46**	**0.97**
	M5	42	160-180	40	3	25	5.11	2.00	1.14	20 - 35	5.0	3.06	**1.48**	**0.95**
	M4	42	120-180	60	3	35	5.11	1.85	1.09	15 - 35	5.0	3.06	**1.38**	**0.90**
3	M11	40-41	140-160	35	3	37	5.11	1.83	1.17	30 - 40	5.3	2.89	**1.32**	**0.87**
	M4	40-41	100-140	13	3	15	5.11	2.18	1.20	30 - 40	5.3	2.89	1.54	**0.97**
	M2	39-40	120-140	20	3	25	5.11	2.00	1.14	30 - 40	5.3	2.89	**1.32**	**0.92**
4	M13	47-48	220-260	26	3	25	5.11	2.00	1.14	5 - 20	4.1	3.70	1.67	1.02
5	M3	42	120-180	25	3	30	5.11	1.93	1.12	20 - 30	4.7	3.25	**1.49**	**0.95**
	M6	43-47	140-200	40	3	25	5.11	2.00	1.14	5 - 30	4.7	3.25	1.54	**0.97**
	M15	47-49	150-200	40	3	25	5.11	2.00	1.14	5 - 30	4.7	3.25	1.54	**0.97**
6	M1	39-40	120-150	17	3	30	5.11	2.91	1.40	40 - 60	6.4	2.38	1.63	**0.96**
	M8	40-42	100-140	40	3	23	5.11	3.10	1.44	40 - 70	7.0	2.18	**1.48**	**0.95**
	M9	47-48	100-120	17	3	25	5.11	3.04	1.43	50 - 70	7.0	2.18	1.51	**0.94**
	M10	49-50	120-140	10	3	25	5.11	3.04	1.43	40 - 60	6.4	2.38	1.65	**0.99**

WFC = Water-filled crack. EQ = Design Earthquake with acceleration of 0.08g.
Bold - Predicted FoS < Design FoS (see **Section 6.1**).

6.2 Previous Natural Instability and Precedent for Deep Seated Translational Sliding

Based on field mapping and observation of aerial photographs (Google), there was no evidence of existing or past slope instability noted along the existing slope area.

It is noted in a paper on natural land sliding in the Gosford-Lake Macquarie Area by **Fell, 1995** that a deep seated, translational-rotational slide of sandstone over claystone developed in the Clifton Sub-Group along the toe of steep ridge with slopes ranging from 30^o to 42^o (see **Figure 10b**). The slide, located in a commercial subdivision at Memorial Avenue, Blackwall Mountain (near Gosford) was subsequently stabilised with a series of horizontal borehole drains to alleviate water pressure and reduce further sliding movements. It was suspected that the slide had developed prior to excavation works along the toe of the slope for the sub-division; however, the works may have re-activated the slide.

Whilst there is no evidence of existing or past slope instability noted on the steep slopes on the West Wallsend Mine site, it is still possible that localised slope instability can occur in the same geological conditions, if changes to slope equilibrium and bedding shear strength occur (due to mine subsidence).

Based on the above, it is considered that the proposed mining impacts on the slopes could result in marginally stable conditions developing at locations where tensile cracking has occurred and prolonged rainfall events have saturated the soil and filled the cracks to the surface. As this combination of events is possible, it will therefore be necessary for persistent longitudinal cracks to be backfilled after >90% of subsidence has developed.

Visual inspections of surface cracks and results from in-slope displacement monitoring devices (i.e. borehole inclinometers and vibrating wire piezometers) will need to be reviewed by a qualified Geotechnical Engineering Consultant to determine whether a crack needs to be filled or not. As a guide, cracks that are > 50 mm wide and deeper than 1 m would need to be assessed for in-filling.

6.3 Cliffs

A similar approach to that used in **Section 6.1** has been adopted to calculate the FoS of sliding movements of the strata units beneath the terraced cliff lines when subject to mine subsidence; see **Figure 10c**.

Field observations and the lithological sections shown in **Figures 4** and **5**, indicate that the bedding beneath the cliffs generally dip towards the south to south east at 1 to 3 degrees and likely to consist of low strength claystone and shale interbedded with medium to high strength sandstone / conglomerate. Large-scale block sliding of the cliffs with heights of 2 m to 25 m have been assessed for pre-mining and post-mining conditions for the current longwall layout.

Predicted FoS values of sliding on these beds after the effects of mining (with a range of tilts up to 70 mm/m and 85% water filled cracks that are 1 m behind the cliff crests) have been assessed in **Appendix B** and summarised in **Table 6**. Residual shear strengths of cohesion, c=0 and friction angle, phi=15^{o} have again been assumed based on **Fell, 1995**.

The design piezometric level of 0.85 x the crack depth behind the cliff line crests has been assumed to be lower than the steep slopes (i.e. 0.85 v. 1 x the crack depth) due to the presence of persistent, open joints that are likely to provide drainage path ways to the bases of the cliffs.

Table 6 - Summary of Sliding Potential Assessment of the Western Domain Cliffs

Pre-mining Conditions										Post-Mining Conditions for Current Longwall Layout				
Steep Slope No.	**Map Lines**	**LWs**	**Cover Depth (m)**	**Cliff Height (m)**	**Initial Bed Dip (o)**	**Initial Cliff Slope (o)**	**Min Dry FoS**	**Min Wet FoS + WFC**	**Min Wet FoS +WFC +EQ**	**Tilt T_{max} (m/mm) (Mean - U95%CL)**	**Post Mining Bed Dip (o)**	**Dry FoS**	**Wet FoS +WFQ**	**Wet FoS +WFQ +EQ**
1	M11	42-43	200-280	*15*	3	65	5.11	1.58	1.00	15 - 25	4.4	3.46	**1.28**	**0.87**
	M12	42-43	235-320	*25*	3	53	5.11	1.76	1.07	10 - 15	3.9	3.97	1.54	**0.98**
	M7	42-43	200-280	4	3	60	5.11	1.66	1.03	10 - 15	3.9	3.97	**1.45**	**0.95**
	M14	43-47	240-300	3	3	60	5.11	1.66	1.03	10 - 15	3.9	3.97	**1.45**	**0.95**
2	M11	41-42	140-180	*15*	3	39	5.11	1.94	1.14	20 - 30	4.7	3.25	1.50	**0.97**
	M12	41-42	160-220	*20*	3	54	5.11	1.74	1.07	20 - 35	5.0	3.06	**1.31**	**0.88**
	M5	42	160-180	16	3	60	5.11	1.75	1.03	20 - 35	5.0	3.06	**1.25**	**0.85**
	M4	42	120-180	3	3	60	5.11	1.66	1.03	15 - 35	5.0	3.06	**1.25**	**0.85**
3	M11	40-41	140-160	3	3	60	5.11	1.66	1.03	30 - 40	5.3	2.89	**1.20**	**0.83**
	M4	40-41	100-140	*18*	3	60	5.11	1.66	1.03	30 - 40	5.3	2.89	**1.20**	**0.83**
	M2	39-40	120-140	2	3	60	5.11	1.66	1.03	30 - 40	5.3	2.89	**1.20**	**0.83**
4	M13	47-48	220-260	5	3	35	5.11	2.00	1.10	5 - 20	4.1	3.70	1.66	1.03
5	M3	42	120-180	6	3	60	5.11	1.66	1.03	20 - 30	4.7	3.25	**1.29**	**0.87**
	M6	43-47	140-200	3	3	60	5.11	1.66	1.03	5 - 30	4.7	3.25	**1.29**	**0.87**
	M15	47-49	150-200	9	3	45	5.11	1.87	1.11	5 - 30	4.7	3.25	**1.45**	**0.94**
6	M1	39-40	120-150	3	3	30	5.11	3.15	1.48	40 - 60	6.4	2.38	1.63	1.02
	M8	40-42	100-140	None	3	-	5.11	3.33	1.52	40 - 70	7.0	2.18	1.57	1.00
	M9	47-48	100-120	9	3	60	5.11	2.46	1.31	50 - 70	7.0	2.18	**1.22**	**0.84**
	M10	49-50	120-140	6	3	65	5.11	2.32	1.27	40 - 60	6.4	2.38	**1.25**	**0.85**

WFC = Water-filled crack. EQ = Design Earthquake with acceleration of 0.08g. *italics* – terraced minor cliffs. Underline – average terrace cliff angle
Bold - Predicted FoS < Design FoS (see **Section 6.1**).

The results in **Table 6** indicate that cliffs and minor cliffs in the Western Domain in their current, pre-mining condition are likely to have a ‘Low’ sliding potential over an extreme range of climatic conditions (i.e. Dry to Saturated) with an FoS range of 1.58 to 5.11.

If the cliffs are then subjected to the worst-case tilts after mining the current layout, the FoS against sliding is estimated to range from 2.18 to 3.97 for dry, cracked, conditions and from 1.20 to 1.66 for saturated conditions with 85% water filled cracks. The subsided cliffs are therefore assessed to have ‘Low’ to ‘Medium’ sliding potential during worst-case conditions with unrepaired cracks.

A similar scenario therefore also exists for the cliffs in regards to prompt repairs of deep subsidence cracking behind the cliff faces with low-strength grout. Rock toppling failures and overhang collapses along pre-existing joints are also likely to occur due to the predicted tilting and cracking and are further discussed in **Section 6.7**.

6.4 Shallow Soil Instability on Steep Slopes

The stability of shallow clayey sands/sandy clay scree or slope wash on the 20 to 35 degree slopes below the cliff lines in the study area were been assessed for wet (saturated) and dry conditions before and after the effects of longwall mining.

The factor of safety (FoS) for translational sliding of the sandy clay soils over the sandstone and shale strata units has been calculated using a simple force balance model defined in **Das, 1998** and shown in **Figure 10d**. The weight force of a unit width of soil and water (if present) acting down the slope and the frictional resistance against sliding has been calculated as follows:

$W = (d_s g)bh$ = weight of a 1 m wide soil block with density d_s, gravity constant, g, length b, and depth h.

$T = (W+U)\sin(a)$ = driving force along potential failure plane of slope, a.

$V = bd_w gz\cos^2(a)$ = uplift force of seepage water (with density d_w) in a saturated soil of depth z on the slope.

$U = d_w gz^2/2$ = driving force of water (with density d_w) filled crack of depth z on the slope.

$S = c'b + (W\cos(a)-V-U\sin(a))\tan(p')$ = sliding resistance along potential failure plane with drained cohesion, c’ and drained friction angle, p’.

$FoS = S/T$ = factor of safety against sliding.

The drained soil strength parameters c’ and p’ were back calculated for the slopes before mining impacts of cracking and tilting. A conservative thickness of the soil profile on the steep slopes was assumed to be 1.0 m on the 25^o slopes and 0.7 m on the 35^o slopes, based on subsidence crack profiles above LW 39 and 'pot-hole' or piping type features on downside of bed rock exposures present on the site. The knowledge that there have been no shallow translational sliding failures on the slopes to-date was also a consideration, although the presence of trees and vegetation is also likely to have contributed to the soil stability.

The above theory indicates that the stability of the slopes will be most sensitive to (i) soil cover thickness and (ii) water filled cracks with full depth seepage along the slope. The cracking due to subsidence will also reduce the stability of the soils by removing down-side toe support to the section of slope affected by persistent cracking through the soil profile.

Based on reference to **Table D4 - AS4678**, peak soil strength parameters of c' of 5 kPa and p' of 28^o have been assumed for the stiff clayey sands/sandy clays in the Narrabeen Group. An FoS range of 1.28 to 3.16 was estimated for saturated pre-mining conditions with seepage flows along half its depth of 0.7 m and 1.0 m on the 35^o and 25^o slopes respectively.

Based on the predictions of principal tilt and strain on the slopes after mining, the steep slopes were considered likely to be subject to full soil profile cracking at some stage during or soon after mining. The stability assessment was therefore completed for the steep slopes for the range of climatic (i.e. dry or wet) and worst-case mine subsidence impacts.

A summary of the stability assessment is presented in **Table 7** and shown in **Figures 11a** and **11b**.

Table 7 - Summary of Sliding Potential Assessment of the Steep Slopes

Case	Conditions	Driving Forces (kN/m)	Resisting Forces (kN/m)	Factor of Safety
Maximum Slope Angle = 35^o				
Pre-Mining (h= 0.3 to 0.7 m)	Dry Slope	3.71 - 8.66	8.92 - 12.68	2.40 - 1.46
	Saturated Slope	4.05 - 9.44	8.65 - 12.05	2.14 - 1.28
Post Mining (Tilt = 10 to 40 mm/m)	Dry Slope	8.78 - 9.14	12.67 - 12.67	1.44 - 1.39
	Saturated Slope	9.58 - 9.97	12.06 - 12.09	1.26 - 1.21
	Saturated Slope + water filled cracks	11.53 - 11.89	10.85 - 10.94	0.94 - 0.92
Maximum Slope Angle = 25^o				
Pre-Mining (h = 0.3 to 1.0 m)	Dry Slope	2.73 - 9.11	8.63 - 15.91	3.16 - 1.75
	Saturated Slope	2.98 - 9.94	8.28 - 14.71	2.78 - 1.48
Post Mining (Tilt = 10 - 70 mm/m)	Dry Slope	9.31 - 10.45	15.88 - 15.74	1.71 - 1.51
	Saturated Slope	10.15 - 11.40	12.58 - 12.67	1.24 - 1.11
	Saturated Slope + water filled cracks	14.57 - 15.69	12.58 - 12.67	0.86 - 0.81

h = back analysed soil depth for existing slopes of 25^o to 35^o.

Details of the stability analysis and schematic drawing of the force system assumed are presented in **Appendix B**.

Based on the slope stability criteria given in **Section 6.1**, the slopes in the Western Domain (in their current condition) are assessed to have a 'Low' to 'Medium' Sliding Potential over an extreme range of climatic conditions (i.e. Dry to Saturated) with an FoS range of 1.28 to 3.16.

The FoS of the soil slopes after the proposed mining ranges from 1.21 to 1.71 for dry to saturated soils (without cracks) when tilted between 70 mm/m and 10 mm/m. The presence of water filled cracks reduces the FoS to between 0.81 and 0.94, which suggests marginally stable conditions are likely to develop at locations where tensile cracking has occurred and prolonged rainfall events have saturated the soil and filled the cracks to the surface (i.e. there will be 'High' potential for instability).

However, it is considered that the high density of tree and vegetation coverage on the slopes will mitigate against widespread translational slide failures and therefore considered acceptable in risk management terms, provided the cracks are grouted as soon as practicable.

In summary, it is considered that the potential for steep soil slope failure after mining would be 'High' for the predicted tilts, strains and cracks, but may be reduced to 'Medium' potential overall, due to the high density of trees and vegetation with crack grouting completed.

The consequence of a shallow translational slope failure is likely to be localised and unlikely to impact on slope aesthetics. Public safety however, is a significant issue that will require further assessment (see **Section 7.0**).

6.5 Cliff Face Damage Classification and Ranking System

Local instability of cliff faces can also occur from longwall mining due to the tilting and bending of the surface supporting the cliff. Overhangs and continuous, sheer faces are particularly vulnerable to collapse and the development of rock falls and toppling failures due to subsidence cracking and bending deformations. Cliffs that are segmented or discontinuous, due to weathered, open jointing are less prone to new cracking and likely to have lower rock fall occurrences.

It is apparent from the site observations, that the cliffs are susceptible to natural rock falls caused by undercutting of basal mudstone beds. Exfoliation and honeycomb weathering of sandstone beds have also contributed to overhang development, however these features are more localised and considered less of an stability risk than the former mechanism.

As was presented in the EIS Report, the **ACARP, 2002** model was developed to provide a holistic approach to the response of cliff faces to mine subsidence, and includes the following three impact categories:

(i) the impacts of mining induced deformation (i.e. expressed in terms of the % length of cliff line affected by rock falls),

(ii) exposure of the public (and mining personnel) to rock falls and the potential loss of aesthetic appeal of the cliffs, and

(iii) the contribution of the natural instability of the cliffs (i.e. the on-going weathering and cliff adjustment processes).

There are a number of factors assigned to each impact category, which are then multiplied by a weighting value to provide a score for each factor. The scores are then summed and ranked as a proportion of the maximum possible score for each category.

It should be noted that it is claimed by the model authors, that any attempt to assess the likelihood of a cliff collapse or rock fall at a **particular** location is not possible, since the actual stability of the rock face cannot be determined by the appearance of it before mining (this is based on the authors experiences of cliff rock fall patterns observed during the development of the model).

It should also be understood that the predicted % length of cliff line affected by rock falls due to mining are worst-case values and also include rock falls due to natural weathering processes. It is therefore possible to calculate the background level or percentage of rock falls along a cliff line due to ‘natural’ causes only by assessing the % of falls for the lowest possible value for the mining impact category at a given site.

The **ACARP, 2002** rating and ranking system is an empirical model that was developed based on similar stability and risk assessment methods used by the RTA on managing man-made and natural slopes adjacent to the NSW road network. However, it has recently been reported that the RTA has recently revised its slope risk assessment system, as experience has shown that the slope rating system involving assigning values for slope (and cliff face) parameters under a weighting system is a *poor* indicator of slope (or cliff) failure risk.

At this stage the **ACARP, 2002** system, which is based on a rating and ranking system, has performed reasonably well at other mines to-date. It does appear however, from a review of similar mining and cliff / steep slope geometries (see **Section 6.6**), the predicted lengths of cliff line damage (from rock falls) are likely to be significantly higher than the measured damage.

Furthermore, it is considered that the response of the discontinuous, low level cliff lines in the Western Domain may not be fairly represented in the database of cliff lines used in the **ACARP, 2002** report, which was essentially developed to take into account the measured responses of higher and more aesthetically pleasing cliff lines in the Southern and Western Coalfields in NSW to mine subsidence.

The cliff heights in the **ACARP, 2002** model database range between 10 m and 150 m and are significantly greater in height than the cliffs at West Wallsend Colliery. The authors of the model also suggest that for cliffs that are deemed to be outside the limits of the database (or in a different coalfield), it may be necessary for the impact parameter limits in the model to be re-calibrated or adjusted upon review of local mining experience.

Another issue of concern is that the **ACARP, 2002** model has all cliff subsidence > 0.5 m defined as 'very high' to 'extremely high' Mining Impact Rating (or Mining Induced Impact) but may still result in an overall ‘low’ to ‘moderate’ Overall Impact due to ‘very low’ to ‘low’ Aesthetic Appeal / Public Exposure and Natural Instability Ratings.

Despite the above issues, it is assessed that the use of the **ACARP, 2002** model in the Newcastle Coalfield is likely to result in over-estimation of subsidence impacts on the cliffs and steep slopes at West Wallsend.

In an attempt to calibrate the likely impacts on the steep slopes and cliff lines above West Wallsend Colliery to the outcomes indicated by **ACARP, 2002**, measured impacts above several longwall mines with similar cliff and steep slopes and lithology to the proposed West Wallsend mining layout have been reviewed.

DgS was involved in a triennial audit of the Annual Environmental Management Reports and observed the impacts that occurred at the Dendrobium Mine for LWs 1 to 3, which are located beneath very steep terrain and cliff lines associated with the Cataract Dam's catchment area. A review of the Dendrobium case studies and the published information for the Baal Bone and Metropolitan Mines in the Western and Southern NSW Coalfields are discussed in the next section to demonstrate the conservative nature of the **ACARP, 2002** model outcomes.

6.6 Review of Figure 10.1 in ACARP, 2002 and the Cliff Line Impacts for the Dendrobium, Baal Bone and Metropolitan Mines

The worst-case mining impacts on the cliffs at West Wallsend have been assessed with the chart values presented in Figure 10.1 from **ACARP, 2002** (see **Appendix C**). However, due to aforementioned issues with the database on which the curves have been based, it was considered necessary to review their validity based on observed impacts at other mines with similar conditions.

The estimate of maximum length of cliff line that may be impacted involves the plotting of the Mining Impact proportion of the subsided length of cliff on the appropriate Natural Instability curve provided in **ACARP, 2002**.

For the purpose of improving our understanding of the likely range of the West Wallsend Colliery longwall impacts, the measured data has been re-plotted in **Figure 12** of this report with regression curves of ‘best-fit’. The U95%CL curves have then been determined statistically to provide a range of expected damage for the cliff lines.

The data base for the **ACARP, 2002** chart was interpreted as having 19 ‘Very Low’, 16 ‘Low’ and 5 ‘Moderate’ Natural Instability cases. The outcome of the review study infers that the mean curves for the ‘Very Low’ and ‘Low’ cases are similar, with U95%CL values slightly greater for the Low cases v. Very Low Cases. The ‘Moderate’ curves were higher than the lower ranked curves as would be expected.

In order to complete the review, a comparison of the outcomes of the damage assessments for the available data for observed and predicted impacts at the Dendrobium, Baal Bone and Metropolitan Mines are summarised in **Tables 8A** and **8B**.

Table 8A - Review Summary of ACARP, 2002 Cliff Damage Assessment Figure 10.A

Mine	LWs	Panel Width W (m)	Cover depth H (m)	Panel W/H	Subsidence (m)	Tilt (mm/m)	Strain (mm/m)	Cliff Heights (m)	Talus Slopes (o)	Mining Impact Score	Mining Impact Rating	Aesthetics/ Public Exposure Rating	Natural Instability Rating	Overall Rating
Dendrobium	1-3	245	170-320	1.44-0.77	0.34 - 1.3	15-30	-11 to 5	10 - 30	15-25	0.61-0.83	EH	VL	L	**Moderate**
Baal Bone	1-23	200-240	100-250	2.00 - 0.96	0.1 - 1.8	15 - 40	-15 to 10	20 - 50	15-30	0.61-0.83	EH	VL	L	**Moderate**
Metropolitan	1-15	133-163	400-420	0.33-0.41	0.34-1.25	1-5	-1.8 to 1.3	4.5 - 22	18 - 27	0.14-0.31	EH	M	VL	**Low**

VL = Very Low; L = Low; M = Moderate; H = High; VH = Very High Impact; EH = Extremely High.

Table 8B - Review Summary (cont…) of ACARP, 2002 Cliff Damage Assessment Figure 10.A

Mine	LWs	Predicted ACARP, 2002 Upper-bound Damage (%Cliffs)	Observed Cliff Damage (%Cliffs)	Observed Impact Description	Assessed Background Stability (%)	Mean Cliff Damage (%Cliffs)	Mean Cliff Damage Increase (%Cliffs)	(%Cliffs)
Dendrobium	1-3	27 - 56	**7-10**	Eight isolated rock falls and talus soil slope cracking. Some tree felling and exposed soil erosion.	15	25	**10**	Erosion controls implemented below cliff lines with rock falls. Cracks in steep slopes repaired with crushed and screened (free draining) sandstone gravel.
Baal Bone	1-23	27 - 56	**27**	Isolated rock face / overhang falls along pre-existing joints	0	25	**25**	None required - visual impact of fresh cliff faces diminished significantly in 10 years.
Metropolitan	1-15	14	**0**	No rock falls reported	9	9	**0**	None required

As mentioned earlier, it is concerning that the subsidence or mining impact outcomes for the three cases are all assessed as being 'extremely high' when the overall impact was 'moderate'. The predicted mining impact is also contradicted by the relatively low impact that was actually observed for the cliffs (i.e. 10 - 27%). If the mining impact was assessed as 'high', then it would be consistent if the 'very low' aesthetics and 'low' natural instability impacts resulted in a 'moderate' overall outcome. It is therefore suggested that a 'very high' and 'extremely high' mining impact category is probably only a 'high' impact rating.

Based on **Figure 12**, the mean and U95%CL outcomes for the 'very low' and 'low' Natural Instability (NI) curves in Figure 10.1 of **ACARP, 2002** are also similar statistically, with only a marginal increase in cliff line damage indicated for the 'low' NI cases. The 'moderate' instability curves are also probably applicable to the 'high' to 'extremely high' NI cases, because these cases have been inferred only and are not actually represented in the database. It is also assessed that the 'insignificant' NI curve should be deleted, as it infers that weathering can be lower than 'very low' which seems unlikely and adds unnecessary complexity to the model.

Overall, it is proposed that the Natural Instability curves be limited to just the three curves for the West Wallsend site, as represented in the database, ie 'very low', 'low' and 'moderate' cases. A 'high' natural instability curve may exist, but there are no points in the database to allow this category to be included at this stage.

The results in **Table 8B** also indicate that there is 'background' instability at a given site due to natural weathering processes and should be allowed for. For the three cases assessed the background instability was determined by subtracting the observed instability data from the mean or best fit regression curves of the natural instability curves. The back ground instability for the Dendrobium Cliff Line was 15% of its subsided length. The background results for the Metropolitan and Baal Bone Sites was 9% and 0% respectively.

For the purposes of a consistent representation of the cliff damage database presented in **ACARP, 2002**, and providing a reasonable assessment of the proposed West Wallsend longwalls, the mean curves presented in **Figure 12** of this report are a considered to be a valid alternative to the original model curves. It should be noted that the U95%CL curves will significantly over predict the damage due to the upper bound ‘low’ and ‘very vow’ natural instability cases. The mean curves have subsequently been adopted for assessing the proposed longwall impacts and the possible range of mining layout alternatives.

6.7 Results of Cliff Line Impact Ranking Assessment due to the Proposed Longwalls

The worst-case values for each cliff line damage impact categories for Cliff No.s 1 to 6 have been assessed and summarised in **Table 9A**. Details of the analysis are presented in **Appendix D** for the cliffs in their current condition. Predicted values of subsidence, tilt, strain and horizontal displacement (at the crest of the cliff) were derived from the subsidence contours presented in **Figures 6** to **8**.

Table 9A - Summary of Average and Worst-Case Overall Cliff Line and Steep Slope Impact Rankings due to Mine Subsidence from Proposed Western Domain Longwall Panels

Steep Slope No. (see Fig. 2a,b)	**Cliff Face Height (m)**	**Talus Slope + Cliff Height (m)**	**Talus Slope (o)**	**Mining Impact: Category 1**		**Public Exposure/ Aesthetics: Category 2**		**Natural Instability: Category 3**		**Overall Cliff Impact Ranking**
				Rating	Ranking	Rating	Ranking	Rating	Ranking	
1	15 - 25	72-103	10-38	0.61	*EH*	0.29	L	0.29	L	**High**
2	10 - 20	53-60	19-35	0.78	*EH*	0.20	L	0.30	L	**High**
3	15 - 18	22-38	10-37	0.89	*EH*	0.11	VL	0.29	L	**Moderate**
4	<10	29-33	16-25	0.61	*EH*	0.17	VL	0.29	L	**Moderate**
5	<10	51-55	15-30	0.78	*EH*	0.13	VL	0.29	L	**Moderate**
6	<10	16-40	15-23	0.89	*EH*	0.13	VL	0.28	L	**Moderate**

VL = Very Low; L = Low; M = Moderate; H = High; VH = Very High Impact; EH = Extremely High.
italics - should probably be assessed as High impact.
Shaded - Cliffs and or steep slopes visible from off site.

A summary of the mean and U95%CL values for the worst-case cliff line and steep slope impact rankings due to the proposed longwall panels at West Wallsend Colliery is presented in **Table 9B**. The results have also been plotted with the estimated FoS results against 'deep seated' translational sliding of the cliffs and steep slopes (see **Sections 6.1** and **6.3**)

Table 9B - Summary of Cliff Impact Damage for Proposed Longwalls

Steep Slope No.	LWs	Mining Impact Ratio (MIR)	Predicted Subsidence Effects (U95%CL)				Proportion of Cliff Damaged By Mine Subsidence					Factors of Safety for Deep Seated Slope Instability			
			Subsidence (m)	Tilt (mm/m)	Tensile Strain (mm/m)	Crack Width^ (mm)	NBI (%)	Total Cliff Impact Mean (Fig 12) (%)	Mining Impact (less NBI) Mean (Fig 12) (%)	Cliff# Lengths Above LWs (m)	Total Cliff Damage Length (less NBI) (m)	Cliffs/ Minor Cliffs		Steep Slopes	
												Dry	Wet	Dry	Wet
1	42-43	0.61	0.6 - 1.0	25	4	250	10	19	9	600	114 (54)	3.46	**1.28**	3.46	**1.48**
2	41-42	0.78	0.2 - 1.4	35	5	350	10	24	14	900	216 (126)	3.06	**1.25**	3.06	**1.38**
3	40-41	0.89	0.6 - 2.2	40	10	400	10	27	17	200	54 (34)	2.89	**1.20**	2.89	**1.32**
4	47-48	0.61	0.2 - 1.2	20	4	200	10	19	9	0	0	3.70	1.66	3.70	1.67
5	42-50	0.78	0.2 - 1.4	30	6	300	10	24	14	0	0	3.25	**1.29**	3.25	**1.49**
6	39-50	0.89	0.2 - 2.5	70	15	700	10	27	17	0	0	2.18	**1.22**	2.18	**1.48**
Mean	**-**	**0.76**	-	-	-	-	**10**	**23**	**13**	**1700**	**384 (214)**	-	-	-	-

^ - Steep slope cracks estimated by multiplying the tilt and by 10.
NBI - Natural Background Instability.
# - Only cliffs and terraces > 10 m in height with slopes >50^{o} are included in rock fall impact assessment.
Dry = Cracked slope in dry conditions. Wet = Saturated slope with water filled cracks (85% of crack depth behind cliffs and 100% crack depth in steep slopes).
Bold - Predicted FoS < Design FoS (see **Section 6.1**).
Shaded - Cliffs and or steep slopes visible from off site.

The results of the analysis suggest 13% of the total cliff line length of 1700 m will be damaged due to mining, with a further 10% due to natural weathering processes over the life of mine. The total length of damage due to the proposed mining is therefore predicted to range from 13% to 23%.

However, based on (i) the observed cliff and steep slope damage of 7% to 10% above LWs 1 and 2 at the Dendrobium Mine, and (ii) the terraced and discontinuous nature of the Western Domain cliffs, it is assessed that the overall cliff damage estimates due to the proposed longwall mining in the Western Domain are conservative.

In regards to cliff damage visibility concerns, it is likely that the impacts to Cliffs No. 1 (9% to 19%) and possibly No. 2 (14 - 24%). Several mining layout options have therefore been assessed in **Section 7.0** to reduce the Overall Cliff Impact from a ‘High’ rating to a ‘Moderate’, ‘Low’ or ‘Very Low’ rating.

The factors of safety of the cliffs and slopes against deep seated sliding along softened claystone beds after mining ranges between 2.18 and 3.46 for dry slopes, and between 1.20 and 1.49 for saturated slopes with water filled cracks. The minimum FoS of 1.5 for a ‘low’ sliding potential, indicates that filling cracks with a low-strength grout will probably be necessary to maintain the long-term stability of the cliffs and steep slopes after mining. FoS values of between 1.2 and 1.5 are considered acceptable for the assumed lower bound or residual strengths and water-filled crack conditions in the short-term only (and prior to grouting works).

Note: the specific location of the cracks is not relevant to the FoS estimates; it is the presence of a crack on the slope or behind a cliff that may fill with water is the issue of concern due to (i) the increase in driving forces acting on the slopes and cliffs and (ii) the potential softening of claystone beds and decrease in sliding resistance.

6.8 Rolling Rock Fall Hazard Assessment

Whilst the rock fall rolling hazard is already present on the West Wallsend lease due to natural weathering processes, it is indicated by this study that the frequency (and hence opportunities for interaction with property and people) may increase due to the proposed mining effects.

The potential sources of rock fall may be assumed to exist along all cliffs and steep slopes with talus boulders in the study area. The high hazard tracks and roads include the section of the Great North Walk between Steep Slope No. 1 and 5 above LW43 and 47 and the access track along the toe of Steep Slope No. 1 cliff above LW 43. The remaining tracks and gravel access roads are deemed to be far enough downslope of the cliffs or protected by topographic highs. These features and the sources of the potential rock fall hazard are shown in **Figure 2a**.

A sub-spherical boulder will sustain energy losses during its travel down slope due to falling and bouncing impacts and general rolling resistance from slope roughness, soil ‘stiffness’, boulder shape irregularities and vegetation (shrubs and saplings). According to **Pells, 1984**, the energy losses sustained by a rolling and bouncing boulder down a 35° slope consisting of soft loose rubble and soil is estimated to be 90% of the total free fall energy.

The mitigating effects of dense stands of trees are also likely to be significant and have been used as a valid and effective forest management technique to protect villages in the Swiss Alps from rock fall roll out (refer to **Dorren et al, 2005**). Rock rolling trials described in **Dorren et al, 2007** measured boulder velocities on average slopes of 33° and 40°, which ranged between 15 and 25 m/s (54 to 90 km/h). Bounce heights of 1 to 2 m were also observed for the boulders using video camera technology.

It has been also demonstrated in **Dorren and Berger, 2006** that tree impacts can stop or deviate boulders by +/- 10° from their starting positions and estimated rolling paths along the line of steepest descent without trees present. The loss of energy due to the direct impact with a 450 mm diameter tree was estimated to be 230 kJ from field trials.

The average tree diameter and density for the West Wallsend slopes have been estimated at 200 mm and 1 tree / 5 m down the lines of steepest descent. The impact energy loss for a 200 mm diameter tree may be derived from the 450 mm diameter tree results mentioned above as follows:

$$KE\ loss_{(d=0.2m)} = KE\ loss_{(d=0.45m)}.0.2^3/0.45^3 = 20\ kJ/tree.$$

This tree impact-loss value can be re-derived using the method suggested by **Pells, 1984** for sizing cantilever posts designed to absorb rock fall impact energy. The energy loss due to tree impacts may be based on probabilities of boulders of a certain diameter impacting with a grid of 200 mm diameter trees with a spacing of 5 m. The expected energy loss for a given slope due to tree impacts may be calculated as follows:

Energy Loss = Slope Distance x probability of tree impact/tree grid spacing x 20 kJ/tree.

The probabilities of tree impact/5m of travel down the slopes for 0.5, 1.0 and 1.5 m spherical boulders is estimated to be 0.35, 0.45 and 0.6 respectively.

A summary of potential velocities in which a loose boulder may have if it reaches a walking track at the bottom of the talus slopes are presented in **Table 10**.

Table 10 - Rock Rollout Velocities at Public Walking Track below Cliff No. 1

Boulder diameter	Boulder mass (t)	Cliff+ Talus Slope Height (m)	Talus Slope Angle (o)	Talus Slope Length to Track (m)	Total Potential Energy (kJ)	Available Rolling Energy at Toe of Slope (kJ)	Residual Energy at Track (kJ)	Velocity at Track (km/h)
0.5	0.16						50	90
1.0	1.31	78	35	100	1911	190	10	14
1.5	4.42						0	0

Without conducting a full rock rollout analysis using established software, it is assessed that boulders between 0.5 m to 1.0 m diameter could reach the access tracks at significant velocities (i.e. 14 to 90 km/h of > 4 to 25 m/s) if tree impacts don't stop them first.

The exposure of the public to rock fall impact may be assessed using proprietary rock fall modelling software such as the Colorado Rock Fall Simulation® package be undertaken to quantify this risk level where required. Based on the frequency of existing natural cliff line rock falls and the degree of public exposure (utilisation) of the access tracks, the risk to the public due to rock falls associated with natural cliff line instability is likely to be 'very low' and fall within established acceptability criteria published in the Landslide Risk Management Guidelines by the Australian Geomechanics Society (**AGS, 2007**).

The increase in rock fall probability associated with mine subsidence is unlikely to increase this risk level to beyond acceptable criteria. A quantified risk assessment to **AGS, 2007** could be undertaken to provide an assessment of the annual probability of loss of life due to rock falls, based on existing and post-mining conditions.

The expected outcome is likely to be 1×10^{-6} or less, which is within acceptable limits, and can be managed by the various subsidence management controls provided in **Section 8.0**.

7.0 Potential Slope Instability Hazard Zone Identification

7.1 General

Based on the fieldwork and subsidence effect predictions presented in **DgS, 2010**, the following short and long term potential slope instability hazards have been identified in the the Western Domain:

- Cracking and tilting of cliffs and steep slopes may result in deep and/or shallow translational sliding and toppling failures;
- Cracking and degradation of public access roads and mountain bike tracks;
- Collapse of overhangs and rock fall movements from cliffs and steep slopes towards public access areas (i.e. gravel access roads and tracks);

The likely outcomes of the proposed mining method in regards to the above hazards have been assessed in the following section. Options to manage these hazards appropriately have also been provided.

Discussions of likelihood of an impact event occurrence in the following sections generally refer to the qualitative measures of likelihood described in **Table 11**, and are based on terms used in **AGS, 2007** and **Vick, 2002**.

Table 11 - Qualitative Measures of Likelihood

Likelihood of occurrence	**Event implication**	**Indicative relative probability of a single event**
Almost Certain	The event is expected to occur.	90-99%
Very Likely	The event is expected to occur, although not completely certain.	75-90%
Likely+	The event will probably occur under normal conditions.	50-75%
Possible	The event could occur under normal conditions.	10-50%
Unlikely	The event is conceivable under adverse conditions.	5-10%
Very* Unlikely	The event probably won't occur, even under adverse conditions.	1-5%
Not Credible	The event is inconceivable or practically impossible.	<1%

Notes:
\+ - Equivalent to the mean or line-of-best fit regression lines for a given impact parameter presented in **ACARP, 2003**.
* - Equivalent to the worst-case or U95%CL subsidence impact parameter in **ACARP, 2003**.

It should be understood that the terms 'likely' and 'worst-case' used in this study generally infer that the predictions will be exceeded by 50% and 5% of the time over longwall panels with similar geometry and geology etc.

7.2 Overall Impact Ratings for the Cliffs and Steep Slopes

Based on risk management matrix charts of likelihood v. consequence normally used for civil and mining projects, it is considered that the Overall Impact Ratings to the cliff terraces and steep slopes presented in **Section 6.7** may be used to assess the risk level implications normally applied in practice, see **Table 12**.

Table 12 - Risk Level Implications Assumed for Cliff/Steep Slope Instability Management

Instability Risk or Overall Impact Rating		**Example Implication Guide**
VH	Very High	Unacceptable - Subsidence control measures likely to be required to reduce risk to a manageable level before mining (i.e. to at least Moderate or lower).
H	High	Unacceptable - Subsidence control measures required to reduce risk to a manageable level before mining (i.e. to at least Moderate or lower).
M	**Moderate or Medium**	**May be tolerated provided appropriate management and mitigation measures are implemented to limit or reduce risk during and after mining.**
L	Low	Usually acceptable provided appropriate management and mitigation measures are implemented to limit or reduce risk during or after mining.
VL	Very Low	Acceptable provided appropriate management and mitigation measures are implemented to limit risk during or after mining.

Bold - Maximum preferred ranking of steep slopes and cliff terraces.

Based on **Table 12**, it is apparent that the steep slopes and cliff terraces assessed to have a 'High' Overall Impact Rating in **Section 6.7** may be unacceptable to stakeholders and it will be necessary to use appropriate mine planning controls and management / mitigation measures to reduce the instability risk to more appropriate levels, usually 'Moderate' to 'Low', before mining commences.

Cliffs which have been given a 'Moderate' Overall Impact Rating will require a reasonable degree of mine planning control and management / mitigation measures to be implemented during and after completion of a panel.

Cliffs undermined which have been assessed as having a 'Low' Overall Impact Rating are usually not likely to require further subsidence controls other than provision of normal subsidence monitoring and post-mining repair works to limit long-term degradation of the local environment.

In the West Wallsend case, the cliffs along the northern 600 m to 700 m of Steep Slope No. 1 and 2 respectively are considered 'High' Overall Impact-rated cliffs and steep slopes, as they have the highest public exposure. Any impact to these cliffs or slopes may therefore lead to significant community concern. Their accessibility to effect repairs in a timely manner also needs to be considered, as well as the management of public and employee safety during mining and subsequent grouting works.

The remaining cliff terraces, minor cliffs and steep slopes along Steep Slope No.s 1 to 6 have a ‘Moderate’ to ‘Low’ Overall Impact Ratings, and are generally lower in height and have less public exposure than the ‘High’ impact rated cliffs and steep slopes. However, the impact on these features will still require prompt and effective repairs to be undertaken to minimise the potential for long-term degradation.

Based on **Table 9A**, the Overall Impact Ratings for the cliff terraces and steep slopes above the proposed longwalls are shown in **Figure 13**. All areas where slopes are < 18^{o} and not associated with Steep Slope No.s 1 to 6, have been given a ‘Low’ Overall Impact or instability hazard rating.

Appropriate subsidence management control options are discussed in the following sections.

7.3 Mine Planning Subsidence Control Options

Based on **Section 7.2**, the subsidence parameters beneath the ‘High’ risk cliff terraces will need to be reduced to the limits shown in **Table 13** in order to decrease the mining impact from ‘extremely high’ to a ‘high’ or 'moderate' mining impact level (see Table 10.7 in **ACARP, 2002**). The resulting Overall Cliff Impacts would then be reduced to 'moderate', 'low' and ‘very low’ impact categories.

Table 10.4 in **ACARP, 2002** indicates that a ‘high’ Mining Impact requires a maximum score proportion of between 0.4 and 0.5. A ‘moderate’ Mining Impact requires a score of between 0.3 and 0.4 and a ‘very low’ Mining Impact needs a score between 0.1 and 0.2.

Table 13 - Subsidence Effect Limits Required to Reduce Cliff Impacts from ‘Extremely High’ to ‘High’ and 'Moderate' Impact Levels

Impact Parameter	**Units**	**Maximum Limits for 'high' Mining Impact in ACARP, 2002**	**Maximum Limits for 'Moderate' Mining Impact in ACARP, 2002**	**Maximum Limits for 'Very Low' Mining Impact in ACARP, 2002**
Subsidence	mm	<600	<200	<50
Tilt	mm/m	<10	<5	<1
Horizontal Displacement of Cliff Crest	mm	<100	<50	<50
Strain	mm/m	<5	<2	<1
Mining Impact Proportion	ACARP, 2002	0.47	0.28	0.11
Overall Impact Rating		**Moderate**	**Low**	**Very Low**

The results of the reduced cliff line mining impact strategies are summarised below with details provided in **Appendix E**.

In order for the above subsidence decreases to occur beneath Steep Slope No.s 1 and 2, the following practical mine planning options are suggested in order of decreasing risk to the cliff line from 'High' back to 'Moderate', 'Low' or 'Very Low' Overall Impact Rating:

- Option 1 - Extract LWs 40 to 42 as proposed and pull back the starting position of LW43 to the 'medium' or 'moderate' Slope Instability Risk Zones as shown in **Figure 14a**. See indicative subsidence contours for this option in recent SMP application for LWs 41 and 42 (**DgS, 2011b**). Overall Cliff Impact Rating: 'Moderate' to 'Low' - see **Table 14A**.

- Option 2 - Pull back the starting position of LW42 only to the 'medium' or 'moderate' Slope Instability Risk Zones (as shown in **Figure 14b**) and extract LW43 as currently shown. Overall Cliff Impact Rating: 'Low' to 'Moderate' - see **Table 14.2**.

- Option 3 - Pull back the starting positions of LWs 42 and 43 to the 'medium' or 'moderate', Slope Instability Risk Zones (as shown in **Figure 14c**). Overall Cliff Impact Rating: 'Low' - see **Table 14.3**.

- Option 4 - Reduce the panel width of LWs 42 and 43 to sub-critical magnitudes in 'high' Slope Instability Risk Zones (i.e. W/H<0.5 for a cover depth of 240 m, gives a maximum panel width of 115 m and a chain pillar width of 90 m, while LW43 will have a W/H ratio of 0.33 with a cover depth of 340 m) - see **Figure 14d**. Overall Cliff Impact Rating: 'Low' - see **Table 14.4**.

- Option 5 - Pull back the starting positions of LWs 41 to 43 to the 'Medium' or 'Moderate' Slope Instability Risk Zones (as shown in **Figure 14e**). Overall Cliff Impact Rating: ' Very Low' - see **Table 14.5**.

Preliminary discussions with DII and mine representatives indicate that Options 3 to 5 are likely to be the primary candidates for the controlling impacts to the cliff terraces along the crests of Steep Slopes No. 1 and 2 to acceptable levels. It should be noted that the likelihood of impact to Cliff No. 1 is considered to be the primary point of reference in the Overall Impact Ratings, which have also considered the potential for impacts to develop due to undermining the lower level cliffs and slopes (i.e. Cliff No.s 2 and 3).

Options 3 and 4 are assessed to have a 'Low' Overall Impact of the two cliff terraces No.s 1 and 2; however, Cliff Terrace No.2 is more likely to be affected than Cliff Terrace No. 1, due to the possibility that cracking on the steep slopes above LW41 could lead to further upslope instability to develop in the vicinity of Cliff Terrace No. 2. It is considered very unlikely that deep seated sliding will develop in the vicinity of Cliff Terrace No. 1 due to favourability of the bedding dip. As a precautionary measure, this option will therefore require any deep cracking on the slopes below Cliff Terrace No. 1 to be repaired promptly.

Option 5 is assessed to have a 'Very Low' Overall impact because the slopes below Cliff Terrace No. 2 will not be subsided or cracked. This Option is therefore unlikely to require any grouting on the slopes below the 'High' Risk Zone of Cliff Terrace No 1.

Table 14.1 - Summary of Cliff Impact Damage for Proposed Longwall Layout Option 1 (First 700 m of LW43 Deleted)

Steep Slope No.	LWs	Mining Impact Proport-ion	Predicted Subsidence Effects (U95%CL) [Cliff / Steep slope]				Proportion of Cliff Damaged By Mine Subsidence					Factors of Safety for Deep Seated Slope Instability			
			Subsidence (m)	Tilt (mm/m)	Tensile Strain (mm/m)	Crack Width+ (mm)	NBI* (%)	Total Cliff Impact Mean (Fig 12) (%)	Mining Impact (less NBI) Mean (Fig 12) (%)	Cliff# Lengths Above LWs (m)	Total Cliff Damage Length (less NBI) (m)	Cliffs & Minor Cliffs		Steep Slopes	
												Dry	Wet	Dry	Wet
1	42	*0.28*	0.2 / 0.6	4 / 9	2 / 5	40 / 90	10	*8*	*3^*	500	40 (15)	*4.75*	*1.69*	*4.36*	*1.69*
1	42	*0.47*	0.6 / 0.6	5 / 9	5 / 5	90 / 90	10	*14*	*4*	100	14 (4)	*4.67*	*1.50*	*4.36*	*1.69*
2	41-42	*0.47*	0.2-0.8/ 1.0	2-9 / 20	2-5 / 5	20-90/ 200	10	*14*	*4*	700	98 (28)	*4.36*	*1.59*	*3.97*	*1.69*
2	41-42	0.78	1.8 / 1.8	35 / 35	5 / 5	350 / 350	10	24	14	200	48 (28)	3.06	**1.25**	3.06	**1.38**
3	40-41	0.89	2.2 / 2.2	40 / 40	10 / 10	400 / 400	10	27	17	200	54 (34)	2.89	**1.20**	2.89	**1.32**
4	47-48	0.61	1.4 / 1.4	20 / 20	4 / 4	200 / 200	10	19	9	0	0	3.70	1.66	3.70	1.67
5	42-50	0.78	1.8 / 1.8	30 / 30	6 / 6	300 / 300	10	24	14	0	0	3.25	**1.29**	3.25	**1.49**
6	39-50	0.89	2.5 / 2.5	70 / 70	15 / 15	700 / 700	10	27	17	0	0	2.18	**1.22**	2.18	**1.48**
Mean HVC/Total		**0.40/0.50**	**-**	**-**	**-**	**-**	**10**	**12/15**	**4/8**	**1300/ 1700**	**152/254 (47/131)**	**-**	**-**	**-**	**-**

+ - Steep slope cracks estimated by multiplying the tilt and by 10. *- NBI = Natural Background Instability. ^ - minimum assumed for sub-critical longwall panels.
# - Only cliffs and terraces > 10 m in height with slopes >50^{o} are included in rock fall impact assessment.
Dry = Cracked slope in dry conditions. Wet = Saturated slope with water filled cracks (85% of crack depth behind cliffs and 100% crack depth in steep slopes).
Bold - Predicted FoS < Long-term Design FoS (see **Section 6.1**). *italics* - mitigation measure effect on impact and FoS against deep seated sliding. Shaded – Steep slopes and cliffs may be visible from off site.

Table 14.2 - Summary of Cliff Impact Damage for Proposed Longwall Layout Option 2 (First 700m of LW42 Deleted)

Steep Slope No.	LWs	Mining Impact Proport-ion	Predicted Subsidence Effects (U95%CL) [Cliff / Steep slope]				Proportion of Cliff Damaged By Mine Subsidence					Factors of Safety for Deep Seated Slope Instability			
			Subsidence (m)	Tilt (mm/m) (Cliff / steep slope)	Tensile Strain (mm/m)	Crack Width+ (mm)	NBI* (%)	Total Cliff Impact Mean (Fig 12) (%)	Mining Impact (less NBI) Mean (Fig 12) (%)	Cliff# Lengths Above LWs (m)	Total Cliff Damage Length (less NBI) (m)	Cliffs & Minor Cliffs		Steep Slopes	
												Dry	Wet	Dry	Wet
1	43	*0.28*	0.2 / 0.2	4 / 4	2 / 2	40 / 40	10	*8*	*3^*	600	48 (18)	*4.75*	*1.52*	*4.75*	*1.77*
2	41-42	*0.28*	0.2 / 1.4	4 / 20	2 / 5	40 / 200	10	*8*	*3^*	700	56 (21)	*4.75*	*1.68*	*3.70*	*1.62*
2	41-42	0.78	1.8 / 1.8	35 / 35	5 / 10	350 / 350	10	24	14	200	48 (28)	3.06	**1.25**	3.06	**1.38**
3	40-41	0.89	2.2 / 2.2	40 / 40	10 / 10	400 / 400	10	27	17	200	54 (34)	2.89	**1.20**	2.89	**1.32**
4	47-48	0.61	1.4 / 1.4	20 / 20	4 / 4	200 / 200	10	19	9	0	0	3.70	1.66	3.70	1.67
5	42-50	0.78	1.8 / 1.8	30 / 30	6 / 6	300 / 300	10	24	14	0	0	3.25	**1.29**	3.25	**1.49**
6	39-50	0.89	2.5 / 2.5	70 / 70	15 / 15	700 / 700	10	27	17	0	0	2.18	**1.22**	2.18	**1.48**
Mean HVC/ Total		**0.28/0.41**	-	-	-	-	**10**	**8/12**	**3/6**	**1300/ 1700**	**104/206 (39/101)**	-	**-**	-	**-**

+ - Steep slope cracks estimated by multiplying the tilt and by 10.
*- NBI = Natural Background Instability.
^ - minimum assumed for sub-critical longwall panels.
# - Only cliffs and terraces > 10 m in height with slopes >50^{o} are included in rock fall impact assessment.
Dry = Cracked slope in dry conditions. Wet = Saturated slope with water filled cracks (85% of crack depth behind cliffs and 100% crack depth in steep slopes).
Bold - Predicted FoS < Long-term Design FoS (see **Section 6.1**).
italics - mitigation measure affect on impact and FoS against deep seated sliding.
Shaded - Steep slopes and cliffs may be visible from off site.

Table 14.3 - Summary of Cliff Impact Damage for Proposed Longwall Layout Option 3 (First 700m of LWs 42 & 43 Deleted)

Steep Slope No.	LWs	Mining Impact Proport-ion	Predicted Subsidence Effects (U95%CL) [Cliff / Steep slope]				Proportion of Cliff Damaged By Mine Subsidence					Factors of Safety for Deep Seated Slope Instability			
			Subsidence (m)	Tilt (mm/m) (Cliff / steep slope)	Tensile Strain (mm/m)	Crack Width+ (mm)	NBI* (%)	Total Cliff Impact Mean (Fig 12) (%)	Mining Impact (less NBI) Mean (Fig 12) (%)	Cliff# Lengths Above LWs (m)	Total Cliff Damage Length (less NBI) (m)	Cliffs & Minor Cliffs		Steep Slopes	
												Dry	Wet	Dry	Wet
1	-	*0*	0 / 0	0 / 0	0 / 0	40 / 40	10	*0*	*0*	600	0(0)	-	-	-	-
2	41	*0.28*	0.2 / 1.4	4 / 20	2 / 4	40 / 200	10	*8*	*3^*	700	56 (21)	*4.75*	*1.68*	*3.70*	*1.62*
2	41-42	0.78	1.8 / 1.8	35 / 35	5/5	350 / 350	10	24	14	200	48 (28)	3.06	**1.25**	3.06	**1.38**
3	40-41	0.89	2.2 / 2.2	40 / 40	10 / 10	400 / 400	10	27	17	200	54 (34)	2.89	**1.20**	2.89	**1.32**
4	47-48	0.61	1.4 / 1.4	20 / 20	4 / 4	200 / 200	10	19	9	0	0	3.70	1.66	3.70	1.67
5	42-50	0.78	1.8 / 1.8	30 / 30	6 / 6	300 / 300	10	24	14	0	0	3.25	**1.29**	3.25	**1.49**
6	39-50	0.89	2.5 / 2.5	70 / 70	15 / 15	700 / 700	10	27	17	0	0	2.18	**1.22**	2.18	**1.48**
Mean HVC/ Total		**0.14/0.47**	-	-	-	-	**10**	**4/9**	**2/5**	**1300/ 1700**	**56/158 (21/83)**	-	**-**	-	**-**

+ - Steep slope cracks estimated by multiplying the tilt and by 10.
*- NBI = Natural Background Instability.
^ - minimum assumed for sub-critical longwall panels.
# - Only cliffs and terraces > 10 m in height with slopes >50^o are included in rock fall impact assessment.
Dry = Cracked slope in dry conditions. Wet = Saturated slope with water filled cracks (85% of crack depth behind cliffs and 100% crack depth in steep slopes).
Bold - Predicted FoS < Long-term Design FoS (see **Section 6.1**).
italics - mitigation measure effect on impact and FoS against deep seated sliding.
Shaded - Steep slopes and cliffs may be visible from off site.

Table 14.4 - Summary of Cliff Impact Damage for Proposed Longwall Layout Option 4 (First 700 m of LWs 42 & 43 Sub-Critical)

Steep Slope No.	LWs	Mining Impact Proport-ion	Predicted Subsidence Effects (U95%CL) [Cliff / Steep slope]				Proportion of Cliff Damaged By Mine Subsidence					Factors of Safety for Deep Seated Slope Instability			
												Cliffs & Minor Cliffs		Steep Slopes	
			Subsidence (m)	Tilt (mm/m) (Cliff / steep slope)	Tensile Strain (mm/m)	Crack Width+ (mm)	NBI* (%)	Total Cliff Impact Mean (Fig 12) (%)	Mining Impact (less NBI) Mean (Fig 12) (%)	Cliff# Lengths Above LWs (m)	Total Cliff Damage Length (less NBI) (m)	Dry	Wet	Dry	Wet
1	42-43	*0.28*	0.2 / 0.2	4 / 4	2 / 2	40 / 40	10	*8*	*3^*	600	48 (18)	*4.75*	*1.52*	*4.75*	*1.77*
2	41-42	*0.28*	0.2 / 1.4	4 / 20	2 / 4	40 / 200	10	*8*	*3^*	700	56 (21)	*4.75*	*1.68*	*3.70*	*1.62*
2	41-42	0.78	1.8/1.8	35 / 35	5/5	350/350	10	24	14	200	48 (28)	3.06	**1.25**	3.06	**1.38**
3	40-41	0.89	2.2/2.2	40 / 40	10/10	400/400	10	27	17	200	54 (34)	2.89	**1.20**	2.89	**1.32**
4	47-48	0.61	1.4/1.4	20 / 20	4/4	200/200	10	19	9	0	0	3.70	1.66	3.70	1.67
5	42-50	0.78	1.8/1.8	30 / 30	6/6	300/300	10	24	14	0	0	3.25	**1.29**	3.25	**1.49**
6	39-50	0.89	2.5/2.5	70 / 70	15/15	700/700	10	27	17	0	0	2.18	**1.22**	2.18	**1.48**
Mean HVC/ Total		**0.28/0.41**	-	-	-	-	**10**	**8 / 12**	**3 / 6**	**1300/ 1700**	**104/206 (39/101)**	-	**-**	-	**-**

\+ - Steep slope cracks estimated by multiplying the tilt and by 10.

*- NBI = Natural Background Instability.

^ - minimum assumed for sub-critical longwall panels.

\# - Only cliffs and terraces > 10 m in height with slopes >50^{o} are included in rock fall impact assessment.

Dry = Cracked slope in dry conditions. Wet = Saturated slope with water filled cracks (85% of crack depth behind cliffs and 100% crack depth in steep slopes).

Bold - Predicted FoS < Long-term Design FoS (see **Section 6.1**).

italics - mitigation measure effect on impact and FoS against deep seated sliding. Shaded - Steep slopes and cliffs may be visible from off site.

Table 14.5 - Summary of Cliff Impact Damage for Proposed Longwall Layout Option 5 (First 700m of LWs 41 - 43 Deleted)

Steep Slope No.	LWs	Mining Impact Proport-ion	Predicted Subsidence Effects (U95%CL) [Cliff / Steep slope]				Proportion of Cliff Damaged By Mine Subsidence					Factors of Safety for Deep Seated Slope Instability			
			Subsidence (m)	Tilt (mm/m) (Cliff / steep slope)	Tensile Strain (mm/m)	Crack Width+ (mm)	NBI* (%)	Total Cliff Impact Mean (Fig 12) (%)	Mining Impact (less NBI) Mean (Fig 12) (%)	Cliff# Lengths Above LWs (m)	Total Cliff Damage Length (less NBI) (m)	Cliffs & Minor Cliffs		Steep Slopes	
												Dry	Wet	Dry	Wet
1	-	*0*	0 / 0	0 / 0	0 / 0	0 / 0	10	*0*	*0*	600	0(0)	-	-	-	-
2	-	*0*	0 / 0	0 / 0	0 / 0	0 / 0	10	*0*	*0*	700	0(0)	-	-	-	-
2	41-42	0.78	1.8 / 1.8	35 / 35	5 / 5	350 / 350	10	24	14	200	48 (28)	3.06	**1.25**	3.06	**1.38**
3	40-41	0.89	2.2 / 2.2	40 / 40	10 / 10	400 / 400	10	27	17	200	54 (34)	2.89	**1.20**	2.89	**1.32**
4	47-48	0.61	1.4 / 1.4	20 / 20	4 / 4	200 / 200	10	19	9	0	0	3.70	1.66	3.70	1.67
5	42-50	0.78	1.8 / 1.8	30 / 30	6 / 6	300 / 300	10	24	14	0	0	3.25	**1.29**	3.25	**1.49**
6	39-50	0.89	2.5 / 2.5	70 / 70	15 / 15	700 / 700	10	27	17	0	0	2.18	**1.22**	2.18	**1.48**
Mean HVC/ Total		**0.0/0.20**	-	-	-	-	**10**	**0/6**	**0/4**	**1300/ 1700**	**0/102 (0/62)**	-	**-**	-	**-**

+ - Steep slope cracks estimated by multiplying the tilt and by 10. *- NBI = Natural Background Instability.
^ - minimum assumed for sub-critical longwall panels. # - Only cliffs and terraces > 10 m in height with slopes >50^{o} are included in rock fall impact assessment.
Dry = Cracked slope in dry conditions. Wet = Saturated slope with water filled cracks (85% of crack depth behind cliffs and 100% crack depth in steep slopes).
Bold - Predicted FoS < Long-term Design FoS (see **Section 6.1**). *italics* - mitigation measure effect on impact and FoS against deep seated sliding. Shaded - Steep slopes and cliffs may be visible from off site.

Subsidence effect contours (subsidence, tilt and horizontal strains) have been prepared for the last three Options (3 to 5) and are presented in **Figures 15a-c** and **17a-c** respectively.

Of the five mine adjustment options considered, Option 5 in **Table 14.5** has the lowest estimated mining impact on the 'High' Risk cliff terraces along Steep Slope No.1 (0%) and Steep Slope No.2 (0%).

The overall cliff impact along Steep Slope No.s 1 to 3 for Option 5 is estimated to be 4% (allowing for natural background instability) and 6% (including background instability).

Options 3, 4, 2 and 1 (in order of increasing cliff impact) will reduce mining impacts to the 'High' Risk terraces on Steep Slope No. 1 to <3%, 3%, 3% and 4% respectively, with 3% to 4% impact for the cliffs along Steep Slope No.2 in the north-western area of the site.

The overall mining impacts to the cliffs along Slopes No. 1 to 3 for these options are 5%, 6%, 6% and 8% (excluding background instability) and 9%, 12%, 12% and 15% for these options if natural instability is included.

It is assessed that 'High' Overall Impact Ratings for Steep Slope No. 1 and 2 will be decreased to a 'Low' to 'Moderate' Overall Impact Rating for the proposed impact mitigation Options 1 to 4 and to 'Very Low' Impact for Option 5. Cliff face rock fall and steep slope cracking management plans will still apply however, for all of the options considered above (see below for further explanation).

The estimated minimum long-term FoS values for the cliffs and steep slopes along Steep Slope No. 1 after applying one of the first four options proposed, have been increased to > 1.5 to give a 'low' potential for deep seated sliding after mining is completed (and prior to grouting). In-filling cracks with low-strength grout will further increase the long-term FoS to a value > 4 and decrease the probability of a landslip during an earthquake. Option 5 removes the mining impact for these slopes almost entirely.

The effects of LW41 on the steep slope below Cliff Line No. 2 could result in deep cracking occurring on the steep slope below the cliff line or on the slope above it. An assumed angle of draw of 26.5^o suggests that the angle of draw could result in further cracking upslope that may influence Slope No 1.

In the context of the preceding stability analysis it is considered that the potential for cracking occurring anywhere on the steep slopes and cliffs has already been allowed for and therefore, the migration of deep, longitudinal cracks does not change the overall assessment. The favourable bedding dip, shallow soil cover and reinforcing effect of trees also contributes to the likelihood of short term slope stability after mine induced cracking.

The cliff line impact damage proportions and FoS against deep seated sliding at cliffs and along steep talus slopes for an extreme range of climatic conditions after mining are summarised in **Table 15**.

It should be noted that the saturated slope conditions with water-filled cracks are representative of the ungrouted FoS values for deep-seated sliding after subsidence effects. The dry FoS values are considered representative of the post-grouted response of the steep slopes and cliff lines.

The minor (but visible from Mulbring) cliff and steep slopes along Steep Slope No. 4 are estimated to have a worst-case FoS > 1.5 after mining of LWs 47 and 48. It is therefore considered uncessary to implement any subsidence impact management controls other than repairing significant cracks with low-strength growth.

Table 15 - Cliff & Steep Slope Instability Summary for the Proposed Mining Impact Mitigation Options

Case	Steep Slope No	Cliff Height (m)	Cliff >10m High Length (m)	Cliff FoS		Slope Length (m)	Steep Slope FoS		Cliff# Damage %	Cliff# Damage (m)	Overall Cliff# Impact Rating
				Dry	Wet		Dry	Wet			
Current	1	3-25	600	3.46	**1.28**	2200	3.46	**1.48**	9-19	54 - 114	**High**
	2	3-20	700	3.06	**1.25**	1600	3.06	**1.38**	14-24	98 - 168	**High**
	2	3-20	200	3.06	**1.25**	600	3.06	**1.38**	14-24	28 - 48	Mod
	3	2-18	200	2.89	**1.20**	2600	2.89	**1.32**	17-27	34 - 54	Mod
	4	5	0	3.70	1.66	2000	3.70	1.67	9-19	0	Mod
	5	3-9	0	3.25	**1.29**	1900	3.25	**1.49**	14-24	0	Mod
	6	3-9	0	2.18	**1.22**	3000	2.18	**1.48**	17-27	0	Mod
	Visible		1300			5,100			12-22	152 - 282	M-High
	Total		1700			13,900			13-23	214 - 384	Mod-H
Option 1	1	15-25	500	4.75	1.69	-	4.75	1.79	3-8	15 - 40	Low
	1	15-25	100	4.69	1.50	800	4.36	1.69	4-14	4 - 14	Mod
	2	10-20	700	4.36	1.59	800	4.36	1.78	4-14	8 - 28	Mod
	2	10-20	200	3.06	**1.25**	1400	3.06	**1.38**	14-24	70 - 120	Mod
	3	2-18	200	2.89	**1.20**	2600	2.89	**1.32**	17-27	34 - 54	Mod
	4	5	0	3.70	1.66	2000	3.70	1.67	9-19	0	Mod
	5	3-9	0	3.25	**1.29**	1900	3.25	**1.49**	14-24	0	Mod
	6	3-9	0	2.18	**1.22**	3000	2.18	**1.48**	17-27	0	Mod
	Visible		1,300			3,600			4-12	47-152	Low
	Total		1,700			13,900			8-15	131-254	L-Mod
Option 2	1	15-25	600	4.75	1.52	700	4.75	1.77	3-8	18 - 48	Low
	2	10-20	700	4.75	1.68	1700	4.75	1.87	3-8	18 - 48	Low
	2	10-20	200	3.06	**1.25**	500	3.06	**1.38**	14-24	14 - 24	Mod
	3	2-18	200	2.89	**1.20**	2600	2.89	**1.32**	17-27	34 - 54	Mod
	4	5	0	3.70	1.66	2000	3.70	1.67	9-19	0	Mod
	5	3-9	0	3.25	**1.29**	1900	3.25	**1.49**	14-24	0	Mod
	6	3-9	0	2.18	**1.22**	3000	2.18	**1.48**	17-27	0	Mod
	Visible		1,300			4,400			3-8	39-104	Low
	Total		1,700			13,900			6-12	101-206	L-Mod
Option 3	1	15-25	600	-	-	800	-	-	-	-	V. Low
	2	10-20	700	4.75	1.68	1200	4.75	1.87	3-8	18 - 48	Low
	2	10-20	200	3.06	**1.25**	1000	3.06	**1.38**	14-24	14 - 24	Mod
	3	2-18	200	2.89	**1.20**	2600	2.89	**1.32**	17-27	34 - 54	Mod
	4	5	0	3.70	1.66	2000	3.70	1.67	9-19	0	Mod
	5	3-9	0	3.25	**1.29**	1900	3.25	**1.49**	14-24	0	Mod
	6	3-9	0	2.18	**1.22**	3000	2.18	**1.48**	17-27	0	Mod
	Visible		1,300			4,000			2-4	21-56	Low
	Total		1,700			13,900			5-9	83-158	L-Mod

Table 15 (Cont…) - Cliff & Steep Slope Instability Summary for the Proposed Mining Impact Mitigation Options

Case	Steep Slope No	Cliff Height (m)	Cliff >10m High Length (m)	Cliff FoS		Slope Length (m)	Steep Slope FoS		Cliff# Damage %	Cliff# Damage (m)	Overall Cliff# Impact Rating
				Dry	Wet		Dry	Wet			
Option 4	1	15-25	600	4.75	1.52	800	4.75	1.77	3-8	18 - 48	Low
	2	10-20	700	4.75	1.52	1200	4.75	1.77	3-8	18 - 56	Low
	2	10-20	200	3.06	**1.25**	1000	3.06	**1.38**	14-24	14 - 24	Mod
	3	2-18	200	2.89	**1.20**	2600	2.89	**1.32**	17-27	34 - 54	Mod
	4	5	0	3.70	1.66	2000	3.70	1.67	9-19	0	Mod
	5	3-9	0	3.25	**1.29**	1900	3.25	**1.49**	14-24	0	Mod
	6	3-9	0	2.18	**1.22**	3000	2.18	**1.48**	17-27	0	Mod
	Visible		1300			4,000			3-8	39-104	Low
	Total		1700			13,900			6-12	101-206	L-Mod
Option 5	1	15-25	600	-	-	800	-	-	0	0	V. Low
	2	10-20	700	-	-	1200	-	-	0	0	V. Low
	2	10-20	200	3.06	**1.25**	1000	3.06	**1.38**	14-24	14 - 24	Mod
	3	2-18	200	2.89	**1.20**	2600	2.89	**1.32**	17-27	34 - 54	Mod
	4	5	0	3.70	1.66	2000	3.70	1.67	9-19	0	Mod
	5	3-9	0	3.25	**1.29**	1900	3.25	**1.49**	14-24	0	Mod
	6	3-9	0	2.18	**1.22**	3000	2.18	**1.48**	17-27	0	Mod
	Visible		1,300			4,000			0	0	V. Low
	Total		1,700			13,900			3-5	48-78	L-Mod

- Mining and Mining + Natural Instability Results for cliffs and terraces >10 m in height with average slopes >50^o are included in rock fall impact assessment.
Bold - Predicted FoS < Design FoS (see **Section 6.1**).
Shaded - High visibility cliffs (HVC) only.

The FoS predictions against deep seated sliding of cliffs and slopes after the proposed subsidence effects are considered reasonably conservative in light of the available published information of residual and peak shear strength values and the proposed crack grouting program. Installation and monitoring of groundwater (deep and shallow) piezometers and slope movement inclinometers would allow a more detailed probabilistic analysis of the proposed mining layouts and the response of the slopes to rainfall events.

8.0 Cliff Line Rock Fall and Steep Slope Impact Mitigation and Management

8.1 General

In summary, all or some of the following subsidence impact mitigation works may be required in the 'Medium' to 'High' Slope Instability Hazard areas, to reduce the exposure of vehicles, people and property to potential cliff and steep slope instability (e.g. landslips and rock falls):

(i) Develop a Landscape Impact Assessment and Management Plan (LIAMP) that allows rapid assessment of cliff and slope conditions and timely decisions on appropriate management actions required to maintain overall integrity and stability of the slopes and cliffs.

(ii) Infill deep, longitudinal cracks above extracted panels in the Moderate to High Slope Instability Risk Zones (see **Figure 13**) with slopes > 26.5^o with pumpable, low-strength grout (UCS 2 - 5 MPa) to minimise surface erosion and runoff ingress into the steep slopes (see **Section 7.2** for recommended grout mix design). It is envisaged that grouting may need to be completed on cracks >50 mm wide and > 1 m deep done (pending inspection by a suitably qualified geotechnical engineer). Grouting may also need to be completed on a fortnightly to monthly basis once cracking of the steep slopes starts to develop. The grouting works should be reviewed and monitored using surface and sub-surface monitoring of the slope (i.e. inclinometers and piezometers) to manage instability risks.

Filling of deep longitudinal cracks in the 18^o to 26.5^o slope areas may be required if there is potential for instability (if it occurs) to regress further upslope to steeper areas. Gravel filled cracks should be sealed with 300 mm of sandy clay fill or low-strength grout to minimise water ingress.

Transient tensile cracks of up to 500 mm width that have occurred on slopes > 18^o behind the retreating LW39 face have been observed to close to < 100 mm after full subsidence develops. As these cracks are likely to be orientated down slope, it is not considered necessary to grout these types of cracks due to (i) their propensity to fill naturally with sediment over time and (ii) they do not represent a significant instability risk.

(iii) Warning signs along access roads / walkways with mine site contact numbers to report damage.

(iv) Restrict access to vulnerable locations in recreation areas during mining, with a view to re-open access after repairs / safety can be restored. If it is not possible to limit public access, then it may be necessary to provide a subsidence damage 'observation and repair crew' to provide daily surveillance and erect security fences around subsidence affected areas before or as soon as they occur.

(v) Strategic removal or stabilisation of loose boulders along cliff lines and slopes above public access roads and tracks before and after mining impacts or prevent access using temporary security fencing during mining. Other measures may also include:

- Installation of temporary 'drapery' mesh over cliff faces in high risk areas to contain rock fall roll out.
- Scaling of rock faces after subsidence to remove loose rock.
- Install boulder catch ditches or fences at strategic locations upslope of access tracks.

(vi) Monitoring of cliff lines and steep slopes and review of damage after each panel is extracted beneath a cliff. Installed inclinometers and extensometers for grouting to provide on-going slope creep data after panel and grouting works completed.

(vii) Installation of erosion controls (silt fences down slope of rock fall effected sections of cliff line) and surface/sub-surface slope drainage systems in areas where subsidence has resulted in slope erosion or instability.

(viii) Any inspections of cliff lines and rock overhangs etc. by stakeholder groups during and after mining impacts, should be accompanied by mine site representatives familiar with the rock and tree fall hazards likely to be present.

(ix) The majority of grouting and/or repair works are likely to require tracked equipment to haul equipment and materials to the work sites.

8.2 Preliminary Grout Mix Design for Steep Slope Repairs

The deep longitudinal cracks in on slopes >26.5^{o} and behind cliffs should be repaired reasonably promptly with an approved pumpable grout mix with low strength (2 to 5 MPa UCS) and resistance to erosion. The purpose of the grout is to provide a long-term stable, non-erodible crack infill, that will not shrink or 'bleed' excessively in its solid and fluid states respectively.

Infilling of cracks with spoil or granular material is not considered appropriate for the steep slopes >26.5^{o} at this site due to access constraints, and it is considered likely that pumping from the slope crest or toe depending on crack location will be necessary.

It is recommended that the grout mix comprise sand and Type A cement or an equivalent mix of environmentally safe (to EPA Standards), pozzolanic (self-cementing) granular material (eg power station flyash and bottom ash) with a 7-day characteristic strength or UCS of 2 MPa.

Other grout mix design criteria will relate to the pumpability of the grout and the need to minimise bleed water once in-situ. **Fell et al 1992** suggests that pumpable grout mixes will probably need to have Water: Cement ratio of 1:1 to 2:1 (by volume) with the addition of 2-4% bentonite to control bleed water volumes.

Laboratory testing of proposed grout mixes in fluid and solid states should be prepared for approval to demonstrate pumbability, bleed volume, strength and appropriate environmental criteria will be achieved. Field sampling and laboratory testing of grout placed in situ to Australian or British Standards will also be necessary.

The above grout mix design is has been provided for planning purposes only and may need to be amended after consultation with grouting contractors and stakeholders. The specification of grout preparation, placement and testing is beyond the scope of this report.

9.0 Monitoring

Monitoring of cliff lines is difficult and can be dangerous for survey personnel in an actively subsiding area. The hazards present will range from rock falls, rock roll out, wide cracks (trip hazard) and tree falls.

Usual cliff line monitoring techniques include (i) cliff top monitoring 'grids' established at a safe distance from the crest (with lines parallel and perpendicular to the face), and (ii) Electronic Distance Measurement (EDM) or 3-Dimensional monitoring of reflectors fixed to the cliff face.

Survey lines may also be installed near the base of cliff lines and on steep talus slopes, however, reflectometers are preferred to minimise exposure of the surveying team to rock and tree fall hazards during mining.

The monitoring of mass movement of cliff lines and steep slopes on mudstone beds will require deep borehole extensometers to a depth of approximately 30 m and installed at a safe distance from behind the cliff crests. Steep slope monitoring lines may also be installed to supplement the inclinometer results where access is possible and tree and rock roll out hazards can be minimised.

The monitoring pegs on steep slopes and along cliff tops should be robust enough so as not to be affected by soil shrink/swell movements or accidental disturbance / vandalism. Public visibility and injury considerations should also be considered.

Detailed photogrammetry of the cliff and steep areas before mining to establish baseline conditions would enable post mining impacts, including the extent of rock falls and disturbance to the cliff / steep slopes to be verified remotely and also provide data to correlate with the **ACARP, 2002** model.

Mapping of fresh cracking or rock and tree falls during mining will be necessary to ascertain expected damage is within reasonable or expected limits. Monitoring should continue for a minimum period of 2 years and extended to 5 years if instability occurs that requires mitigation works to be undertaken.

Details of the monitoring programs may be defined once the mine layouts are finalised.

10.0 Conclusions

There are six multi-terraced cliff lines and steep slopes that have been identified within the Western Domain. The cliffs and steep slopes will be subsided by the proposed longwalls 40 to 43 and 47 to 50 at West Wallsend Colliery. Representative cliff and slope sections have been mapped for the purposes of impact management assessment.

The total length of steep slope that will be subsided is estimated to be 13.9 km with gradients ranging from (18^o to 45^o). Based on the definitions of cliff lines at other NSW mine sites, there are approximately 1.7 km of discontinuous, single and multi-tiered cliff faces with heights ranging from 10 m to 25 m with average slopes ranging from 50^o to 70^o. The multi-terraced cliff faces have two to five tiers with individual cliff faces ranging in height from 3 m to 11 m. The slopes on the cliff tiers range from 45^o to 80^o and are typically 65^o.

Minor cliffs (< 10 m high) and rock outcrops (< 5 m high) are common along the rest of the steep slopes.

The cliff faces are predominately conglomerate and quartz-lithic sandstone of the Triassic Narrabeen Group (Munmorah Conglomerate and Tuggerah Formations). Interbedded sandstones and mudstones (shale) form the steep talus slopes, which have undercut the sandstone cliff line to produce overhangs in places. Persistent widely spaced vertical jointing parallel and perpendicular to the cliff faces is the primary mechanism for rock roll out and talus slope development along the cliff lines.

The bedding dip is approximately 3^o to the south and south east and considered favourable for slope stability along the upper level eastern and western cliffs and talus slopes (No. 1, 2 and 4).

The proposed longwalls 40 to 50 are 178.6 m wide (void) with 35 m wide chain pillars (solid). The mining heights range from 3.6 m to 4.0 m. The cover depth to the West Borehole Seam below the steep slopes and cliffs ranges from 100 m to 340 m.

The upper level cliffs and steep slopes (No.1, 2 and 4) are likely to be subsided by 0.1 m to 1.4 m after extraction of the proposed mining layout. The tilts are estimated to range from 10 to 30 mm/m and tensile strains are likely to range between 5 mm/m and 10 mm/m. These effects are similar to the Dendrobium Mine's cliffs and slopes, which have resulted in only 7 - 10% impact to a 2 km cliff face length.

The lower level cliffs and steep slopes (No. 3, 5 and 6) along the eastern and southern foot slopes of the Sugarloaf Range may be subject to subsidence of 0.1 to 2.5 m, tilts of 6 to 70 mm/m and tensile/compressive strains of 2 to 20 mm/m.

Surface cracks ranging from 100 mm to 350 mm width may develop on the upper slopes (No. 1, 2 and 4) with cracks ranging from 50 mm to 700 mm estimated for the lower slopes (No. 3, 5 and 6).

The predicted tilting, bending and cracking along the cliff lines > 10 m high may generate rock falls and release boulders that may subsequently roll down the steep talus slopes. Based on the data base of NSW cliff lines and in particular, the cliff lines and steep slopes above Dendrobium Mine in the Southern Coalfield, it is estimated that the proposed longwalls may cause rock falls along 13% to 23% of the 1.7 km of cliff lines. Approximately 10% of the impacted length is likely to be the result of natural instability (and is included in the 23%).

The development of deep cracks on the steep slopes and behind cliff lines are likely to result in the lowering of the Factors of Safety against deep-seated sliding from > 3.0 (after mining) to between 1.2 and 1.5 if the cracks fill with water during wet weather. It is considered that a minimum design FoS for the post-mining slopes should not be < 1.5 for an extreme range of weather conditions (excluding earthquakes). To increase and maintain the FoS to > 1.5 in the long term, it will be necessary to infill significant longitudinal cracks after mining with low-strength grout (2 to 5 MPa) to minimise water ingress into the slopes.

If the cracks are not repaired with grout, the development of perched water table conditions in the steep slopes could cause softening on mudstone/claystone beds and result in a large-scale land slip after mine subsidence is completed. Durable gravel backfill may be used to backfill cracks on accessible slopes provided the top 300 mm is backfilled with clay fill, bentonite or low strength grout.

Based on observations of similar steep slopes in the Central Coast, it is considered imperative that any deep mine subsidence cracking on the steep slopes >26.5^o (1V:2H) in the Moderate to High Slope Stability Risk Zones (see **Figure 13)** be repaired in a reasonable time frame (weeks) with low-strength grout (comprising a sand-cement-bentonite mix or equivalent).

Significant longitudinal tensile cracks that occur on the steep slopes > 26.5^o should probably be grouted at this stage for planning purposes, however, confirmation of necessary crack repairs on all of the Western Domain slopes should be assessed, based on inspection by a suitably qualified geotechnical engineer.

Surface and subsurface monitoring of the steep slopes will also be required during and up to 2 years after mining (and possibly longer if slope creeps have developed). It is not considered necessary to grout transient tensile cracks generally, unless there is significant long-term slope stability concerns identified after mine subsidence has fully developed.

Approximately 600 m of terraced cliff line 10 to 25 m high along Steep Slope No. 1 forms a ridge along the Sugarloaf Range that is likely to be visible to the west of Newcastle and Lake Macquarie communities. Approximately 260 m of the east facing Steep Slope No. 1 is > 20 m.

Another similar length (700 m) of terraced cliff line > 10 m high exists along Steep Slope No. 2, and is located > 100 m further down slope of the upper cliff line. Slope No. 2 may just be visible from the communities to the north-east and east.

A 2 km long ridgeline (Steep Slope No. 4) with minor cliffs (heights < 10 m) and rocky outcrops may be visible from Mulbring to the west of the Sugar Loaf Range.

All other cliffs (>10 m high) above LWs 41 and 42 are not visible from these communities and can only be accessed (and viewed) with difficulty from the Great Northern Walk, Mount Sugarloaf Road and several mountain bike tracks and fire trails. Impacts to the cliff lines and steep slopes therefore represent a public safety hazard.

Based on the cliff impact models used herein, the upper level cliffs and steep talus slopes in the north western area of the site (Steep Slope No. 1) are considered to be a 'High' instability and aesthetic risk, and will require mine planning adjustment to reduce subsidence impacts to manageable levels.

The minor cliff line sections and steep talus slopes are assessed as having a 'Moderate' instability risk or mining impact potential, and will also require backfilling of longitudinal cracks where slopes are > 26.5^{o}. The cracks are likely to develop on the high side of a given panel. Backfilling materials should be either durable gravel (sealed with the top 300 mm with sandy clay) or 2 to 5 MPa UCS sand-cement-bentonite grout (or equivalent).

Four subsidence control and impact mitigation options have been developed for reducing the predicted ‘High’ Overall Mining impacts along Steep Slope No.s 1 and 2 to either ‘Moderate’ or ‘Low’ Impact. A fifth subsidence control option will further reduce the instability risk to ‘Very Low’.

The estimated FoS values for the cliffs and steep slopes along Steep Slope No.s 1 and 2 for the first four slope impact mitigation options proposed, have been increased to > 1.5 to give a ‘low’ potential for deep seated sliding after mining is completed. In-filling cracks with low-strength grout in the vicinity of the cliff lines will further increase the FoS > 4. The fifth option will not subside Slopes 1 and 2 and is therefore unlikely to require grouting.

The subsidence control measures suggested herein should also reduce mining impacts to 3% or less for the cliffs along Steep Slope No.s 1 and 2, and from 4 to 8% for all cliffs > 10 m high on site generally (excluding natural instability).

The proposed grouting of deep cracks is intended to reduce surface runoff inflows into the slopes from concentrating at a given location and minimise the potential for perched water table conditions to develop and result in deep-seated sliding. The possible opening of existing joints or bedding may increase surface runoff into the slope, but the overall effect will be countered by the slopes ability to drain more freely. The slopes will also be monitored and inspected on a regular basis during mine subsidence development, and the need for additional grouting will be made.

Preliminary discussions with DII and mine representatives indicate that Options 3 to 5 are likely to be the primary candidates for the controlling impacts to the cliff terraces along the crests of Steep Slopes No. 1 and 2 to acceptable levels. It should be noted that the likelihood of impact to Cliff No. 1 is considered to be the primary point of reference in the Overall Impact Ratings, which have also considered the potential for impacts to develop due to undermining the lower level cliffs and slopes (i.e. Cliff No.s 2 and 3).

Options 3 and 4 are assessed to have a 'Low' Overall Impact of the two cliff terraces; however, cliff terrace No.2 is more likely to be affected than Cliff Terrace No. 1, due to the possibility that cracking on the steep slopes above LW41 could lead to further upslope instability to develop in the vicinity of Cliff Terrace No. 2. It is considered very unlikely that deep seated sliding will develop in the vicinity of Cliff Terrace No. 1 due to favourability of the bedding dip. As a precautionary measure, this option will therefore require any deep cracking on the slopes below Cliff Terrace No. 1 to be repaired promptly.

Option 5 is assessed to have a 'Very Low' Overall Impact because the slopes below Cliff Terrace No. 2 will not be subsided or cracked. This Option is therefore unlikely to require any grouting on the slopes below the 'High' Risk Zone of Cliff Terrace No 1.

The proposed mining layout amendments should enable appropriate subsidence management plans to be implemented without significant risk to the safety of public and mining personnel, cliff / steep slope aesthetics, or damage to existing infrastructure (i.e. Gencom Towers).

On-going monitoring and review of the effectiveness of the methodology used and management plans developed from it will be required as mining progresses. The impact review process may also indicate that some further subsidence control zone restrictions may be required after each longwall panel is completed, and if predicted impacts are higher than anticipated. It is recommended that impacted slopes should be monitored for a minimum of 2 and maximum of 5 years after mining has been completed.

The longwall mining layout and subsidence impact management measures proposed in this report is similar to that of the Dendrobium Mine and their Corrective Management Actions for undermining steep slopes and cliffs in the vicinity of the Cataract Reservoir. The same approach has been applied to the Metropolitan Mine longwalls beneath the Waratah Rivulet.

The proposed subsidence control options and crack grouting works are provided to minimise the potential for long-term instability on the steep slopes and cliff terraces that are likely to be visible from communities to the east and west of the application area.

Grouting of the remaining slopes on site should also provide long-term stability measures to ensure reasonable rates of rejuvenation from mining impacts.

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