Tasman Extension Project
Environmental Impact Statement

APPENDIX A

SUBSIDENCE ASSESSMENT

Resource Strategies

DONALDSON COAL
Part of Gloucester Coal

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Donaldson Coal Pty Ltd

Subsidence Predictions and General Impact Assessment for the Tasman Extension Project

DGS Report No. TAS-005/1

Date: 20 June 2012

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20 June 2012

Mr Tony Sutherland
Technical Services Manager - Underground Operations
Donaldson Coal
Abel Mine
1132 John Renshaw Drive,
Black Hill NSW 2322

DGS Report No. TAS-005/1

Dear Tony,

Subject: Subsidence Predictions and General Impact Assessment for the Proposed Pillar Extraction Panels at Tasman Extension Project

This report has been prepared in accordance with the brief provided on the above project.

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 presents a preliminary mine subsidence impact assessment for the proposed pillar extraction panels in the West Borehole Seam for the Tasman Extension Project, Mulbring.

The report will be used for the purpose of preparing an Environmental Impact Statement under Part 4 of the *Environmental Planning and Assessment Act 1979 (EP&A Act)* for State Significant Development to the Department of Planning & Infrastructure (DP&I).

The subsidence assessment has considered the Department of Mineral Resources (now Department of Resources and Energy (DRE) of Trade & Investment, Regional Infrastructure & Services (DTIRIS)) Guideline for Applications for Subsidence Management Approvals (SMP).

The report has assessed the proposed mining layout of thirty-two pillar extraction panels (Panels 1 - 32) and three main headings panels (M1-M3). The panels beneath non-sensitive areas will be totally extracted with a combination of partial pillar extraction and first workings methods used to control mine subsidence effects to appropriate levels where required.

Subsidence Control Zones (SCZ) have been proposed to limit impacts to within tolerable levels at the following features:

- 3rd Order stream sections along Surveyors Creek No. 2
- Ephemeral 1st and 2nd Order Tributaries sections where cover depth is < 80 m (to avoid connective cracking to mine workings).
- Principal Residences on Private Land holdings (3 only at this stage but could be more required).
- Groundwater Dependent Ecosystems (GDEs) associated with sensitive Lowland Rainforest and Alluvial Tall Moist Forest Endangered Ecological Communities (EECs).
- Riparian vegetation associated with the Hunter Lowlands Redgum Forest EEC.
- Two TransGrid Towers (suspension) supporting 330 kV Cable.
- TransGrid (suspended), AAPT and Telstra (buried) Fibre Optic Cables (FOCs).
- Steep Slopes > 26.5°, minor cliffs between 5 m and 10 m high and cliff lines > 10 m high.

The proposed setback distances applied for the SCZs at this stage are considered conservative; however, they will still need to be confirmed by subsidence monitoring programs and adaptive management as mining progresses.

The proposed performance criteria will be achieved in the SCZ with first workings only or a partial pillar extraction layout provided the long-term stability of remnant pillars and tolerable impacts to surface features can be demonstrated.

The maximum first and final subsidence predictions for the proposed 160.5 m wide total extraction Panels 1 to 32 and 105 m wide main headings panels (M1 to M3) range from 0.58 m to 1.27 m below the flatter areas of the mining lease with cover depths of 55 m to 185 m. Below the ridges of the Sugarloaf Range where cover depths range from 155 m to 350 m, maximum subsidence is estimated to range from 0.10 m to 1.12 m.

The predicted subsidence represents 5% to 58% of the effective mining height of 2.2 m. The proposed 19.5 m wide barrier pillars are likely to go into yield at depths > 150 m.

Predictions of final maximum tilt values for the pillar extraction panels below the flatter areas range from 13 mm/m to 60 mm/m and from 3 mm/m to 19 mm/m below the ridges. Maximum horizontal displacements are estimated to range from 130 mm to 600 mm below the flatter areas from 30 mm to 190 mm below the ridges.

Predictions of final maximum hogging curvature values for the pillar extraction panels below the flatter areas range from 0.55 km^{-1} to 2.91 km^{-1} with maximum tensile strains estimated to range from 5 to 29 mm/m. Final maximum hogging curvature values for the pillar extraction panels below the ridges range from 0.20 km^{-1} to 0.79 km^{-1} with maximum tensile strains estimated to range from 2 to 8 mm/m.

Predictions of final maximum sagging curvature values for the pillar extraction panels below the flatter areas range from 0.70 km^{-1} to 3.69 km^{-1} with maximum tensile strains estimated to range from 7 to 37 mm/m. Final maximum sagging curvature values for the pillar extraction panels below the ridges range from 0.25 km^{-1} to 1.00 km^{-1} with maximum compressive strains estimated to range from 3 mm/m to 10 mm/m.

The predicted maximum panel subsidence magnitudes are likely to result in surface cracks developing within the limits of the extracted panels (without SCZs). Surface cracks are not expected to develop where the proposed SCZs are left in place.

Connective sub-surface cracking to the surface is considered ‘likely’ to ‘possible’ for cover depths < 80 m above total extraction panels. The height of direct hydraulic connection is expected to decrease to below 60 m for partial pillar extraction panels with stable remnant pillars.

It is assessed that the use of partial pillar extraction areas beneath the watercourses and GDE areas above the proposed mining layout will provide a high level of protection from continuous fracturing from surface to seam.

Discontinuous fracturing may interact with surface cracks above total pillar extraction zones where cover depths are < 200 m, however, this will be decreased to < 80 m above partial pillar extraction panels. Discontinuous fractures occur where subsidence causes the strata bedding partings to ‘open’ or dilate, which increases the storage capacity of the overburden in this zone and may cause a temporary lowering of groundwater tables. Temporary runoff diversion may also occur if surface cracks develop. The rate of groundwater recovery will depend on prevailing climatic conditions after mining impacts and has been numerically modelled as part of a Groundwater Assessment by RPS Aquaterra.

Mitigation works alternatives such as the removal and re-routing of FOCs around the proposed mining area may remove the need for an SCZ beneath the Telstra and AAPT FOCs.

No Aboriginal rock shelters with PADs or grinding groove sites with ‘moderate’ to ‘high’ archaeological significance are located above total extraction panel areas and these sites will have a an unlikely to very unlikely cracking or toppling damage potential due to mine subsidence.

No practically measureable mine subsidence or far-field displacement movements or impacts are expected along George Booth Drive, the Hunter Expressway or the Orica site due to the proposed mining layout.

The subsidence effect and impact assessment predictions have also been validated against surface and subsurface monitoring programs at Abel and Tasman Mine sites with similar geological conditions and mining methods.

Overall, it is concluded that the assessed range of potential subsidence and far-field displacement impacts after the mining of the proposed pillar extraction panels will be manageable for the majority of the site features, based on the analysis outcomes and discussions with the stakeholders.

If the estimated worst-case impacts cannot be reasonably managed in the event that exceedances occur through mitigation or amelioration strategies, then it will be necessary to adjust to the mining layout further to provide a more acceptable risk to the stakeholders.

The extent of mining layout adjustment will also require further discussions (and review of monitoring data) after the completion of a given panel with stakeholder and government agencies.

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Appendix B - Extract from SDPS® User Manual

Glossary of Terms

Angle of Draw (AoD)	The angle to the vertical from the sides or ends of an extracted panel and the line drawn from the limits of extraction at seam level to the 20 mm subsidence contour at the surface. The 20 mm subsidence contour is an industry defined limit and represents the practical measurable limit of subsidence.
Barrier Pillar	The pillar of coal left between adjacent pillar extraction panels. This forms a barrier that allows the goaf to be sealed off and facilitates regional workings stability during pillar extraction.
Compressive Strain	A decrease in the distance between two points on the surface. Compressive strains may cause shear cracking or steps at the surface if > 3 mm/m and are usually associated with concave curvatures near the middle of the panels.
Confidence Limits	A term used to define the level of confidence in a predicted *Subsidence Effect* (see definition below) subsidence impact parameter and based on a database of previously measured values above geometrically similar mining layouts.
Cover Depth	The depth (H) from the surface to the mine workings roof horizon.
Critical Panels	Pillar extraction panels that are almost as deep as they are wide (W) (i.e. $0.9 < W/H < 1.4$) and is the point where failure of the overburden starts to occur if no massive strata is present (i.e. panel geometries are transitional between sub and super critical panels). Massive strata may continue to span but the maximum subsidence will be greater due to the bending action rather than the natural arching mechanism. Maximum subsidence above panels with non-spanning strata will approach values that are proportional to the mining height.
Curvature	The rate of change of tilt between three points (A, B and C), measured at set distances apart (usually 10 m). The curvature is plotted at the middle point or point B and is usually concave in the middle of the panel and convex near the panel edges. i.e. curvature = (tilt between points A and B - tilt between points B and C)/(average distance between points A to B and B to C) and usually expressed in 1/km. Radius of curvature is the reciprocal of the curvature is usually measured in km (i.e. radius = 1/curvature). The curvature is a measure of surface ‘bending’ and is generally associated with cracking.

Credible Worst-Case	The Credible Worst-Case (CWC) prediction for a given *Subsidence Effect* and is normally the Upper 95% Confidence Limit determined from measured data and the line of 'best fit' or mean used to calculate the mean value. The CWC values are typically 1.5 to 2 times the mean values.
Design Angle of Draw (**Design AoD**)	The 'practical' angle of draw (AoD) used to define minimum or allowable distances from the sides and ends of an extracted pillar panel to sensitive surface features. It is considered to be an effective impact management tool in which to minimise impact from differential subsidence effects parameters such as tilt, curvature and strain, which may cause cracking or instability. A Design AoD of 26.5^o has been used with negligible impact to surface features at the Abel Mine to-date.
Development Height	The height at which the first workings (i.e. the main headings) are driven; usually equal to or less than the pillar extraction height in the production panels or second workings areas.
Dry-schlerophyll Forest	Multi-aged stands of eucalypts with a forest floor dominated by hard leafed shrubs such as banksias, wattle and tea trees.
Extraction Height	The height at which the seam is mined or extracted across a pillar extraction face by the continuous miner.
Factor of Safety (FoS)	The ratio between the strength of a pillar divided by the load applied to the pillar.
Far-Field Displacement	Horizontal displacement outside of the AoD, associated with movement, is due to horizontal stress relief above an extracted panel of coal. The strains due to these movements are usually < 0.5 mm/m outside a 26.5^o AoD and do not cause damage directly. Such displacements have been associated with differential movement between bridge abutments and dam walls in the Southern Coalfield, but generally have not caused any damage to structures in the Newcastle Coalfield.
First Workings	The tunnels or roadways driven by a continuous mining machine to provide access to the production panels in a mine (i.e. main headings). The roof of the roadways is generally supported by high strength steel rock bolts encapsulated in chemical resin. Subsidence above first workings pillars and roadways is generally < 20 mm.

Full Tributary Area Load	Refers to the full weight of the prism of rock directly above the pillar of coal supporting it. The prism area is defined by the line drawn half-way between the pillar and the adjacent pillars surrounding it. The volume of rock above the pillar is then determined by multiplying the Tributary Area by the depth of cover. The load is then determined by multiplying the volume by the density of rock (normally assumed to be 2.5 t/m^3).
Goaf	The extracted area that the immediate roof of the overburden collapses into, following the extraction of the coal. The overburden above the ‘goaf’ sags as the goaf compresses under load, resulting in a subsidence 'trough' at the surface.
Horizontal Displacement	Horizontal displacement of a point after subsidence has occurred above an underground mining area within the AoD. It can be predicted by multiplying the tilt by a factor derived for the near surface lithology at a site (e.g. a factors of around 7 to 10 are normally applied in the Newcastle Coalfield).
Inbye	An underground coal mining term used to describe the relative position of some feature or location in the mine that is closer to the workings coal face than the reference location.
Inflexion Point	The point above a subsided area where tensile strain changes to compressive strain along the deflected surface. It is also the point where maximum tilt occurs above an extracted longwall panel. It is typically located between 0.25 and 0.4 x cover depth from the panel sides, depending on panel W/H ratio.
Longitudinal Subsidence Profile	Subsidence measured (or predicted) along an extraction panel or centre line.
Mean Values	The average value of a given *Subsidence Effect* value (i.e. of subsidence, tilt and strain) predicted using a line of 'best fit' through a set of measured data points against key independent variables (e.g. panel width, cover depth, extraction height). The mean values are typically two-thirds to half of the Credible Worst-Case values and sometimes lower.
Mining Height	Refers to the height or thickness of coal extracted in a production panel or second workings area.
Outbye	An underground coal mining term used to describe the relative position of some feature or location in the mine that is closer to the point of mine entry than the reference location.

Outlier	A data point well outside the rest of the observations, representing an anomaly (e.g. a measurement related to a structural discontinuity or fault in the overburden that causes a compressive strain concentration at the surface, in an otherwise tensile strain field).
Panel Width	The width of an extracted area between chain pillars.
Primary Subsidence	The subsidence which is directly caused by second workings and the sagging of overburden or compression of adjacent barrier pillars. Primary subsidence usually occurs after undermining of a given surface location and then again after three or four adjacent pillar extraction panel face pass the point.
Residual Subsidence	The last 5% to 10% of subsidence that occurs after primary subsidence is complete and is due to the re-consolidation or re-compaction of goaf and overburden. It is a time dependent component of the subsidence and is unlikely to cause further impact to surface features.
Secondary Subsidence	See *Residual Subsidence*.
Second Workings	Refers to the removal of part or all of first workings pillars and usually results in goaf formation as spans between pillars are increased. Second workings are therefore performed on retreat out of a production panel or main headings area that will no longer be required to provide access or ventilation to a given section of mine.
Shoving	The shortening and distorting effect of compressive strains and shear strains due to mine subsidence on surface terrain, which results in localised shear failures or movements and uplift of soils and rock.
Strain	The change in horizontal distance between two points at the surface after mining, divided by the pre-mining distance between the points. i.e. Strain = ((post-mining distance between A and B) - (pre-mining distance between A and B))/(pre-mining distance between A and B) and is usually expressed in mm/m. Strain can be estimated by multiplying the curvature by a factor derived for the near surface lithology at a site (e.g. a factor of around 7 to 10 is normally applied in the Newcastle Coalfield). Discontinuous overburden behaviour however, can result in local strain and curvature concentrations at cracks, making accurate predictions difficult. A rule of thumb is normally applied to allow for these effects, which is to increase smooth profile strains (and curvatures) by 2 to 4 times occasionally at a given location. The increase in strain also

	usually develops at locations with shallow rock profiles, as opposed to areas with deep soil profiles.
Study Area	The area which may be influenced by mine subsidence from the extraction of the proposed pillar extraction panels.
Sub-critical Panels	Pillar Extraction panels that are deeper than they are wide ($W/H < 0.6$) and cause lower magnitudes of subsidence than shallower panels due to natural arching of the overburden across the extracted coal seam.
Subsidence	The difference between the pre-mining surface level and the post-mining surface level at a point, after it settles above an underground mining area.
Subsidence Control Zone (SCZ)	Reducing the impact of subsidence on a feature by modifying the mining layout and set back distances from the feature (normally applied to sensitive natural features that can't be protected by mitigation or amelioration works).
Subsidence Effect	The term used to define the subsidence and differential subsidence parameters (i.e. subsidence, tilt, strain and horizontal displacement) that may or may not have an impact on natural or man-made surface and sub-surface features above a mining area.
Subsidence Impact	The impact that a subsidence effect has on natural or man-made surface and sub-surface features above a mining area.
Subsidence Management Plan	Refers to the approval process for managing mine subsidence impacts, in accordance with the Department of Resources and Energy (DRE) of Trade and Investment, Regional Infrastructure and Services Guidelines. The mine must prepare a Subsidence Management Plan (SMP) to the satisfaction of the Director-General, before the commencement of operations that will potentially lead to subsidence of the land surface.
Subsidence Mitigation/ Amelioration	Modifying or reducing the impact of subsidence on a feature, so that the impact is within safe, serviceable, and repairable limits (normally applied to moderately sensitive man-made features that can tolerate a certain amount of subsidence).
Subsidence Reduction Potential	Refers to the potential reduction in subsidence due to massive strata in the overburden being able to either ‘bridge’ across an extracted panel with sub-critical or critical geometry, or have a greater bulking volume when it fails above super-critical panel geometry. The term was defined in an **ACARP, 2003** study into this phenomenon and is common in NSW Coalfields where massive sandstone / conglomerate units exist.

Super-Critical Panels	Pillar Extraction panels that are not as deep (H) as they are wide (W) (ie W/H > 1.4) and will cause failure of the overburden and maximum subsidence that is proportional to the mining height (i.e. 0.5 to 0.6 T).
Tilt	The rate of change of subsidence between two points (A and B), measured at set distances apart (usually 10 m). Tilt is plotted at the mid-point between the points and is a measure of the amount of differential subsidence. i.e. Tilt = (subsidence at point A - subsidence at point B)/(distance between the points) and is usually expressed in mm/m.
Tensile Strain	An increase in the distance between two points on the surface. Tensile strains > 2 mm/m are likely to cause cracking at the surface with shallow soil profiles over rock and are usually associated with convex curvatures near the sides (or ends) of the panels. Tensile strain also usually develops above barrier pillars.
Transverse Subsidence Profile	Subsidence measured (or predicted) across a pillar extraction panel or cross line.
Valley Closure	The inward (or outward) movement of valley ridge crests due to subsidence trough deformations or changes to horizontal stress fields associated with longwall mining. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and are usually visually imperceptible.
Valley Uplift	The phenomenon of upward movements along the valley floors due to **Valley Closure** and buckling of sedimentary rock units. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and may cause surface cracking in exposed bedrock on the floor of the valley (or gorge).

1.0 Introduction

This report presents a preliminary mine subsidence impact assessment for the proposed pillar extraction panels in the West Borehole Seam for the Tasman Extension Project, Mulbring.

The report will be used for the purpose of preparing an Environmental Impact Statement under Part 4 of the *Environmental Planning and Assessment Act 1979 (EP&A Act)* for State Significant Development to the Department of Planning & Infrastructure (DP&I).

The subsidence assessment has considered the Department of Mineral Resources (now Department of Resources and Energy (DRE) of Trade & Investment, Regional Infrastructure & Services (TIRIS)) Guideline for Applications for Subsidence Management Approvals (SMP).

The report has assessed the proposed mining layout of thirty-two pillar extraction panels (Panels 1 - 32) and three main headings panels (M1-M3), as shown in **Figure 1a**. The panels beneath non-sensitive areas will be totally extracted with a combination of partial pillar extraction and first workings methods used in more sensitive areas to control mine subsidence effects to appropriate levels where required.

The surface and subsurface features of interest that exist within the proposed mining area include:

- 1st, 2nd and 3rd Order Streams associated with Surveyors Creek No. 2 and Wallis Creek.

- Steep slopes and sandstone cliff lines between 10 m and 60 m high.

- Dry sclerophyll forest (eucalypts and hard leafed shrubs).

- Groundwater dependent ecosystems (GDEs) associated with Lowland Rainforest Endangered Ecological Community (EEC) (MU1a), Alluvial Tall Moist Forest EEC (MU5) and Sugarloaf Uplands Paperbark Thicket (MU15(p)).

- Riparian vegetation associated with Hunter Lowlands Redgum Forest EEC (MU19).

- Aboriginal heritage sites, including 38 Artefact Scatters, 36 Grinding Grooves, 26 Rock Shelters with Potential Archaeological Deposits (PADs).

- Eight TransGrid 330 kilovolt (kV) Towers, including six suspension and two tension towers.

- TransGrid Fibre Optic Cable (FOC) (suspended on the southern 81 Series 330kV Towers) and AAPT FOC (buried).

- Ausgrid 132 kV timber power poles and Telstra FOC (buried).

- Twelve private rural residential land holdings (DP1061633 - Lots 3, 5 to 7, 9 to 14, and 16 to 17) along Sheppeard Drive.

- HL Eco Trades (DP1061633 - Lot 4).

- Richmond Vale Futures Pty Ltd (DP1061633 - Lot 8).

- Orica Limited Research and Testing Facility and ammonium nitrate emulsion (ANE) plant(DP809377 - Lot 2).

- Proposed TransGrid Sub-Station (DP1061633 - Lot 15).

- Sheppeard Drive and George Booth Drive (Cessnock City Council and Roads and Maritime Services).

- Ausgrid 11 kV power line along Sheppeard Drive.

- Telstra copper cabling (buried) to residents along Sheppeard Drive.

- Unsealed gravel fire trails and infrastructure access roads.

- One TV transmission and two telecommunications towers (NBN, TransGrid and Broadcast Australia) on Mount Sugarloaf.

The location of the features is given in **Figures 1** to **3a** and **3b**.

Subsidence effect and impact predictions have been based on **ACARP, 2003** and subsidence effect data from nearby mines with similar geology and mining methods. Statistical inference techniques have been applied to estimate confidence levels in the predicted values.

2.0 Scope of Work

The scope of work for this report included an assessment of subsidence effects on the surface and subsurface features with and without Subsidence Control Zones (SCZ) present and involved the following activities:

(i) The development of a geotechnical model of the overburden and immediate roof-pillar-floor system using available borehole logging and testing data.

(ii) The development of SCZ criteria to meet performance measures for sensitive surface features (i.e. streams, GDEs, principal residences, steep slopes and cliff lines, TransGrid towers and FOCs), including the appropriate level of extraction and/or setback from the feature.

(iii) Review of measured subsidence effects and impacts at the nearby Abel and Tasman Mines.

(iv) Prediction of maximum subsidence effect parameters for the proposed Tasman Extension Project.

(v) Prediction of subsidence effect profiles and contours with cumulative effects from the Fassifern Seam workings and assessment of cumulative impacts.

(vi) Prediction of pre- and post-mining topography.

(vii) Prediction of sub-surface heights of continuous and discontinuous fracturing above the panels.

(viii) Potential cracking widths and their location.

(ix) Potential ponding depth locations along creeks within the site.

(x) Potential surface gradient changes.

(xi) Far-field horizontal displacements and strains.

(xii) Predicted impacts on natural features, man-made developments and Aboriginal heritage sites.

The predictions in this study have been based on three empirical models developed for the Newcastle and US Coalfields (refer to **Holla, 1987, ACARP, 2003** and **SDPS, 2007**).

Reference has also been made to relevant information provided in the Preliminary Environmental Assessment submission for the Tasman Extension Project to the NSW Department of Planning and Infrastructure (**Donaldson Coal, 2011**).

Mean and Credible Worst-Case subsidence impact parameter predictions, with or without impact management controls (SCZs), have been estimated in this study to assist specialist consultants assess the potential impact to a given feature. The necessary mine planning adjustments or mitigation measures will then be implemented to deliver satisfactory outcomes to the feature and for the stakeholders.

3.0 Available Information

The following information was provided by the mine to prepare this report:

(i) The proposed mining layout.

(ii) Cover depth contours to the West Borehole Seam and seam thickness isopachs.

(iii) Borehole log and core testing data (point load and immersion tests) from the proposed mining area.

(iv) Geophysical logging (in-situ sonic velocity profiling).

(v) Geological structure (fault and dyke) locations.

(vi) Surface topographic levels and existing drainage regime locations.

(vii) Locations of surface developments and infrastructure in the study area.

(viii) Location and significance of Aboriginal heritage sites.

(ix) Subsidence results from Abel Mine's total extraction panels and Tasman Mine's Partial Pillar extraction panels.

Plans of the proposed mining layout with cover depth contours, seam thickness isopachs and pre-mining surface topography are presented in **Figures 1a**, **1b**, **2**, **3a** and **3b** respectively.

Data from thirty-four boreholes to the West Borehole Seam have been referred to in the study to develop a geotechnical model of the mining area. The name and location of the boreholes are shown in **Figure 4** and summarised in **Table 1**.

The proposed panels will be located where seam thickness contours exceed approximately 2.5 m (see **Figure 5**).

Table 1 - Borehole Log Data Summary

Borehole Number	Easting (MGA)	Northing (MGA)	WBH Seam$^+$ Workings Cover Depth (m)	Seam Thickness T (m)
BO01	361120	6361067	35	3.56
BO02	361949	6360972	98	4.03
BO03	363156	6362962	75.8	1.91
BO04	363050	6362107	105.4	3.71
BO05	363765	6361992	182.4	4.41
BO06	364145	6362726	84.84	4.95
BO07	362299	6362996	25.22	2.06
BO08	362000	6361999	43.52	2.05
BO09	363034	6361308	130.9	3.04
BO10	362851	6362431	77.49	1.54
BO11	362581	6362726	44.11	2.56
BO12	362833	6363068	60.6	1.00
BO13	360120	6360053	26.5	3.21
BO14	363699	6363541	30.5	2.90
BO15	363624	6362925	65.5	4.67
BO16	363139	6363463	56.3	1.30
BO17	360804	6359937	49.7	3.81
BO18	362539	6361942	79.8	1.28
BO19	362735	6361731	97.3	0.26
BO20	362443	6361009	133.6	1.44
BO21	362073	6361648	76.2	3.75
BO22	362070	6361411	92.7	3.88
BO23	362100	6360553	121.4	2.9
BO24	362583	6361350	109.8	0.95
BO25	363697	6363545	30.9	1.55
TA28	364167	6361241	237.2	4.91
BO27	363384	6362481	100.5	4.88
BO28	363624	6362921	65.4	4.75
BO29	361362	6360639	66.7	4.21
BO30	361400	6359400	96.8	3.91
BO31	360189	6358952	119.4	3.73
BO32	360147	6358424	137.5	3.53
STIB1	363713	6360635	288.0	4.38
TA30	363509.5	6361606	234.2	4.83

± WBH Seam = West Borehole Seam.

4.0 Site Conditions

4.1 Land Use and General Surface Conditions

The majority of the surface land of the proposed mining area is Sugarloaf State Conservation Area, managed by the Office of Environment and Heritage, and Heaton State Forest, managed by Forests NSW. The western portion of the mining area is private rural residential and commercial property. There are several existing residential properties, public utility easements, fire trails and a Cessnock City Council road present above the site.

Topographic relief ranges from RL 40 m AHD to RL 320 m AHD across the panels. Surface slopes range from 1^o to 5^o in the flat, low lying areas in the west and steepen up to 45^o along the Sugarloaf Range ridges to the east and Mount Vincent to the south. Several semi-continuous sandstone cliff lines on the southern ridge range between 10 m to 60 m high, with 10 to 25 m high ridges present along the eastern ridge.

There are several 1st to 3rd Order Streams (Strahler System/**DIPNR, 2005**) associated with Surveyors Creek No. 2 and Wallis Creek which drain the site towards the north-west.

There are many significant Aboriginal heritage sites identified along the Sugarloaf Range and site tributaries. The sites consist of grinding grooves, rock shelters with Potential archaeological deposits (PADs) and scattered archaeological finds. An Aboriginal look-out also exists on Summit Point to the immediate south of the underground mining area.

There are three Broadcasting communications towers on Mount Sugarloaf adjacent to the existing Tasman Mine in the Fassifern Seam and are required to be isolated from measureable mine subsidence effects.

The surface topography and surface feature locations are shown in **Figures 3a** and **3b**. Site Photographs are provided at the end of the text in this document. Further details of surface features are provided in the following sub-sections.

4.2 Watercourses

The streams above the proposed mining area include eight 1st Order Streams that are ephemeral watercourses, three 2nd order Streams and one 3rd order Stream with pond chains, shallow incised stream sections and intermittent sandstone rock bars.

4.3 Cliffs and Steep Slopes

The cliffs above the site (i.e. > 10 m in height) are predominantly coarse to fine grained sandstone of the Triassic Narrabeen Group. It is estimated from aerial Light Detection and Ranging (LIDAR) surveys and site inspections that there are approximately 10.3 km of steep slopes ($>18^o$), 4.41 km of minor continuous cliffs between 5 and 10 m high and 4.87 km of continuous cliffs between 10 m and 60 m high. Numerous discontinuous, minor cliffs or rock formations between 2 to 5 m high also exist along sections of the steep slopes associated with the ridges.

Note: The term continuous cliff face infers that the length of the cliff face (along it's crest is > 20 m). A discontinuous cliff face infers the cliff or rock features are broken up into segments < 20 m in length. A discontinuous cliff line has greater in-built articulation than a continuous face and can therefore tolerate higher magnitudes of subsidence without cracking damage compared to a continuous cliff face.

The cliff lithology comprises 0.5 m to 1.5 m thick beds of pebbly sandstone, fine to coarse grained, yellow brown to grey brown with open vertical joints spaced between 2 m to 5 m. The cliff faces are bedding and joint controlled with strikes of 060^o (NNE-SSW) and 120^o (WNW-ESE) along the southern ridge and 030^o (NE-SW) along the eastern ridge.

The bedding dips generally at 2^o to 5^o towards the south/south east (i.e. into or along the north and west facing ridge slopes).

Light grey mudstone or shale beds exist along the bases of some of the cliffs with undercutting of sandstone beds apparent. Some localised honeycombed weathering had formed 2 - 3 m deep overhangs along the southern cliff faces. The rock strength on the cliff faces was estimated to range between 20 megapascals (MPa) and 50 MPa with some low strength beds of 2 MPa to 15 MPa associated with mudstone and weathered sandstone units.

Large sandstone talus boulders (2 - 5 m in diameter) form rocky steep slopes between 28^o and 45^o below the cliffs and extend for approximately one hundred metres down to the foot slopes. Natural instability is primarily due to the undercutting of mudstone beds and the release of overlying sandstone blocks along existing orthogonal joint patterns. Tree-root wedging is also a contributing factor to cliff face instability.

4.4 Vegetation

Vegetation on the site consists of dry schlerophyll forest (eucalpypts and hard leafed shrubs) on the steep slopes and ridges with dense riparian vegetation and melaleucas along the watercourses noted.

GDEs listed as State EECs associated with Lowland Rainforest (MU1a) and Alluvial Tall Moist Forest (MU5) are present along the watercourses at several locations. In addition, Hunter Lowlands Redgum Forest EEC (MU19) is located along the 3rd order stream in the proposed mining area. The Sugarloaf Uplands Paperbark Thicket (MU15[p]) is also considered an potential GDE.

4.5 Aboriginal Heritage Sites

There have been one hundred Aboriginal Heritage Sites identified within the vicinity of the proposed mining area to-date and are predominately located on the steep slopes and ridges or at the rock bar locations along the watercourses. These include 38 Artefact Scatters, 36 Grinding Groove sites and 26 Rock Shelter sites (see **Figure 3b**).

In addition, there are three cultural features of special significance that are located along the lower cliff lines of the Sugarloaf range. It has been requested by the Aboriginal Groups not to disclose the specific location or provide a description of these features in this report.

There is also a possibility that scarred trees exist within the proposed mining area that have not yet been recorded.

4.6 Services Easements

Eight TransGrid 330 kV, including six suspension towers and two tension towers (No.s TG1 and TG2 on **Figure 1a**), TransGrid FOC (suspended on the southern 81 Series 330kV towers) and AAPT FOC (buried) exist along an east-west easement which crosses two extraction panels in the north of the site.

Only two of the towers (suspension) are located above the production panels and the rest are > 1 cover depth away from these panels. The towers have four bored pier footings (5 m by 7 m to 9 m dimension) and the legs of the steel tower frames are concrete encased.

The Ausgrid 132 kV power poles and Telstra FOC (buried) exist on the north-west easement which crosses the Sugarloaf Ridge. The power line conductors are suspended on timber pole pairs that are approximately 5 m apart.

An Ausgrid 11 kV power line and Telstra copper cable (buried) runs alongside the eastern side of Sheppeard Road.

4.7 Private Lots

There are 16 Privately Owned Lots (Lot No. 2, DP 809377, Lot Nos. 3-17, DP 1061633) that have some or none of the proposed pillar extraction panels below them. The relevant lot details available for subsidence impact assessment are presented in **Table 2**.

Three of the lots (No. 7, 9 and 11) have existing residences with driveway access from Sheppeard Drive. Access to the properties had only been granted to inspect two of the properties (No. 7 and 9), which was done briefly on 28/7/11. The features on the properties inspected to-date included:

- Lot 7 - A single storey weatherboard clad house (10.8 m x 12.5 m) on strip and pad footings with a sheet metal-clad shed and two above ground concrete water tanks on the K & D Starr Property.

- Lot 9 - A two storey sheet metal-clad shed on concrete slab (13.6 m x 23.6 m) and a small water feature dam exists on the G & K Cameron property. The shed is currently being used for both business and residential purposes.

Table 2 - Available Private Lot Details

Lot No	Owner	Proposed Panels Nos.	Cover Depth to WBH Seam (m)	Distance to Buildings from Goaf Edge Limits (m)	AoD (z/H)	SCZ Required
2	Orica Australia Pty. Limited	1,2	120 - 190	413 to 973	3.44 - 8.0	No
3	J.M. Spruce	3	60	Unknown	?	Unknown
4	H.L. Eco Trades	Nil	<20	N/A	N/A	No
5	P.W. & D.L. Dryden	3	65	296 from cnr of Panel 11	4.55	No
6	P.J. Crowhurst	10 – 13	55 - 100	97	1.94	No
7	K.H. & D.M. Starr	9 - 13	60 - 120	-8	-0.13	Yes
8	Richmond Vale Futures Pty Limited	9 - 13	50 - 120	Unknown	?	Unknown
9	G.W. & K.M. Cameron	9 - 13	60 - 120	-58	-0.83	Yes
10	J.L. Parkinson	M2, 23 - 27	80 - 120	Unknown	?	Unknown
11	D.H. & J.A. Hoey	M2, 8, 9-22	55 - 100	-49	-0.58	Yes
12	M.A. Honeysett	4,8	55 - 80	120	2.2	No
13	K.R. & R.L. Mitchell	8	55 - 60	Unknown	?	Unknown
14	G.K. Hooler	9	60	108	1.8	No
15	TransGrid	Nil	60	200	3.33	No
16	A.S. & K.L. Green	Nil	60	624 - 751	10.4	No
17	B.G. & M. Smith	Nil	60	1,150	19.1	No

It is understood that the Parkinson’s (Lot 10) are currently constructing a new residence. Two other residences (on Lots 12 & 14) exist 120 m and 108 m to the west of the proposed Panels 8 and 9 respectively and are well outside the angle of draw (AoD) to the proposed mine workings.

The Orica Limited Research and Testing Facility is located 413 m to 973 m to the north west of the proposed panels and is understood to have several administration, explosives testing and storage buildings. Orica has established an ANE production facility and associated infrastructure on this site (Project Approval 09_0090).

All properties observed have gravel access driveways from Sheppeard Drive and timber or steel post and wire boundary and internal fencing.

4.8 Public Roads and Fire Trails

George Booth Drive and the Hunter Expressway are outside the limits of mining. Access to the new pit top facility will be via an intersection with George Booth Drive.

Sheppeard Drive is a 7 m wide dual carriage way with spray bitumen seal and gravel shoulders. A 2 x 1100 mm diameter concrete pipe culvert is located in 2 m of fill beneath the road where it crosses one of the 1st order streams (see Point 11 on **Figure 2**).
The above roads are within the Cessnock City Council local government area.

Unsealed gravel fire trails and infrastructure access roads cross the site and follow the ridge lines. The condition of the roads was fair to poor, with some roads being severely eroded or rutted.

4.9 Sub-Surface Conditions

Reference to the 1:100,000 Geological Sheet for the Newcastle Coalfield (**DMR, 1995**), indicates the proposed mining area is located within the Boolaroo to Lambton Sub-groups of the Permian Newcastle Coal Measures.

The overburden for the area will consist of gently, south-west dipping (i.e. 2 to 5 degrees) sedimentary strata, which generally comprise interbedded sandstone, siltstone, shale, carbonaceous mudstone, tuffaceous claystone and coal. The coal seams present in the overburden (in descending order) include the Australasian, Montrose, Wave Hill, Fern Valley, Victoria Tunnel and West Borehole Seams.

The available borehole data included core log and laboratory tests (point load and immersion tests for moisture sensitivity) and in-situ geophysics data (sonic velocity profiling below steel casing). The geophysics sonic velocity profiles have been converted into unconfined compressive strength (UCS) values and are presented in **Figures 6a** to **6e**.

The West Borehole Seam in the southern area of the site typically consists of 4 seams (Borehole + Yard + Dudley + Nobbys) and ranges in thickness from 3.2 m to 4.95 m. The immediate roof includes 1 m to 2 m of coal and the Nobbys Tuff, which is a 1 m to 8 m thick unit of low to medium strength tuffaceous claystone (UCS ranges from 19 to 50 MPa with mean of 31 MPa) with high moisture sensitivity (Immersion Test [IT] results of 9 to 15) that exists 0.8 m to 2.4 m above the workings; see **Figures 7a** and **7b**.

A medium to high strength sandstone channel unit (UCS ranges from 46 to 102 MPa and mean of 70 MPa) splits the upper two or three seams in the northern area of the proposed workings, with the Nobbys Tuff located between 5 m and 42 m above the mine roof horizon; see **Figures 7a** and **7c**.

The proposed workings floor is situated in high strength Waratah Sandstone UCS ranges from 36 MPa to 127 MPa (mean of 69 MPa).

The south-eastern bedding dip across the site is associated with the southern arm of the Four Mile Creek Anticline, which is located to the west of the site.

Surface joint patterns measured on the sandstone cliff lines and outcrops to the south of the mining area consist of a sub-vertical, widely spaced, planar to wavy, persistent joint sets striking between 025° and 035° (NNE to NE). A sub-vertical joint set striking at

approximately 135º (NW:SE) is also present. The trends of the cliff faces are similar to the above joint sets.
The West Borehole Seam has low strength with sonic derived UCS values ranging from 11 to 20 MPa with mean of 17 MPa.

The UCS and stiffness properties of the immediate roof and floor materials have been derived from laboratory and point load strength test results from core taken from six boreholes and in-situ geophysical testing data. Good correlation was apparent between the laboratory derived and *in situ* sonic UCS results presented in the exploration borehole BO32 (refer to borehole location on **Figure 4**).

Estimates of the range of material strength and stiffness properties present in the roof and floor of the West Borehole Seam are summarised in **Table 3**.

Table 3 - Strength Property Estimates for West Borehole Seam, Roof and Floor Lithology

Lithology	Strata Thickness (m)	UCS Range+ [Mean] (MPa)	Elastic Moduli Range* [Mean] (GPa)	Average Moisture Sensitivity^
Interbedded sandstone/ siltstone beds above the West Borehole Seam	> 20	46 - 102 [70]	13 - 30 [21]	Non-Sensitive (IT = 1-3)
Nobbys Tuff	1 – 8	19 - 50 [31]	5.7 - 15 [9]	Highly Sensitive (IT=9-15)
West Borehole Seam	2 – 5	11 - 20 [17]	2 - 4 [2]	Non- Sensitive
Waratah Sandstone	>10	36 - 127 [69]	19 - 25 [21]	Non- Sensitive (IT = 1-3)

+ Unconfined Compressive Strength derived from point load testing to **ISRM, 1985** on bore core samples taken from SMP area.
* Laboratory Young's Modulus (E) derived from laboratory and sonic UCS data, E = 300 x UCS (units are in gigapascals [GPa]).
^ Moisture sensitivity testing determined from the Immersion Test procedure presented in **Mark & Molinda, 1996**.

Based on the available geotechnical data, the following parameters have been derived that are relevant to the behaviour of the overburden and subsidence predictions:

- the seam split thickness or location of Nobbys Tuff above the workings;
- thickness of massive sandstone units; and
- the distance of the massive units above the workings.

The above geotechnical model parameters are presented in **Figures 8a** to **8c**.

5.0 Mining Geometry

5.1 Proposed West Borehole Workings

The following mine workings details have been assumed in this assessment:

(i) The first workings roadways will be 5.5 m wide x 2.5 m high and located in the lower two seams of the West Borehole Seam (Borehole and Yard Seams). The upper two seams will form the immediate roof (Dudley and Nobbys Seams). In some areas the working section will have a stone roof instead of coal due to sandstone channel seam splitting in the northern area of the site.

(ii) The mine access roadways will initially be oriented towards the west for the first 700 m of development and then head south for 1.8 km. The mains will be developed on a six heading layout with 25 m wide centre spacing and 45 m cut-through spacing.

(iii) The production panels (i.e. second workings panels) will be developed to the north and south from three east-west oriented mains panels (M1-M3).

(iv) Parts of the production panels (Panels 1 to 32) are likely to be either total or partial pillar extraction panels and located at depths ranging from 60 m to 200 m. The panels will have four or five headings (roadways) and will be 160.5 m wide (rib to rib). The design of the remnant pillars within the panels will depend on the maximum tolerable subsidence effect limit or sub-surface fracture height controls beneath sensitive surface features.

(v) The barriers between the extracted pillar panels will be dependent on the long-term stability requirement and design of the production panels. They will range in length from 0.5 km to 1.5 km long.

(vi) For the pillar extraction panels beneath non-sensitive features, it has been assumed that approximately 88% of the pillars (high extraction mining) will be extracted during second workings on retreat, using continuous miners and Mobile Breaker Line Supports (MBLS) to provide temporary roof control.

(vii) The design of partial pillar extraction panels have not been determined at this stage and will depend upon the required SCZ performance criteria (see **Section 6.4**).

(viii) The span left between remnant pillars in the partial pillar extraction panels should not exceed 0.45 times the depth of cover where cover depths are < 80 m for surface to seam fracture connectivity control (e.g. the maximum span between remnant pillars should be limited to 27 m for a cover depth of 60 m).

(ix) A solid barrier should be left between the finishing ends of the production panels with similar design constraints similar to the inter-panel barriers.

The panel width to cover depth ratio (W/H) for the proposed pillar extraction panels will range from 0.67 to 2.92, indicating sub-critical to supercritical subsidence behaviour is likely to occur.

Note: Critical subsidence refers to the point where sub-critical or natural overburden 'arching' behaviour stops (i.e. when W/H exceeds 0.7) and the development of maximum subsidence or super-critical overburden behaviour starts (i.e. maximum possible subsidence occurs when W/H > 1.4 and is a function of mining height and goaf stiffness).

The development heading and panel layouts (such as areas of total and partial extraction and mining height) would be finalised as a component of the Extraction Plan process. The Extraction Plan process would include revised subsidence predictions for any changes made to the assumptions outlined above.

5.2 Existing West Borehole Seam Workings

Old Stockrington Colliery workings exist in the West Borehole Seam to the east of the proposed Tasman Extension Project. A minimum 50 m barrier will be maintained between the new workings and the worst case position of the Old Stockrington Colliery workings to avoid activities within the inrush control zone defined under the Coal Mine Health and Safety Regulation, 2006.

The Stockrington Colliery workings are approximately 150 m beneath the majority of the proposed and existing partial pillar extraction panels in the Fassifern Seam; see **Figures 1a** and **1b**. The workings consist of first workings (Welsh Bords) and pillar extraction panels. Mining was completed in the early 1980's, although the workings below the Tasman Mine mining lease are probably much older than this.

It is possible that the proposed mine workings area may have already been subsided due to apparent lack of horizontal stress in development headings to-date (albeit they are in a topographical relief area). Open jointing and moderate levels of bedding shear would also be expected in the upper levels of the overburden previously subject to mine subsidence. There is however, no evidence of surface cracking above the old pillar extraction areas.

A review of the available mine plan for the Stockrington Colliery workings indicates panel widths of between 125 m and 250 m, which are separated by 16 to 35 m wide barriers. The depth of cover ranges between 250 m and 350 m and the working height was approximately 2 m (based on discussions with Tasman Mine representatives).

The pillar extraction areas were mined by stripping, splitting and pocketing techniques with final bord widths ranging from 4.2 to 8.4 m, indicating an overall pillar extraction ratio range of 27% to 51%. The effective mining height is therefore assessed to be 50% of the mining height or 1 m for subsidence prediction purposes.

Based on a Panel W/H ratio of range of 0.4 to 0.7 and reference to Figure 6.12 in **ACARP, 2003** it is possible that the panels were essentially sub-critical with maximum panel subsidence that was 0.1 to 0.2 times the effective working height (i.e. an S_{max} range of 0.2 to 0.4 m). It is therefore possible that that only minimal impact occurred at the surface as the maximum tensile strains would have been in the order of 1 to 2 mm/m (with crack widths of < 20 mm).

In the areas of first workings panels, the solid pillar dimensions range from 10 to 30 m in width and 22 to 33 m in length. Based on an assumed mining height of 2.0 m, the pillars were essentially ‘squat’ (i.e. w/h > 5), with minimum pillar width to height ratios ranging from 5.1 to 15.2.

Based on full tributary area (FTA) analysis and University of NSW Pillar strength formulae, the factor of safety (FoS) for the first workings pillar panels sampled range between 1.55 to 7.56 with an average of 5.2 and standard deviation of 2. As the majority of the pillars are in the sub-critical range, the assumed loading scenario on the pillars is therefore conservative with the majority of the pillars in each panel likely to have FoS values > 2.11 for the assumed mining height.

It is also assessed that the overall stability of the standing pillars beneath the proposed barrier and remnant pillars in the Fassifern Seam are unlikely to be affected by vertical stress interaction caused by over mining. Based on reference to US multi-seam coal mine databases described in **Mark et al, 2007**, a cover depth / interburden thickness (H/I) ratio range of < 7 indicates that negligible impact would be expected. The H/I for the Fassifern and Borehole Seams at Tasman ranges between 1.7 and 2.3.

However, due to the uncertainty in the mine plan and actual mining height (there are areas on the mine plan which do not show any pillar dimension details except for the workings limits), it would be prudent to consider that subsidence could occur above these mine workings at some time in the future.

This assumption has significant ramifications for the predicted subsidence beneath the ridges above the Tasman Extension Project if the Stockrington Colliery workings were to collapse at some time in the future (i.e. predicted subsidence may increase by 0.2 m to 0.4 m) and will therefore need to be addressed in subsequent management plans as a precautionary measure.

5.3 Proposed Fassifern Seam Workings

The current Tasman Mine operates in the 2.4 m thick Fassifern Seam to the east of the proposed Tasman Extension Project. The mine uses a partial pillar extraction system to limit subsidence beneath the Sugarloaf Range to <150 mm. Measured tilts and horizontal strains above these panels have been < 3 mm/m and 1.5 mm/m respectively.

To-date, the Tasman Mine has completed nine partial pillar extraction panels and one total extraction panel (Panels 1 to 10) at cover depths ranging from 60 m to 200 m with no surface cracking or visual impact occurring as a direct result of this method of coal extraction.

The proposed partial extraction mining method to be used in Panels 11 to 22 will be the Modified Duncan Method. This method has been used successfully to-date in Panels 5b, 6 and 8 and 10. Other mining methods such as single sided lifting (Panels 2a and 3 to 4) and total extraction (Panel 1) were used. Panel 9 was not taken due to operational issues.
The proposed panels will be developed on a 5-heading layout with 45 m centre-centre square pillar spacing and 5.5 m wide headings and cut-throughs. The mining height has been assumed to be 2.4 m for subsidence prediction purposes.

The panels will typically have final mined widths (W) of approximately 203 m to 366 m with cover depths (H) ranging between 50 m and 240 m. The panels will have *super-critical* to *critical* W/H ratios of 4.5 to 0.84, indicating the maximum pillar loads will be close to or equal to FTA magnitudes.

Where appropriate for the SCZ above a given panel, the pillars will then be 'stripped' or reduced in width along four sides on retreat, leaving square remnant pillars with factors of safety (FoS) > 1.6 (under the assumed design loading conditions) and w/h ratios >5.

A 39.5 m wide solid barrier will be formed on development between each panel. The barrier pillar ribs may then also be lifted along each side during retreat out of the panels, leaving a reduced barrier width after mining is completed.

To-date, the rib-stripping has involved effective cut widths of 6.4 m to 10.75 m, which indicates a final remnant pillar width range of 18 m to 27 m is possible. The pillar w/h ratio will range from 7.5 to 11.25, based on a height of 2.4 m.

It should be noted that the maximum span between the remnants should not exceed 0.45 x cover depth (i.e. 27 m spans for 60 m of cover) in order to maintain sub-critical behaviour above the panels with cover depths < 80 m. Reference to the longwall panel database for the Newcastle Coalfield in **ACARP, 2003** suggests that subcritical panel behaviour occurs up to panel width to cover depth ratios of 0.6, despite the overburden geology or Subsidence Reduction Potential of the strata (see **Glossary**).

Further details of the design and required performance of the partial pillar extraction panels for the current Tasman Mine are provided in **DgS, 2007a, 2007b** and **2007c** and **DgS, 2010**.

5.4 Performance Measures and Subsidence Control Zones

As part of the Tasman Extension Project, Donaldson Coal would implement performance measures for significant surface features. These performance measures would be achieved by implementing Subsidence Control Zones (SCZs) to manage subsidence effects on the surface feature and achieve the performance measure. The SCZ may involve partial extraction or limiting extraction to first workings (i.e. no secondary extraction) in some areas. The mine design will be such that the performance measures are achieved.

A similar approach has been undertaken successfully to-date for the current Tasman Mine in the Fassifern Seam.

Five SCZs have been applied to the proposed mine workings layout to meet the proposed performance measures as follows:

Level 1 - No constraints on development with post-mining impacts either mitigated against through modification to the feature or removing it prior to mining, or repairing or replacing it after mining in accordance with Stakeholder agreement.

Level 2A - Partial Pillar Extraction with mine subsidence from second workings limited to < 300 mm with strain hardening remnant pillars that will support the applied service loads. Minimum set-back from total extraction or Level 1 areas to be not less than half the cover depth from the feature (i.e. 26.5^o AoD).

Level 2B - Partial Pillar Extraction with mine subsidence from second workings limited to < 150 mm with strain hardening remnant pillars that will support the applied service loads. Minimum set-back from total extraction or Level 1 areas to be not less than half the cover depth from the feature (i.e. 26.5^o AoD).

Level 3 - First Workings only with mine subsidence from second workings limited to < 20 mm. Level 2 zones may also be added to achieve the required subsidence limits. Minimum set-back from total extraction or Level 1 areas to be not less than half the cover depth from the feature (i.e. 26.5^o AoD).

Level 4 - First Workings with mine subsidence from secondary extraction areas limited to nil measureable. Minimum set-back from total extraction or Level 1 areas to be not less than the cover depth from the feature (i.e. 45^o AoD).

For the purposes of this report, the use of the term SCZ in the rest of the study, generally infers Level 2A, 2B and 3 controls as Level 1 infers no subsidence control (but does require impact management) and Level 4 only applies to the communications towers on Mount Sugarloaf.

For mine workings below sensitive surface features or Level 2 to 4 SCZs, the following design assumptions have been applied:

(i) The SCZ will have either first workings or partial extraction pillars that will have a high probability of remaining stable or limiting subsidence to the limits specified in the long-term.

(ii) The SCZ pillars should be designed to behave elastically under design loading conditions and not suddenly lose strength if overloading occurs (i.e. they will exhibit strain hardening behaviour).

For strain-hardening behaviour, a minimum pillar width/height ratio of 5 is considered likely to provide sufficient pillar core confinement to allow the pillars to ‘squeeze’ slowly rather than ‘crush’ suddenly under over loading conditions (see **Section 6.3** for further details).

Minimum pillar factors of safety (FoS) against crushing or roof/floor strata bearing failure under service loading should be determined based on consideration of post-yielded pillar behaviour. A minimum FoS of 1.6 is suggested for pillar stability / serviceability at this stage unless Donaldson Coal can demonstrate through a practical research and monitoring program (as part of the Extraction Plan process in consultation with DTIRIS) that lower FoS values can meet the performance criteria of a given SCZ.

The performance measures and recommended SCZs for the Tasman Extension Project are summarised in **Table 4A** for man-made developments and **Table 4B** for the natural features and Aboriginal heritage sites. The locations of the proposed SCZs are shown in **Figures 3a** and **3b**.

Donaldson Coal would implement an adaptive management approach to ensure the performance measures are achieved for the Tasman Extension Project. Adaptive management would involve the monitoring and periodic evaluation of environmental consequences against the performance measures, and adjustment (if necessary) of the subsidence control zones through the Extraction Plan process to achieve the adopted performance measures.

Table 4A - Tasman Extension Project Proposed Subsidence Performance Measures and Control Zones for Developments

Surface Constraint	Performance Measure	Proposed SCZ		Notes
		Level	Effect Limits	
Communication Towers on Mt Sugarloaf	Maintain safety and serviceability. No damage to structures or loss of service.	4	< 2 mm subsidence & < 10 mm horizontal displacement	1. First workings only within 45^{o} AoD (1H) from corners of structure.
Fibre Optic Cables (FOCs)	Maintain safety and serviceability. Damage must be fully repaired or compensated.	2A	<300mm Subsidence	1. Partial extraction with stable remnant pillars under design loading located within 26.5^{o} AoD from feature. 2. SCZ may be relaxed to Level 1 if FOC can be relocated by agreement with Telstra/AAPT or is suspended (i.e. TransGrid FOC).
TransGrid Towers	Maintain safety and serviceability. Damage must be fully repaired or compensated.	3	<20 mm subsidence, <5 mm/m tilt, <2 mm/m strain	1. First workings only within 26.5^{o} AoD (0.5H) from corners of structure with partial extraction with remnant pillars under design loading located within 45^{o} AoD (1H) from corners of structure. 2. May be relaxed to Level 1 if cruciform footings can be installed and agreement reached with stakeholder.
		1	Maximum extraction, no subsidence effect limits	1. Installation of engineer designed cruciform footings and flexible conductor stringers. 2. Where agreement reached with stakeholder.
Ausgrid 132 kV Easements	Maintain safety and serviceability. Damage must be fully repaired or compensated.	1	Maximum extraction, no subsidence effect limits	1. Where agreement can be reached with the infrastructure owner. 2. Does not apply where FOC exists (see Level 2A constraints for FOC)
Principal Residences	Maintain safety. Serviceability to be maintained and/or fully compensated. Damage must be fully repaired or compensated.	3	<20 mm subsidence, <5 mm/m tilt, curvature < 0.2 km^{-1}, & <2 mm/m strain.	1. First workings only within 26.5^{o} AoD (0.5H) from corners of structure for Safe, Serviceable & Repairable impacts. 2. May be relaxed to Level 1 if agreement can be reached with the landholder.
		1	Maximum extraction, no subsidence effect limits	1. Where agreement can be reached with the landholder.

Table 4B - Tasman Extension Project Proposed Subsidence Performance Measures and Control Zones for Natural Features

Surface Constraint	Performance Measure	Proposed SCZ		Notes
		Level	Effect Limits	
Cliff Lines (i.e. continuous rock faces > 20 m in length with minimum height of 10 m and slope > 1H:2V)	Minor impact resulting in negligible environmental consequence. No additional risk to public safety.	2B	< 150mm Subsidence	1. First workings only within ± 30 m of cliff line[#]. # Assumes partial pillar extraction zone as per Minor Cliff Lines and Steep Slopes are adjacent.
Minor Cliff Lines (i.e. discontinuous rock face with minimum heights of 10 m and slope > 1H:2V)	Minor impact resulting in negligible environmental consequence. No additional risk to public safety.	2A	< 300mm Subsidence	1. Partial extraction with long-term stable remnant pillars under design loading and located within 26.5° AoD from toe of minor cliff or steep slope of greater than 26.5° (2H:1V). 2. Maximum extraction beneath steep slopes between 18° (3H:1V) and 26.5° (2H:1V).
Steep slopes and rock outcrops (i.e. an area of land having gradient between 3H:1V and 1H:2V)				
3rd Order Streams or Above	Negligible environmental consequences (i.e. negligible diversion of flows or change in the natural drainage behaviour of pools, and no connective cracking to underground workings).	3	< 20 mm at edge of the bank.	1. First workings only within 26.5° AoD (0.5H) + 40 m buffer from centre of stream bed. 2. SCZ may be relaxed to Level 3 or 2 if it can be demonstrated that height of fracturing and surface impacts will not impact on surface waters or groundwater.
Hunter Lowlands Redgum Forest along 3rd Order Streams and Groundwater Dependent Ecosystems (MU1a and MU5)	Negligible environmental consequence.	2A	< 300mm subsidence	1. Partial extraction with long-term stable remnant pillars under design loading and located directly below feature.
1st and 2nd Order Streams	Minor environmental consequences only. Negligible connective cracking to underground workings.	2A	< 300mm subsidence where DOC < 80m	1. First workings only within 26.5° AoD (0.5H) + 40 m buffer from centre of stream bed.

6.0 Design Considerations for Subsidence Control Zones

6.1 Background

The control of subsidence beneath sensitive surface features will be achieved by leaving groups of stable remnant pillars beneath the feature and to provide adequate set-back distances from total extraction panels (i.e. to allow for the angle of draw). The reliability of the design of such stable remnant pillars has been assessed based in reference to international research on the stability of pillar panels in South Africa, USA and Australia.

The strength and stability of coal pillars has been the topic of interest for numerous rock mechanics researchers over the past 50 years since the South African Coalbrook Colliery disaster in 1960, which involved violent, sudden failure of over 4,400 pillars with w/h ratios of 0.87 in a matter of minutes (and 7,700 pillars over several hours) (**ACARP, 2005**).

Based on the outcomes of this research, it has been found that the most reliable way to estimate the strength of a coal pillar is to apply empirical methods and statistical analysis techniques within the bounds of experience.

The most reliable empirical pillar strength formulae to-date have used the pillar width, pillar height and a database of ‘failed’ and ‘un-failed’ pillar cases to derive ‘calibrated’ pillar factor of safety (FoS) values. The FoS of a panel of pillars is the ratio of pillar strength/average pillar stress.

The pillar strength formulae currently used in the Australian coal industry is based on a non-linear power law, which assumes that for a FoS of 1, the pillar panel will have a Probability of Failure (PoF) of 50%. The database includes ‘failed’ and ‘un-failed’ pillar panels from the South African and Australian coal industries and is plotted in terms of pillar strength v. pillar load in **Figure 9a**. The pillars within the panels were all generally considered to be subject to full tributary area (FTA) loading conditions, except for one case, which apparently had an abutment load applied to it from adjacent goaf development.

In **Figure 9a**, several FoS lines have been drawn through the database of 177 cases, 35% of which represent pillar panel failures. The panel failures occurred between FoS values of 0.74 and 1.62 and there is a mix of failed and un-failed cases between FoS values of 1.0 and 1.3.

The pillar width/height ratio is also a very important factor that indicates the post-yield behaviour of the pillars when they are overloaded. The width to height ratio of the pillars in the database ranges from 0.87 to 12 with the failed pillar panels having a w/h range between 0.87 and 8.16. Pillars with w/h ratios < 3 are considered most likely to ‘strain-soften’ and result in rapid failure and pillar runs, whereas w/h ratios > 5 are more likely to ‘strain-harden’ and fail slowly or ‘squeeze’. These types of post-yield behaviour have been discussed in **ACARP, 2005** and demonstrated in **Figures 9b - 9d** for various in-situ observations and laboratory experiments.

Note: - What also needs to be considered here is whether the long-term behaviour of the pillars, roof and floor could cause time-dependent subsidence effects to develop if the mine workings conditions deteriorate significantly (i.e. due to flooding, faulting or on-going roof and rib spall).

The likelihood of pillar instability in the West Borehole Seam mine workings has therefore been based on the pillar Factor of Safety (FoS) and reference to probability of failure (PoF) correlations presented in **ACARP, 1998a**. The FoS was calculated by dividing the pillar strength, S_p, with the average pillar stress, σ, under worst-case loading conditions.

6.2 Pillar Load Models

6.2.1 First Workings or Remnant Partial Extraction Pillars

Panels with Supercritical geometries (i.e. W/H > 1.4) will have overburden that is **unlikely to span** across the panel and remnant pillars in the panel are likely to be subject to the maximum full tributary area (FTA) load generated by the weight of the overlying rock; see **Figure 10a**.

Panels with Sub-critical geometries (i.e. W/H < 0.7) infer that the overburden is **likely to span** the panels due to natural compressive arching action. The remnant pillar loads will therefore be lower than FTA Loading values and controlled by the ratio between overburden deflection or sagging stiffness and the remnant pillar stiffness; see **Figure 10b**.

Panels with Critical geometries (i.e. 0.7 < W/H < 1.4) infer that the overburden **may or may not span** the panels and will depend on whether a thick and relative strong ‘beam’ exists at a reasonable height above the workings and can span through shallow Voussoir arching action.

Note: Shallow Voussoir arching action refers to the spanning action of a confined rock beam with vertical joints and subject to ‘bending’ moments (and tensile stresses) from overlying rock loading. It is a less stiffer action than a natural compression arch, as it is a compressive arch that develops within a massive strata unit, rather than the entire overburden (i.e. the span of the panel is too wide for the available cover depth to allow the natural deep compression arch to develop).

The remnant pillar loads **may or may not** be lower than FTA Loading values and will also be controlled by the ratio between overburden deflection or sagging stiffness and the stiffness of the remnant pillar stiffness.

The subsidence above several of the panels will therefore be controlled by the stiffness and stability of the first workings and remnant second workings pillars and immediate mine workings roof and floor strata. The barrier pillars between the panels will also control subsidence if sub-critical interburden geometries exist and the remnant pillars go into yield.

Overall, the stability of the remnant, barriers and first workings pillars will be governed by the pillar width to height ratio (w/h) as discussed in **Section 6.1**.

Based on the FTA theory, the total stress acting on the pillars after development may be estimated as follows:

σ = pillar load/area = P/wl

where:

P = full tributary area (FTA) load of column of rock above each pillar;

$= (l+ r)(w + r).\rho.g.H$;

w = pillar width (solid)

l = pillar length (solid)

r = roadway width

ρ = average rock mass density (MPa/m depth below surface)

g = acceleration due to gravity (10 m/s^2)

H = cover depth to a given seam.

The pillars in the SCZs will range from FTA loading to side abutment loading adjacent to totally extracted panel areas.

The total stress acting on the first and subsequent row of pillars in the SCZ has been estimated using the abutment load concept defined in **ACARP, 1998a** for estimating single abutment loads on pillars with an adjacent goaf. The load model is shown schematically in **Figure 10c**.

The total stress acting on the pillars after mining may be estimated as follows:

σ_{pillar} = pillar load/area = (P+RA)/wl

where:

P/wl = Full tributary area load of column of rock above each pillar;

$= (w+ r)(l+r).\rho.g.H$;

RA/wl = Single Abutment load due to cantilever action of overburden over goaf

$= 0.5\ u\ H^2 \tan(\theta)(l+r)/(wl)$ (where u = unit weight of overburden 0.025 MPa/m
θ = abutment angle (normally taken as 21^o))

R = Proportion of abutment load acting on first row of SCZ pillars;

= 1- $[(D-w-r)/D]^3$ (where D = distance (m) that load distribution will extend from goaf edge according to **Peng & Chiang**, **1984**: D = 5.13 H

= 1 (assumed for Tasman SCZs)

w = pillar width (solid);
l = pillar length (solid);
r = roadway width;
H = depth of cover;

The roadways between first workings pillars will be 5.5 m wide. The partial pillar extraction panel spans will increase to the width of the removed pillar plus the number of roadway widths in between them.

6.2.2 Barrier Pillars

The proposed mining layout will have total extraction panels only where cover depths are less than 200 m. SCZs will be located between 60 m and 410 m of cover.

Barrier pillars will be subject to double abutment loading conditions where total extraction mining will take place (i.e. at cover depths < 200 m). Barrier pillars adjacent to SCZs are unlikely to be subject to greater than FTA loads, as the remnant partial extraction panel or first workings pillars will be designed to remain stable in the long term.

The estimate of the total stress acting on the proposed barrier pillars under double abutment loading conditions may be based on the abutment angle concept described in **ACARP, 1998a** as follows. *Note : This loading scenario would only occur in sub-critical panels (i.e. W/I < 0.7) or if the remnant pillars in the production panels go into yield on both sides of the barrier for critical and supercritical panels (i.e. W/H > 0.7*), see **Figure 10d**.

σ = pillar load/area = $(P+A_1+A_2)/wl$

where:

P = full tributary area (FTA) load of effective column of rock above each pillar;

= $(l+ r)(w + r).\rho.g.H$;

$A_{1,2}$ = total abutment load from each side of pillar in MN/m, and

= $(l+r)\rho g(0.5W'H - W'^2/8\tan\phi)$ (for sub-critical panel widths) or

= $(l+r)(\rho gH^2\tan\phi)/2$ (for super-critical panel widths);

w = pillar width (solid);

l = pillar length;

r = roadway width;

H = depth of cover;

ϕ = abutment angle (normally 21° adopted for cover depths < 350 m in the NSW Coalfields and then decreases with increasing cover depth due to goaf load transfer);

W' = effective panel width (rib to rib distance minus the roadway width).

A panel is deemed sub-critical when $W'/2 < H\tan\phi$ (ie $W/H < 0.7$)

6.3 Pillar Strength

The strength of the first and second workings remnants and barrier pillars in the West Borehole Seam should be estimated based on the empirical formulae presented **ACARP, 1998b**. As details of remnant pillar geometries are unknown at this stage, estimates of subsidence above control zones were derived based on assumed minimum recommended panel geometries for 'squat' width/height (w/h) ratios >5.

The currently accepted strength formula for ‘squat’ pillars in Australian Coal Mines is as follows:

$$S = 27.63\Theta^{0.51}(0.29((w/5h)^{2.5} - 1) + 1)/(w^{0.22}h^{0.11})$$

where:

h = pillar height;

Θ = a dimensionless ‘aspect ratio’ factor or w/h ratio in this case.

6.4 Pillar Factor of Safety

It is considered that the design of the remnant pillars should also include a minimum FoS to reduce the probability of panel yielding to an acceptable level under design service loading conditions. Designing for elastic remnant pillar behaviour will also maintain surface subsidence to meet the proposed performance measures (**Section 5.4**).

According to **ACARP, 2005**, **Table 5** and **Figure 11** indicates a range of FoS values which correspond with probabilities of panel failure.

Table 5 - Pillar Panel Factor of Safety v. Panel Failure Probability

Pillar Factor of Safety Under Design Load	Probability of Pillar Panel Failure	Probability of Pillar Panel Failure
0.87	0.8	1 in 1.25
1	0.5	1 in 2
1.22	0.1	1 in 10
1.29	0.05	1 in 20
1.38	0.02	1 in 50
1.44	0.01	1 in 100
1.63	0.001	1 in 1,000
1.79	0.0001	1 in 10,000
1.95	0.00001	1 in 100,000
2.11	0.000001	1 in 1,000,000
2.23	0.0000001	1 in 10,000,000

Shaded - Probability of Pillar Panel Failure is considered to be 'not credible' for PoF < 1 in 1000 for squat pillars with w/h > 8.

There has been much debate in the Australian Coal Industry over the appropriate minimum pillar FoS that should be assumed to limit the risk of significant subsidence effects above old mine workings to an acceptable level (i.e. As Low as Practically Possible).

For sensitive surface structures that may cause a loss of life in the event of a bord and pillar 'run' or large-scale pillar crush event, a PoF of 1 in 1,000,000 (i.e. a minimum FoS of 2.11) has been required by the regulatory authorities in NSW. What should also be considered here as well is how the pillars will fail in the panel. Many old mine workings panels beneath the Newcastle CBD and harbour were conducted at relative shallow depth (i.e. < 100 m cover) and pillars tended to be 'slender' in shape with w/h ratios < 3.

The consequences of under-designed pillars for these old mine workings was that a pillar 'run' or rapid progression of pillar failure would result. Several pillar run events occurred soon after second workings in the early 1900's. Whilst damage occurred to old masonry structures up to 3 storeys high due subsidence of between 0.5 m and 1.0 m, no building collapses or loss of life resulted.

At the Tasman Extension Project, the proposal to leave 'squat' remnant pillars in the workings with a minimum w/h of 5, means that the likelihood of a pillar run occurring will be negligible as the pillars will tend to squeeze or yield slowly due to high inner core confinement. The subsidence effects are therefore likely to be limited by the available volume of void left in the workings in which the pillars may crush and 'bulk' into.

Based on reference to **Figures 9c** and **11** and **Table 5**, it is considered that a minimum FoS of 1.6 will provide a high level of certainty that the panels will remain stable if the remnant pillars also have a minimum width/height ratio (w/h) of 5 or more.

If a lower probability of failure than 1 in 1,000 is required, then a higher FoS and wider remnant pillar may be determined based on **Table 5**. The selection of a higher FoS however, will only have a marginal reduction in yield potential or the resultant subsidence effects (see **Section 7** for more details).

6.5 Pillar Stability

The FoS of the SCZ pillars may be calculated by dividing the pillar strength, S, with the pillar stress, σ_{pillar}:

$$\text{FoS} = S/\sigma_{pillar}.$$

Detailed assessment of partial pillar extraction design is beyond the scope of this report and will be assessed as a component of the Extraction Plan process.

7.0 Subsidence Prediction Methodology

7.1 General

This study included the following activities and the application of several industry established empirical models to predict the 'mean' and 'credible worst-case' subsidence for a given total or partial pillar extraction layout:

(i) Development of a geotechnical model for the study area (i.e. mining geometry, geology, material properties etc).

(ii) Calculation of maximum subsidence impact parameter predictions and representative parameter profiles using the **ACARP, 2003** and **Holla, 1987** empirical subsidence models and the mining geometries proposed for the total extraction panels.

(iii) Assessment of barrier pillar subsidence between total extraction panels, based on empirical load and strength models defined in **ACARP, 1998a** and **ACARP, 1998b** and the modified subsidence prediction model presented in **ACARP, 2003**.

(iv) Development and calibration of **SDPS®** models (using the subsidence, tilt and strain profiles from (ii)) to generate subsidence and associated impact parameter contours above the proposed total and partial extraction panels.

(v) Development of an analytical remnant pillar or first workings subsidence prediction model based on established theories and measured strength and stiffness properties of the strata. The model calibrated to measured data in similar conditions (i.e. Tasman Mine).

(vi) Generation of subsidence, tilt, strain, horizontal displacement, post mining topography, potential cracking width, ponding location and surface slope gradient change contours for the proposed mining layouts using **Surfer8®** contouring software.

(vii) Estimation of sub-surface fracturing heights above the panels using empirically based models in **ACARP, 2003**, **Forster, 1995** and **Mark, 2007**.

(viii) Estimation of the extent and magnitude of far-field displacements (FFD) and strains (FFE), based on empirically based models developed from Newcastle Coalfield data by **DgS, 2007c**.

The terms 'mean' and 'Upper 95% Confidence Limit' (U95%CL) used in these predictions consider that the predicted maximum subsidence effect values may be exceeded by 50% and 5% respectively for the panels mined. Therefore on a small number of occasions, the predicted values and impacts may be exceeded generally by a range of 5-20% (as has been the case with the panels extracted to date in SMP Area 1 at Abel Mine). These are generally found to be related to the presence of adverse or anomalous geological or topographical conditions.

7.2 Subsidence Prediction Model Details

7.2.1 Total Extraction Panels

Two empirically based prediction models (**ACARP, 2003** and **SDPS**®) have been used to generate maximum subsidence prediction for total pillar extraction areas.

ACARP, 2003 is an empirical model that was originally developed for predicting maximum single and multiple longwall panel subsidence, tilt, curvature and strain in the Newcastle Coalfield. The model database includes measured subsidence parameters and overburden geology data, which have been back analysed to predict the subsidence reduction potential (SRP) of massive lithology in terms of ‘Low’, ‘Moderate’ and ‘High’ SRP categories.

The **ACARP, 2003** model database also includes chain or barrier pillar subsidence, inflexion point distance from panel edges, inflexion point subsidence, goaf edge subsidence and angle of draw prediction models. These models allow subsidence profiles to be generated for any number of panels within a range of appropriate statistical confidence limits. The mean and U95%CL values have been adopted in this study for predictions of the mean and Credible Worst-Case values expected, due to the proposed mining activities.

The **ACARP, 2003** model may also be used for predicting maximum subsidence above pillar extraction panels by applying the ‘effective’ mining height principle (i.e. extraction ratio x mining height) defined in **Van de Merwe and Madden, 2002**. The principle allows for subsidence reducing effect of crushed out remnant coal that will be left behind in the workings.

Based on a comparison between high extraction panel and longwall panel subsidence databases in **ACARP, 2003** and **Holla, 1987**, an extraction ratio of 88% and a maximum longwall panel subsidence of 58% of the mining height, give a maximum pillar extraction panel subsidence of 51% of the mining height for supercritical panels for the Tasman Extension Project total pillar extraction areas.

It is also apparent from mining experience at the nearby Abel Mine that mine subsidence is affected by the leaving of additional stooks to support mine roof where sub-vertical faults have intersected the workings. The stooks at these locations are estimated to have decreased maximum subsidence to a range of 40% to 44% of the mining height with panel extraction ratios of approximately 75% to 85%.

A summary of the **ACARP, 2003** model, which defines the parameters and terms used, is presented in **Appendix A**.

SDPS®, 2007 is a US developed (Virginia Polytechnical Institute) influence function model for subsidence predictions above longwalls or pillar extraction panels. The model requires calibration to measured subsidence profiles to reliably predict the subsidence and differential subsidence profiles required to assess impacts on surface features.

The **SDPS**® model also includes a database of percentage of hard rock (i.e. massive sandstone / conglomerate) that effectively reduces subsidence above super-critical and sub-critical panels, due to either bridging or bulking of collapsed material. An extract from the **SDPS®** user manual defining the parameters and terms used is presented in **Appendix B**.

Overall, the **SDPS®** model has been calibrated to predicted **ACARP, 2003** model profiles successfully at the Abel Mine and Tasman Mine and compared with measured subsidence profiles above total and partial pillar extraction workings with similar geological conditions as the Tasman Extension Project (**Section 8**). The calibration procedure applied in this study is considered best practice.

The modifications to the **ACARP, 2003** model by DgS included adjustments to the following key parameters, which were made to improve compatibility between the two models used in this study:

- Chain (and barrier) pillar subsidence prediction is now based on pillar subsidence over extraction height (S_p/T) v. pillar stress (under double abutment loading conditions).

- Distance of the inflexion point from rib sides and inter-panel pillars in similar terms to SDPS® software (i.e. d/H v. W/H).

- The horizontal strain coefficient (β_s) is the linear constant used to estimate strain based on predicted curvature, and is equivalent to the reciprocal of the neutral axis of bending, d_n used in **ACARP, 2003**. Based on local Tasman Mine data, a value of d_n = 10 m or a $\beta_s = 0.1$ m^{-1} has been applied to predict 'smooth' profile strains using the calibrated SDPS® model.

Multiple-panel effects are determined by the **ACARP, 2003** model by adding a proportion of the chain (or barrier) pillar subsidence to the predicted single panel subsidence. Estimates of first and final subsidence above a given set of pillar extraction panels use this general approach. The definition of First and Final S_{max} is as follows:

First S_{max} = the first maximum subsidence after the extraction of a panel, including the effects of previously extracted panels adjacent to the subject panel;

Final S_{max} = the final maximum subsidence over an extracted panel, after at least three more panels have been extracted, or when mining is completed.

First and Final S_{max} for a panel are predicted by adding 50% and 100% of the predicted subsidence over the respective barrier pillars (i.e. between the previous and current panel), less the goaf edge subsidence (which occurs before the barrier pillar is loaded from both sides). The maximum subsidence is limited to 58% of the effective mining height for the panels.

The subsidence above chain and barrier pillars has been defined in this study as follows:

First S_p = the first subsidence over a pillar after panels have been extracted on both sides of the pillar;

Final S_p = the final subsidence over a pillar after at least another three more panels have been extracted, or when mining is completed.

A conceptual model of the multiple panel subsidence mechanism is given in **Figure 12a**.

Residual subsidence above chain (and barrier) pillars and extracted panels tend to occur after mining of adjacent panels due to (i) increased overburden loading on the pillars, and (ii) on-going goaf consolidation or creep of the collapsed roof or goaf in the panel. The residual movements can increase subsidence by a further 10 to 30% above chain (and barrier) pillars after the first pillar subsidence occurs. Residual subsidence is likely to decrease exponentially as mining moves further away from a given panel. A subsidence increase of 20% after double abutment loading occurs (i.e. First S_p) has been assumed in this study to allow for long-term loading effects (i.e. Final S_p).

Unless otherwise stated the predicted values presented in the following sections of this report are given as a range between the Lower to the U95%CL values. The measured subsidence will be expected to be somewhere between these values.

Tilts and curvatures have been assessed using the empirical techniques presented in **ACARP, 2003** and by also taking first and second derivatives of the predicted subsidence profiles for comparative purposes.

Predictions of strain and horizontal displacement were made based on the relationship between the measured curvatures and tilt respectively as discussed in **ACARP, 1993** and **ACARP, 2003**.

The expected distribution of tilt, curvature and horizontal strain across a total extraction panel is presented in **Figure 12b**.

Structural and geometrical analysis theories indicate that strain is linearly proportional to the curvature of an elastic, isotropic bending ‘beam’. This proportionality actually represents the depth to the neutral axis of the beam, or in other words, half the beam thickness. **ACARP, 1993** studies returned strain over curvature ratios ranging between 6 and 11 m for NSW and Queensland Coalfields. Near surface lithology strata unit thickness and jointing therefore dictate the magnitude of the proportionality constant between curvature and strain. Similar outcomes are found for tilt and horizontal displacement.

ACARP, 2003 continued with this approach and introduced the concept of secondary curvature and strain concentration factors due to cracking. The mean and median peak strain / curvature ratios for the Newcastle Coalfield was assessed to equal 5.2 m and 7.3 m respectively, with strain concentration effects increasing the ‘smooth-profile’ strains by 2 to 4 times occasionally. A review of the local strain database for Area 1 at Abel Mine has led to the value of 10 m being adopted as a more appropriate value for impact prediction purposes.

A d_n value of 10 m has also been applied to the predicted ‘smooth’ curvature and tilt profiles to estimate strain and horizontal displacement respectively above the proposed Tasman Extension Project panels. These values may then be compared to the empirical model outcomes to estimate localised, concentrated strain effects due to cracking. Cracking is expected to occur in zones of peak tensile (or compressive) strains when tensile and compressive strains exceed 1 to 3 mm/m respectively and where surface rock exposures are present.

Surface crack widths (in mm) may be estimated by multiplying the predicted strains by 10, which is an empirical factor based on the distance between the pegs in the **ACARP, 2003** model database and the measured strains and crack widths above extracted panels. As mentioned earlier these predictions may be exceeded from time to time by anomalous conditions.

7.2.2 Partial Extraction Panels

Prediction of maximum subsidence predictions for the proposed partial extraction panels and inter-panel barriers may be based on elastic and non-linear pillar-roof and floor strata models derived from **Das, 1998** and in-situ rock mass / coal pillar strength and stiffness properties derived from **Hoek and Diederichs, 2006, Das, 1986** and **Zipf, 1999**.

The compression of the remnant pillar and barrier pillars and immediate roof and floor strata has also been estimated using two relatively simple analytical models for a loaded spring (the pillar) and elastic foundations (the roof and floor of the remnant pillars).

The outcomes should be compared or the models calibrated to measured subsidence data and/or empirical model predictions. The comparisons should be viewed in consideration of the differences between the particular coalfield geologies and the range of measured physical parameters of the immediate roof and floor rock mass and coal seam.

Given that the stress on the remnant pillars may exceed the in-situ strength of the coal and/or roof / floor materials, the analytical models needed to consider both the elastic and post-yield stiffness moduli of the pillar-roof-floor system. The empirical model presented in **ACARP, 2003** also includes squat pillars (i.e. with w/h > 5).

The roof and floor strata FoS values will also indicate whether the compression of these materials in their elastic range may be estimated using laboratory test results that have been adjusted to reflect the stiffness of the overall rock mass.

The compression of the remnant and barrier pillars in the elastic and post-yielded regimes may be calculated by assuming the pillars will behave elastically under load until their peak strength is reached. For pillars with w/h ratios > 5, the pillars may be assumed to soften to their residual stiffness initially and then strain-harden as follows:

$$s_{pillar} = \sigma_{net}T_s/E_p + (\sigma_{max} - S_p)T_s/E_r \quad (1)$$

where:

s_{pillar} = pillar compression;

σ_{net} = pillar stress increase = total pillar stress - virgin stress;

T_s = seam thickness;

E_p = Peak Young's Modulus of coal (GPa);

E_r = Residual Young's Modulus of squat coal pillars = 0.437 - 1.75/(w/h) (GPa) (see **Figure 9d**);

σ_{max} = maximum stress on pillar after load redistribution to the goaf (if applicable).

S_p = pillar strength (**ACARP, 1998b**)

The above relationships are represented by a non-linear stress-strain curve shown in **Figure 13**.

The analytical model adopted to estimate the immediate compression of the floor and roof was taken from Boussinesq's elastic pressure bulb theory beneath strip footings of varying aspect ratio, see **Das, 1998**:

$$s_{roof} = \sigma_{net}\, w(1-v^2)I/E_{roof} \quad (2)$$

$$s_{floor} = \sigma_{net}\, w(1-v^2)I/E_{floor} \quad (3)$$

where:

s_{roof} = roof compression above pillar;

s_{floor} = floor compression below pillar;

σ_{net} = net pillar stress increase (= total stress - effective virgin stress);

w = pillar width;

E_{roof} = average Young’s Modulus of roof material for a distance of W above the pillar;

E_{floor} = average Young’s Modulus of floor material for a distance of w below the pillar;

v = Poisson's Ratio;

I = Influence function for various footing shape geometries (unity assumed for range of rockmass stiffness values).

The above relationships are represented by a linear stress-strain curve also shown in **Figure 13**.

The estimate of expected and credible worst-case surface subsidence (s_{total}) above a pillar subject to the assumed loading may be estimated by summing equations (1), (2) and (3):

$s_{total} = s_{pillar} + s_{roof} + s_{floor}$ (expected)

Lesser of 2 $s_{total} = 2(s_{pillar} + s_{roof} + s_{floor})$ and 60% Effective Mining Height (worst case)

As previously discussed, the loading conditions acting on the remnant pillars may be conservatively assumed to be FTA for all the sub-critical to supercritical panels.

Predicted subsidence above the barrier pillars may be determined using a similar analytical approach to the remnant pillars. However, for the sub-critical panels, if the barriers are wide enough, it is likely that the loads on the remnant pillars will be <FTA due to natural arching of the overburden transferring the balance to the barrier pillars.

Note: A ‘natural arch’ refers to a scenario where the load is transferred through the overburden via a parabolic profile of compressive forces only (i.e. the interburden is thick enough for a given span for arching to occur without tensile stresses developing).

The first one to two rows of pillars in an SCZ that are adjacent to a total extraction panel should be assumed to have a side abutment load acting upon them.

8.0 Review of Measured Subsidence Measured at Nearby Mines

8.1 Abel Mine's Total Extraction Panels

The Abel Mine has developed and completed total extraction panels with similar geometries to those being proposed for the Tasman Extension Project in non-sensitive areas. The panels were 160.5 m wide with cover depths ranging from 55 m to 120 m. The mining height was approximately 2.5 m in the Upper Donaldson Seam, which is located in the Tomago Coal measures to the north-east of the proposed Tasman Extension Project mining area.

The Abel Mine is also required to leave SCZs below 3rd order streams (e.g. Viney Creek) and Principal Residences (as will be the case for the Tasman Extension Project panels).

8.1.1 Mining Method Details

The typical effective mining heights for Panel 1 were assumed to be 98% of the actual mining heights of 2.35 m to 3.0 m, due to the single row of remnant pillars (stook 'X') left in the goaf. The stooks have effectively reduced the available volume in which the fallen roof and crushed out remnant pillars could occupy, and is in proportion to the overall coal pillar extraction ratio for the panel. The typical effective mining heights for Panels 2 to 4 were assumed to be 88% of the actual mining heights of 2.5 m, due to the two rows of remnant pillars (stook 'X') left in the goaf and measured subsidence.

8.1.2 Predicted v. Measured Subsidence Data for Panels 1 to 4

The measured subsidence effects above the first four panels at the Abel Mine are compared with the predictions made with the **ACARP, 2003** empirical database model in **Table 6A**.

The outcome of the subsidence review indicates that in general, the measured maximum subsidence values plot below the predicted U95%CL for the given panel geometries; see **Figure 14a**.

Table 6A - Summary of Predicted v. Measured Maximum Subsidence

Panel No.	Line/ Chain from start	Panel Width W (m)	Cover Depth H (m)	Panel W/H	Mining Height T (m)	Panel[#] e%	Predicted (mean - U95%CL)		Measured	
							Subsidence S_{max} (m)	S_{max}/Te (m/m)	Subsidence S_{max} (m)	S_{max}/Te (m/m)
1	CL 60	120	105	1.14	3.0	98	1.17 - 1.25	0.38 - 0.43	1.228	0.41
	CL 137	120	100	1.20	2.8	83*	0.91 - 1.02	0.39 - 0.44	0.822	0.35
	CL 626	120	90	1.33	2.35	98	0.97 - 1.08	0.42 - 0.47	1.059	0.46
	XL 275	120	98	1.22	2.35	98	0.91 - 1.03	0.40 - 0.45	0.996	0.43
2	CL 75	150	67	2.24	2.5	88	1.19 - 1.23	0.54 - 0.58	1.041	0.47
	XL 124	150	75	2.00	2.5	83*	1.14 - 1.20	0.55 - 0.58	0.966	0.47
3	CL 73	160.5	60	2.68	2.5	88	1.19 - 1.23	0.54 - 0.58	0.835	0.38
	CL 260	160.5	78	1.89	2.5	88	1.19 - 1.23	0.54 - 0.58	0.933	0.42
	XL 170	160.5	70	2.29	2.5	88	1.19 - 1.23	0.54 - 0.58	0.817	0.37
4	CL 45	160.5	55	2.92	2.5	88	1.19 - 1.23	0.54 - 0.58	0.900	0.41

[#] e% = panel extraction ratio. Panel 1 had only one central row of 3 m wide (average) x 19 m long stooks. Panels 2 to 4 had 2 stook rows with additional stooks left adjacent to the fault through Panel 2.

* Subsidence in Panel 1 and 2 reduced by additional coal stooks left beneath a fault line.

The measured subsidence for Panel 1 ranged between 35% to 46% of the effective mining height, and correlates reasonably well with the predicted mean to U95%CL range of 38% to 47%.

The extra stooks left below the fault through Panel 1 (and where the MBLS's were buried by an intersection roof fall) appear to have reduced subsidence by approximately 30%. The effective mining height at this location was 93% of the average mining height of 2.8 m.

The measured subsidence for Panels 2 to 4 ranged from 37% to 47% of the effective mining height, and appears to be significantly lower than the predicted mean and U95%CL range of 54% to 58%, despite the allowance for the additional stooks that were required for roof control (the effective mining height for the panel ranged from 83% to 88%).

The measured cross line and centreline subsidence effect surveys are presented in **Figures 14b-14e** (Panel 1 XL data); **15a-15d** (Panel 1 CL data); **16a-16d** (Panel 2 XL data) and **17a-17d** (Panel 2 CL data).

Based on a review of the prediction model databases (**Holla, 1987** and **ACARP, 2003**), it would be expected that the subsidence would have been between 52% and 58% of the effective mining heights if the panels were longwall panels. It is considered that the prediction models are therefore conservative for supercritical pillar extraction panels where cover depths are relatively shallow (i.e. < 80 m) and is likely to be caused by significantly lower overburden pressures acting on the goaf and remnant pillars or stooks.

It is however, not considered necessary to adjust the prediction models at this stage, as the prediction of tilt, strain and curvature have higher levels of uncertainty associated with the shallower cover depths.

Predicted values of maximum tilt for the Area 1 Panels 1 to 4 have been compared to the measured values in **Table 6B**.

Table 6B - Summary of Predicted v. Measured Maximum Tilts

Panel No.	Line/Chain from start	Panel Width W (m)	Cover Depth H (m)	Panel W/H	Mining Height T (m)	Panel[#] e%	Predicted Tilts (mean - U95%CL) (mm/m)	Measured (mm/m)
1	CL 60	120	105	1.14	3.0	98	27 - 41	**50**
	CL 137	120	100	1.20	2.8	83*	21 - 32	27
	CL 626	120	90	1.33	2.35	98	24 - 36	22
	XL 275	120	98	1.22	2.35	98	22 - 33	34 - **42**
2	CL 75	150	67	2.24	2.5	88	44 - 66	44
	XL 124	150	75	2.00	2.5	83*	36 - 54	19 - 27
3	CL 73	160.5	60	2.68	2.5	88	44 - 66	41
	CL 260	160.5	85	1.89	2.5	88	32 - 48	29
	XL 170	160.5	70	2.29	2.5	88	44 - 66	14 - 45
4	CL 45	160.5	55	2.92	2.5	88	44 - 66	58

e% = panel extraction ratio. Panel 1 had only one central row of 3 m wide (average) x 19 m long stooks. Panels 2 to 4 had 2 stook rows with additional stooks left adjacent to the fault through Panel 2.

* Subsidence in Panel 1 and 2 reduced by additional coal stooks left beneath a fault line.

Bold Measured value exceeded predictions by > 10%.

The outcome of the review indicates that 88% of the measured maximum tilts plot within the upper and lower 95% confidence limits for the predicted values. Predicted tilts were exceeded by 1.20 and 1.27 times the measured values at two locations (see below for further discussion).

Predicted values of maximum convex and concave curvature for the Area 1 Panels 1 to 4 have also been compared to the measured values in **Table 6C**.

Table 6C - Summary of Predicted v. Measured Maximum Curvature Data

Panel No.	Line/Chain from start Line	Panel Width W (m)	Cover Depth H (m)	Panel W/H	Mining Height T (m)	Panel[#] e%	Predicted Curvatures (mean - U95%CL)		Measured Curvatures	
							Convex C_{max} (km-1)	Concave C_{min} (km-1)	Convex C_{max} (km-1)	Concave C_{min} (km-1)
1	CL 60	120	105	1.14	3.0	98	1.17-1.74	1.48-2.22	**2.56**	2.32
	CL 137	120	100	1.20	2.8	83*	1.00-1.47	1.27-1.90	1.09	0.93
	CL 626	120	90	1.33	2.35	98	1.06-1.58	1.35-2.03	2.20	2.10
	XL 275	120	98	1.22	2.35	98	1.00-1.48	1.27-1.90	2.3-**3.55**	1.74-**2.16**
2	CL 75	150	67	2.24	2.5	88	1.93-2.88	2.45-3.67	**3.21**	3.22
	XL 124	150	75	2.00	2.5	83*	1.62-2.41	2.05-3.08	1.23-2.43	0.97-2.17
3	CL 73	160.5	60	2.68	2.5	88	1.93-2.88	2.45-3.68	1.96	3.27
	CL 260	160.5	78	1.89	2.5	88	1.30-1.92	1.65-2.48	**2.30**	1.58
	XL 170	160.5	70	2.29	2.5	88	1.94-2.88	2.46-3.97	**4.43**	2.40
4	CL 45	160.5	55	2.92	2.5	88	1.93-2.88	2.45-3.68	**5.29**	3.43

e% = panel extraction ratio. Panel 1 had only one central row of 3 m wide (average) x 19 m long stooks. Panels 2 to 4 had 2 stook rows with additional stooks left adjacent to the fault through Panel 2.

** Subsidence in Panel 1 reduced by additional coal stooks left beneath a fault and where the Breaker line supports were buried by a goaf fall.

Bold Measured value exceeded predictions by > 10%.

The outcome of the review indicates that 70% of the measured maximum curvatures plot within the upper and lower 95% confidence limits for the predicted values. Predicted curvatures were exceeded by approximately 1.2 to 2.4 times the measured values at seven locations above Panels 1 to 4 (see below for further discussion).

The prediction exceedances for tilt and curvatures above Panels 1 to 4 may have been due to 'discontinuous' subsidence behaviour exacerbated by sloping surface topography near water courses and/or secondary subsidence profile development due to irregular stook geometry or face extraction height variation in the workings. Further data is required to determine if the model is actually under-predicting tilt and curvature significantly and therefore require re-calibration.

Predicted values of maximum tensile and compressive strain for the Area 1 Panels 1 to 4 have been compared to the measured values in **Table 6D**.

Table 6D - Summary of Area 1 Predicted v. Measured Maximum Horizontal Strain Data

Panel No.	Line	Panel Width W (m)	Cover Depth H (m)	Panel W/H	Mining Height T (m)	Panel$^{\#}$ e%	Predicted Strains^ (mean - U95%CL)		Measured Final Strains [Inferred transient strains]^	
							Tensile $+E_{min}$ (mm/m)	Compressive $-E_{max}$ (mm/m)	Tensile $+E_{min}$ (mm/m)	Compressive $-E_{max}$ (mm/m)
1	CL 60	120	105	1.14	3.0	98	12-17	15-22	12 [26]	11 [23]
	CL 137	120	100	1.20	2.8	83*	9-14	12-18	4 [11]	5 [9]
	CL 626	120	90	1.33	2.35	98	11-16	14-20	4 [22]	9 [21]
	XL 275	120	98	1.22	2.35	98	10-15	13-19	8 [36]	11 [22]
2	CL 75	150	67	2.24	2.5	88	20-30	25-38	6 [32]	9 [32]
	XL 124	150	75	2.00	2.5	83*	16-24	21-31	5 [24]	7 [22]
3	CL 73	160.5	60	2.68	2.5	88	21-31	27-40	7 [20]	2 [33]
	CL 260	160.5	78	1.89	2.5	88	21-31	24-36	8 [23]	6 [16]
	XL 170	160.5	70	2.29	2.5	88	19-28	27-40	9 [44]	6 [24]
4	CL 45	160.5	55	2.92	2.5	88	19-29	24-37	10 [53]	17 [34]

e% = panel extraction ratio. Panel 1 had only one central row of 3 m wide (average) x 19 m long stooks. Panels 2 to 4 had 2 stook rows with additional stooks left adjacent to the fault through Panel 2.

^ Strains calculated by multiplying predicted or measured curvatures (see **Table 6C**) by 10.

To-date, maximum measured tensile and compressive strains above Panels 1 to 4 have ranged between 4 mm/m and 17 mm/m, with local strains of up to 30 mm/m indicated by observed crack widths of 180 mm (Panel 1), 50 mm (Panel 2) 260 mm (Panel 3), 300 mm (Panel 4). Estimates of maximum strains from curvatures indicate transient tensile and compressive strains ranged from 9 mm/m to 53 mm/m using a multiplying factor of 10.

Several compressive shear failures and associated ‘upsidence’ of 100 mm to 150 mm were observed above Panel 3.

It is apparent that the prediction model has overestimated the final measured strains, however, they are reasonably consistent if measured crack widths and transient curvatures are taken into consideration during subsidence development.

Predicted values of goaf edge subsidence and AoD for the Area 1 Panels 1 to 4 have also been compared to the measured values in **Table 6E**.

Table 6E - Summary of Predicted v. Measured Goaf Edge and AoD Data

Panel No.	Line	Panel Width W (m)	Cover Depth H (m)	Panel W/H	Mining Height T (m)	Panel[#] e%	Predicted Goaf Edge Subsidence and AoD (mean - U95%CL)		Measured Goaf Edge Subsidence and AoD	
							S_{goe} (m)	AoD (degrees)	S_{goe} (m)	AoD (degrees)
1	CL 60	120	105	1.14	3.0	98	0.05-0.14	10-19	0.049	10
	CL 861	120	85	1.41	2.35	98	0.03-0.09	5-14	0.050	8
	XL 275	120	98	1.22	2.35	98	0.04-0.11	8-16	0.026 0.05	6-**23**
2	CL 75	110	65	2.25	2.5	88	0.04-0.11	7-16	0.025	2
	CL 264	160	85	1.88	2.5	88	0.04-0.10	7-16	0.05	7
	XL 124	150	75	2.00	2.5	83*	0.030-0.10	7-15	-0.035 0.045	7-9
3	CL 73	160.5	60	2.68	2.5	88	0.04-0.11	7-16	*0.12*	**20**
	CL 260	160.5	78	1.89	2.5	88	0.04-0.11	7-16	0.036	3
	XL 170	160.5	70	2.29	2.5	88	0.04-0.11	7-16	0.001 0.05	0-4
4	CL 45	160.5	55	2.92	2.5	88	0.04-0.11	7-16	0.006	0

AoD	Angle of draw to 20 mm subsidence contour.
#	e% = panel extraction ratio. Panel 1 had only one central row of 3 m wide (average) x 19 m long stooks. Panels 2 to 4 had 2 stook rows with additional stooks left adjacent to the fault through Panel 2.
Bold	Measured value exceeded predictions by > 10%.
Italics	Measured value exceeded predictions by < 10%.
-	Negative goaf edge subsidence values indicate uplift.

The measured goaf edge subsidence has ranged from 35 mm of uplift to 120 mm with angles of draw to the 20 mm subsidence contour ranging between 0^{o} and 23^{o} (mean of 8^{o}).

The outcome of the review indicates that 92% of the measured goaf edge and 84% of the AoD (to 20 mm subsidence) values plot below the upper 95% confidence limits for the predicted values. The two exceedances in predicted AoD that did occur was less than the design AoD of 26.5^{o}. The one exceedance in predicted goaf edge subsidence (Panel 3) was less than 10% greater than the upper 95% confidence limit.

Overall, it is assessed that the **ACARP, 2003** model with the inclusion of the effective mining height, is likely to provide reasonably conservative subsidence impact parameter predictions for the proposed total extraction panels. It will however be necessary to review the predictions once the details of the proposed mining method are provided by the mine.

8.2 Tasman Mine's Partial Pillar Extraction Panels

Partial pillar extraction panels have been used in the Fassifern Seam workings of the current Tasman Mine to minimise surface impacts to steep slopes, cliff lines and publicly accessible walking trails and recreation areas associated with Mount Sugarloaf. Similar SCZ levels (Levels 1 to 4) were established prior to mining as those proposed for the Tasman Extension Project.

Several partial extraction mining methods have been used to date and include:

- Single sided lifting (i.e. pillar width reduction) on retreat of rectangular first workings pillars (known as ‘run-outs’ from central access headings).
- Double-sided lifting of rectangular ‘run-out’ pillars on retreat.
- Four-sided lifting of square first workings pillars on retreat (known as the Modified Duncan method).

The design of the remnant pillars (i.e. the pillars left behind after ‘lifting’ or second workings is completed) required the pillars to have a high likelihood of remaining stable in the long term (post-mining) and control surface subsidence to < 150 mm with negligible surface impacts (i.e. no cracking or cliff line instability).

To-date, subsidence above the partial extraction panels at the Tasman Mine has ranged between 9 mm and 101 mm. Subsidence contour predictions have been derived for Panels 10 to 22 and are presented in **Section 10**.

8.2.1 Mining Method Details

The single sided and double-sided pillar lifting panels were generally developed on a 5-heading layout with two central spine pillar rows or three headings at 20 m spacing. Six or seven run-outs at 40 m centre-centre spacing were then developed from the central spine pillars to form 34.5 m wide and 80 m long first workings pillars. The roadways were nominally 5.5 m wide and 2.4 m high.

The 'run-out' pillars were then lifted / reduced in width by 10.75 m along both sides on retreat, leaving remnant pillars with final widths of 13 m and spans between the ‘lifted’ pillars of 27 m. The remnant pillars are required to have factors of safety (FoS) > 1.6 (under FTA loading) and w/h ratios of 5.4.

The pillar panels were 56 m to 200 m wide with cover depths ranging from 60 m to 140 m. The panel width to cover depth ratios ranged from 0.62 to 2.8, giving both critical (0.6 < W/H < 1.4) and super-critical (W/H > 1.4) panel geometries.

A 16 m to 25 m wide solid barrier was left between the panels, giving a pillar w/h ratio range of 6.7 to 10.4. The barrier pillar stability was assessed based on double abutment loading conditions that could develop in the unlikely event that the remnant run-out pillars crush in the adjacent panels.

Based on reference to **ACARP, 2005** and **Zipf, 1999**, all of the remnant pillar dimensions proposed will have strain-hardening characteristics with pillar w/h ratios >5. It is expected that subsidence will be limited to maximum levels of < 200 mm in the unlikely event of pillar overload conditions developing.

The bearing capacity of the workings roof (Awaba Tuff) and carbonaceous mudstone floor was also considered by limiting long-term pillar stresses to < 15 MPa and Bearing FoS values to > 2.

8.2.2 Subsidence Monitoring Program Details

Subsidence monitoring above the mined panels to-date have been measured along several survey lines consisting of steel star pickets, pins installed into rock or plastic dumpys (Feno marks) at a spacing of 10 m. Reflectors were also installed on cliff lines and power poles.

The locations of the survey lines have generally been constrained by access due to the topography or specific surface features such as a cliff line crests and public access walkway.

The absolute movements (Eastings, Northings and Reduced Levels) were measured using combined global positioning system (GPS) baseline and terrestrial traverse techniques with precise digital levelling used to measure subsidence. In-line horizontal strains were measured using a standardized steel tape.

The accuracy of the surveying was typical for the methods used in the mining industry, with digital levelling having an accuracy of ± 2 mm, Easting and Northings to ± 10 mm for ground stations and ± 25 mm for reflectors. Strains were measured to ± 0.2 mm/m.

8.2.3 Calibration of Model Input Parameters using Subsidence Results

Measured maximum subsidence values above Panels 3 to 5 and 8 beneath high visibility cliff lines and sensitive archaeological sites (grinding grooves) or Level 2 Subsidence Control Zones (SCZs) have ranged from 9 mm to 24 mm and significantly less than the predicted worst-case value of 150 mm.

A summary of the measured subsidence and pillr / panel geometries is presented in **Table 7**.

Table 7 - Pillar Roof and Floor Stiffness and Massive Conglomerate Strata Deflection Analysis Results for Tasman Panels 3 to 5 and 8 Below Level 2 SCZ Areas

Location	Remnant Pillar Dimensions w x l x h (m)	Cover Depth (m)	Measured Subsidence (m)	Current Roof and Floor Moduli (GPa)	Minimum Voussoir Beam Thickness* (m)	Voussoir Beam Distance Above Workings (m)
2-South Eastern Runouts (Panel 3)	9.75 x 29 - 33.5 x 2.3	105	**0.013**	6 / 1	35	60
2-South Western Runouts (Panel 3)	9.75 x 29 - 33.5 x 2.3	120	**0.016**	6 / 1	35	60
2-South Spine (Panel 3)	2 x 14.5 x 19.5 x 2.3	120	**0.009**	6 / 1	n.a.	60
3–South Runouts (Panel 4)	9.75 x 44.5 x 2.3	130	**0.015**	6 / 1	35	60
4-South Western Remnants (Panel 8)	22.5 x 22.5 x 2.4	140	**0.024**	6 / 1	40	80

n.a. not applicable.

* Beam thickness based on geophysical logs and that required for beam deflection to be < or equal to measured subsidence.

8.2.4 Measured v. Predicted Subsidence Effects

The measured subsidence effects above several of the partial pillar extraction panels for restricted (Level 2 and 3 SCZ) and unrestricted subsidence areas (Level 1 SCZ) at the Tasman Mine have been compared to the predictions made using the **ACARP, 2003** empirical model in **Tables 8A** and **8B**.

Table 8A - Summary of Measured Subsidence Data above Panels 3 to 5a v. Predicted Values (Conventional Partial Extraction Panels)

Parameter	**Units**	**Level 1 SCZ Panel 3 (2-South)**		**Level 2 SCZ Panel 4 (3-South)**		**Level 1 SCZ Panel 5a (2a-North)**	
Panel Geometry							
Maximum Span, W	m	80		80		120	
Cover Depth, H	m	100 - 140		90 - 140		100 - 130	
W/H		0.80 - 0.57		0.88 - 0.57		1.20 - 0.92	
Mining Height	m	2.3		2.3		2.3	
Subsidence Effect Results							
Parameter	**Units**	**Measured**	**Predicted**	**Measured**	**Predicted**	**Measured**	**Predicted**
Maximum Panel Subsidence, S_{max}	mm	16	< 150	15	< 150	11	< 150
Maximum Tilt, T_{max}	mm/m	0.8	< 3	0.8	< 3	1.2	< 3
Maximum Tensile Strain, E_{max}	mm/m	*0.3*	< 1	0.4	< 1	1.1	< 1
Maximum Compressive Strain, E_{min}	mm/m	*0.2*	< 1	0.2	< 1	0.9	< 1

Table 8B - Summary of Measured Subsidence Data Above Panels 5b, 6 and 8 v. Predicted Values (Modified Duncan Partial Extraction Panels)

Parameter	Units	Level 1 SCZ Panel 5b (2b-North)		Level 1 SCZ Panel 6 (3-North)		Level 2 SCZ Panel 8 (4-South)	
Panel Geometry							
Maximum Span, W	m	202[2]		248 - 203		156	
Cover Depth, H	m	75 - 70		105 - 110		140	
W/H	m/m	2.8 - 2.9		2.4 - 1.8		1.11	
Mining Height	m	2.2		2.2		2.4	
Pillar Dimensions (l x w x h)	m	21.5 x 21.5 x 2.2		18 x 18 x 2.4		22.5 x 22.5 x 2.4	
Subsidence Effect Results							
Parameter	**Units**	**Measured**	**Predicted**	**Measured**	**Predicted**	**Measured**	**Predicted**
Maximum Panel Subsidence, S_{max}	mm	27 - 31	< 150	*422 - 98*	*<150*	19	< 150
Maximum Tilt, T_{max}	mm/m	1.1 - 2.0	< 3	*5 - 1.2*	*< 3*	0.2	< 3
Maximum Tensile Strain, E_{max}	mm/m	0.6	< 1	*1.5 (1.8)*	*< 1.5*	0.25	< 1.5
Maximum Compressive Strain, E_{min}	mm/m	0.7	< 1	*3.2 (1.4)*	*< 1.5*	0.55	< 1.5

[2] - Square shaped panel with 2-way spanning action likely.
( ) - value recorded outside of panel mining limits.
Italics - prediction exceedances due to over loading the weak claystone floor units in Level 1 areas. Performance data used to back analysis floor strength and stiffness properties for minimum pillars required in Level 3 areas above the Sugarloaf range.

Representative subsidence, in-line tilt and strain results above Level 1 and 3 SCZ panels for the Tasman Mine panels are presented in **Figures 18a** to **18c** (Panel 5), **19a** to **19c** (Panel 5), **20a** to **20c** (Panel 6) and **21a** to **21c** (Panel 8).

The outcomes of the survey results indicate that the measured subsidence, tilt and strains were all less than predicted worst-case values above proposed Level 2 SCZ areas. No surface impacts have been observed above the Level 2 SCZ partial extraction panel's to-date.

An exceedance of the predicted mine subsidence has been measured above one Modified Duncan Panel, 3-North, with subsidence increasing from 122 mm to 422 mm due to overloading of the weak claystone and shaley coal floor below the Fassifern Seam. A 20 mm wide tension crack developed just outside of the panel limits and above the Level 1 SCZ panel (i.e. with no subsidence restrictions). The panel response has enabled the mine to further improve the design parameters required for Level 2 and 3 SCZ areas for future panels beneath the high level cliffs and ridge lines at Tasman and weak claystone floors.

8.2.5 Goaf Edge Subsidence and Angle of Draw

The measured goaf edge subsidence for Panels 3 to 5a ranged from 5 mm to 9 mm.

The angle of draw (AoD) to the 20 mm and 2 mm of vertical movement from the limits of panel second workings limits are presented in **Table 9**.

Table 9 - Measured Angle of Draw to the 20 mm and 2 mm Subsidence Contours for Panels 3 to 5a

Panel Edge	**Cover Depth at Survey Peg (m)**	**Distance to Design Subsidence Contour (m)**		**z/H**		**AoD (degrees)**	
		20mm	2mm	20mm	2mm	20mm	2mm
Panel 3 (2-South)	110 (110)	0	>1	0	>0.01	0	>1
	140 (140)	0	>10	0	>0.07	0	>4
Panel 4 (3-South)	140 (140)	0	>20	0	>0.14	0	>8
Panel 5a (2a-North)	165 (125)	0	94	0	0.56	0	29
	110 (110)	0	16	0	0.15	0	8

( ) - cover depth at panel limits

The measured AoD of 0^{o} to the 20 mm subsidence contour and up to 29^{o} to the 2 mm subsidence contour is consistent with the predicted worst-case Design AoD of 26.5^{o} to the 20 mm subsidence contour and 45^{o} to the 2 mm subsidence contour or 'nil' subsidence that was recommended in previous reports due to the presence of steep slopes.

9.0 Subsidence Predictions for the Proposed Tasman Extension Project

As described in **Section 5.4**, the development heading and panel layouts (such as areas of total and partial extraction and mining height) would be finalised as a component of the Extraction Plan process. The Extraction Plan process would include revised subsidence predictions for any changes made to the mine layout assessed in this report.

In addition, subsidence assessments prepared as a component of the Extraction Plan process would involve the review and evaluation of subsidence monitoring results.

9.1 Subsidence Reduction Potential

The Subsidence Reduction Potential (SRP) refers to the subsidence reducing effect of massive conglomerate / sandstone units above longwall or pillar extraction panels of a given width. The typical stratigraphy over the Tasman Extension Project area is shown in **Figure 7a** to **7c** and indicates massive sandstone units are 1 m to 100 m above the West Borehole Seam and are 5 m to 23 m thick, with the thickest units associated with the eastern and southern ridge lines.

The thickness (t) of the sandstone units above the proposed Tasman Extension Project panels were plotted against panel width (W) and distance (y) of the unit above the panels (and normalised to cover depth, H) as shown in **Figures 22a** to **22c** for the 100 m, 200 m and 300 m cover depth categories.

Based on the database, the sandstone units within the overburden above the low lying terrain are likely to have 'Low' SRP for unit thicknesses < 20 m. This outcome generally applies to all of the 160.5 m wide panels with cover depths ranging from 60 m to 250 m.

For panels beneath the eastern and southern ridge lines, the overlying sandstone units, which are > 20 m thick, are assessed as having a ‘High’ SRP for the given panel geometries.

The actual SRP of the strata units within the proposed mining may be further assessed once there is sufficient local subsidence data available.

9.2 Single Panel Subsidence Predictions

Based on the SRP assessment, the range of subsidence for the ‘Low’ SRP limit lines below the low lying areas and ‘High’ SRP below the ridges was determined from the subsidence prediction curves for the three depth categories present at the site (i.e. 100 m, 200 m and 300 m ± 50 m), as shown in **Figures 23a** to **23c**. The results are also summarised in **Table 10**.

The predictions of maximum single panel subsidence for the total extraction panels below the flatter areas of the site range between 0.58 m and 1.32 m. Cover depths range between 55 m and 185 m with panel W/H ratios of 0.78 to 2.92.

For the High SRP Cases below the ridges, the cover depths range from 155 m to 350 m with maximum single panel subsidence predicted to range between 0.10 m and 0.88 m for Panel W/H ratios of 0.46 to 1.04.

Subsequent mining of adjacent panels will result in further subsidence increases due to barrier pillar compression and are presented in **Section 9.3**.

Table 10 - Predicted Single Panel Subsidence (based on ACARP, 2003 Empirical Model)

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	W/H	SRP	Mining Height T (m)	Extraction Ratio e (%)	S_{max} Single (mean) (m)	S_{max} Single (U95%CL) (m)
1	1	160.5	110	1.46	Low	2.5	88	0.98	1.09
1	2	160.5	120	1.34	Low	2.5	88	0.93	1.04
2	1	160.5	105	1.53	Low	2.5	88	1.01	1.12
2	2	160.5	125	1.28	Low	2.5	88	0.90	1.01
3	5b	160.5	60	2.68	Low	2.5	88	1.23	1.27
3	6b	160.5	75	2.14	Low	2.5	88	1.23	1.32
3	7b	160.5	85	1.89	Low	2.5	88	1.16	1.27
4	5b	160.5	70	2.29	Low	2.5	88	1.23	1.27
4	6b	160.5	80	2.01	Low	2.5	88	1.21	1.32
4	7b	160.5	100	1.61	Low	2.5	88	1.04	1.15
Mains1	4	105.3	135	0.78	Low	2.5	88	0.58	0.69
5	8	160.5	130	1.23	Low	2.5	88	0.90	1.23
6	8	160.5	140	1.15	Low	2.5	88	0.90	1.15
6	9	160.5	155	1.04	Low	2.5	88	0.91	1.02
7	8	160.5	160	1.00	Low	2.5	88	0.92	1.00
7	9	160.5	185	0.87	Low	2.5	88	0.90	1.01
8	12	160.5	65	2.47	Low	2.5	88	1.23	1.32
9	11	160.5	55	2.92	Low	2.5	88	1.23	1.32
9	12	160.5	70	2.29	Low	2.5	88	1.23	1.32
10	10	160.5	60	2.68	Low	2.5	88	1.23	1.32
10	11	160.5	70	2.29	Low	2.5	88	1.23	1.32
10	12	160.5	75	2.14	Low	2.5	88	1.23	1.32
11	3	160.5	65	2.47	Low	2.5	88	1.23	1.27
11	10	160.5	75	2.14	Low	2.5	88	1.23	1.32
11	11	160.5	85	1.89	Low	2.5	88	1.16	1.27
11	12	160.5	85	1.89	Low	2.5	88	1.16	1.27
12	3	160.5	80	2.01	Low	2.5	88	1.21	1.27
12	10	160.5	85	1.89	Low	2.5	88	1.16	1.27
12	11	160.5	95	1.69	Low	2.5	88	1.08	1.19
12	12	160.5	95	1.69	Low	2.5	88	1.08	1.19
13	10	160.5	105	1.53	Low	2.5	88	1.01	1.12
13	11	160.5	115	1.40	Low	2.5	88	0.96	1.07
13	12	160.5	110	1.46	Low	2.5	88	0.98	1.09
14	10	160.5	130	1.23	Low	2.5	88	0.90	1.01
14	11	160.5	135	1.19	Low	2.5	88	0.90	1.01
14	12	160.5	130	1.23	Low	2.5	88	0.90	1.01
15	11	160.5	160	1.00	Low	2.5	88	0.92	1.03
15	12	160.5	155	1.04	Low	2.5	88	0.91	1.02
16	11	160.5	200	0.80	Low	2.5	88	0.77	0.88
16	12	160.5	175	0.92	Low	2.5	88	0.96	1.07

Table 10 (cont…) - Predicted Single Panel Subsidence (based on ACARP, 2003 Empirical Model)

Panel #	**XL #**	**Panel Width W (m)**	**Cover Depth H (m)**	**W/H**	**SRP**	**Mining Height T (m)**	**Extraction Ratio e (%)**	**S_{max} Single (mean) (m)**	**S_{max} Single (U95%CL) (m)**
17	12	160.5	220	0.73	Low	2.5	88	0.57	0.78
18	15	160.5	155	1.04	High	2.5	88	0.63	0.74
19	13	160.5	100	1.61	Low	2.5	88	1.04	1.15
19	14	160.5	95	1.46	Low	2.5	88	0.98	1.09
19	15	160.5	85	0.84	High	2.5	88	0.23	0.34
20	13	160.5	75	2.14	Low	2.5	88	1.23	1.32
20	14	160.5	95	1.28	Low	2.5	88	0.90	1.01
20	15	160.5	105	0.67	High	2.5	88	0.13	0.35
21	13	160.5	110	1.69	Low	2.5	88	1.08	1.19
21	14	160.5	115	2.39	Low	2.5	88	1.23	1.23
21	15	160.5	135	0.67	High	2.5	88	0.13	0.35
22	13	160.5	180	1.89	Low	2.5	88	1.16	1.27
22	14	160.5	240	1.61	Low	2.5	88	1.04	1.15
22	15	160.5	350	0.70	High	2.5	88	0.10	0.32
23	13	160.5	110	2.14	Low	2.5	88	1.23	1.32
23	14	160.5	125	1.40	Low	2.5	88	0.96	1.07
23	15	160.5	90	0.70	High	2.5	88	0.10	0.32
24	13	160.5	100	1.69	Low	2.5	88	1.08	1.19
24	14	160.5	115	1.04	Low	2.5	88	0.91	1.02
25	13	160.5	155	1.53	Low	2.5	88	1.01	1.12
25	14	160.5	145	1.11	Low	2.5	88	0.90	1.01
26	13	160.5	135	1.46	Low	2.5	88	0.98	1.09
26	14	160.5	135	1.19	Low	2.5	88	0.90	1.01
27	13	160.5	140	1.40	Low	2.5	88	0.96	0.86
27	14	160.5	200	1.19	Low	2.5	88	0.90	1.01
28	13	160.5	290	1.19	Low	2.5	88	0.90	0.77
28	14	160.5	155	1.15	Low	2.5	88	0.90	1.01
29	13	160.5	190	0.89	Low	2.5	88	0.94	1.05
29	14	160.5	240	0.80	Low	2.5	88	0.77	0.88
30	13	160.5	240	0.67	Low	2.5	88	0.44	0.66
30	14	160.5	230	0.55	Low	2.5	88	0.37	0.43
31	13	160.5	230	0.46	Low	2.5	88	0.31	0.37
32	5a	160.5	150	1.07	Low	2.5	88	0.90	1.07
32	6a	160.5	140	1.15	Low	2.5	88	0.90	1.07
32	7a	160.5	160	1.09	Low	2.5	88	0.92	1.09

9.3 Barrier Pillar Subsidence Predictions

9.3.1 Model Development

The predicted subsidence values above the barrier pillars have been estimated based on an empirical model of the roof-pillar-floor system.

The empirical model has been developed from measured NSW Coalfields subsidence data over chain pillars (S_p) divided by the mining height (T) v. total pillar stress after longwall panel extraction on both sides.

Reference to the longwall chain pillar database indicates that the subsidence measured above 'squat' chain pillars (i.e. w/h>5) may increase significantly when total average pillar stresses exceed 25 MPa (see **Figure 24a**) or when the pillar stress exceeds 0.5 times the pillar strength (see **Figure 24b**). This is equivalent to a Factor of Safety (FoS) of <2.0.

It is also apparent from the measured data in **Figure 24a** that the subsidence above the pillars is not just a function of the strength and stiffness of the coal pillars and surrounding rock mass (i.e. higher subsidence is measured above weak shale roof compared to a strong sandstone one).

The estimate of the total stress acting on the proposed barrier pillars under double abutment loading conditions (which will occur after the mining of high pillar extraction panels along both sides) is based on the abutment angle concept described in **ACARP, 1998a** as follows:

σ = pillar load/area = $(P+A_1+A_2)/wl$

where:

P = full tributary area (FTA) load of column of rock above each pillar;

= $(l+r)(w+r).\rho.g.H$;

$A_{1,2}$ = total abutment load from each side of pillar in MN/m, and

= $(l+r)\rho g(0.5W'H - W'^2/8\tan\phi)$ (for sub-critical panel widths) or

= $(l+r)(\rho g H^2 \tan\phi)/2$ (for super-critical panel widths);

w = pillar width (solid);

l = pillar length;

r = roadway width;

H = depth of cover;

ϕ = abutment angle (normally 21° adopted for cover depths < 350 m in the NSW Coalfields);

W' = effective panel width (rib to rib distance minus the roadway width).

A panel is deemed sub-critical when $W'/2 < H\tan\phi$.

As presented in **ACARP, 1998b** the FoS of the barrier and chain pillars were based on the strength formula for ‘squat’ pillars with w/h ratios > 5 as follows:

$$S = 27.63\Theta^{0.51}(0.29((w/5h)^{2.5} - 1) + 1)/(w^{0.22}h^{0.11})$$

where:

h = pillar height;

Θ = a dimensionless ‘aspect ratio’ factor or w/h ratio in this case.

The FoS was calculated by dividing the pillar strength, S, with the pillar stress, σ.

9.3.2 Model Results

Predictions of the maximum first and final barrier pillar subsidence for panels adjacent to Total Extraction Panels and are summarised in **Table 11**.

Table 11 - Predicted Pillar Subsidence under Double Abutment Loading (based on Modified ACARP, 2003 Empirical Model)

Panel #	XL#	Pillar Width (m)	Cover Depth H (m)	Pillar Stress (MPa)	Pillar* FoS	Sp First (mean)	Sp First (U95%CL)	Sp Final (mean)	Sp Final (U95%CL)
1	1	19.5	110	9.32	3.10	0.07	0.13	0.08	0.14
1	2	19.5	120	11.36	2.54	0.08	0.14	0.10	0.16
2	1	19.5	105	8.39	3.44	0.06	0.12	0.07	0.13
2	2	19.5	125	11.23	2.57	0.08	0.14	0.10	0.16
3	5b	19.0	60	4.13	6.80	0.04	0.10	0.04	0.10
3	6b	19.0	75	5.51	5.09	0.04	0.10	0.05	0.11
3	7b	19.0	85	7.17	3.91	0.05	0.11	0.06	0.12
Mains1	4	55.7	135	5.33	33.57	0.04	0.10	0.05	0.11
5	8	19.5	130	13.29	2.17	0.10	0.16	0.12	0.18
6	8	19.5	140	15.78	1.83	0.13	0.25	0.16	0.28
6	9	19.5	155	19.51	1.48	0.19	0.31	0.23	0.35
7	8	39.7	160	12.63	7.14	0.09	0.15	0.11	0.17
7	9	19.5	185	29.92	0.97	0.38	0.50	0.46	0.58
8	12	19.5	65	4.38	6.60	0.04	0.10	0.04	0.10
9	11	19.5	55	3.75	7.69	0.03	0.09	0.04	0.10
9	12	19.5	70	4.89	5.91	0.04	0.10	0.05	0.11
10	10	19.5	60	4.24	6.81	0.04	0.10	0.04	0.10
10	11	19.5	70	5.28	5.47	0.04	0.10	0.05	0.11

Table 11 (Cont…) - Predicted Pillar Subsidence under Double Abutment Loading (based on Modified ACARP, 2003 Empirical Model)

Panel #	XL#	Pillar Width (m)	Cover Depth H (m)	Pillar Stress (MPa)	Pillar* FoS	Sp First (mean)	Sp First (U95%CL)	Sp Final (mean)	Sp Final (U95%CL)
10	12	19.5	75	5.63	5.13	0.04	0.10	0.05	0.11
11	3	19.5	65	4.75	6.08	0.04	0.10	0.05	0.11
11	10	19.5	75	5.63	5.13	0.04	0.10	0.05	0.11
11	11	19.5	85	6.80	4.25	0.05	0.11	0.06	0.12
11	12	19.5	85	6.80	4.25	0.05	0.11	0.06	0.12
12	10	19.5	85	7.29	3.96	0.05	0.11	0.06	0.12
12	11	19.5	95	8.61	3.35	0.06	0.12	0.07	0.13
12	12	19.5	95	8.33	3.47	0.06	0.12	0.07	0.13
13	10	19.5	105	10.35	2.79	0.07	0.13	0.09	0.15
13	11	19.5	115	11.55	2.50	0.08	0.14	0.10	0.16
13	12	19.5	110	10.78	2.68	0.08	0.14	0.09	0.15
14	11	19.5	135	15.28	1.89	0.13	0.25	0.15	0.27
14	12	19.5	130	14.39	2.01	0.11	0.17	0.14	0.20
15	11	19.5	160	21.50	1.34	0.22	0.34	0.27	0.39
15	12	19.5	155	18.62	1.55	0.17	0.29	0.21	0.33
16	11	19.5	200	16.43	1.76	0.14	0.26	0.17	0.29
16	12	19.5	175	25.25	1.14	0.29	0.41	0.35	0.47
17	12	19.5	220	27.15	1.06	0.33	0.45	0.40	0.52
18	15	39.5	155	11.85	7.54	0.09	0.15	0.10	0.16
19	13	19.5	100	7.13	4.05	0.05	0.11	0.06	0.12
19	14	19.5	110	10.46	2.76	0.07	0.13	0.09	0.15
19	15	19.5	190	29.11	*0.99*	0.37	0.49	0.44	0.56
20	13	19.5	75	6.07	4.75	0.04	0.10	0.05	0.11
20	14	19.5	125	9.95	2.90	0.07	0.13	0.08	0.14
20	15	19.5	240	35.71	*0.81*	0.47	0.59	0.56	0.68
21	13	19.5	95	7.12	4.06	0.05	0.11	0.06	0.12
21	14	19.5	90	7.42	3.89	0.05	0.11	0.06	0.12
21	15	19.5	240	34.71	*0.83*	0.46	0.58	0.55	0.67
22	13	19.5	85	5.95	4.85	0.04	0.10	0.05	0.11
22	14	19.5	100	9.02	3.20	0.06	0.12	0.08	0.14
22	15	19.5	230	33.38	*0.87*	0.44	0.56	0.53	0.65
23	13	19.5	75	6.07	4.75	0.04	0.10	0.05	0.11
23	14	19.5	115	12.99	2.22	0.10	0.16	0.12	0.18
23	15	19.5	230	20.42	1.41	0.20	0.32	0.24	0.36
24	13	19.5	95	8.07	3.58	0.06	0.12	0.07	0.13
24	14	19.5	155	16.23	1.78	0.14	0.26	0.17	0.29
25	13	19.5	105	9.16	3.15	0.06	0.12	0.08	0.14
25	14	19.5	145	14.46	2.00	0.12	0.24	0.14	0.26
26	13	19.5	110	9.86	2.93	0.07	0.13	0.08	0.14
26	14	19.5	135	13.44	2.15	0.10	0.16	0.12	0.18
27	13	19.5	115	11.55	2.50	0.08	0.14	0.10	0.16
27	14	19.5	135	18.86	1.53	0.18	0.30	0.21	0.33
28	13	19.5	135	16.97	1.70	0.15	0.27	0.18	0.30
28	14	19.5	140	19.36	1.49	0.19	0.31	0.22	0.34

Table 11 (Cont…) - Predicted Pillar Subsidence under Double Abutment Loading (based on Modified ACARP, 2003 Empirical Model)

Panel #	XL#	Pillar Width (m)	Cover Depth H (m)	Pillar Stress (MPa)	Pillar* FoS	Sp First (mean)	Sp First (U95%CL)	Sp Final (mean)	Sp Final (U95%CL)
29	13	19.5	180	27.86	1.04	0.34	0.46	0.41	0.53
30	13	19.5	240	21.75	1.33	0.23	0.35	0.27	0.39
30	14	19.5	290	28.39	1.02	0.35	0.47	0.42	0.54
31	13	19.5	350	61.38	*0.47*	0.59	0.71	0.71	0.83
32	Not applicable as it is a single panel only								

* - Pillar FoS based on development height of 2.5 m and w/h = 7.8.
italics - barrier pillar FoS < 1 and likely to yield after mining is completed

The predictions of first and final subsidence above the 19.5 m wide barriers between Panels 1 to 31 ranges from 0.03 m to 0.83 m for a development height of 2.5 m and cover depths between 55 m and 350 m. Pillar stresses are estimated to range from 3.75 MPa to 61.4 MPa with post-mining FoS for these barrier pillars are estimated to range from 0.47 to 7.69. Subsidence above the chain pillars is expected to exceed 300 mm in areas where average cover depths are > 150 m.

The w/h ratio range of 7.8 for the barrier pillars assessed indicates that the barrier pillars are likely to strain-harden if overloaded.

9.4 Bearing Capacity of Roof and Floor Strata

The bearing capacity of the roof and floor strata should be considered when designing the barrier pillars for long-term subsidence control.

Reference to **Pells *et al* , 1998** indicates that the bearing capacity of sedimentary rock under shallow footing type loading conditions is 3 to 5 times its UCS strength. Based on the estimated average UCS values in the immediate sandstone floor and competent sandstone roof (where it occurs) of 70MPa, the general bearing capacity of the floor and competent sandstone roof strata is estimated to range between 210 MPa and 350 MPa. The UCS for coal and Nobbys Tuff roof strata areas is estimated to average at 15 MPa, indicating a bearing strength of 45 to 75 MPa.

Based on the predicted average pillar stress range of 4.5 to 30.1 MPa after the mining of the total pillar extraction panels up to cover depths of 200 m, an overall FoS bearing failure of the sandstone roof and floor strata ranges from 7.0 to 78. The areas with Nobbys Coal and Nobbys Tuff roof strata are estimated to have a FoS range of 1.5 to 17.1.

The roof and floor strata are therefore likely to behave elastically where FoS values are > 2.0, but may experience some localised creep or yielding where FoS is < 2.0 in the medium to long term. Some local shear failure may also occur in the wetter areas of the mine with weaker Nobbys Coal roof units, but will probably not lead to significant time dependent subsidence increases.

The observed behaviour of longwall chain pillars and roof / floor system has also been used to develop a simple analytical model in **Section 9.5**.

9.5 Goaf Edge Subsidence Prediction

The predictions of goaf edge subsidence around total extraction panels have been derived from the modified **ACARP, 2003** model's curves shown in **Figure 25**.

The goaf edge subsidence predictions for Panels 1 to 32 panels are estimated to range from 0.03 m to 0.29 m for cover depths from 55 m to 350 m.

9.6 Angle of Draw Prediction

The angle of draw (AoD) values around the limits of total extraction panels have been estimated from the prediction curves shown in **Figure 26** and range from 6^o to 26^o for cover depths of 55 m to 350 m.

The AoD predictions have been derived from the goaf edge subsidence predictions given in **Section 9.5** for Panels 1 to 32.

9.7 Inflexion Point and Peak Strain Locations

The subsidence development process causes tensile and compressive strains to develop above an extracted high pillar extraction panel, due to the sagging and bending of the overburden strata.

Tensile strains are generally located in the outer third zone above an extracted panel and the compressive strains will occur above the central or middle third area. The point where the tensile strains become compressive is called the inflexion point. The relative locations of the peak surface impact parameters above an extracted panel are shown schematically in **Figure 12b**.

The Newcastle Coalfield database of pillar extraction and longwall inflexion point and tensile/compressive strain or convex/concave curvature peak locations, are shown in **Figure 27a**. The measured values for Abel Mine are shown on **Figures 27b** to **27d** and generally plot within the Newcastle Coalfield database, but nearer to the lower bound limits. It is considered that the difference between the coalfield and Abel Mine data is indicative of the lack of massive units in the overburden strata at Abel.

The predicted locations of the inflexion and peak strain location points for the proposed Tasman Extension Project panels 1 – 32 based on total extraction are given in **Table 12** and are derived from the Newcastle Coalfield database curves less 10 m (to be consistent with the Abel Mine data).

Table 12 - Predicted Inflexion and Strain Peak Location Summary

Panel #	XL #	Cover Depth H (m)	Panel W/H	Inflexion Point Location Factor d/H	Inflexion Point Location from Panel Rib, d	Tensile Strain Peak Location Factor d_t/H	Tensile Strain Peak Location From Panel Rib, d_t	Compressive Strain Peak Location Factor d_c/H	Compressive Strain Peak Location from Panel Rib, d_c
1	1	110	1.46	0.30	33	0.18	20	0.41	45
1	2	120	1.34	0.30	36	0.18	22	0.40	49
2	1	105	1.53	0.30	31	0.18	19	0.41	43
2	2	125	1.28	0.29	36	0.18	23	0.40	49
3	5b	60	2.68	0.23	14	0.11	7	0.34	20
3	6b	75	2.14	0.26	19	0.14	11	0.37	28
3	7b	85	1.89	0.27	23	0.16	13	0.38	33
4	5b	70	2.29	0.25	17	0.13	9	0.36	25
4	6b	80	2.01	0.27	21	0.15	12	0.38	30
4	7b	100	1.61	0.29	29	0.18	18	0.40	40
Mains1	4	135	0.78	0.17	24	0.10	14	0.24	33
5	8	130	1.23	0.28	37	0.18	23	0.39	50
6	8	140	1.15	0.27	38	0.17	24	0.37	52
6	9	155	1.04	0.25	39	0.16	25	0.35	54
7	8	160	1.00	0.25	40	0.16	25	0.34	54
7	9	185	0.87	0.22	41	0.14	26	0.30	56
8	12	65	2.47	0.24	15	0.12	8	0.35	23
9	11	55	2.92	0.21	12	0.09	5	0.32	18
9	12	70	2.29	0.25	17	0.13	9	0.36	25
10	10	60	2.68	0.23	14	0.11	7	0.34	20
10	11	70	2.29	0.25	17	0.13	9	0.36	25
10	12	75	2.14	0.26	19	0.14	11	0.37	28
11	3	65	2.47	0.24	15	0.12	8	0.35	23
11	10	75	2.14	0.26	19	0.14	11	0.37	28
11	11	85	1.89	0.27	23	0.16	13	0.38	33
11	12	85	1.89	0.27	23	0.16	13	0.38	33
12	3	80	2.01	0.27	21	0.15	12	0.38	30
12	10	85	1.89	0.27	23	0.16	13	0.38	33
12	11	95	1.69	0.29	27	0.17	16	0.40	38
12	12	95	1.69	0.29	27	0.17	16	0.40	38
13	10	105	1.53	0.30	31	0.18	19	0.41	43
13	11	115	1.40	0.30	35	0.19	22	0.41	48
13	12	110	1.46	0.30	33	0.18	20	0.41	45
14	10	130	1.23	0.28	37	0.18	23	0.39	50
14	11	135	1.19	0.28	38	0.17	24	0.38	51
14	12	130	1.23	0.28	37	0.18	23	0.39	50
15	11	160	1.00	0.25	40	0.16	25	0.34	54
15	12	155	1.04	0.25	39	0.16	25	0.35	54
16	11	200	0.80	0.21	41	0.13	27	0.28	57
16	12	175	0.92	0.23	40	0.15	26	0.32	55
17	12	220	0.73	0.12	27	0.12	26	0.25	56

Table 12 (Cont…) - Predicted Inflexion and Strain Peak Location Summary

Panel #	XL #	Cover Depth H (m)	Panel W/H	Inflexion Point Location Factor d/H	Inflexion Point Location from Panel Rib, d	Tensile Strain Peak Location Factor d_t/H	Tensile Strain Peak Location From Panel Rib, d_t	Compressive Strain Peak Location Factor d_c/H	Compressive Strain Peak Location from Panel Rib, d_c
18	15	155	1.04	0.25	39	0.16	25	0.35	54
19	13	100	1.61	0.29	29	0.18	18	0.40	40
19	14	110	1.46	0.30	33	0.18	20	0.41	45
19	15	190	0.84	0.22	41	0.14	27	0.30	56
20	13	75	2.14	0.26	19	0.14	11	0.37	28
20	14	125	1.28	0.29	36	0.18	23	0.40	49
20	15	240	0.67	0.17	41	0.10	24	0.24	57
21	13	95	1.69	0.29	27	0.17	16	0.40	38
21	14	90	2.39	0.28	25	0.16	15	0.39	35
21	15	240	0.67	0.17	41	0.10	24	0.24	57
22	13	85	1.89	0.27	23	0.16	13	0.38	33
22	14	100	1.61	0.29	29	0.18	18	0.40	40
22	15	230	0.70	0.18	41	0.11	25	0.25	57
23	13	75	2.14	0.26	19	0.14	11	0.37	28
23	14	115	1.40	0.30	35	0.19	22	0.41	48
23	15	230	0.70	0.18	41	0.11	25	0.25	57
24	13	95	1.69	0.29	27	0.17	16	0.40	38
24	14	155	1.04	0.25	39	0.16	25	0.35	54
25	13	105	1.53	0.30	31	0.18	19	0.41	43
25	14	145	1.11	0.27	39	0.17	24	0.36	52
26	13	110	1.46	0.30	33	0.18	20	0.41	45
26	14	135	1.19	0.28	38	0.17	24	0.38	51
27	13	115	1.40	0.30	35	0.19	22	0.41	48
27	14	135	1.19	0.28	38	0.17	24	0.38	51
28	13	135	1.19	0.34	47	0.17	24	0.38	51
28	14	140	1.15	0.32	45	0.17	24	0.37	52
29	13	180	0.89	0.20	35	0.15	26	0.31	56
29	14	200	0.80	0.16	31	0.13	27	0.28	57
30	13	240	0.67	0.10	24	0.10	24	0.24	57
30	14	290	0.55	0.06	16	0.06	18	0.20	58
31	13	350	0.46	0.03	9	0.02	7	0.16	56
32	5a	150	1.07	0.26	39	0.16	25	0.35	53
32	6a	140	1.15	0.27	38	0.17	24	0.37	52
32	7a	160	1.00	0.25	40	0.16	25	0.34	54

9.8 Multiple Panel Subsidence Predictions

Maximum subsidence predictions for multiple panels may be estimated by adding 50% to 100% of the chain or barrier pillar subsidence predictions to the mean single panel S_{max}. The predicted goaf edge subsidence is subtracted from the chain pillar subsidence (as it is included in the single panel predictions).

The maximum subsidence impact parameter predictions (i.e. tilt, curvature and strain etc) for multiple panels may then be derived using the empirical relationships defined in **ACARP, 2003** (see the following sections).

9.8.1 Maximum Subsidence above Total Pillar Extraction Panels

The maximum first and final subsidence predictions for the proposed 160.5 m wide total extraction Panels 1 to 32 and 105 m wide main headings panels based on total extraction (i.e. assuming no SCZs) are summarised in **Table 13** for the range of cover depths of 55 m to 350 m. An average panel mining height of 2.5 m has been assumed together with an extraction ratio of 88% (i.e. effective mining heights then of 2.2 m).

The predicted first and final maximum subsidence for the total extraction panels range from 0.58 m to 1.27 m below the flatter areas with cover depths < 200 m and from 0.10 m to 1.12 m below the ridges, where cover depths range from 155 m to 350 m (i.e. 5% to 58% of the effective mining height of 2.2 m). The 19.5 m wide barrier pillars are likely to go into yield at depths > 150 m.

Representative first and final subsidence profiles have been prepared along cross line XL in **Figure 28** (the location of the cross line is shown in **Figure 1**).

Table 13 - Predicted Maximum Subsidence for Multiple Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Average Mining Height T (m)	W/H (m/m)	Final TG Barrier Pillar Subsidence S_p (m)		First Panel S_{max} (m)		Final Panel S_{max} (m)	
						mean	U95%CL	mean	U95%CL	mean	U95%CL
1	1	160.5	110	2.5	1.46	0.13	0.14	0.98	1.15	1.03	1.19
1	2	160.5	120	2.5	1.34	0.14	0.16	0.93	1.09	0.99	1.16
2	1	160.5	105	2.5	1.53	0.12	0.13	1.01	1.17	1.05	1.21
2	2	160.5	125	2.5	1.28	0.14	0.16	0.90	1.06	0.96	1.13
3	5b	160.5	60	2.5	2.68	0.10	0.10	1.23	1.27	1.24	1.27
3	6b	160.5	75	2.5	2.14	0.10	0.11	1.23	1.27	1.24	1.27
3	7b	160.5	85	2.5	1.89	0.11	0.12	1.16	1.27	1.19	1.27
4	5b	160.5	70	2.5	2.29	0.09	0.09	1.23	1.27	1.24	1.27
4	6b	160.5	80	2.5	2.01	0.09	0.09	1.21	1.27	1.21	1.27
4	7b	160.5	100	2.5	1.61	0.09	0.10	1.04	1.21	1.05	1.21
m1	4	105.3	135	2.5	0.78	0.10	0.11	0.58	0.74	0.59	0.75
5	8	160.5	130	2.5	1.23	0.16	0.18	0.90	1.06	0.98	1.14

Table 13 (Cont...) - Predicted Maximum Subsidence for Multiple Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Average Mining Height T (m)	W/H (m/m)	Final TG Barrier Pillar Subsidence S_p (m)		First Panel S_{max} (m)		Final Panel S_{max} (m)	
						mean	U95%CL	mean	U95%CL	mean	U95%CL
6	8	160.5	140	2.5	1.15	0.25	0.28	0.90	1.06	1.01	1.18
6	9	160.5	155	2.5	1.04	0.31	0.35	0.91	1.07	1.07	1.24
7	8	160.5	160	2.5	1.00	0.15	0.17	0.92	1.08	0.97	1.13
7	9	160.5	185	2.5	0.87	0.50	0.58	0.90	1.06	1.26	1.27
8	12	160.5	65	2.5	2.47	0.10	0.10	1.23	1.27	1.24	1.27
9	11	160.5	55	2.5	2.92	0.09	0.10	1.23	1.27	1.24	1.27
9	12	160.5	70	2.5	2.29	0.10	0.11	1.23	1.27	1.24	1.27
10	10	160.5	60	2.5	2.68	0.10	0.10	1.23	1.27	1.24	1.27
10	11	160.5	70	2.5	2.29	0.10	0.11	1.23	1.27	1.24	1.27
10	12	160.5	75	2.5	2.14	0.10	0.11	1.23	1.27	1.24	1.27
11	3	160.5	65	2.5	2.47	0.10	0.11	1.23	1.27	1.24	1.27
11	10	160.5	75	2.5	2.14	0.10	0.11	1.23	1.27	1.24	1.27
11	11	160.5	85	2.5	1.89	0.11	0.12	1.16	1.27	1.19	1.27
11	12	160.5	85	2.5	1.89	0.11	0.12	1.16	1.27	1.19	1.27
12	3	160.5	80	2.5	2.01	0.09	0.09	1.21	1.27	1.21	1.27
12	10	160.5	85	2.5	1.89	0.11	0.12	1.16	1.27	1.19	1.27
12	11	160.5	95	2.5	1.69	0.12	0.13	1.08	1.24	1.12	1.27
12	12	160.5	95	2.5	1.69	0.12	0.13	1.08	1.24	1.12	1.27
13	10	160.5	105	2.5	1.53	0.13	0.15	1.01	1.17	1.07	1.23
13	11	160.5	115	2.5	1.40	0.14	0.16	0.96	1.12	1.03	1.19
13	12	160.5	110	2.5	1.46	0.14	0.15	0.98	1.15	1.05	1.21
14	10	160.5	130	2.5	1.23	0.10	0.10	0.90	1.06	0.91	1.07
14	11	160.5	135	2.5	1.19	0.25	0.27	0.90	1.06	1.01	1.17
14	12	160.5	130	2.5	1.23	0.17	0.20	0.90	1.06	1.00	1.16
15	11	160.5	160	2.5	1.00	0.34	0.39	0.92	1.08	1.12	1.27
15	12	160.5	155	2.5	1.04	0.29	0.33	0.91	1.07	1.06	1.22
16	11	160.5	200	2.5	0.80	0.26	0.29	0.77	0.93	0.84	1.00
16	12	160.5	175	2.5	0.92	0.41	0.47	0.96	1.12	1.22	1.27
17	12	160.5	220	2.5	0.73	0.45	0.52	0.57	0.81	0.87	1.12
18	15	160.5	155	2.5	1.04	0.15	0.16	0.63	0.79	0.69	0.85
19	13	160.5	100	2.5	1.61	0.11	0.12	1.04	1.21	1.07	1.24
19	14	160.5	110	2.5	1.46	0.13	0.15	0.98	1.15	1.04	1.21
19	15	160.5	190	2.5	0.84	0.49	0.56	0.23	0.40	0.65	0.81
20	13	160.5	75	2.5	2.14	0.10	0.11	1.23	1.27	1.25	1.27
20	14	160.5	125	2.5	1.28	0.13	0.14	0.90	1.06	0.95	1.11
20	15	160.5	240	2.5	0.67	0.59	0.68	0.13	0.38	0.66	0.91
21	13	160.5	95	2.5	1.69	0.11	0.12	1.08	1.24	1.11	1.27
21	14	160.5	90	2.5	2.39	0.11	0.12	1.23	1.27	1.26	1.27
21	15	160.5	240	2.5	0.67	0.58	0.67	0.13	0.38	0.65	0.90
22	13	160.5	85	2.5	1.89	0.10	0.11	1.16	1.27	1.18	1.27
22	14	160.5	100	2.5	1.61	0.12	0.14	1.04	1.21	1.09	1.25
22	15	160.5	230	2.5	0.70	0.56	0.65	0.10	0.35	0.61	0.86

Table 13 (Cont...) - Predicted Maximum Subsidence for Multiple Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Average Mining Height T (m)	W/H (m/m)	Final TG Barrier Pillar Subsidence S_p (m)		First Panel S_{max} (m)		Final Panel S_{max} (m)	
						mean	**U95%CL**	**mean**	**U95%CL**	**mean**	**U95%CL**
23	13	160.5	75	2.5	2.14	0.10	0.11	1.23	1.27	1.25	1.27
23	14	160.5	115	2.5	1.40	0.16	0.18	0.96	1.12	1.05	1.21
23	15	160.5	230	2.5	0.70	0.32	0.36	0.10	0.35	0.33	0.58
24	13	160.5	95	2.5	1.69	0.12	0.13	1.08	1.24	1.11	1.27
24	14	160.5	155	2.5	1.04	0.26	0.29	0.91	1.07	1.01	1.18
25	13	160.5	105	2.5	1.53	0.12	0.14	1.01	1.17	1.06	1.22
25	14	160.5	145	2.5	1.11	0.24	0.26	0.90	1.06	0.99	1.15
26	13	160.5	110	2.5	1.46	0.13	0.14	0.98	1.15	1.04	1.20
26	14	160.5	135	2.5	1.19	0.16	0.18	0.90	1.06	0.98	1.14
27	13	160.5	115	2.5	1.40	0.14	0.16	0.96	1.12	1.03	1.19
27	14	160.5	135	2.5	1.19	0.30	0.33	0.90	1.06	1.07	1.23
28	13	160.5	135	2.5	1.19	0.27	0.30	0.90	1.06	1.04	1.20
28	14	160.5	140	2.5	1.15	0.31	0.34	0.90	1.06	1.08	1.24
29	13	160.5	180	2.5	0.89	0.46	0.53	0.94	1.10	1.26	1.27
29	14	160.5	200	2.5	0.80	0.10	0.11	0.77	0.90	0.78	0.91
30	13	160.5	240	2.5	0.67	0.35	0.39	0.44	0.69	0.62	0.87
30	14	160.5	290	2.5	0.55	0.47	0.54	0.37	0.50	0.67	0.81
31	13	160.5	350	2.5	0.46	0.71	0.83	0.31	0.44	0.85	0.99
32	5a	160.5	150	2.5	1.07	0.00	0.00	0.90	1.01	0.90	1.01
32	6a	160.5	140	2.5	1.15	0.00	0.00	0.90	1.02	0.90	1.02
32	7a	160.5	160	2.5	1.00	0.00	0.00	0.92	1.03	0.92	1.03

U95%CL Final S_{max} = Mean Final S_{max} + U95%CL error

9.8.2 Maximum Panel Tilts and Horizontal Displacements

The maximum first and final tilt predictions for the proposed 160.5 m wide total pillar extraction Panels 1 to 32 and 105 m wide main headings panels based on total extraction (i.e. assuming no SCZs) are summarised in **Table 14** for the range of cover depths and average panel mining heights of 2.5 m.

Predictions of final maximum tilt values for the pillar extraction panels below the flatter areas with cover depths of 55 m to 185 m range from 13 mm/m to 60 mm/m. Maximum horizontal displacements are estimated to range from 130 to 600 mm for the predicted tilts and a 'K' factor of 10.

Predictions of final maximum tilt values for the pillar extraction panels below the ridges with cover depths of 155 m to 350 m range from 3 mm/m to 19 mm/m. Maximum horizontal displacements are estimated to range from 32 to 189 mm for the predicted tilts and a 'K' factor of 10.

Representative first and final tilt and horizontal displacement profiles have been prepared along cross lines XL 12 in **Figure 28** (the location of the cross lines is shown in **Figure 1**).

Table 14 - Predicted Maximum Tilt and Horizontal Displacement for Multiple Total Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Seam Thickness T (m)	Mean Final S_{max} (m)	Final Panel, T_{max} (mm/m)		Final Panel HD_{max} (mm)	
						Mean	**U95%CL**	**Mean**	**U95%CL**
1	1	160.5	110	2.5	0.98	17	25	170	254
1	2	160.5	120	2.5	0.93	15	23	152	228
2	1	160.5	105	2.5	1.01	19	28	186	279
2	2	160.5	125	2.5	0.90	15	22	145	218
3	5b	160.5	60	2.5	1.23	40	60	399	599
3	6b	160.5	75	2.5	1.23	38	56	375	563
3	7b	160.5	85	2.5	1.16	30	44	296	444
4	5b	160.5	70	2.5	1.23	40	60	399	598
4	6b	160.5	80	2.5	1.21	33	50	331	496
4	7b	160.5	100	2.5	1.04	20	30	199	298
Mains1	4	105.3	135	2.5	0.58	13	20	131	197
5	8	160.5	130	2.5	0.90	15	22	150	224
6	8	160.5	140	2.5	0.90	16	23	156	234
6	9	160.5	155	2.5	0.91	17	25	169	254
7	8	160.5	160	2.5	0.92	15	22	146	219
7	9	160.5	185	2.5	0.90	21	32	212	318
8	12	160.5	65	2.5	1.23	40	60	399	599
9	11	160.5	55	2.5	1.23	40	60	399	599
9	12	160.5	70	2.5	1.23	40	60	400	600
10	10	160.5	60	2.5	1.23	40	60	399	599
10	11	160.5	70	2.5	1.23	40	60	401	602
10	12	160.5	75	2.5	1.23	38	56	376	564
11	3	160.5	65	2.5	1.23	40	60	400	600
11	10	160.5	75	2.5	1.23	38	56	376	564
11	11	160.5	85	2.5	1.16	29	44	295	442
11	12	160.5	85	2.5	1.16	29	44	295	442
12	3	160.5	80	2.5	1.21	33	50	331	496
12	10	160.5	85	2.5	1.16	30	44	296	444
12	11	160.5	95	2.5	1.08	23	35	233	350
12	12	160.5	95	2.5	1.08	23	35	232	349
13	10	160.5	105	2.5	1.01	19	29	190	286
13	11	160.5	115	2.5	0.96	16	24	159	239
13	12	160.5	110	2.5	0.98	17	26	173	259
14	10	160.5	130	2.5	0.90	13	20	133	200
14	11	160.5	135	2.5	0.90	15	23	155	232
14	12	160.5	130	2.5	0.90	15	23	153	229
15	11	160.5	160	2.5	0.92	18	27	179	269
15	12	160.5	155	2.5	0.91	17	25	165	248

Table 14 (Cont…) - Predicted Maximum Tilt and Horizontal Displacement for Multiple Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Seam Thickness T (m)	Mean Final S_{max} (m)	Final Panel, T_{max} (mm/m)		Final Panel HD_{max} (mm)	
						Mean	U95%CL	Mean	U95%CL
16	11	160.5	200	2.5	0.77	12	18	121	181
16	12	160.5	175	2.5	0.96	20	30	203	305
17	12	160.5	220	2.5	0.57	13	19	126	189
18	15	160.5	155	2.5	0.63	9	14	91	137
19	13	160.5	100	2.5	1.04	20	31	205	307
19	14	160.5	110	2.5	0.98	17	26	172	258
19	15	160.5	190	2.5	0.23	8	13	83	125
20	13	160.5	75	2.5	1.23	38	57	377	565
20	14	160.5	125	2.5	0.90	14	21	143	214
20	15	160.5	240	2.5	0.13	9	13	87	130
21	13	160.5	95	2.5	1.08	23	34	230	344
21	14	160.5	90	2.5	1.23	30	44	295	443
21	15	160.5	240	2.5	0.13	8	13	84	126
22	13	160.5	85	2.5	1.16	29	44	293	439
22	14	160.5	100	2.5	1.04	21	31	209	313
22	15	160.5	230	2.5	0.10	8	12	77	115
23	13	160.5	75	2.5	1.23	38	57	377	565
23	14	160.5	115	2.5	0.96	16	24	163	245
23	15	160.5	230	2.5	0.10	3	5	32	48
24	13	160.5	95	2.5	1.08	23	35	232	348
24	14	160.5	155	2.5	0.91	16	23	156	234
25	13	160.5	105	2.5	1.01	19	28	188	281
25	14	160.5	145	2.5	0.90	15	23	151	227
26	13	160.5	110	2.5	0.98	17	26	171	256
26	14	160.5	135	2.5	0.90	15	22	149	224
27	13	160.5	115	2.5	0.96	16	24	159	239
27	14	160.5	135	2.5	0.90	17	25	168	253
28	13	160.5	135	2.5	0.90	16	24	161	241
28	14	160.5	140	2.5	0.90	17	26	170	255
29	13	160.5	180	2.5	0.94	21	32	212	317
29	14	160.5	200	2.5	0.77	11	16	108	162
30	13	160.5	240	2.5	0.44	8	12	79	119
30	14	160.5	290	2.5	0.37	9	13	88	131
31	13	160.5	350	2.5	0.31	12	18	123	184
32	5a	160.5	150	2.5	0.90	13	20	130	200
32	6a	160.5	140	2.5	0.90	13	20	130	200
32	7a	160.5	160	2.5	0.92	14	21	140	210

Mean Final T_{max} = 1.1925[(Mean Final S_{max})/(Effective Panel Width)]$^{1.3955}$
U95%CL Final T_{max} = Mean Final T_{max} + U95%CL error (= 0.4*mean value); HD_{max} = 10 T_{max}

9.8.3 Maximum Panel Hogging Curvature and Tensile Strains

The maximum first and final hogging curvature and tensile strain predictions for the proposed 160.5 m wide total extraction Panels 1 to 32 and 105 m wide main headings panels based on total extraction (i.e. assuming no SCZs) are summarised in **Table 15A** for the range of cover depths and average panel mining heights of 2.5 m. An assumed maximum extraction ratio of 88% gives an effective mining height of 2.2 m.

Predictions of final maximum hogging curvature values for the pillar extraction panels below the flatter areas with cover depths of 55 m to 185 m, range from 0.55 km^{-1} to 2.91 km^{-1} with maximum tensile strains are estimated to range from 5 to 29 mm/m for the above curvatures and a 'K' factor of 10.

Predictions of final maximum hogging curvature values for the pillar extraction panels below the ridges with cover depths of 155 m to 350 m, range from 0.20 km^{-1} to 0.79 km^{-1} with maximum tensile strains are estimated to range from 2 to 8 mm/m for the above curvatures and a 'K' factor of 10.

Representative first and final curvature and horizontal strain profiles have been prepared along cross lines XL 12 in **Figure 28** (the location of the cross lines is shown in **Figure 1**).

As discussed previously, discontinuous displacements can result in secondary curvatures and strains, which exceed predicted ‘smooth’ profile values by 2 to 4 times occasionally. The discrepancy between the two models is therefore not surprising, as the data base will be strongly dependent on surface topography and near surface lithologies.

Table 15A - Predicted Maximum Hogging Curvature and Tensile Strains for Multiple Pillar Extraction Panels

Panel #	**XL #**	**Panel Width W (m)**	**Cover Depth H (m)**	**Seam Thickness T (m)**	**Mean Final Panel S_{max} (m)**	**Final Panel Hogging Curvature C_{max} (km^{-1})**		**Final Panel Tensile Strain $+E_{max}$ (mm/m)**	
						Mean	**U95%CL**	**Mean**	**U95%CL**
1	1	160.5	110	2.5	0.98	0.68	1.02	7	10
1	2	160.5	120	2.5	0.93	0.60	0.90	6	9
2	1	160.5	105	2.5	1.01	0.76	1.14	8	11
2	2	160.5	125	2.5	0.90	0.58	0.88	6	9
3	5b	160.5	60	2.5	1.23	1.93	2.90	19	29
3	6b	160.5	75	2.5	1.23	1.76	2.64	18	26
3	7b	160.5	85	2.5	1.16	1.31	1.96	13	20
4	5b	160.5	70	2.5	1.23	1.93	2.89	19	29
4	6b	160.5	80	2.5	1.21	1.51	2.26	15	23
4	7b	160.5	100	2.5	1.04	0.84	1.25	8	13
Mains1	4	105.3	135	2.5	0.58	0.83	1.24	8	12
5	8	160.5	130	2.5	0.90	0.60	0.89	6	9
6	8	160.5	140	2.5	0.90	0.61	0.92	6	9
6	9	160.5	155	2.5	0.91	0.65	0.98	7	10
7	8	160.5	160	2.5	0.92	0.58	0.88	6	9
7	9	160.5	185	2.5	0.90	0.76	1.15	8	11
8	12	160.5	65	2.5	1.23	1.93	2.90	19	29
9	11	160.5	55	2.5	1.23	1.93	2.90	19	29
9	12	160.5	70	2.5	1.23	1.93	2.90	19	29
10	10	160.5	60	2.5	1.23	1.93	2.90	19	29
10	11	160.5	70	2.5	1.23	1.94	2.91	19	29
10	12	160.5	75	2.5	1.23	1.76	2.64	18	26
11	3	160.5	65	2.5	1.23	1.93	2.90	19	29
11	10	160.5	75	2.5	1.23	1.76	2.64	18	26
11	11	160.5	85	2.5	1.16	1.31	1.96	13	20
11	12	160.5	85	2.5	1.16	1.31	1.96	13	20
12	3	160.5	80	2.5	1.21	1.51	2.26	15	23
12	10	160.5	85	2.5	1.16	1.31	1.96	13	20
12	11	160.5	95	2.5	1.08	0.99	1.48	10	15
12	12	160.5	95	2.5	1.08	0.98	1.48	10	15
13	10	160.5	105	2.5	1.01	0.77	1.16	8	12
13	11	160.5	115	2.5	0.96	0.62	0.93	6	9
13	12	160.5	110	2.5	0.98	0.69	1.03	7	10
14	10	160.5	130	2.5	0.90	0.55	0.82	5	8
14	11	160.5	135	2.5	0.90	0.61	0.92	6	9
14	12	160.5	130	2.5	0.90	0.60	0.91	6	9
15	11	160.5	160	2.5	0.92	0.68	1.02	7	10
15	12	160.5	155	2.5	0.91	0.64	0.96	6	10
16	11	160.5	200	2.5	0.77	0.51	0.77	5	8
16	12	160.5	175	2.5	0.96	0.74	1.11	7	11
17	12	160.5	220	2.5	0.57	0.53	0.79	5	8
18	15	160.5	155	2.5	0.63	0.42	0.63	4	6

Table 15A (Cont…) - Predicted Maximum Hogging Curvature and Tensile Strains for Multiple Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Final Panel Hogging Curvature C_{max} (km^{-1})		Final Panel Tensile Strain $+E_{max}$ (mm/m)	
						Mean	**U95%CL**	**Mean**	**U95%CL**
19	13	160.5	100	2.5	1.04	0.85	1.28	9	13
19	14	160.5	110	2.5	0.98	0.69	1.03	7	10
19	15	160.5	190	2.5	0.23	0.39	0.59	4	6
20	13	160.5	75	2.5	1.23	1.76	2.65	18	26
20	14	160.5	125	2.5	0.90	0.58	0.86	6	9
20	15	160.5	240	2.5	0.13	0.40	0.60	4	6
21	13	160.5	95	2.5	1.08	0.98	1.47	10	15
21	14	160.5	90	2.5	1.23	1.23	1.85	12	19
21	15	160.5	240	2.5	0.13	0.39	0.59	4	6
22	13	160.5	85	2.5	1.16	1.30	1.95	13	19
22	14	160.5	100	2.5	1.04	0.87	1.30	9	13
22	15	160.5	230	2.5	0.10	0.37	0.55	4	6
23	13	160.5	75	2.5	1.23	1.76	2.65	18	26
23	14	160.5	115	2.5	0.96	0.63	0.95	6	10
23	15	160.5	230	2.5	0.10	0.20	0.30	2	3
24	13	160.5	95	2.5	1.08	0.98	1.47	10	15
24	14	160.5	155	2.5	0.91	0.61	0.92	6	9
25	13	160.5	105	2.5	1.01	0.76	1.15	8	11
25	14	160.5	145	2.5	0.90	0.60	0.90	6	9
26	13	160.5	110	2.5	0.98	0.68	1.02	7	10
26	14	160.5	135	2.5	0.90	0.59	0.89	6	9
27	13	160.5	115	2.5	0.96	0.62	0.93	6	9
27	14	160.5	135	2.5	0.90	0.65	0.97	6	10
28	13	160.5	135	2.5	0.90	0.63	0.94	6	9
28	14	160.5	140	2.5	0.90	0.65	0.98	7	10
29	13	160.5	180	2.5	0.94	0.76	1.14	8	11
29	14	160.5	200	2.5	0.77	0.47	0.71	5	7
30	13	160.5	240	2.5	0.44	0.38	0.57	4	6
30	14	160.5	290	2.5	0.37	0.41	0.61	4	6
31	13	160.5	350	2.5	0.31	0.52	0.77	5	8
32	5a	160.5	150	2.5	0.90	0.55	0.83	6	8
32	6a	160.5	140	2.5	0.90	0.55	0.83	6	8
32	7a	160.5	160	2.5	0.92	0.56	0.84	6	8

Mean Final Hogging C_{max} = 15.603(Mean Final S_{max})/(Effective Panel Width)^2]
U95%CL Final C_{max} = Mean Final C_{max} + U95%CL error (= 0.5*mean value)
$+E_{max}$ = Maximum Tensile Strain = 10 C_{max} (applies to mean and U95%CL values).

9.9 Maximum Panel Sagging Curvature and Compressive Strains

The maximum first and final sagging curvature and compressive strain predictions for the proposed 160.5 m wide total extraction Panels 1 to 32 and 105 m wide main headings panels based on total extraction (i.e. assuming no SCZs) are summarised in **Table 15B** for the range of cover depths and average panel mining heights of 2.5 m. An assumed maximum extraction ratio of 88% gives an effective mining height of 2.2 m.

Predictions of final maximum sagging curvature values for the pillar extraction panels below the flatter areas with cover depths of 55 m to 185 m, range from 0.70 km^{-1} to 3.69 km^{-1} with maximum tensile strains are estimated to range from 7 to 37 mm/m for the above curvatures and a 'K' factor of 10.

Predictions of final maximum sagging curvature values for the pillar extraction panels below the ridges with cover depths of 155 m to 350 m, range from 0.25 km^{-1} to 1.00 km^{-1} with maximum compressive strains are estimated to range from 3 to 10 mm/m for the above curvatures and a 'K' factor of 10.

Representative first and final sagging curvature and horizontal compressive strain profiles have been prepared along cross lines XL 12 in **Figure 28** (the location of the cross lines is shown in **Figure 1**).

As discussed previously, discontinuous displacements can result in secondary curvatures and strains, which exceed predicted ‘smooth’ profile values by 2 to 4 times occasionally. The discrepancy between the two models is therefore not surprising, as the database will be strongly dependent on surface topography and near surface lithologies.

Table 15B - Predicted Maximum Sagging Curvature and Compressive Strains for Multiple Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Final Panel Sagging Curvature $-C_{max}$ (km^{-1})		Final Panel Compressive Strain $-E_{max}$ (mm/m)	
						Mean	U95%CL	Mean	U95%CL
1	1	160.5	110	2.5	0.98	0.86	1.29	9	13
1	2	160.5	120	2.5	0.93	0.76	1.15	8	11
2	1	160.5	105	2.5	1.01	0.96	1.45	10	14
2	2	160.5	125	2.5	0.90	0.74	1.11	7	11
3	5b	160.5	60	2.5	1.23	2.45	3.68	25	37
3	6b	160.5	75	2.5	1.23	2.23	3.35	22	33
3	7b	160.5	85	2.5	1.16	1.66	2.49	17	25
4	5b	160.5	70	2.5	1.23	2.45	3.67	24	37
4	6b	160.5	80	2.5	1.21	1.91	2.87	19	29
4	7b	160.5	100	2.5	1.04	1.06	1.59	11	16
Mains1	4	105.3	135	2.5	0.58	1.05	1.57	10	16
5	8	160.5	130	2.5	0.90	0.76	1.13	8	11
6	8	160.5	140	2.5	0.90	0.78	1.17	8	12
6	9	160.5	155	2.5	0.91	0.83	1.24	8	12
7	8	160.5	160	2.5	0.92	0.74	1.11	7	11
7	9	160.5	185	2.5	0.90	0.97	1.46	10	15
8	12	160.5	65	2.5	1.23	2.45	3.68	25	37
9	11	160.5	55	2.5	1.23	2.45	3.67	24	37
9	12	160.5	70	2.5	1.23	2.45	3.68	25	37
10	10	160.5	60	2.5	1.23	2.45	3.68	25	37
10	11	160.5	70	2.5	1.23	2.46	3.69	25	37
10	12	160.5	75	2.5	1.23	2.23	3.35	22	34
11	3	160.5	65	2.5	1.23	2.45	3.68	25	37
11	10	160.5	75	2.5	1.23	2.23	3.35	22	34
11	11	160.5	85	2.5	1.16	1.66	2.49	17	25
11	12	160.5	85	2.5	1.16	1.66	2.49	17	25
12	3	160.5	80	2.5	1.21	1.91	2.87	19	29
12	10	160.5	85	2.5	1.16	1.66	2.49	17	25
12	11	160.5	95	2.5	1.08	1.25	1.88	13	19
12	12	160.5	95	2.5	1.08	1.25	1.87	12	19
13	10	160.5	105	2.5	1.01	0.98	1.47	10	15
13	11	160.5	115	2.5	0.96	0.79	1.19	8	12
13	12	160.5	110	2.5	0.98	0.87	1.31	9	13
14	10	160.5	130	2.5	0.90	0.70	1.04	7	10
14	11	160.5	135	2.5	0.90	0.77	1.16	8	12
14	12	160.5	130	2.5	0.90	0.77	1.15	8	12
15	11	160.5	160	2.5	0.92	0.86	1.29	9	13
15	12	160.5	155	2.5	0.91	0.81	1.22	8	12
16	11	160.5	200	2.5	0.77	0.65	0.97	6	10
16	12	160.5	175	2.5	0.96	0.94	1.41	9	14
17	12	160.5	220	2.5	0.57	0.67	1.00	7	10

Table 15B (Cont...) - Predicted Maximum Sagging Curvature and Compressive Strains for Multiple Pillar Extraction Panels

Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Final Panel Sagging Curvature $-C_{max}$ (km^{-1})		Final Panel Compressive Strain $-E_{max}$ (mm/m)	
						Mean	**U95%CL**	**Mean**	**U95%CL**
18	15	160.5	155	2.5	0.63	0.53	0.80	5	8
19	13	160.5	100	2.5	1.04	1.08	1.63	11	16
19	14	160.5	110	2.5	0.98	0.87	1.31	9	13
19	15	160.5	190	2.5	0.23	0.50	0.75	5	7
20	13	160.5	75	2.5	1.23	2.24	3.36	22	34
20	14	160.5	125	2.5	0.90	0.73	1.10	7	11
20	15	160.5	240	2.5	0.13	0.51	0.77	5	8
21	13	160.5	95	2.5	1.08	1.24	1.86	12	19
21	14	160.5	90	2.5	1.23	1.57	2.35	16	23
21	15	160.5	240	2.5	0.13	0.50	0.75	5	7
22	13	160.5	85	2.5	1.16	1.65	2.47	16	25
22	14	160.5	100	2.5	1.04	1.10	1.65	11	16
22	15	160.5	230	2.5	0.10	0.47	0.70	5	7
23	13	160.5	75	2.5	1.23	2.24	3.36	22	34
23	14	160.5	115	2.5	0.96	0.80	1.21	8	12
23	15	160.5	230	2.5	0.10	0.25	0.38	3	4
24	13	160.5	95	2.5	1.08	1.25	1.87	12	19
24	14	160.5	155	2.5	0.91	0.78	1.17	8	12
25	13	160.5	105	2.5	1.01	0.97	1.46	10	15
25	14	160.5	145	2.5	0.90	0.76	1.14	8	11
26	13	160.5	110	2.5	0.98	0.87	1.30	9	13
26	14	160.5	135	2.5	0.90	0.75	1.13	8	11
27	13	160.5	115	2.5	0.96	0.79	1.19	8	12
27	14	160.5	135	2.5	0.90	0.82	1.23	8	12
28	13	160.5	135	2.5	0.90	0.80	1.19	8	12
28	14	160.5	140	2.5	0.90	0.83	1.24	8	12
29	13	160.5	180	2.5	0.94	0.97	1.45	10	15
29	14	160.5	200	2.5	0.77	0.60	0.90	6	9
30	13	160.5	240	2.5	0.44	0.48	0.72	5	7
30	14	160.5	290	2.5	0.37	0.52	0.77	5	8
31	13	160.5	350	2.5	0.31	0.66	0.98	7	10
32	5a	160.5	150	2.5	0.90	0.70	1.05	7	11
32	6a	160.5	140	2.5	0.90	0.70	1.05	7	11
32	7a	160.5	160	2.5	0.92	0.71	1.07	7	11

Mean Final Sagging C_{max} = 19.79(Mean Final S_{max})/(Effective Panel Width)^2]

U95%CL Final C_{max} = Mean Final C_{max} + U95%CL error (= 0.5*mean value)

$-E_{max}$ = Maximum Compressive Strain = 10 C_{max} (applies to mean and U95%CL values).

9.10 Subsidence Effects above Subsidence Control Zones

As details of remnant pillar geometries are unknown at this stage, estimates of subsidence above control zones were derived based on assumed minimum recommended pillar geometries for w/h = 5 and FoS > 1.6 under design loading conditions.

The subsidence effect limits and extent of the zoned areas are in accordance with **Tables 4A** and **4B** for the given features and were used to develop the subsidence parameter contours in **Section 10**.

10.0 Prediction of Subsidence Impact Parameter Contours

10.1 Calibration of the SDPS® Model

Credible worst-case subsidence contours for the proposed pillar extraction panels without SCZs have been generated using SDPS® influence function-based subsidence prediction software.

As there is no readily available subsidence data yet available for the Tasman Extension Project mining area, the SDPS® model was calibrated to the credible worst-case (U95%CL) profiles predicted by the **ACARP, 2003** empirical model. The calibration of the SDPS® model would be revised as part of the Extraction Plan process, if the subsidence monitoring results indicate it is necessary.

The outcome of the model calibration exercise is summarised in **Table 16**.

Table 16 - SDPS® Model Calibration Summary for the Proposed Pillar Extraction Panels

Input Parameters from Modified ACARP, 2003	**Value**
Panel Nos. below XL s 1 - 15 shown in **Figure 1**	Panels 1-32, m1
Panel Void Widths, W (m)	160.5, 105
Cover Depth, H (m)	55 – 350
Maximum Panel Extraction Ratio Assumed, e (%)	88
Actual Mining Height, T (m)	2.5
Effective Mining Height, h (m)	2.2
W/H range	0.46 - 2.92
SRP for Mining Area	Low to High
Maximum Final Panel Subsidence*, S_{max} (m)	0.58 - 1.27
Effective S_{max}/Te Range	0.26 - 0.58
Barrier Pillar Width, w_{cp} (m)	19.5 - 39.5
Roadway width (m)	5.5
Pillar Height, h(m)	2.5
Barrier Pillar Subsidence* S_p (m)	0.03 - 0.17
S_p/h Range	0.01 - 0.07
Distance to Influence Inflexion Point from Rib-Side (m) (d/H)	9 - 47 (0.03 - 0.34)
SDPS Calibration Results for 'Best Fit' Solution to the Modified ACARP, 2003 Model Predictions^	**Optimum Values**
Influence Angle (Tan(beta))	1.73
Influence Angle (beta)	60°
Supercritical Subsidence Factors (S_{max}/T)	0.26 - 0.58
Distance to Influence Inflexion Point from Rib-Side (m) (d/H)	20 - 36 (0.03 - 0.34)

Notes:
* - Upper 95% Confidence Limits predicted from modified version of **ACARP, 2003**
^ - See SDPS manual extract in **Appendix B** for explanation of methodology and terms used.

The predicted **ACARP, 2003** and **SDPS®** model subsidence impact parameter profiles for Panels 8 - 17 along XL 12 have been compared in **Figures 29a** to **29c**.

The predicted **SDPS®** subsidence and tilt profiles were generally located within +/- 10 to 20% of the predicted modified **ACARP, 2003** models U95%CL. This outcome is considered a reasonable fit considering that the **ACARP, 2003** profiles represent measured tilt profiles that are invariably affected by 'skewed' or kinked subsidence profiles.

The results of the analysis indicate that the majority of the predicted convex curvature (and tensile strain) and concave curvature (and compressive strains) predicted by the **SDPS®** model would fall within +/- 50% of the modified **ACARP, 2003** model predictions. This result is also considered reasonable in the context that the **ACARP, 2003** model represents measured profile data that includes strain concentration effects such as cracking and shearing. As mentioned earlier, this 'discontinuous' type of overburden behaviour can increase 'smooth' profile strains by 2 to 4 times occasionally.

10.2 Predicted Subsidence Contours

Based on the calibrated SDPS® model, predictions of final worst-case mean subsidence effect contours (subsidence, tilt, curvature and horizontal strain) for the total pillar extraction panels without SCZs in the West Borehole Seam are presented in **Figures 30a** to **30d**.

The subsidence effect contours for the total pillar extraction panels in the West Borehole Seam with partial pillar extraction and first workings within the proposed SCZs are presented in **Figures 31a** to **31d**.

The predicted subsidence contours above the Tasman Mine panels 1 to 22 in the Fassifern Seam have been derived based on the methodology described in **DgS, 2007a** and are presented in **Figure 32a**.

The cumulative worst-case subsidence effect of the Tasman mine workings in both the Fassifern and West Borehole Seam are presented in **Figures 32b to 32e** (without SCZs) and **Figures 32f to 32i** (with SCZs).

Note: Subsidence contours above the Stockrington Mine workings in the West Borehole Seam (i.e. partial pillar extraction workings) have not been derived at this stage due to the complex nature of the workings. The potential for an additional 200 mm to 400 mm of subsidence has been mentioned previously however, and has therefore been included in a qualitative manner where impact management assessment on sensitive surface features warrants it.

Pre- and cumulative post-mining surface levels for the above SCZ cases are shown in **Figures 33a** and **33b** respectively.

11.0 Subsidence Impacts and Management Strategies

11.1 General

Based on the predicted maximum panel subsidence, tilt and strain values for the total extraction panel layouts, the potential for the following subsidence related impacts and their likely effect on natural and man-made features have been assessed:

- surface cracking;
- height of sub-surface fracturing above the panels (direct and in-direct hydraulic connection zones);
- surface gradient changes;
- ponding;
- general slope stability and erosion;
- valley uplift and closure;
- far-field horizontal displacements and strains;

Based on the observation that a finite range of subsidence effect values can occur at a given location above an extracted total extraction or longwall panel of known mining geometry and geology, it is possible to provide a range of predictions that are likely to occur within a nominal confidence limit (i.e. usually 95%). This approach will allow specialist consultants and stakeholders to apply risk management principles in a practical way.

Discussions of likelihood of impact occurrence in the following sections generally refer to the qualitative measures of likelihood described in **Table 17**, and are based on terms used in **AGS, 2007** and **Vick, 2002**.

As explained in **Appendix A**, the terms ‘mean' and ‘Upper 95% Confidence Limit’ (U95%CL) infer that the predicted maximum subsidence effect values may be exceeded by 50% and 5% of the observations above the mined panels respectively. Therefore on a small number of occasions, the predicted values and impacts may be exceeded due to the presence of adverse or anomalous geological or topographical conditions.

The selection of an appropriate ‘credible worst-case’ is normally defined by the U95%CL value, however, a higher confidence limit may need to be applied in consideration of the reliability of current survey technology, available mitigation techniques or likely response action times should an exceedance occur.

Table 17 - 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.	25-75%
Possible	The event may occur under normal conditions.	10-25%
Unlikely*	The event is conceivable, but only if adverse conditions are present.	5-10%
Very Unlikely	The event probably will not occur, even if adverse conditions are present.	1-5%
Not Credible	The event is inconceivable or practically impossible, regardless of the conditions.	<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 credible worst-case or U95%CL subsidence impact parameter in **ACARP, 2003**.

The predicted impacts and suggested management strategies for the natural and man-made features in the proposed mining area are presented in the following sections.

11.2 Surface Cracking

11.2.1 Predicted Impacts

The development of surface subsidence above total pillar extraction panels is caused by the bending of the overburden strata as it sags down into the newly created void in the workings. The sagging strata are supported in turn by the collapsed immediate roof, which then slowly compresses to a maximum subsidence limit.

The predicted maximum panel subsidence magnitudes of 0.58 m to 1.27 m are likely to result in surface cracks developing within the limits of the extracted panels (without SCZs). Surface cracks are not expected to develop where the proposed SCZs are left in place.

It is ‘very unlikely’ that surface cracks will develop above first workings pillars, where subsidence magnitudes of < 20 mm are expected and ‘unlikely’ where subsidence magnitudes < 300 mm may occur above partial pillar extraction panels. It is not credible that cracks will occur in the Level 4 SCZ due to the 45^o AoD imposed from secondary workings limits.

For the total extraction panels, cracks are likely to develop in the tensile strain zones that will typically occur within an area that extends 9 m to 47 m in from the rib-sides of each panel. Crack widths of up to 10 mm may start to develop at the surface where tensile strains exceed 1 mm/m over a distance of 10 m. The cracks generally develop where maximum tensile strains occur. The tensile cracks will probably be tapered and extend to depths ranging from 5 to 10 m, and possibly deeper if near surface bedrock exposures and steep slopes are present.

Compressive strains > 2 to 3 mm/m can also cause cracking and upward ‘buckling’ of near surface rock beds due to low-angle shear failures. The compressive strains generally peak at one or two locations in the middle third area of the panels.

The maximum tensile strains above the panels beneath the low lying areas are predicted to range from 5 mm/m to 29 mm/m for cover depths of 55 m to 185 m, with 2 mm/m to 8 mm/m predicted beneath the steep slopes and ridges with cover depths of 155 m to 350 m.

Based on the predicted tensile strains, maximum surface crack widths are estimated to range from 50 mm and 300 mm and within the limits of extraction (i.e. goaf) for the full range of cover. Strain concentration in near surface rock could double the above crack widths locally to 100 mm and 600 mm respectively, with the maximum crack widths likely to occur along the high side of an extraction panel that extends below a steep slope.

It should be understood, that 5% of the measured crack widths would be expected to exceed the U95%CL indicated by the subsidence prediction model. These are generally found to be related to the presence of adverse or anomalous geological or topographical conditions.

The predicted range of maximum transverse compressive strains (i.e. 3 to 37 mm/m) may result in shear displacements or 'shoving' of between 30 mm and 370 mm within the central limits of proposed panels. Compressive strain peaks and resultant shoving is also likely to occur on the down-slope side of panels beneath steep slopes.

In addition, tensile cracks of similar magnitudes to those mentioned above will probably develop up to 30 m behind the advancing goaf edge of the total pillar extraction panels. The majority of these cracks are transient however, and some may partially close in the central areas of the panels, where permanent compressive strains develop after mining is completed. The typical crack pattern development behind a retreating pillar extraction face is presented in **Figure 34**.

Based on the similarity in width observed between the transient and final cracks to-date at the Abel Mine and the measured average retreat rates of 23 m/week to 37 m/week, it is assessed that the extraction face does not move fast enough for transient crack width reduction to occur generally. The face retreat rates can also vary significantly from < 10 m/week to 50 m/week, depending on mine roof conditions and operational factors, so it is possible that transient cracking will vary between dynamic and final static magnitudes.

It has therefore been assumed in this study that the transient crack widths will be similar in width to final subsidence crack width predictions above the proposed Tasman Extension Project panels.

11.2.2 Impact Management Strategies

For Level 1 SCZs (i.e. total extraction areas), surface crack repair works may need to be implemented around the affected areas of the site, and in particular, where public roads and 1st and 2nd order ephemeral watercourses at depths > 80 m are present.

The decision on whether crack repairs need to be undertaken will depend upon the perceived risk to public safety, the potential for self-healing or long-term degradation, site accessibility to effect repairs or the requirements of the stakeholder agreement.

General crack repairs in the flatter areas may involve ripping, backfilling and top dressing works or the pouring of cement-based grout, crushed rock into the wider, deeper cracks.

For the 1st and 2nd Order Creeks with cover depths > 80 m, the following remediation strategies are proposed:

- Undertake pre-mining and post-mining inspections along the creek, with the results of these inspections communicated to the stakeholders through Extraction Plans and End of Year Reports.

- Trigger Action Response Plans and remediation strategies would be developed and outlined in Extraction Plans.

- Consultation with relevant government agencies at other mine sites has suggested that natural regeneration may be the favoured management strategy in most scenarios, due to the likely level of disturbance caused by other remediation strategies, such as back filling with imported, free-draining materials from haulage trucks.

Based on the proposed performance measures and SCZs, surface cracking is unlikely to occur within 1st and 2nd Order Streams with depth of cover < 80 m, MU1a and MU5 GDEs, Hunter Lowlands Redgum Forest, steep slopes and cliff lines. Notwithstanding, Extraction Plans will include Trigger Action Response Plans and remediation strategies for the rare event that a significant crack does occur.

Crack repairs on steep slopes will probably require the use of tracked equipment and should consider the potential for water ingress into the slope and large-scale instability to develop. Sealing of cracks on steep slopes may also require the use of erosion resistant materials such as sand-cement grout.

In regards to the 3rd Order tributary areas of Surveyors Creek No. 2, surface cracking will be limited by the panel geometries and proposed first working buffer zones. It is considered 'very unlikely' that surface cracks will develop along the creek bed; however Extraction Plans will include Trigger Action Response Plans.

11.3 Sub-Surface Cracking

11.3.1 Sub-Surface Fracturing Zones

The caving and subsidence development processes above a longwall or pillar extraction panel usually results in sub-surface fracturing and shearing of sedimentary strata in the overburden, see **Figure 35a**. The extent of fracturing and shearing is dependent on mining geometry and overburden geology.

International and Australian research on longwall mining interaction with groundwater systems indicates that the overburden may be divided into essentially three or four zones of surface and subsurface fracturing. The zones are generally defined (in descending order) as:

- Surface Zone
- Continuous or Constrained Zone
- Fractured Zone
- Caved Zone

Starting from the seam level, the Caved Zone refers to the immediate mine workings roof above the extracted panel, which has collapsed into the void left after the coal seam has been extracted. The Caved Zone usually extends for 3 to 5 times the mining height above the roof of the mine workings.

The Fractured Zone has been affected by a high degree of bending deformation, resulting in significant fracturing and bedding parting separation and shearing. The Fractured Zone is supported by the collapsed material in The Caved Zone, which usually has a bulked volume equal to 1.2 to 1.5 times its undisturbed volume.

The Continuous or Constrained Zones refer to the section of overburden which has also been deformed by bending action, but to a lesser degree than the Fractured Zone below it.

The Surface Zone includes the tensile and compressive surface cracking caused by mine subsidence and is assumed to extend to depths of 5 to 10 m in the Newcastle Coalfield.

Based on reference to **Whittaker, Gaskell and Reddish, 1990** and **ACARP, 2003**, the impact of mining on the sub-surface aquifers and surface waters, requires an estimate of the '*Continuous*' and '*Discontinuous*' heights of fracturing or the A and B Zones - shown schematically in **Figure 35b**.

Continuous sub-surface fracturing (A-Zone) refers to the zone of cracking above a longwall or pillar extraction panel that is likely to result in a direct flow-path or hydraulic connection to the workings, if a sub-surface (or shallow surface) aquifer was intersected.

Discontinuous sub-surface fracturing (B-Zone) refers to the zone above the A-Zone where there could be a general increase in horizontal and vertical rock mass permeability, due to bending or curvature deformation of the overburden. This type of fracturing does not usually provide a direct flow path or connection to the mine workings like the A-Zone; however, it is possible that B-Zone fracturing may interact with surface cracks, joints, or faults. This type of fracturing can therefore result in an adjustment to surface and sub-surface flow paths, but may not result in a significant change to the groundwater or surface water resource in the long-term.

In regards to the general zones of fracturing mentioned earlier, the A-Zone may be assumed to include the Caved and Fractured Zones, and the B-Zone will develop in the Constrained Zone. Both A and B-Zones can extend to the Surface Zone and will depend on the mining height, cover depth, geology and panel width.

Two empirically-based models (**Forster, 1995** and **ACARP, 2003**) and have been used in this study to predict the A and B-Zone heights of sub-surface fracturing within the study area.

The **Forster, 1995** model was developed from deep multi-piezometer data from subsided overburden in the Central-Coast area of the Newcastle Coalfield and indirectly defines the A- and B-Zones as a function of the mining height (the model refers to the A and B-Zones as the tops of the Fractured and Confined Zones respectively - see **Figure 35b** for the model fracture zone definitions).

The **Forster, 1995** model predicts that the height of the Fractured or A-Zone will generally range between 21 and 33 times the mining height (T). The predicted extent or height of the Confined or B-Zone and its thickness will be dependent on the cover depth and height of A-Zone fracturing. A similar US version of the **Forster, 1995** model indicates that the height of continuous fracturing could range between 10T and 24T with discontinuous fracturing from 24T to 60T. A comment is made in a paper by **Mark, 2007**, that the “variation is also probably due to differences in geology and panel geometry”.

The **ACARP, 2003** model was derived from the **Forster, 1995** Model data, and supplemented with drilling fluid loss records from surface to seam drilling logs in subsided, fractured overburden from the NSW Southern Coalfield and Oaky Creek Mine in the Bowen Basin (**Colwell, 1993**).

The **ACARP, 2003** model includes several of the key parameters defined by **Whittaker and Reddish, 1989** and referred to in **Mark, 2007**. The additional parameters include the panel width, cover depth, maximum single panel subsidence and geological conditions (i.e. Subsidence Reduction Potential [SRP]). The mining height is not applied directly, but indirectly through the subsidence prediction (further model development details may be found in **Appendix A**).

The measured data in **ACARP, 2003** has been plotted as the height of A or B-Zone fracturing /cover depth v. S_{max}/Effective Panel Width^2. A log-normal regression line has subsequently been derived to give predictions of mean and U95%CL values for both fracture zones.

For partial pillar extraction cases, the predicted maximum subsidence of 300 mm may be substituted into the **ACARP, 2003** model to provide a conservative indication of fracture heights above the panels. In the **Forster, 1995** model, the effective mining height based on the proposed extraction ratio should be used.

11.3.2 Sub-Surface Fracture Height Predictions

The predicted values for the **ACARP, 2003** model's continuous and discontinuous sub-surface fracturing heights above the proposed total pillar extraction panels are summarised in **Table 18** and presented in **Figures 36a** and **36b**.

Table 18 - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed Total Pillar Extraction Panels

Panel No.	XL	Cover Depth H (m)	Panel Width W (m)	First Panel S_{max} (mean) (m)	Panel S_{max}/W'^2 (mean) (mm/m^2 or km^{-1})	Predicted Fracture Heights (m)					
						Continuous Fracture Zone (A Horizon)				Discontinuous Fracture Zone (B Horizon)	
						ACARP, 2003 (mean - U95%CL)		Forster, 1995) (21-33Te)		ACARP, 2003 Model (mean - U95%CL)	
1	1	110	160.5	0.98	0.041	44	74	46	73	93	*112*
1	2	120	160.5	0.93	0.036	44	77	46	73	98	*119*
2	1	105	160.5	1.01	0.047	45	73	46	73	91	*109*
2	2	125	160.5	0.90	0.035	45	79	46	73	102	*123*
3	5b	60	160.5	1.23	0.123	39	**55**	46	**73**	62	*72*
3	6b	75	160.5	1.23	0.112	47	**67**	46	**73**	76	*89*
3	7b	85	160.5	1.16	0.082	47	70	46	73	81	*96*
4	5b	70	160.5	1.23	0.123	46	**64**	46	**73**	72	*84*
4	6b	80	160.5	1.21	0.096	48	69	46	73	79	*93*
4	7b	100	160.5	1.04	0.053	46	73	46	73	88	*106*
M1	4	135	105.3	0.58	0.052	61	98	46	73	119	*143*
5	8	130	160.5	0.90	0.035	47	82	46	73	106	*128*
6	8	140	160.5	0.90	0.035	51	88	46	73	114	*138*
6	9	155	160.5	0.91	0.035	57	98	46	73	126	*153*
7	8	160	160.5	0.92	0.036	59	102	46	73	131	*159*
7	9	185	160.5	0.90	0.035	67	117	46	73	150	*183*
8	12	65	160.5	1.23	0.123	42	**60**	46	**73**	67	*78*
9	11	55	160.5	1.23	0.123	36	**51**	46	**73**	56	*66*
9	12	70	160.5	1.23	0.123	46	**64**	46	**73**	72	*84*
10	10	60	160.5	1.23	0.123	39	**55**	46	**73**	62	*72*
10	11	70	160.5	1.23	0.123	46	**64**	46	**73**	72	*84*
10	12	75	160.5	1.23	0.112	47	**67**	46	**73**	76	*89*
11	3	65	160.5	1.23	0.123	42	**60**	46	**73**	67	*78*
11	10	75	160.5	1.23	0.112	47	**67**	46	**73**	76	*89*
11	11	85	160.5	1.16	0.082	47	70	46	73	81	*96*
11	12	85	160.5	1.16	0.082	47	70	46	73	81	*96*
12	3	80	160.5	1.21	0.096	48	69	46	73	79	*93*
12	10	85	160.5	1.16	0.082	47	70	46	73	81	*96*
12	11	95	160.5	1.08	0.061	47	72	46	73	86	*103*
12	12	95	160.5	1.08	0.061	47	72	46	73	86	*103*
13	10	105	160.5	1.01	0.047	45	73	46	73	91	*109*
13	11	115	160.5	0.96	0.037	43	74	46	73	95	*115*
13	12	110	160.5	0.98	0.041	44	74	46	73	93	*112*
14	10	130	160.5	0.90	0.035	47	82	46	73	106	*128*
14	11	135	160.5	0.90	0.035	49	85	46	73	110	*133*

Table 18 (Cont…) - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed Total Pillar Extraction Panels

Panel No.	**XL**	**Cover Depth H (m)**	**Panel Width W (m)**	**First Panel S_{max} (mean) (m)**	**Panel S_{max}/W'^{2} (mean) (mm/m^2 or km^{-1})**	**Predicted Fracture Heights (m)**					
						Continuous Fracture Zone (A Horizon)				**Discontinuous Fracture Zone (B Horizon)**	
						ACARP, 2003 (mean - U95%CL)		**Forster, 1995**) (21-33Te)		**ACARP, 2003** Model (mean - U95%CL)	
14	12	130	160.5	0.90	0.035	47	82	46	73	106	*128*
15	11	160	160.5	0.92	0.036	59	102	46	73	131	*159*
15	12	155	160.5	0.91	0.035	57	98	46	73	126	*153*
16	11	200	160.5	0.77	0.030	65	119	46	73	157	*192*
16	12	175	160.5	0.96	0.037	66	113	46	73	144	*175*
17	12	220	160.5	0.57	0.022	56	115	46	73	161	200
18	15	155	160.5	0.63	0.024	43	85	46	73	116	144
19	13	100	160.5	1.04	0.053	46	73	46	73	88	*106*
19	14	110	160.5	0.98	0.041	44	74	46	73	93	*112*
19	15	190	160.5	0.23	0.009	10	61	46	73	111	144
20	13	75	160.5	1.23	0.112	47	**67**	46	**73**	76	*89*
20	14	125	160.5	0.90	0.035	45	79	46	73	102	*123*
20	15	240	160.5	0.13	0.005	22	43	46	73	115	157
21	13	95	160.5	1.08	0.061	47	72	46	73	86	*103*
21	14	90	160.5	1.23	0.078	49	73	46	73	85	*101*
21	15	240	160.5	0.13	0.005	22	43	46	73	115	157
22	13	85	160.5	1.16	0.082	47	70	46	73	81	96
22	14	100	160.5	1.04	0.053	46	73	46	73	88	*106*
22	15	230	160.5	0.10	0.004	15	30	46	73	102	142
23	13	75	160.5	1.23	0.112	47	**67**	46	**73**	76	*89*
23	14	115	160.5	0.96	0.037	43	74	46	73	95	*115*
23	15	230	160.5	0.10	0.004	15	30	46	73	102	142
24	13	95	160.5	1.08	0.061	47	72	46	73	86	*103*
24	14	155	160.5	0.91	0.035	57	98	46	73	126	*153*
25	13	105	160.5	1.01	0.047	45	73	46	73	91	*109*
25	14	145	160.5	0.90	0.035	53	92	46	73	118	*143*
26	13	110	160.5	0.98	0.041	44	74	46	73	93	*112*
26	14	135	160.5	0.90	0.035	49	85	46	73	110	*133*
27	13	115	160.5	0.96	0.037	43	74	46	73	95	*115*
27	14	135	160.5	0.90	0.035	49	85	46	73	110	*133*
28	13	135	160.5	0.90	0.035	49	85	46	73	110	*133*
28	14	140	160.5	0.90	0.035	51	88	46	73	114	*138*
29	13	180	160.5	0.94	0.036	67	115	46	73	148	*179*
29	14	200	160.5	0.77	0.030	65	119	46	73	157	*192*
30	13	240	160.5	0.44	0.017	48	112	46	73	166	208
30	14	290	160.5	0.37	0.014	45	123	46	73	192	242
31	13	350	160.5	0.31	0.012	40	134	46	73	220	282
32	5a	150	160.5	0.90	0.035	54	95	46	73	122	148

Heights of fracturing based on effective mining heights Te= 0.85T; Effective Panel Width = lesser of actual width and 1.4H (i.e. the super-critical width).

Bold - Mean or U95%CL A-Horizon prediction is within 10 m of the surface.

Italics - Mean or U95%CL B-Horizon prediction is within 10 m of surface.

The predicted values for the **ACARP, 2003** model's continuous and discontinuous sub-surface fracturing heights above the proposed partial pillar extraction panels (with 60% extraction ratio and 300 mm of maximum subsidence assumed) are summarised in **Table 19** and presented in **Figures 36c** and **36d**.

Table 19 - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed Partial Pillar Extraction Panels

Panel No.	**XL**	**Cover Depth H (m)**	**Panel Width W (m)**	**First Panel S_{max} (mean) (m)**	**Panel S_{max}/W'^2 (mean) (mm/m^2 or km^{-1})**	**Predicted Fracture Heights (m)**					
						Continuous Fracture Zone (A Horizon)				**Discontinuous Fracture Zone (B Horizon)**	
						ACARP, 2003 (mean - U95%CL)		**Forster, 1995**) (21-33Te)		**ACARP, 2003** Model (mean - U95%CL)	
1	1	110	160.5	0.30	0.013	14	44	32	50	70	90
1	2	120	160.5	0.30	0.012	13	45	32	50	75	96
2	1	105	160.5	0.30	0.014	16	44	32	50	69	87
2	2	125	160.5	0.30	0.012	14	47	32	50	78	100
3	5b	60	160.5	0.30	0.030	20	36	32	50	47	*58*
3	6b	75	160.5	0.30	0.027	23	43	32	50	58	*71*
3	7b	85	160.5	0.30	0.021	21	44	32	50	62	77
4	5b	70	160.5	0.30	0.030	23	42	32	50	55	*67*
4	6b	80	160.5	0.30	0.024	22	44	32	50	60	74
4	7b	100	160.5	0.30	0.015	17	44	32	50	67	85
M1	4	135	105.3	0.15	0.014	20	56	32	50	88	112
5	8	130	160.5	0.30	0.012	14	49	32	50	81	104
6	8	140	160.5	0.30	0.012	15	53	32	50	88	112
6	9	155	160.5	0.30	0.012	17	59	32	50	97	124
7	8	160	160.5	0.30	0.012	18	61	32	50	100	128
7	9	185	160.5	0.30	0.012	20	70	32	50	116	148
8	12	65	160.5	0.30	0.030	21	39	32	50	51	*63*
9	11	55	160.5	0.30	0.030	18	33	32	50	43	*53*
9	12	70	160.5	0.30	0.030	23	42	32	50	55	*67*
10	10	60	160.5	0.30	0.030	20	36	32	50	47	*58*
10	11	70	160.5	0.30	0.030	23	42	32	50	55	*67*
10	12	75	160.5	0.30	0.027	23	43	32	50	58	*71*
11	3	65	160.5	0.30	0.030	21	39	32	50	51	*63*
11	10	75	160.5	0.30	0.027	23	43	32	50	58	*71*
11	11	85	160.5	0.30	0.021	21	44	32	50	62	77
11	12	85	160.5	0.30	0.021	21	44	32	50	62	77
12	3	80	160.5	0.30	0.024	22	44	32	50	60	74
12	10	85	160.5	0.30	0.021	21	44	32	50	62	77
12	11	95	160.5	0.30	0.017	19	44	32	50	66	82
12	12	95	160.5	0.30	0.017	19	44	32	50	66	82
13	10	105	160.5	0.30	0.014	16	44	32	50	69	87
13	11	115	160.5	0.30	0.012	13	44	32	50	72	92
13	12	110	160.5	0.30	0.013	14	44	32	50	70	90
14	10	130	160.5	0.30	0.012	14	49	32	50	81	104
14	11	135	160.5	0.30	0.012	15	51	32	50	85	108
14	12	130	160.5	0.30	0.012	14	49	32	50	81	104
15	11	160	160.5	0.30	0.012	18	61	32	50	100	128
15	12	155	160.5	0.30	0.012	17	59	32	50	97	124
16	11	200	160.5	0.30	0.012	22	76	32	50	125	160
16	12	175	160.5	0.30	0.012	19	66	32	50	110	140
17	12	220	160.5	0.30	0.012	24	83	32	50	138	176
18	15	155	160.5	0.30	0.012	17	59	32	50	97	124
19	13	100	160.5	0.30	0.015	17	44	32	50	67	85
19	14	110	160.5	0.30	0.013	14	44	32	50	70	90
19	15	190	160.5	0.30	0.012	21	72	32	50	119	152
20	13	75	160.5	0.30	0.027	23	43	32	50	58	*71*
20	14	125	160.5	0.30	0.012	14	47	32	50	78	100
20	15	240	160.5	0.30	0.012	26	91	32	50	150	192
21	13	95	160.5	0.30	0.017	19	44	32	50	66	82
21	14	90	160.5	0.30	0.019	20	44	32	50	64	80

Table 19 (Cont…) - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed Partial Pillar Extraction Panels

Panel No.	XL	Cover Depth H (m)	Panel Width W (m)	First Panel S_{max} (mean) (m)	Panel S_{max}/W'^2 (mean) (mm/m^2 or km^{-1})	Predicted Fracture Heights (m)					
						Continuous Fracture Zone (A Horizon)				Discontinuous Fracture Zone (B Horizon)	
						ACARP, 2003 (mean - U95%CL)		**Forster, 1995**) (21-33Te)		**ACARP, 2003** Model (mean - U95%CL)	
21	15	240	160.5	0.30	0.012	26	91	32	50	150	192
22	13	85	160.5	0.30	0.021	21	44	32	50	62	77
22	14	100	160.5	0.30	0.015	17	44	32	50	67	85
22	15	230	160.5	0.30	0.012	25	87	32	50	144	184
23	13	75	160.5	0.30	0.027	23	43	32	50	58	*71*
23	14	115	160.5	0.30	0.012	13	44	32	50	72	92
23	15	230	160.5	0.30	0.012	25	87	32	50	144	184
24	13	95	160.5	0.30	0.017	19	44	32	50	66	82
24	14	155	160.5	0.30	0.012	17	59	32	50	97	124
25	13	105	160.5	0.30	0.014	16	44	32	50	69	87
25	14	145	160.5	0.30	0.012	16	55	32	50	91	116
26	13	110	160.5	0.30	0.013	14	44	32	50	70	90
26	14	135	160.5	0.30	0.012	15	51	32	50	85	108
27	13	115	160.5	0.30	0.012	13	44	32	50	72	92
27	14	135	160.5	0.30	0.012	15	51	32	50	85	108
28	13	135	160.5	0.30	0.012	15	51	32	50	85	108
28	14	140	160.5	0.30	0.012	15	53	32	50	88	112
29	13	180	160.5	0.30	0.012	20	68	32	50	113	144
29	14	200	160.5	0.30	0.012	22	76	32	50	125	160
30	13	240	160.5	0.30	0.012	26	91	32	50	150	192
30	14	290	160.5	0.30	0.012	32	110	32	50	182	232
31	13	350	160.5	0.30	0.012	39	133	32	50	219	281
32	5a	150	160.5	0.30	0.012	54	95	46	73	122	148

Heights of fracturing based on effective mining heights Te= 0.6T; Effective Panel Width = lesser of actual width and 1.4H (i.e. the super-critical width); **Bold** - Mean or U95%CL A-Horizon prediction is within 5 m of the surface; *Italics* - Mean or U95%CL B-Horizon prediction is within 5 m of surface; *Note: Surface cracking is not expected to occur above partial pillar extraction panels, so 10 m rule may be reduced to 5 m.*

11.3.3 Discussion of A-Zone Horizon Model Predictions Above Total Pillar Extraction Panels

The **ACARP, 2003** model's predictions for the mean A-Zone horizon above the proposed total pillar extraction panels (see **Figure 36b**) are likely to be within 10 m of the surface if mining occurred at cover depths of < 50 m, regardless of any adverse conditions (such as a fault) being present.

For panel cover depths of between 55 m and 79 m, the predicted U95%CL A-Zone horizon values are within 10 m of the surface, and it is considered that the potential for connective cracking to within 10 m of the surface is 'possible'.

The **Forster, 1995** model indicates a similar range of connective cracking heights 46 m to 73 m above the workings.

Connective cracking to the surface is considered 'unlikely' for depths of cover between 80 m and 100 m as the U95%CL values for A-Zone Horizon are predicted to range between 11 m and 27 m from the surface. Connective cracking is considered 'very unlikely' for cover depths ranging from 100 m to 250 m with the A-Zone Horizon predicted to be 27 m to 125 m below the surface.

11.3.4 Discussion of B-Zone Horizon Model Predictions Above Total Pillar Extraction Panels

The **ACARP, 2003** model predicts that the *mean* B-Zone Horizon values will occur within 10 m of the surface for cover depths < 100 m above the total pillar extraction panels for the given mining geometries (**Table 18**). *Discontinuous sub-surface fracturing* for these panels is considered 'likely' to interact with surface cracks.

The predicted *U95%CL* B-Horizon values are all within 10 m of the surface for cover depths < 200 m. It is therefore assessed that surface water impacts from *Discontinuous sub-surface fracturing* interaction will be ‘possible’ where cover depths range between 100 m and 200 m.

Mark, 2007 indicates that the height of *Discontinuous fracturing* could range between 53 m to 132 m above the workings depending on geology.

Therefore, it may be assumed that in areas of shallow or exposed surface rock, creek flows may be re-routed to below-surface pathways and re-surface down-stream of the total pillar extraction mining limits where cover depth is <200 m.

11.3.5 Discussion of A-Zone Horizon Model Predictions Above Partial Pillar Extraction Panels

The **ACARP, 2003** model's predictions for the A-Zone horizon above the proposed partial pillar extraction panels (see **Figures 36c** and **36d**) range from 18 to 22 m (mean) and 33 to 44 m (U95%CL) for cover depths of 55 m to 80 m. Direct cracking is therefore very unlikely to occur within 10 m of the surface regardless of any adverse conditions (such as a fault) being present.

The **Forster, 1995** model indicates a similar range of connective cracking heights 32 m to 50 m above the workings.

Connective cracking to the surface is therefore considered 'unlikely' to ‘very unlikely’ for depths of cover between 60 m and 80 m, as the U95%CL values for A-Zone Horizon are predicted to range between 17 m and 36 m from the surface.

The above analysis outcomes are also conservative as it is unlikely that surface cracking will develop above areas where maximum panel subsidence is < 300 mm.

11.3.6 Discussion of B-Zone Horizon Model Predictions Above Partial Pillar Extraction Panels

The **ACARP, 2003** model predicts that the B-Zone Horizon values will occur within 5 m of the surface for cover depths < 80 m above the partial pillar extraction panels for the given mining geometries. *Discontinuous sub-surface fracturing* for these panels is considered 'likely' to interact with surface cracks if they occur.

In areas of shallow or exposed surface rock, creek flows may be re-routed to below-surface pathways and re-surfacing down-stream of the mining extraction limits in these areas. As discussed in the previous section, it is considered ‘very unlikely’ however, that the surface flows will then interact with the A-Zone fractures and retort to the mine workings.

11.3.7 Impact on Rock Mass Permeability

In regards to changes to rock mass permeability, **Forster, 1995** indicates that horizontal permeability in the fractured zones above longwall mines (see **Figure 35b**) could increase by 2 to 4 orders of magnitude (e.g. pre-mining $k_h = 10^{-9}$ to 10^{-10} m/s; post-mining $k_h = 10^{-7}$ to 10^{-6} m/s).

Vertical permeability could not be measured directly from the boreholes but could be inferred by assuming complete pressure loss in the ‘A-Zone’, where direct hydraulic connection to the workings occurs. Only a slight increase in the ‘B-Zone’ or indirect / discontinuous fracturing develops (mainly due to increase in storage capacity) from bedding parting separation. It is possible however, that minor vertical flows will occur from B-Zone into the A-Zone (and workings) as well.

Discontinuous fracturing would be expected to increase rock mass storage capacity and horizontal permeability without direct hydraulic connection to the workings. Rock mass permeability is unlikely to increase significantly outside the limits of extraction.

11.3.8 Discussion of Prediction Model Uncertainties

In regards to prediction model uncertainty, both models are consistent in that they indicate surface connection could occur for cover depths up to 80 m due to potential interaction with surface cracks.

However, it is clear from the database on which the models were derived, that there is a high degree of variability in the data. This means that there will always be uncertainty in predicting the A and B-Zone horizons using any of the available models. The measurement of sub-surface fracturing and their impact on groundwater should therefore be undertaken in non-sensitive areas or cognisance made of all available local information at nearby mine sites. An adaptive management approach should be adopted to avoid continuous fracturing beneath streams to achieve the performance measures in Table 4B. Height of fracturing and groundwater response to total extraction panels has been measured over the first two panels at the Abel Mine, and has been referred to here for the purpose of validating the prediction models applied in this study; see **Section 11.3.9**.

11.3.9 Measured v. Predicted Heights of Fracturing above Panels 1 and 2 at Abel Mine

The measured heights of fracturing zones (A and B Zones) above Panels 1 and 2 at the nearby Abel Mine were based on deep borehole extensometer anchor displacements, vibrating wire piezometers and shallow slotted standpipe measurements. The locations of the monitoring bores are shown in **Figure 37**.

It is considered that the geological conditions and proposed mining geometries at the Abel Mine and Tasman Extension Project are similar and that the height of fracturing data from Abel may be used to validate the Tasman Extension Project predictions at this stage. Local data will also be required to be obtained at the Tasman Extension Project site to review the predictions.

Pre- and post-mining piezometric head and extensometer measurements are summarised in **Tables 20A** and **20B**. Plots of the data are presented in **Figures 38a** to **38f**.

Table 20A - Summary of Measured Deep and Shallow Piezometric Levels above Panels 1 and 2 at Abel Mine

Piezo #	**Panel No.**	**Depth of Cover H (m)**	**Piezometer Locations (m)**		**Pre-mining Piezometric Heads (m)**		**Post-mining Piezometric Heads (m)**		**Head Drop (m)**	**Fracture Zone***
			DBG	**y**	**DBG**	**y**	**DBG**	**y**	**dh**	
Bore 1	1	99.3	**30**	69.3	**17.2**	82.1	**>28.4**	<70.9	**>11.1**	B
Piezo 1	1	99.3	**35**	64.3	**19.6**	79.7	**34.9**	64.4	**15.3**	B
			55	44.3	**22.5**	76.8	**>50.5**	<48.9	**>27.9**	A
			75	24.3	**29.6**	69.8	**>70.4**	<28.9	**>40.9**	A
Bore 2	2	73.2	**30**	43.2	**16.7**	56.5	**21.2**	52.0	**4.5**	B
Piezo 2	2	73.2	**30**	43.2	**9.3**	63.9	**>29.0**	<44.3	**>19.7**	A
			50	23.2	**20.9**	52.3	**>47.6**	<25.6	**>26.7**	A
			70	3.2	**34.4**	38.8	**>59.8**	<13.4	**>25.4**	A

DBG = depth below ground.
y = height above workings.
> or < indicates groundwater depth or level above workings has fallen below piezometer.
* - see **Section 11.3.1** for definitions.

The deep piezometers (Piezo 1 and 2) in the boreholes to the south of Panel 1 and east of Panel 2 respectively, indicated that there are three distinct semi-confined aquifers of thinly interbedded bedded sandstone/siltstone overburden strata that are separated by claystone/mudstone aquitards. The aquifers are gravity fed by seepages into strata unit sub-crops to the north.

Pre-mining piezometric heads in Piezo 1 were 79.7 m, 76.8 m and 69.8 m above the workings The shallow piezometer (Bore 1) in next to Panel 1 consists of a 30 m deep PVC standpipe with a 3 m to 6 m slotted screen, gavel packing and a bentonite seal. Groundwater level measurements in Bore 1 indicated an uppermost aquifer level of 82.1 m, which was similar to the piezometric head level indicated by the adjacent deep bore piezometer (Piezo 1).

Piezo 2 to the north east of Piezo 1 indicated that the three aquifers in the overburden had pre-mining piezometric heads above the workings of 63.9 m, 52.3 m and 32.8 m. The shallow standpipe piezometer (Bore 2) indicated a piezometric head above the workings of 56.5 m in the uppermost aquifer; however this was 7.4 m below the deep piezo cell water level reading at the same depth. On closer inspection of the borehole locations in **Figure 37** it would appear that the shallow piezometer is located east of a NW trending fault line and the deep piezometer is located to the west of it. It is considered possible that there is a disconnect between the groundwater levels on either side of the fault.

After extraction of Panel 1, the piezometric heads dropped 15.3 m in the uppermost aquifer and > 27.9 m and > 40.9 m in the lower aquifers (i.e. the piezometric levels dropped below the cells at these depths). The deep borehole piezometric heads above Panel 2 dropped >19.74 m in the uppermost aquifer and > 26.7 m and > 25.4 m in the lower aquifers. The response of the groundwater levels in the standpipe piezometer to the east of the fault appears to be slower than the deep borehole piezometer, with a total head loss of only 4.5 m occurring to-date.
Again, there appears to be a discrepancy in the groundwater level responses between the two instruments in the upper aquifer adjacent to Panel 2.

In general, the likely causes of the piezometric head drops above both panels is primarily linked to the development of A and B Zone Fracturing above each panel; see **Table 20B**.

Table 20B - Summary of Measured Deep Borehole Extensometer Anchor Displacements above Panels 1 and 2

Exto #	Panel No.	Depth of Cover H (m)	Anchor Location DBG (m)	Anchor Location y (m)	Maximum Anchor Displacement (mm)	Fracture Zone*
Exto 1	1	95	10	85	14	B
			20	75	13	B
			30	65	31	B
			40	55	27	B
			50	**45**	**33**	**B/A**
			60	35	1351	A
			70	25	868	A
			80	15	734	A
Exto 2	2	76	10	66	-13	B
			20	56	-19	B
			30	**46**	**-18**	**B/A**
			40	36	n.m.	A
			50	26	298	A
			60	16	78	A
			70	6	264	A

DBG = depth below ground
y = height above workings.
* - see **Section 11.3.1** for definitions.

The maximum anchor displacements in **Table 20B** are relative displacements and indicate strata dilation or separation of sagging rock beds over extracted areas; see **Figures 38c** and **38f**. The extensometer data clearly defines the boundary between the Continuous or Constrained Zone of elastic bending above the workings, and the Fractured and Caved Zones below it.

The piezometric data generally show (i) complete head drop in the Fractured Zone where continuous fracturing to the workings has developed (i.e. the A-Zone), and (ii) partial head loss or lowering of the groundwater table in the Constrained Zone, where dilation of strata or bed separations have increased the available storage volumes for groundwater in the affected aquifers (i.e. The B-Zone).

It should also be understood however, that some leakage of the upper aquifer in the B Zone may also be occurring into the A Zone, and this may therefore result in complete drainage of the upper aquifer in the short to medium term. The presence and characteristics of geological structure also appears to be affecting the response of the groundwater regime however, with the piezometer west of the NW fault line indicating drainage to the Continuous Fracture zone with a slower, perched aquifer type response to the east of the fault.

Comparison between predicted v. measured heights of sub-surface fracturing zones above Panels 1 and 2 in SMP Area 1 have been assessed for model validation purposes.
The predicted values of A and B Zone Horizons are summarised in **Table 20C** and compared to measured values in **Table 20D**. Graphical comparisons are also presented in **Figures 38g** and **38h**.

Table 20C - Summary of Predicted Sub-Surface Fracturing Heights above the Panels 1 and 2 in Area 1 Pillar Extraction Panels at Abel Mine

Panel No.	**Cover Depth H (m)**	**Panel Width W (m)**	**Effective Mining Height Te (m)**	**First Panel S_{max} (mean) (m)**	**Panel S_{max}/W'^2 (mean) (mm/m^2 or km^{-1})**	**Predicted Fracture Heights (m)**					
						Continuous Fracture Zone (A Horizon)				**Discontinuous Fracture Zone (B Horizon)**	
						ACARP, 2003 Model (mean - U95%CL)		**Forster, 1995**) (21-33Te)		**ACARP, 2003** Model (mean - U95%CL)	
1	95	120	2.55	1.03	0.071	50	76	54	84	*89*	*105*
2	76	150	1.88	1.02	0.045	44	64	39	62	74	*87*

Table 20D - Summary of Predicted v Measured Sub-Surface Fracturing Heights above the Panels 1 and 2 in Area 1 Pillar Extraction Panels at Abel Mine

Panel No.	**Panel Width W (m)**	**Cover Depth H (m)**	**Effective Mining Height Te (m)**	**First Panel S_{max} (m)**		**Continuous Fracture Zone (A Horizon)**		**Discontinuous Fracture Zone (B Horizon)**	
				P	**M**	**P**	**M***	**P**	**M**
1	120	95	2.55	1.03	0.96	50 - 76	47	89 - *95*	*85- 95*
2	150	76	1.88	1.02	1.02	44 - 64	45	74 - *76*	*66- 76*

P - Predicted; M - Measured.
italics - strata dilation of <13 mm indicated at 10 m depth below surface suggests that interaction of B Zone with surface cracks is possible.
* - Height of continuous fracturing may increase with time due to leakage from B-Zone.

The measurement of the A-Zone horizon above Panels 1 and 2 indicates the height of continuous sub-surface fracturing in the Fractured Zone has extended up to between 45 and 50 m above the 120 m and 150 m wide panels with cover depths of 73 m to 95 m. As mentioned earlier, it is apparent that there is some on-going leakage from the Constrained Zone into the Fractured Zone above Panel 1, which may cause that the effective A-Zone Horizon to increase over time.

The presence of a NW trending fault line east of Panel 2 however, appears to have disconnected the groundwater on either side of it and has lowered the near surface water table by approximately 4.5 m east of the fault and >15.3 m to the west of it. The effective height of Continuous fracturing may also increase with time at this location.

The results of the analysis demonstrates that the measured A and B Zones are located within the **ACARP, 2003** prediction model ranges. The height of continuous fracturing (A Horizon) is located within +/- 3 m of the predicted mean values and the discontinuous fracture zone extends to within 10 m of the surface. It is possible that the measured A Zone may increase over time, but should still be within the U95%CLs presented in **Table 20D**.

Overall, it is considered that the measured and predicted fracture zones are in good agreement for Panels 1 and 2 at this stage and indicates the predicted fracture zones for the Tasman Extension Project panels are likely to be within the mean and U95%CL value range estimated by **ACARP, 2003** and **Forster, 1995** models.

11.3.10 Impact Management Strategies

It is understood that there are no subsurface aquifers of potential resource significance within the overburden that could be affected by *continuous and/or discontinuous fracturing* above the extracted pillar panels. The Groundwater Assessment and Surface Water Assessment for the Tasman Extension Project have considered the level of uncertainty (**Section 11.3.8**) in regards to predicting the height of each zone of sub-surface fracturing.

Based on **Table 17**, the **ACARP, 2003** model outcomes have been assessed in accordance with the Likelihood of Occurrence that continuous fracturing will intersect with surface cracks that extend to 10 m depth below the surface. The results are summarised in **Table 21a** and **Figure 36b** for Total Extraction Panels and **Table 21b** and **36d** for Partial Extraction Panels.

Table 21a - Likelihood Assessment for Continuous Fracturing Extending from Mine Workings to Within 10 m of the Surface Above the Proposed Total Pillar Extraction Panels (Level 1 SCZs)

Likelihood of Occurrence*	Mining Height Range	Cover Depth Range (m)	Probability of a Single Hazardous Event
Likely	2.2 - 2.5	< 50	25-75%
Possible	2.2 - 2.5	50 - 80	10-25%
Unlikely	2.2 - 2.5	80 - 100	5-10%
Very Unlikely	2.2 - 2.5	>100	<5%

* - refer to **Table 17** for definitions of likelihood of occurrence.

Table 21b - Likelihood Assessment for Continuous Fracturing Extending from Mine Workings to Within 10 m of the Surface Above the Proposed Partial Pillar Extraction Panels (Level 2 and 3 SCZs)

Likelihood of Occurrence*	Mining Height Range	Cover Depth Range (m)	Probability of a Single Hazardous Event
Likely	2.2 - 2.5	<30	25-75%
Possible	2.2 - 2.5	30 - 50	10-25%
Unlikely	2.2 - 2.5	50 - 80	5-10%
Very Unlikely	2.2 - 2.5	>80	<5%

* - refer to **Table 17** for definitions of likelihood of occurrence.

It is considered “unlikely” to “very unlikely” for continuous fracturing to occur from the mine workings to within 10 m of the surface above partial pillar extraction SCZs (e.g. streams and GDEs) below 80 m depth of cover. It is noted that an adaptive management approach will be adopted to avoid continuous fracturing beneath streams (**Table 4B**).

It is recommended that underground water make records for each of the extracted panels should be reviewed for the purpose of estimating the likely increases in mine water flow due to fracturing of the overlying aquifers. The presence of geological structure should also be viewed with caution and management strategies prepared to deal with disproportionate water inflows into the workings if aquifers become ‘perched’ behind adjacent faults. Undermining faults may also result in higher continuous fracture connectivity and water makes.

Recommendations for monitoring sub-surface fracture heights at the Tasman Extension Project are provided in **Section 12.4**.

11.4 Ponding

11.4.1 Potential Impacts

Ponding refers to the potential for closed-form depressions to develop at the surface after mining of total extraction panels beneath gentle slopes and relatively flat terrain. Ponding could affect drainage patterns, flora, fauna and GDEs.

The actual ponding depths will depend upon several other factors, such as rain duration, surface cracking and effective percolation and evapo-transpiration rates.

The pre- and potential post-mining ponding depths for the proposed mining layout without SCZs have been estimated from the 1 m post-mining topographic contours shown in **Figures 39a** and **39b** respectively. The 1 m post-mining topographic contours for the mining layout with SCZs are shown in **Figure 39c** for comparison.

Analysis of the pre- and post-mining surface levels suggests that ponding (if it occurs) is likely to develop near existing watercourses. Maximum potential ponding depths of between 0.1 and 0.7 m are estimated after Panels 1 to 32 are completed.

The pre-and post-mining surface level profiles with predicted subsidence and gradient changes along Surveyors Creek 2 (S2), S2E, S2DA and S2D, S2C and S2F are shown in **Figures 40a** to **40j** respectively.

The surface level profiles have been generated by digital interpolation of LiDAR topographic data and the ground-truthed alignment of the stream. Due to standard limitations associated with digital data, the profile may not follow the precise centre line of actual drainage lines on the ground in some locations (particularly in steep topography or meandering alignments). Therefore, for the exact location of stream features (e.g. pools), refer to the results of the geomorphic survey conducted of the streams by **Fluvial Systems (2012)**.

The potential worst-case pond depths along the 1st, 2nd and 3rd Order creeks in the low-lying areas above the middle of proposed panels may be increased by 0.5 to 1.0 m after mining. Several out-of channel ‘depressions’ between 0.1 m and 0.7 m may also develop above several of the panels, with their location shown on **Figures 39b** and **39c**.

11.4.2 Impact Management Strategies

An appropriate ponding management strategy may include:

(i) The development of a suitable monitoring and mitigation response plan as a component of the Extraction Plan process, based on consultation with the regulatory government authorities to ensure ponding impacts on existing vegetation do not result in long-term environmental degradation.

(ii) The review and appraisal of changes to drainage paths and surface vegetation in areas of ponding development (if they occur), after each panel is extracted.

(iii) Engineered channel earth works may be necessary to re-establish surface flows between sections of creek within a Level 2 or 3 SCZ and subsided creek areas above total extraction panels. Local experience to-date suggests that if increased in-channel ponding occurs it can either remain as an ‘additional’ pond along the creek or be remediated in consultation with the relevant government agency.

Overall, the impact of the increased ponding along the creek beds is likely to be 'in-channel'.

11.5 Slope Instability and Erosion

11.5.1 Potential Impacts

To-date, local longwall and pillar extraction mining experiences in undulating terrain with ground slopes up to approximately 2H:1V has not resulted in any large scale, *en-masse* sliding instability due to mine subsidence (or other natural weathering processes etc). In general, it is possible that localised instability could occur where ground slopes are greater than 2H:1V and if the slopes are also affected by mining-induced cracking and increased erosion rates due to subsidence in excess of 0.3 m.

As described in **Section 5.4**, SCZs would be applied to steep slopes and cliff lines to minimise impacts to public safety and environmental consequences. It is considered that restricting subsidence to less than 300 mm beneath steep slopes greater than 26.5° (2H:1V) would achieve the subsidence performance measures in **Table 4B**. The subsidence performance measures can be achieved with limiting extraction (i.e. maximum extraction) under slopes between 3H:1V and 2H:1V, based on local mining experience.

Based on reference to **Figures 31e to 31i**, the cumulative subsidence effects predicted along the steep slopes and cliff lines range are within the acceptable ranges defined in **Section 5.4** and are considered unlikely to result in cracking, toppling or slope instability after completion of both the Tasman Mine and Tasman Extension Project. There will of course be potential for instability due to natural weathering and tree root wedging processes and monitoring and review of the rate of rock falls and the like will need to be undertaken during mining activities.

Therefore, due to the difficulties in distinguishing between natural and mining induced instability it is likely that the performance criteria for subsequent management plans will be in the range of 3% to 5% of cliff face and steep slope areas may be impacted during mining.

Existing natural erosion has been observed along steep slope areas (refer to site photographs). Further assessment of the current conditions and background instability along the cliffs and steep slopes is recommended for the Extraction Plan phase of the Project.

The rate of erosion is expected to increase significantly in areas with exposed dispersive / reactive alluvial or residual soils or tuffaceous claystone and where slope gradients are increased by more than 2% (>20 mm/m).

Based on the difference between the post and pre-mining surfaces presented earlier in **Figures 40a** to **40j**, the predicted increase or decrease in surface slope gradients after mining are presented in **Figures 41a** (without SCZs) and **41b (**with SCZs).

A discussion on the generation of the post and pre-mining surfaces along streams is provided in **Section 11.4**.

The above figures indicate that the maximum gradient changes will be located above Panels 1 to 32 and likely to range between +/- 2% and 4% where total extraction mining takes place. It is assessed that some erosion / sedimentation adjustments may develop at these locations where exposed soils are present.

The predicted changes in surface gradients on the steep slopes and cliffs and along Surveyors Creek No. 2 and its 1st and 2nd order tributaries with the proposed SCZs are <0.5% and are unlikely to cause any degradation to the cliffs, slopes and creeks directly.

Any sediment deposits from actively eroding areas upstream of the protected sections of the creeks will need to be monitored (and assessed) as mining progresses.

11.5.2 Impact Management Strategies

To minimise the likelihood of slope instability and increased erosion potential along creeks due to cracking or changes to drainage patterns after mining, the following management strategies may be implemented:

(i) Surface slope monitoring (combined with general subsidence monitoring along cross lines and centre lines).

(ii) Placement of signs along public access ways warning of mine subsidence impacts.

(iii) Infilling of surface cracking to prevent excessive ingress of run-off into the slopes as soon as practicable and preferably after each adjacent panel is completed.

(iv) Slopes that are significantly affected by erosion after mining may need to be repaired and protected with mitigation works such as re-grading and re-vegetation of exposed areas, based on consultation with the relevant government agencies.

(v) On-going review and appraisal of any significant changes to surface slopes such as cracking, increased erosion, seepages and drainage path adjustments observed after each panel is extracted.

11.6 Valley Uplift and Closure

11.6.1 Potential Impacts

Valley uplift and closure movements may occur along the drainage gullies present above the proposed mining area, based on reference to **ACARP, 2002** and local experience.

High horizontal stresses (10 MPa at 27 m depth) have been measured and uplift movements of about 230 mm have occurred along the F3 Freeway cuttings in ridges about 10 km to the south-east of the Tasman Extension Project where massive conglomerate strata existed at the surface.

However, due to the observed low horizontal stress regime in the Tasman Mine workings in the Fassifern Seam, which is just below the ridge to the east and the relatively low horizontal stress in the West Borehole Seam roof at West Wallsend Colliery, it is considered unlikely that similar magnitude movements will occur in the gullies / broad crested valleys above the proposed Tasman Extension Project panels.

Uplift movements of between 100 mm and 150 mm have occurred in compressive strain zones above Abel Mine panels to-date at depths of cover of 60 m to 110 m. Uplift movements of between 10 mm and 35 mm have also occurred just outside the limits of mining above the Abel Mine panels. These movements are not due to the valley closure mechanism, but related to systematic subsidence development of compressive strains and cantilevering of the bending rock mass.

The lack of thick, massive beds of conglomerate and sandstone units along the creeks / valleys at the surface will also mean the development of these phenomena are likely to be limited to < 150 mm. Minor cracking in creek beds may cause some shallow sub-surface re-routing of surface flows due to the valley closure mechanism if it does occur.

11.6.2 Impact Management Strategies

The impact of valley uplift closure effects due to mine subsidence may be managed as follows:

(i) Install and monitor 3-D movements during and after undermining along and across representative drainage gullies where undermined by total extraction panels. Combine with visual inspections to locate damage (cracking, uplift).

(ii) Review predictions of upsidence and valley crest movements after each panel is extracted.

(iii) Assess whether repairs to cracking, as a result of upsidence or gully slope stabilisation works are required to minimise the likelihood of long-term degradation to the environment or risk to personnel and the general public.

11.7 Far-Field Horizontal Displacements and Strains

11.7.1 Background to Prediction Model Development

Far-field displacements (FFDs) generally only have the potential to damage long, linear features such as pipelines, bridges and dam walls.

Horizontal movements due to longwall mining have been recorded at distances well outside of the angle of draw in the Newcastle, Southern and Western Coalfields (**Reid, 1998, Seedsman and Watson, 2001**). Horizontal movements recorded beyond the angle of draw are referred to as far-field horizontal displacements.

For example, at Cataract Dam in the Southern NSW Coalfield, **Reid, 1998** reported horizontal movements of up to 25 mm when underground coal mining was about 1.5 km away. Seedsman reported movements in the Newcastle Coalfield of around 20 mm at distances of approximately 220 m, for a cover depth ranging from 70 to 100 m and a panel width of 193 m. However, the results may have been affected by GPS baseline accuracy limitations.

Based on a review of the above information, it is apparent that this phenomenon is dependent on (i) cover depth, (ii) distance from the goaf edges, (iii) maximum subsidence over the extracted area, (iv) topographic relief and (v) horizontal stress field characteristics.

An empirical model for predicting FFDs in the Newcastle Coalfield is presented in **Figure 42a**. The model indicates that measurable FFD movements (i.e. 20 mm) generally occur in relatively flat terrain for distances up to 3 to 4 times the cover depth.

The direction of the FFD movement is generally towards the extracted area, but can vary due to the degree of regional horizontal stress adjustment around extracted area and the surface topography. The movements also appear to decrease around the corners of longwall or total pillar extraction panels.

An empirical model for predicting far-field strains (FFSs) in the Newcastle Coalfield is presented in **Figure 42b** and **42c**. The model indicates that measureable (but diminishing) strains can also occur outside the limits of longwall extraction for distances up to one cover depth (based on the Upper 99% Confidence limit curve). It is assessed that strains will be <0.5 mm/m at a distance equal to 0.5 x cover depth in the Newcastle Coalfield, and therefore unlikely to cause damage beyond this distance.

It should be noted that the model was based on steel tape measurements which did not extend further than a distance equal to the 1.5 times the cover depth from the extraction limits. Any FFS predictions that are >1.5 times the cover depth from the panels in this report are therefore an extrapolation of the regression lines for the database and likely to be conservative.

11.7.2 Potential Impacts

The surface features that have been assessed in this study for potential FFD and FFS impacts due to mining of the proposed pillar extraction panels include:

- TransGrid Towers TG1-8 (actual names unknown at this stage).
- George Booth Drive.
- Broadcast Towers on Mount Sugarloaf.

As previously discussed, an SCZ setback distance has been applied to the above items that will minimise the potential for significant FFD or FFS impact. The SCZ setbacks are not the same for each feature and have been determined based on conservative tolerance strain limit estimates (shown in brackets below).

The design SCZ setback distances adopted in this study are summarised below in terms of 'AoD' from the surface feature to the total pillar extraction limits:

- Broadcast Towers (negligible tensile strain tolerance < 0.1 mm/m) - 1 x cover depth (45^o AoD).
- TransGrid Tower Nos. 1 and 2 (tension towers with maximum tensile strain tolerance of < 0.5 mm/m) - 1 x cover depth (45^o AoD).
- TransGrid Tower Nos. 3-8 (suspension towers with maximum tensile strain tolerance of < 2.5 mm/m) - 0.5 x cover depth (26.5^o AoD).
- George Booth Drive (tensile strain < 0.5 mm/m and lateral curvature radii > 200 km) - 0.5 x cover depth (26.5^o AoD).

None of the suspension towers within the Tasman Extension Project area have cruciform footings installed and would be therefore require subsidence control zones to be provided to control subsidence effects to within tolerable limits.

Predictions of worst-case FFDs and FFSs are summarised in **Table 22**.

Table 22 - Summary of Far-Field Displacement and Strain Predictions for the Proposed Pillar Extraction Panels

Panel #	Feature	z* (m)	H (m)	z/H	AoD (o)	Final S_{max} (m)	FFD (mm)	FFS (mm/m)	Principal Movement Direction
32	TG1 (Tension)	240	116	2.07	64	1.3	7	0.1	E
32	TG2 (Tension)	250	118	2.12	65	1.3	6	0.1	E
4	TG3 (Suspension)	249	90	2.77	70	1.3	2	0.0	W
4	TG4 (Suspension)	253	90	2.81	70	1.3	2	0.0	W
4	TG5 (Suspension)	75	72	1.04	46	1.3	35	0.4	NE
4	TG6 (Suspension)	75	75	1.00	45	1.3	38	0.4	SE
3	TG7 (Suspension)	205	45	4.56	78	1.3	0	0.0	E
3	TG8 (Suspension)	200	45	4.44	77	1.3	0	0.0	E

z = normal distance to feature from panel centreline.
* - Level 2 & 3 SCZs for distance equal to cover depth from tower centre assumed (unless cruciform installed)
H = Cover depth at panel end.
AoD = effective angle of draw.
Final S_{max} = Final maximum panel subsidence (mean values).
FFD = Predicted far-field displacement (mean value).
FFS = Predicted far-field strain (U99%CL value).

The results of the analysis indicate that the TransGrid Tension Towers (TG 1&2) may be displaced 6 mm to 7 mm towards Panel 32 with negligible tensile strain of 0.1 mm/m (U99%CL). The suspension towers within 2 times the cover depth from the proposed pillar extraction workings may be displaced by 2 mm to 38 mm after Panels 3 and 4 are extracted with the minimum SCZ applied. Tensile ground strains at the towers range from 0.1 mm/m to 0.4 mm/m at an AoD of 64^o and 45^o.

George Booth Drive and the Hunter Expressway are approximately 7 times the cover depth of 100 m from Panel 1 and is assessed to be well outside the limits of measureable horizontal displacement and strain (i.e. +/-10 mm and +/- 0.3 mm/m) and will not require any further management plans to be implemented.

It is considered that the impact of the predicted FFD and FFS values are within the tolerable limits of the features assessed.

11.7.3 Impact Management Strategies

The proposed set-back distances of high extraction mining to the sensitive features will reduce the potential for damage occurring to very low likelihoods (ie < 1% probability of occurrence). Monitoring of ground and tower movement as subsidence develops will be necessary for the eight TransGrid towers assessed.

11.8 Aboriginal Heritage Sites

11.8.1 Predicted Subsidence Effects

There have been one hundred Aboriginal Heritage Sites identified within the vicinity of the proposed mining area to-date, which are predominately located on the steep slopes and ridges or at the rock bar locations along the watercourses. These include 38 Artefact Scatters, 36 Grinding Groove sites and 26 Rock Shelter sites (see **Figure 3b**).

The predicted cumulative subsidence, tilt and horizontal strain for each listed site after the proposed second workings layout in the West Borehole and Fassifern Seam has been estimated from **Figures 32b** to **32e** for the No SCZs case and **32f** to **32i** for panels with the proposed SCZs.

The subsidence assessment results are summarised in **Table 23A**.

Table 23A - Predicted Subsidence Effects at Aboriginal Heritage Sites

Site No	**Archaeological Significance**	**Easting (MGA) (m)**	**Northing (MGA) (m)**	**Subsidence (m)**		**Tilt (mm/m)**		**Horizontal Strain (mm/m)^**	
				No SCZ	**With SCZ***	**No SCZ**	**With SCZ***	**No SCZ**	**With SCZ***
Artefact Scatters									
1.A	Low	363395	6363025	0.00	0.00	0.0	0.0	0.0	0.0
1.B	Low	363529	6362864	0.00	0.00	0.0	0.0	0.0	0.0
10.A	Low	363472	6362509	0.00	0.00	0.0	0.0	0.0	0.0
29.A	Low	363324	6361824	0.00	0.00	0.0	0.0	0.0	0.0
34.A	Low	362916	6361861	0.00	0.00	0.0	0.0	0.0	0.0
50.A	Low	362415	6361701	0.00	0.00	0.0	0.0	0.0	0.0
51.A	Low	361975	6361038	1.00	1.00	20.6	20.5	-8.8	-8.9
53.A	Low	361260	6360803	0.83	0.83	50.3	50.3	-18.2	-18.2
53.B	Low	361402	6360782	0.18	0.18	22.7	24.5	23.9	20.9
56.A	Low	361918	6360705	0.36	0.36	23.4	23.4	5.8	5.8
56.B	Low	361596	6360752	0.16	0.14	12.0	15.6	17.3	13.2
79.B	Low - Mod	362685	6359382	0.07	0.07	1.5	1.5	0.1	0.1
80.A	Low	363024	6359742	0.01	0.01	0.3	0.3	0.1	0.1
80.B	Low	363236	6359651	0.00	0.00	0.1	0.1	0.0	0.0
80.C	Low	363516	6359765	0.00	0.00	0.0	0.0	0.0	0.0
84.A	Low	363374	6359433	0.08	0.08	0.9	0.9	-0.1	-0.1
85.A	**Moderate**	**363360**	**6358775**	0.00	**0.00**	0.0	**0.0**	0.0	0.0
107.A	Low	361718	6358921	0.27	0.18	17.9	11.2	7.7	5.1
124.A	Low	361285	6359435	1.27	0.18	1.5	2.6	-2.4	5.0
126.A	Low	360959	6359845	1.26	0.26	5.5	12.5	-6.9	19.2
126.B	Low	361114	6359646	1.24	0.17	7.3	4.6	-7.4	5.0
126.C	Low	361192	6359529	0.46	0.10	32.5	1.3	8.1	0.7
135.A	Low - Mod	360148	6358428	0.21	0.21	6.8	6.6	7.7	7.3
135.B	Low	360208	6358669	0.23	0.23	9.4	9.4	7.2	7.2
135.C	Low	360203	6358757	0.18	0.18	4.9	4.9	8.0	8.0

Table 23A (Cont…) - Predicted Subsidence Effects at Aboriginal Heritage Sites

Site No	Archaeological Significance	Easting (MGA) (m)	Northing (MGA) (m)	Subsidence (m)		Tilt (mm/m)		Horizontal Strain (mm/m)	
				No SCZ	With SCZ*	No SCZ	With SCZ*	No SCZ	With SCZ*
Artefact Scatters									
135.D	Low	360205	6358813	0.21	0.21	9.7	9.7	7.8	7.8
153.A	Low	360621	6357539	0.00	0.00	0.0	0.0	0.0	0.0
154.B	Low	361022	6357171	0.00	0.00	0.0	0.0	0.0	0.0
154.C	Low	360826	6357349	0.00	0.00	0.0	0.0	0.0	0.0
157.A	**Mod - High**	**360581**	**6357706**	0.01	**0.01**	**0.4**	**0.2**	**0.1**	**-0.1**
181.A	Low	362283	6358198	0.08	0.02	2.2	0.5	0.3	0.0
181.B	Low	362054	6357857	0.00	0.00	0.0	0.0	0.0	0.0
181.C	Low	362116	6357951	0.00	0.00	0.0	0.0	0.0	0.0
182.A	Low	362265	6358449	0.64	0.14	3.9	0.8	-0.3	-0.1
182.B	Low	362203	6358308	0.44	0.10	5.0	1.1	0.0	0.1
188.A	Low	362394	6358025	0.00	0.00	0.0	0.0	0.0	0.0
199.A	Low	362577	6357734	0.00	0.00	0.0	0.0	0.0	0.0
975	Low	362729	6361454	0.00	0.00	0.0	0.0	0.0	0.0
Open Grinding Grooves									
32.A	Low - Mod	363165	6361691	0.00	0.00	0.0	0.0	0.0	0.0
41.A	Low - Mod	363034	6361176	0.09	0.09	8.3	8.3	4.3	4.3
45.A	Low - Mod	363308	6360957	0.00	0.00	0.0	0.0	0.0	0.0
57.A	Low - Mod	362663	6360550	0.24	0.24	12.8	12.8	3.5	3.5
57.B	Low - Mod	362562	6360628	0.74	0.74	18.7	18.7	-2.0	-2.0
67.A	Low - Mod	362331	6359973	0.37	0.33	13.0	11.3	1.4	1.1
67.B	Low - Mod	362303	6360063	0.02	0.02	2.0	2.0	1.3	1.3
71.A	Low	362133	6359830	0.68	0.68	20.2	20.6	2.9	2.4
79.A	Low - Mod	362675	6359376	0.06	0.06	1.4	1.4	0.1	0.1
86.A	Low - Mod	362980	6359311	0.05	0.05	0.4	0.4	0.3	0.3
86.B	Low - Mod	362961	6359249	0.10	0.10	0.9	0.9	-0.3	-0.3
86.C	Low	363189	6359216	0.08	0.08	0.6	0.6	-0.1	-0.1
86.D	Low	362937	6359054	0.00	0.01	0.2	0.2	0.1	0.1
88.A	Low - Mod	362244	6359305	0.57	0.10	16.8	2.3	5.6	1.1
92.A	**High**	**362665**	**6359180**	0.02	**0.02**	**1.3**	**1.3**	**0.4**	**0.4**
154.A	Low	360995	6357422	0.00	0.00	0.0	0.0	0.0	0.0
176.A	Low - Mod	361700	6358302	1.17	0.14	15.6	0.3	-9.6	0.0
Open Grinding Grooves									
440	**High**	**362862**	**6359147**	0.04	**0.04**	**1.3**	**1.3**	**0.2**	**0.2**
443	Low	363025	6359489	0.09	0.09	1.1	1.1	-0.1	-0.1
444	**Moderate**	**363006**	**6359236**	0.10	**0.10**	**0.7**	**0.7**	**-0.3**	**-0.3**
445	**Mod - High**	**362899**	**6359189**	0.09	**0.09**	**1.3**	**1.3**	**-0.2**	**-0.2**
446	**Moderate**	**362720**	**6359160**	0.02	**0.02**	**1.0**	**1.0**	**0.3**	**0.3**
447	**High**	**362609**	**6359202**	0.02	**0.02**	**1.5**	**1.5**	**0.6**	**0.6**
448	Low - Mod	362849	6359087	0.01	0.01	0.3	0.3	0.1	0.1
449	**Moderate**	**362888**	**6359078**	0.00	**0.00**	**0.3**	**0.3**	**0.1**	**0.1**
450	Low - Mod	362305	6358089	0.00	0.00	0.2	0.1	0.0	0.0
457	Low - Mod	361445	6357899	0.00	0.00	0.1	0.1	0.2	0.1

Table 23A (Cont…) - Predicted Subsidence Effects at Aboriginal Heritage Sites

Site No	Archaeological Significance	Easting (MGA) (m)	Northing (MGA) (m)	Subsidence (m)		Tilt (mm/m)		Horizontal Strain (mm/m)	
				No SCZ	With SCZ*	No SCZ	With SCZ*	No SCZ	With SCZ*
Open Grinding Grooves									
486	Low - Mod	362977	6359383	0.08	0.08	1.2	1.2	0.0	0.0
487	Low	362975	6359459	0.11	0.11	0.4	0.4	-0.2	-0.2
488	Low - Mod	362985	6359406	0.10	0.10	0.9	0.9	-0.2	-0.2
610	Low - Mod	360803	6357686	0.00	0.00	0.0	0.0	0.0	0.0
618	Low	360765	6359749	1.27	0.30	1.2	0.8	-2.1	-1.1
619	Low - Mod	360655	6359629	0.00	0.00	0.0	0.0	0.0	0.0
623	Low	360725	6359699	0.86	0.19	46.2	10.0	-17.0	3.3
624	Low	360695	6359679	0.06	0.05	17.2	10.6	20.5	12.4
869	Low - Mod	361143	6357474	0.00	0.00	0.0	0.0	0.0	0.0
Rock Shelter + Potential Archaeological Deposit									
39.A	Low - Mod	363211	6361246	0.27	0.27	15.8	15.8	4.8	4.8
46.A	**Moderate**	**363366**	**6360845**	**0.04**	**0.04**	**1.9**	**1.9**	**0.6**	**0.6**
46.B	**Moderate**	**363372**	**6360844**	**0.04**	**0.04**	**1.9**	**1.9**	**0.6**	**0.6**
46.C	**Moderate**	**363377**	**6360851**	**0.05**	**0.05**	**2.3**	**2.3**	**0.4**	**0.4**
46.D	**Moderate**	**363405**	**6360851**	**0.06**	**0.06**	**2.1**	**2.1**	**0.2**	**0.2**
64.A	Low	363105	6360333	0.08	0.08	1.8	1.8	-0.5	-0.5
64.B	Low	362860	6360279	0.11	0.11	0.8	0.8	0.0	0.0
64.C	**Mod - High**	**363245**	**6360677**	**0.08**	**0.08**	**1.8**	**1.8**	**-0.2**	**-0.3**
64.D	Low - Mod	363212	6360571	0.04	0.04	2.1	2.1	0.1	0.1
77.A	Low	362524	6359657	0.20	0.07	3.5	0.3	0.6	0.2
77.B	Low	362593	6359662	0.11	0.07	0.8	0.6	0.2	0.2
77.C	Low	362667	6359764	0.10	0.10	0.8	0.7	-0.3	-0.3
79.C	Low	362683	6359343	0.08	0.08	1.5	1.5	-0.1	0.0
79.D	Low	362667	6359361	0.06	0.06	1.3	1.4	0.2	0.1
92.B	Low	362807	6359130	0.02	0.02	0.7	0.7	0.2	0.2
96.A	Low	362329	6358806	0.60	0.08	4.8	0.7	-0.7	0.1
96.B	Low	362303	6358796	0.67	0.08	2.8	0.6	-1.1	0.1
96.C	Low	362287	6358743	0.68	0.09	2.3	0.6	-0.9	0.0
104.A	Low	362151	6358448	0.79	0.16	2.0	0.2	0.6	0.0
104.B	Low	362176	6358488	0.78	0.16	1.0	0.2	0.3	0.0
104.C	**Moderate**	**362209**	**6358690**	**0.74**	**0.13**	**1.3**	**0.5**	**0.3**	**-0.2**
Rock Shelter + Potential Archaeological Deposit									
152.A	Low	360554	6357465	0.00	0.00	0.0	0.0	0.0	0.0
152.B	Low	360521	6357421	0.00	0.00	0.0	0.0	0.0	0.0
155.A	Low	361172	6357492	0.00	0.00	0.0	0.0	0.0	0.0
178.A	Low	361377	6357423	0.00	0.00	0.0	0.0	0.0	0.0
200.A	**Mod - High**	**362476**	**6357815**	**0.00**	**0.00**	**0.0**	**0.0**	**0.0**	**0.0**

Table 23A (Cont…) - Predicted Subsidence Effects at Aboriginal Heritage Sites

Site No	Archaeological Significance	Easting (MGA) (m)	Northing (MGA) (m)	Subsidence (m)		Tilt (mm/m)		Horizontal Strain (mm/m)	
				No SCZ	With SCZ*	No SCZ	With SCZ*	No SCZ	With SCZ*
Cultural Sites of Special Significance									
SC1	**High**	**n.f.p.**	**n.f.p.**	**0.01**	**0.01**	**0.9**	**0.9**	**0.5**	**0.5**
SC2	**High**	**n.f.p.**	**n.f.p.**	**0.05**	**0.05**	**2.1**	**2.1**	**0.3**	**0.3**
SC3	**High**	**n.f.p.**	**n.f.p.**	**0.07**	**0.07**	**1.8**	**1.8**	**-0.2**	**-0.2**

Bold - Moderate to High Archaeological Significance.
Shaded - Site is within zone of subsidence effects from proposed West Borehole Seam Workings.
*- The predictions for the "With SCZ" case refer to the overall mine plan only and do not necessarily mean a given archaeological site is located within one. Results include Tasman Mine workings effects in the Fassifern Seam. The 'No SCZ' cases do not include the Tasman Mine workings effects in the Fassifern Seam to show impact of each seam workings.
^ - Tensile strain is positive.
n.f.p. - not for publication due to request by Aboriginal Groups.

The results in **Table 23A** indicate the following subsidence effects for sites of Low, Moderate and High Archaeological Significance:

- One (1) Artefact Scatter site of Moderate or Moderate-High Significance may be subsided by 0.01 m after the proposed total extraction panels (with SCZs) are mined. The tilts and strains associated with this magnitude of subsidence will be < 0.2 mm/m.

- Sixteen (16) Artefact Scatter site of Low or Low-Moderate Significance may be subsided by between 0.1 m and 1.0 m after the proposed total extraction panels (with SCZs) are mined. The tilts associated with this magnitude of subsidence is predicted to range between 1 mm/m and 51 mm/m with horizontal strains ranging from -18 mm/m (compressive) to 21 mm/m (tensile).

- No grinding groove sites of Moderate, Moderate-High or High Significance may be subsided by the Proposed Tasman Extension Project panels, however, six (6) sites may be subsided by between 0.02 m and 0.1 m after the proposed Tasman Mine panels in the Fassifern Seam. The tilts and strains associated with this magnitude of subsidence will be generally <0.5 mm/m.

- Twenty-one (21) Grinding Groove sites of Low or Low-Moderate Significance may be subsided by between 0.01 m and 0.74 m after the proposed total extraction panels (with SCZs) are mined. The tilts associated with this magnitude of subsidence are predicted to range between 0.1 mm/m and 20 mm/m with horizontal strains ranging from -2 mm/m (compressive) to 12 mm/m (tensile).

- Six (6) Rock Shelter site of Moderate or Moderate-High Significance may be subsided by between 0.04 m and 0.13 m after the proposed total extraction panels (with SCZs) are mined. The tilts associated with this magnitude of subsidence is predicted to range between 0.5 mm/m and 2.3 mm/m with horizontal strains ranging from -0.2 mm/m (compressive) to 0.6 mm/m (tensile).

- Fifteen (15) Rock Shelter sites of Low or Low-Moderate Significance may be subsided by between 0.02 m and 0.27 m after the proposed total extraction panels (with SCZs) are mined. The tilts associated with this magnitude of subsidence is predicted to range between 0.2 mm/m and 16 mm/m with horizontal strains ranging from -0.5 mm/m (compressive) to 4.8 mm/m (tensile).

- None of the three Cultural Sites of Special Significance are likely to be subsided by the Proposed Tasman Extension Project panels, however, the sites may be subsided 0.01 m to 0.07 m after the proposed Tasman Mine panels in the Fassifern Seam. The tilts associated with this magnitude of subsidence may range between 0.9 mm/m to 2.1 mm/m with horizontal strains ranging from -0.2 mm/m (compressive) to 0.5 mm/m (tensile).

11.8.2 Potential Impacts

The likelihood of damage occurring at the sites has been assessed based on the following impact parameter criteria (see **Table 23B**). The criteria consider the theoretical cracking limits of rock of 0.3 to 0.5 mm/m and the ‘system’ slackness or strain ‘absorbing’ properties of a jointed and weathered rock mass during subsidence deformation. The lack of measured observed impact (i.e. surface cracking) due to measured strains of up to 1.5 mm/m above the Tasman Mine is an example of the difference between theoretical and in-situ rock mass cracking behaviour.

If necessary, the span or dimensions of rock shelters or grinding groove sites and the orientation of natural jointing and mining panels proposed, may also be factored into the assessment of the criteria for individual sites (refer to **Shepherd and Sefton, 2001**). At this stage, the specific geotechnical characteristics of each site have not been included, but may be necessary for Extraction Plan development.

Table 23B – Impact Potential Criteria for Aboriginal Heritage Sites

<table>
<tr><th rowspan="2">Cracking Potential - Indicative Probabilities of Occurrence</th><th colspan="2">Predicted 'smooth profile' Horizontal Strain (mm/m)</th></tr>
<tr><th>Tensile</th><th>Compressive</th></tr>
<tr><td>Very Unlikely (<5%)</td><td><0.5</td><td><2</td></tr>
<tr><td>Unlikely (5 - 10%)</td><td>0.5 - 1.5</td><td>2 - 3</td></tr>
<tr><td>Possible (10 - 25%)</td><td>1.5 - 2.5</td><td>3 - 5</td></tr>
<tr><td>Moderate (>25%)</td><td>>2.5</td><td>>5</td></tr>
<tr><th>Toppling Damage Potential - Indicative Probabilities of Occurrence</th><th colspan="2">Predicted Surface Gradient Change or Tilt Increase</th></tr>
<tr><td>Very Unlikely (<5%)</td><td colspan="2"><0.3% (<3 mm/m)</td></tr>
<tr><td>Unlikely (5 - 10%)</td><td colspan="2">0.3-1% (3 - 10 mm/m)</td></tr>
<tr><td>Possible (10 - 25%)</td><td colspan="2">1-3% (10 - 30 mm/m)</td></tr>
<tr><td>Moderate (>25%)</td><td colspan="2">>3% (>30 mm/m)</td></tr>
</table>

The ‘Cracking Potential’ is considered the primary damage potential indicator and the ‘Toppling Potential’ is an additional criterion that is relevant to slender or sensitive rock features or rock shelters with large overhangs.

The results of the impact assessment are presented in **Table 23C**.

Table 23C - Predicted Subsidence Impacts at Aboriginal Heritage Sites

Site No	**Tilt (mm/m)**		**Horizontal Strain (mm/m)^**		**Cracking or Toppling Damage Potential**	
	No SCZ	**With SCZ***	**No SCZ**	**With SCZ***	**No SCZ**	**With SCZ***
Artefact Scatters						
1.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
1.B	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
10.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
29.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
34.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
50.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
51.A	20.6	20.5	-8.8	-8.9	Moderate	Moderate
53.A	50.3	50.3	-18.2	-18.2	Moderate	Moderate
53.B	22.7	24.5	23.9	20.9	Moderate	Moderate
56.A	23.4	23.4	5.8	5.8	Moderate	Moderate
56.B	12.0	15.6	17.3	13.2	Moderate	Moderate
79.B	1.5	1.5	0.1	0.1	V.Unlikely	V.Unlikely
80.A	0.3	0.3	0.1	0.1	V.Unlikely	V.Unlikely
80.B	0.1	0.1	0.0	0.0	V.Unlikely	V.Unlikely
80.C	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
84.A	0.9	0.9	-0.1	-0.1	V.Unlikely	V.Unlikely
85.A	**0.0**	**0.0**	**0.0**	**0.0**	V.Unlikely	V.Unlikely
107.A	17.9	11.2	7.7	5.1	Moderate	Moderate
124.A	1.5	2.6	-2.4	5.0	Unlikely	Moderate
126.A	5.5	12.5	-6.9	19.2	Moderate	Moderate
126.B	7.3	4.6	-7.4	5.0	Moderate	Moderate
126.C	32.5	1.3	8.1	0.7	Moderate	Unlikely
135.A	6.8	6.6	7.7	7.3	Moderate	Moderate
135.B	9.4	9.4	7.2	7.2	Moderate	Moderate
135.C	4.9	4.9	8.0	8.0	Moderate	Moderate
135.D	9.7	9.7	7.8	7.8	Moderate	Moderate
153.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
154.B	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
154.C	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
157.A	**0.4**	**0.2**	**0.1**	**-0.1**	V.Unlikely	V.Unlikely
181.A	2.2	0.5	0.3	0.0	V.Unlikely	V.Unlikely
181.B	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
181.C	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
182.A	3.9	0.8	-0.3	-0.1	V.Unlikely	V.Unlikely
182.B	5.0	1.1	0.0	0.1	V.Unlikely	V.Unlikely
188.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely

Table 23C (Cont…) - Predicted Subsidence Impacts at Aboriginal Heritage Sites

Site No	**Tilt (mm/m)**		**Horizontal Strain (mm/m)**		**Cracking Damage Potential**	
	No SCZ	**With SCZ***	**No SCZ**	**With SCZ***	**No SCZ**	**With SCZ***
Artefact Scatters						
199.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
975	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
Grinding Grooves						
32.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
41.A	8.3	8.3	4.3	4.3	Moderate	Moderate
45.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
57.A	12.8	12.8	3.5	3.5	Moderate	Moderate
57.B	18.7	18.7	-2.0	-2.0	V.Unlikely	V.Unlikely
67.A	13.0	11.3	1.4	1.1	Unlikely	Unlikely
67.B	2.0	2.0	1.3	1.3	Unlikely	Unlikely
71.A	20.2	20.6	2.9	2.4	Moderate	Possible
79.A	1.4	1.4	0.1	0.1	V.Unlikely	V.Unlikely
86.A	0.4	0.4	0.3	0.3	V.Unlikely	V.Unlikely
86.B	0.9	0.9	-0.3	-0.3	V.Unlikely	V.Unlikely
86.C	0.6	0.6	-0.1	-0.1	V.Unlikely	V.Unlikely
86.D	0.2	0.2	0.1	0.1	V.Unlikely	V.Unlikely
88.A	16.8	2.3	5.6	1.1	Moderate	Unlikely
92.A	**1.3**	**1.3**	**0.4**	**0.4**	V.Unlikely	V.Unlikely
154.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
176.A	15.6	0.3	-9.6	0.0	Moderate	V.Unlikely
440	**1.3**	**1.3**	**0.2**	**0.2**	V.Unlikely	V.Unlikely
443	1.1	1.1	-0.1	-0.1	V.Unlikely	V.Unlikely
444	**0.7**	**0.7**	**-0.3**	**-0.3**	V.Unlikely	V.Unlikely
445	**1.3**	**1.3**	**-0.2**	**-0.2**	V.Unlikely	V.Unlikely
446	**1.0**	**1.0**	**0.3**	**0.3**	V.Unlikely	V.Unlikely
447	**1.5**	**1.5**	**0.6**	**0.6**	Unlikely	Unlikely
448	0.3	0.3	0.1	0.1	V.Unlikely	V.Unlikely
449	**0.3**	**0.3**	**0.1**	**0.1**	V.Unlikely	V.Unlikely
450	0.1	0.1	0.0	0.0	V.Unlikely	V.Unlikely
457	0.1	0.1	0.2	0.1	V.Unlikely	V.Unlikely
486	1.2	1.2	0.0	0.0	V.Unlikely	V.Unlikely
487	0.4	0.4	-0.2	-0.2	V.Unlikely	V.Unlikely
488	0.9	0.9	-0.2	-0.2	V.Unlikely	V.Unlikely
610	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
618	1.2	0.8	-2.1	-1.1	Unlikely	V.Unlikely
619	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely
623	46.2	10.0	-17.0	3.3	Moderate	Moderate
624	17.2	10.6	20.5	12.4	Moderate	Moderate
869	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely

Table 23C (Cont…) - Predicted Subsidence Effects at Aboriginal Heritage Sites

Site No	Tilt (mm/m)		Horizontal Strain (mm/m)		Cracking Damage Potential		Toppling Damage Potential	
	No SCZ	With SCZ*	No SCZ	With SCZ*	No SCZ	With SCZ*	No SCZ	With SCZ*
Rock Shelter + PAD								
39.A	15.8	15.8	4.8	4.8	Moderate	Moderate	Possible	Possible
46.A	**1.9**	**1.9**	**0.6**	**0.6**	Unlikely	Unlikely	V. Unlikely	V.Unlikely
46.B	**1.9**	**1.9**	**0.6**	**0.6**	Unlikely	Unlikely	V. Unlikely	V.Unlikely
46.C	**2.3**	**2.3**	**0.4**	**0.4**	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
46.D	**2.1**	**2.1**	**0.2**	**0.2**	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
64.A	1.8	1.8	-0.5	-0.5	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
64.B	0.8	0.8	0.0	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
64.C	**1.8**	**1.8**	**-0.2**	**-0.3**	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
64.D	2.1	2.1	0.1	0.1	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
77.A	3.5	0.3	0.6	0.2	Unlikely	V.Unlikely	Unlikely	V.Unlikely
77.B	0.8	0.6	0.2	0.2	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
77.C	0.8	0.7	-0.3	-0.3	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
79.C	1.5	1.5	-0.1	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
79.D	1.3	1.4	0.2	0.1	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
92.B	0.7	0.7	0.2	0.2	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
96.A	4.8	0.7	-0.7	0.1	V.Unlikely	V.Unlikely	Unlikely	V.Unlikely
96.B	2.8	0.6	-1.1	0.1	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
96.C	2.3	0.6	-0.9	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
104.A	2.0	0.2	0.6	0.0	Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
104.B	1.0	0.2	0.3	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
104.C	**1.3**	**0.5**	**0.3**	**-0.2**	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
152.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
152.B	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
155.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
178.A	0.0	0.0	0.0	0.0	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
200.A	**0.0**	**0.0**	**0.0**	**0.0**	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
Cultural Sites of Special Significance								
SC1	**0.9**	**0.9**	**0.5**	**0.5**	Unlikely	Unlikely	V. Unlikely	V.Unlikely
SC2	**2.1**	**2.1**	**0.3**	**0.3**	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely
SC3	**1.8**	**1.8**	**-0.2**	**-0.2**	V.Unlikely	V.Unlikely	V. Unlikely	V.Unlikely

Bold - Moderate to High Archaeological Significance.
Shaded - Possible to Moderate Damage Potential.
*- The predictions for the “With SCZ” case refer to the overall mine plan only and do not necessarily mean a given archaeological site is located within one.
^ - Tensile strain is positive.

The results in **Table 23C** indicate the following potential impacts to the Aboriginal Heritage Sites:

- All Artefact Scatter sites of Moderate to High Significance have a Very Unlikely Cracking Damage potential due to subsidence by the proposed total extraction panels with SCZs.

- Thirteen (13) Artefact Scatter sites of Low to Moderate Significance have a Moderate Cracking Damage Potential. The cracking impacts refer to the likelihood of ground cracks developing and the loss of artefacts into the cracks through erosional processes.

- The grinding groove sites of Moderate to High Significance are all assessed to have Unlikely to Very Unlikely Cracking Damage Potential.

- Four (4) Grinding Groove sites of Low to Moderate Significance have a Moderate Cracking Damage Potential.

- All Rock Shelters with Moderate to High Significance are assessed to have an Unlikely to Very Unlikely Cracking and/or Toppling Damage Potential.

- One (1) Rock Shelter site of Low to Moderate Significance is assessed to have Moderate Cracking and Possible Toppling Damage Potential.

- The three Cultural Sites of Special Significance are all assessed to have Unlikely to Very Unlikely Cracking and/or Toppling Damage Potential.

11.8.3 Impact Management Strategies

Impact management strategies for Aboriginal sites are presented in the Aboriginal Cultural Heritage Assessment for the Tasman Extension Project and have been developed in consultation with Aboriginal stakeholders.

11.9 TransGrid Towers

11.9.1 Predicted Subsidence and Potential Impacts

Eight TransGrid Towers are considered to be within the zone of potential mine subsidence effect from the proposed Tasman Extension Project.

Predictions of worst-case transient and final subsidence, tilt and strain at each of the TransGrid Towers have been made based on the proposed mining layout without and with SCZs (the former case assumes that an engineer design cruciform footing and conductor adjustment have been installed within the required lead time before subsidence develops).

A summary of the subsidence prediction results for each mining scenario is presented in **Tables 24A** and **24B** respectively.

The results are associated with 'smooth' subsidence profile development and do not include discontinuous strata behaviour effects.

Table 24A - Final and Transient* Subsidence Impact Parameter Development at the TransGrid Towers without SCZs

Tower #	TransGrid Tower Reference	Final Tower Subsidence S_{max} (m)	Maximum Tilt T_{max} (mm/m)		Maximum Horizontal Displacement HD_{max} (mm)		Tower Movement Directions	Maximum Horizontal Strain^ E_{max} (mm/m)	
			Trans	Final	Trans	Final		Trans	Final
TG1	**82TL#19**	0.00	0.0	0.0	0.0	0.0	E	0.0	0.0
TG2	**81TL#460**	0.00	0.0	0.0	0.0	0.0	E	0.0	0.0
TG3	82TL#20	0.00	0.0	0.0	0.0	0.0	W	0.0	0.0
TG4	81TL#461	0.00	0.0	0.0	0.0	0.0	W	0.0	0.0
TG5	82TL#21	0.70	38	38	380	380	NE-SE	2.3	2.3
TG6	81TL#462	0.74	39	39	380	380	NE-SE	5.1	5.1
TG7	82TL#22	0.00	0.0	0.0	0.0	0.0	E	0.0	0.0
TG8	81TL#463	0.00	0.0	0.0	0.0	0.0	E	0.0	0.0

Bold - Tension Towers.
* - Refers to subsidence movements directly associated with the retreating extraction face.
^ - Tensile strain is positive. Maximum strains refer to major principal strains. Minor principle strains = 0.25 x major principle strains. Horizontal displacements and strains do not include far-field movements (see **Section 11.7.2**).

In summary, only two towers are within the proposed limits of the pillar extraction panels and are likely to be subjected to subsidence ranging from 0.70 m to 0.74 m at the tower centres.

Transient tilts and strains above the pillar extraction panels are assumed to equal the final values, based on a possible range of retreat rates of 30 m/week or less.

Final tower tilts will range between 38 mm/m and 39 mm/m. Horizontal displacements are estimated to be approximately 380 mm. The tower locations are expected to have residual tensile strains ranging from 2.3 mm/m to 5.1 mm/m, which are generally higher than the expected maximum tensile strain without cruciform footings of 2.5 mm/m.

Surface cracking may increase the estimated 'smooth' profile values by 2 to 4 times occasionally if shallow bedrock exists beneath the towers. Local tilts may exceed the smooth profile tilts by 1.5 times due to secondary surface 'hump' development as the goaf edge retreats along the panel.

If a Level 3 SCZ is proposed to protect the towers, the predicted outcomes are given in **Table 24B**.

Table 24B - Final and Transient* Subsidence Impact Parameter Development at the TransGrid Towers with SCZs

Tower #	TransGrid Tower Reference	Final Tower Subsidence S_{max} (m)	Maximum Tilt T_{max} (mm/m)		Maximum Horizontal Displacement HD_{max} (mm)		Tower Movement Direction	Maximum Horizontal Strain^ $+E_{max}$ (mm/m)	
			Trans	Final	Trans	Final		Trans	Final
TG1	**82TL#19**	0.001	0.0	0.0	0.0	0.0	E	0.0	0.0
TG2	**81TL#460**	0.000	0.0	0.0	0.0	0.0	E	0.0	0.0
TG3	82TL#20	0.000	0.0	0.0	0.0	0.0	W	0.0	0.0
TG4	81TL#461	0.000	0.0	0.0	0.0	0.0	W	0.0	0.0
TG5	82TL#21	0.020	0.0	2.2	22	22	NE-SE	1.6	1.6
TG6	81TL#462	0.019	0.0	2.1	21	21	NE-SE	1.7	1.7
TG7	82TL#22	0.000	0.0	0.0	0.0	0.0	E	0.0	0.0
TG8	81TL#463	0.000	0.0	0.0	0.0	0.0	E	0.0	0.0

Bold - Tension Towers.
* - Refers to subsidence movements directly associated with the retreating extraction face.
^ - Maximum strains refer to major principal strains. Minor principle strains = 0.25 x major principle strains.
Horizontal displacements and strains do not include far-field movements (see **Section 11.7.2**).

11.9.2 Impact Management Strategies

Based on the predicted subsidence profiles for the eight transmission towers, it is assessed that cruciform footings or subsidence protection pillars would be necessary above two of them above the proposed total extraction panels (Panel 4) areas to mitigate subsidence impacts on the towers to tolerable limits.

Alternatively, a Level 3 SCZ may be left below the tower, provided the design limits for the footings (and towers) to resist the predicted movements are checked by a structural engineer before mine subsidence occurs.

Once the tower footings assessment and any necessary mitigation works have been completed, the following monitoring program may be implemented in accordance with a Built Features Management Plan that will be prepared in consultation with TransGrid as a component of the Extraction Plan process:

- Install a minimum of four stable survey pegs or stations in the ground adjacent to each tower leg and on the structure itself. The 8 towers should be monitored.
- Determine 3-D coordinates (E, N, RL), levels and in-line strains between the pegs (perimeter distances only) with a minimum of two base-line surveys prior to mining. Survey accuracy should be within the limits discussed below.
- Conduct visual inspections and measurement of subsidence, total horizontal displacements and in-line distances between ground and tower stations during mine subsidence development. Record and photograph details of any changes to the towers and adjacent ground (i.e. cracking).
- Measure the vertical distance from the ground to the conductor catenaries between each tower before, during and after subsidence development.
- Prepare and distribute results of each survey to relevant stakeholders.
- Review and implement any Trigger Action Response Plans.

Subsidence should be determined using precise levelling and terrestrial total station traverse techniques to determine 3-D coordinates (see **Section 11** for survey accuracy requirements).

11.10 Ausgrid Power Line Easements

11.10.1 Potential Impacts to 132 kV Line

There are approximately sixteen pairs of timber power poles spaced at approximately 200 m along the Ausgrid Easement. The poles in each pair are approximately 15 m high and spaced 5 m apart with a galvanised steel brace between the tops of the poles.

The conductors are supported by relatively flexible vertical 'stringers' that will be able to tolerate some adjustment due to pole movements.

Worst-case predictions of final subsidence, tilt, strain, final tilt direction at each pole and conductor clearance loss between the pole pairs are not possible at this stage, so a general range of values have been provided along the easement in **Tables 25A** (without SCZs) and **25B** (with SCZs).

Table 25A - Worst Case Final Subsidence Predictions for Ausgrid 132 kV Power Poles without SCZs

Panel No.	Final Subs S_{max} (m)	Final Tilt T_{max} (mm/m)	Final Tilt Direction	Final Ground Strain$^+$ (mm/m)	Final HD* Base (mm)	Final HD^ Top (mm)	Conductor Clearance Loss Between Pole pairs (m)
8	0.77	24-26	SW	8.0-15.4	240-260	600-650	0.77
9	1.28	22-24	SW	5.4-13.0	220-240	550-600	1.28
10	1.28	18-20	SW	4.5-8.4	180-200	450-500	1.28
11	1.27	18-21	N	3.5-8.4	180-210	450-525	1.27
M2	0.96	14-15	W	2.2-6.0	140-150	448-480	0.96
27	1.17	13-17	SW	2.8-4.3	130-170	325-425	1.17
28	1.20	13-15	SW	2.7-4.6	130-150	325-375	1.20
29	1.31	8-13	W	1.6-3.2	80-130	200-325	1.31
30	0.95	3-4	W	0.5-1.6	30-40	75-100	0.95

+ - Tensile and compressive phases may occur during subsidence development.
* - HD Base = Absolute horizontal displacement of pole at ground level.
^ - HD top = Absolute horizontal displacement of pole at conductor level (assumed to be 15 m above the ground)

Table 25B - Worst Case Final Subsidence Predictions for Ausgrid 132 kV Power Poles with SCZs

Panel No.	Final Subs S_{max} (m)	Final Tilt T_{max} (mm/m)	Final Tilt Direction (grid bearing) (o)	Final Tensile Ground Strain (mm/m)	Final HD* Base (mm)	Final HD^ Top (mm)	Conductor Clearance Loss Between Pole pairs (m)
8	0.18	5.7-15.6	SW	1.5-2.4	57-156	143-390	0.18
9	0.33	2.1-7.7	SW	2.4-1.0	21-77	53-193	0.33
10	0.20	2.4-2.6	SW	0.9-1.1	24-26	36-101	0.20
11	0.20	1.8-2.8	N	0.5-1.1	18-28	45-70	0.20
M2	0.23	2.9-3.2	W	0.5-0.4	29-32	73-80	0.23
27	0.27	3.0-3.9	SW	0.9-0.8	30-39	75-98	0.27
28	0.23	2.3-2.5	SW	0.5-0.4	23-25	58-63	0.23
29	0.23	1.4-2.0	W	0.4-0.5	14-20	35-50	0.23
30	0.17	0.5-0.6	W	0.1-0.1	5-6	13-15	0.17

* - HD Base = Absolute horizontal displacement of pole at ground level.
^ - HD top = Absolute horizontal displacement of pole at conductor level (assumed to be 15 m above the ground)

Each of the power pole pairs will be subject to transient movements towards the retreating pillar extraction face and then 'swing' around (up to 90 degrees in bearing) to their final positions after subsidence is fully developed.

The poles above the total extraction panels without SCZs are likely to be subject to tensile and compressive strains associated with the subsidence 'wave' as it passes underneath the poles. The transient tilts and strains are expected to range from 50% to 100% of the final values, depending on panel geometry and face retreat rates.

Poles located within an SCZ are likely to be subject to significantly lower tilts and strains than the poles outside these areas.

Conductor clearances are estimated to be decreased by between 0.77 m and 1.31 m along the easement without SCZs and from 0.17 m and 0.33 m with the proposed SCZs.

11.10.2 Potential Impacts to 11 kV Line

There are approximately 7 timber power poles supporting the Ausgrid 11 kV conductors along Sheppeard Drive that will be within the zone of mine subsidence. The poles are approximately 15 m high and 220 m apart on average.

Worst-case predictions of final subsidence, tilt, strain and final tilt direction at each pole are not possible at this stage, so a general range of values have been provided along the easement below.

A summary of the predicted subsidence effects for the timber due to the proposed panels are presented in **Table 26A** (without SCZs) and **Table 26B** (with SCZs).

Table 26A - Summary of Worst-Case Subsidence Predictions for 11kV Lines without SCZs

Panels	Cover Depth (m)	Final Maximum Subsidence S_{max} (m)	Final Maximum Tilt T_{max} (mm/m)	Final Maximum Tensile Strain* (mm/m)	Final Maximum Compressive Strain* (mm/m)	Final Horizontal Displacement (mm)
9	55-75	0.34-0.54	34-48	10 - 29	-	340-480 (East)
M2	80-90	1.05	34-35	13	20	340-350 (South)
22	80	0.13	7.0	2-19	-	70 (East)

* - Tensile and compressive strains may increase 2 to 4 times occasionally due to crack development.

Table 26B - Summary of Worst-Case Subsidence Predictions for 11 kV Line with SCZs

Panels	Cover Depth (m)	Final Maximum Subsidence S_{max} (m)	Final Maximum Tilt T_{max} (mm/m)	Final Maximum Tensile Strain* (mm/m)	Final Maximum Compressive Strain* (mm/m)	Final Horizontal Displacement (mm)
9	55-75	0.12-0.37	10-48	2-29	-	100 - 480 (East)
M2	80-90	1.05	23-32	13	20	230 - 320 (South)
22	80	0.12	7.1	2-29	-	70 (east)

* - Tensile and compressive strains may increase 2 to 4 times occasionally due to crack development.

The predicted subsidence effect profiles for the 11 kV lines are the same as those for Sheppeard Drive (see **Section 11.13**).

Based on the proposed mine plan provided, the poles appear to be positioned directly above the barrier pillar between total extraction panels. The power poles will be subject initially to transient movements towards the retreating pillar extraction face. The poles will generally start moving towards the goaf and then 'swing' around (up to 90 degrees in bearing) to their final positions after subsidence is fully developed.

The conductors are supported by relatively inflexible ceramic insulators that may not be able to tolerate the predicted pole movements without mitigation or repair works either before or during active subsidence development.

Conductor clearances are estimated to be decreased by between 0.00 m and 1.05 m along the easement.

11.10.3 Impact Management Strategies

Appropriate impact management strategies for the power line easements may include:

(i) Development of a Built Features Management Plan based on consultation with Ausgrid as a component of the Extraction Plan process to ensure the predicted subsidence effects on the poles and power lines do not result in unsafe conditions or loss of serviceability during and after mining.

(ii) Replacement of any damaged poles and/or mitigation works to conductors as mine subsidence develops.

Suitable responses to predicted subsidence impacts may be to provide flexible/roller-type conductor sheathing on the poles to control the tension during/after mining impacts. It is noted that shortening of several conductors (to reduce catenary sag) and adjustment to sheathing has been required above the Abel Mine panels.

(iii) Damage from subsidence (i.e. cracking and tilting) can manifest quickly after mining (i.e. within hours). The appropriate management plan will therefore need to consider the time required to respond to an impact exceedance if it occurs. The erection of temporary fencing in critical areas before subsidence develops may also need to be considered.

The Built Features Management Plan may include the following actions:

- Visual inspections of power lines in actively subsiding areas

- Measurement of the vertical distance from the ground to the conductor catenaries between each pole pair before, during and after subsidence development.

- Preparation and distribution of survey results of each survey to relevant stakeholders.

- Review and implementation of Trigger Action Responses as necessary.

11.11 Fibre Optic Cables

11.11.1 Potential Impacts

The AAPT and Telstra FOC are buried within a shallow trench that is located within the TransGrid 330 kV and Ausgrid 132 kV powerline easements respectively (see **Figure 1**). The TransGrid FOC is suspended along its 330 kV southern 81 tower series.

The worst-case final subsidence predictions along the easement after mining are presented in **Table 27A** (without SCZs) and **Table 27B** (with SCZs).

Table 27A - Worst-Case Subsidence Predictions for the Fibre Optic Cable Easements without SCZs

Panel	Cover Depth (m)	Effective Mining Height (m)	Final Subsidence S_{max} (m)	Final Tilt T_{max} (mm/m)	Final In-Line Tensile Ground Strain* (mm/m)	Final In-Line Compressive Ground Strain* (mm/m)
AAPT and TransGrid FOC (along the 330 kV TransGrid Easement)						
32	150	2.2	1.16	15-17	3.0-4.1	5.0-5.4
4	75	2.2	1.27	26-28	8.7-13.4	7.6-9.2
3	72	2.2	1.27	29-30	11.0-13.4	9.8-10.6
Telstra FOC (along 132 kV Ausgrid Easement)						
8	55	2.2	0.77	24-26	8.0-13.0	15.0-15.4
9	65	2.2	1.28	22-24	7.0-13.0	5.4-6.6
10	75	2.2	1.28	18-20	7.2-8.4	4.5-4.8
11	90	2.2	1.27	18-21	5.2-8.4	3.5-4.6
M2	105	2.2	0.96	14-15	2.2-3.1	6.0
27	115	2.2	1.17	13-17	2.8-3.7	4.3
28	135	2.2	1.20	13-15	2.7-2.9	4.6
29	200	2.2	1.31	8-13	1.6-2.5	3.2
30	300	2.2	0.95	3-4	0.5-1.6	0.7

* - Predicted in-line strains are based on 'smooth' subsidence profiles and may increase locally by 2 to 4 times occasionally due to surface cracking.

Table 27B - Worst-Case Subsidence Predictions for the Fibre Optic Cable Easements with SCZs

Panel	Cover Depth (m)	Effective Mining Height (m)	Final Subsidence S_{max} (m)	Final Tilt T_{max} (mm/m)	Final In-Line Tensile Ground Strain* (mm/m)	Final In-Line Compressive Ground Strain* (mm/m)
AAPT and Transgrid FOC (along the 330 kV TransGrid Easement)						
32	150	1.5	0.30	3.9-4.4	0.4-0.6	1.3-1.4
4	75	1.5	0.27	3.9-5.7	0.1-1.9	1.1-1.7
3	72	1.5	0.32	7.3-7.4	2.3-2.6	2.5-2.7
Telstra FOC (along 132 kV Ausgrid Easement)						
8	55	1.5	0.18	2-4	1.0-1.5	1.5-2.0
9	65	1.5	0.33	3-5	2.4-1.0	0.5-0.6
10	75	1.5	0.20	2.4-2.6	0.9-1.1	0.4-0.6
11	90	1.5	0.20	1.8-2.8	0.5-1.1	0.3-0.4
M2	105	1.5	0.23	2.9-3.2	0.5-0.4	1.1
27	115	1.5	0.27	3.0-3.9	0.9-0.8	0.9
28	135	1.5	0.23	2.3-2.5	0.5-0.4	0.7
29	200	1.5	0.23	1.4-2.0	0.4-0.5	0.6
30	300	1.5	0.17	0.5-0.6	0.1-0.1	0.1

* - Predicted in-line strains are based on 'smooth' subsidence profiles and may increase locally by 2 to 4 times occasionally due to surface cracking.

The final subsidence, tilt and strain profiles along the AAPT FOC easement with and without SCZs are presented in **Figures 43a** to **43c**. The profiles for the Telstra FOC are shown in **Figures 44a** to **44c**.

11.11.2 Impact Management Strategies

Based on discussions with AAPT and Telstra regarding FOC impact management strategies at other mine sites, the following strategies are available if horizontal ground strains are likely to exceed 2 mm/m along the cables:

- Uncover and relocate the cable prior to mine subsidence impacts.
- Limit subsidence effects to within tolerable limits.

No specific management strategies are anticipated for the TransGrid FOC additional to the management strategies for the TransGrid 330 kv transmission line (**Section 11.9.2**)

Built Features Management Plans for the FOCs would be developed in consultation with Telstra and AAPT as a component of the Extraction Plan process.

11.12 Telstra Copper Cables

11.12.1 Potential Impacts

Telstra copper cables are buried within shallow trenches along the eastern side of Sheppeard Drive.

The cables are likely to be subject to subsidence between 0.02 m to 1.05 m and in-line ground strains between 2 and 20 mm/m compressive strain and 1 mm/m to 10 mm/m tensile strain.

11.12.2 Impact Management Strategies

Built Features Management Plans would be developed in consultation with Telstra as a component of the Extraction Plan process to maintain the serviceability of the currently in service cables. It is understood that the cables may tolerate strains up to 20 mm/m, depending on location of connections and joints.

11.13 Sheppeard Drive and Drainage Infrastructure

11.13.1 Details and Potential Impacts

Sheppeard Road will be undermined by the proposed Panels 9, M2 and 22.

A summary of the predicted subsidence effects acting on the road, fill embankments and culverts due to the proposed panels are presented in **Table 28A** (without SCZs) and **Table 28B** (with SCZs).

Table 28A - Summary of Worst-Case Subsidence Predictions for Sheppeard Road without SCZs

Panels	Cover Depth (m)	Final Maximum Subsidence S_{max} (m)	Final Maximum Tilt T_{max} (mm/m)	Final Maximum Tensile Strain* (mm/m)	Final Maximum Compressive Strain* (mm/m)	Final Horizontal Displacement (mm)
9	55-75	0.34-0.54	34-48	10 - 29	-	340-480 (East)
M2	80-90	1.05	34-35	13	20	340-350 (South)
22	80	0.13	7.0	2-19	-	70 (East)

* - Tensile and compressive strains may increase 2 to 4 times occasionally due to crack development.

Table 28B - Summary of Worst-Case Subsidence Predictions for Sheppeard Road with SCZs

Panels	Cover Depth (m)	Final Maximum Subsidence S_{max} (m)	Final Maximum Tilt T_{max} (mm/m)	Final Maximum Tensile Strain* (mm/m)	Final Maximum Compressive Strain* (mm/m)	Final Horizontal Displacement (mm)
9	55-75	0.12-0.37	10-48	2-29	-	100 - 480 (East)
M2	80-90	1.05	23-32	13	20	230 - 320 (South)
22	80	0.12	7.1	2-29	-	70 (east)

* - Tensile and compressive strains may increase 2 to 4 times occasionally due to crack development.

The final subsidence, tilt and strain profiles along Sheppeard Road with and without SCZs are presented in **Figures 45a** to **45c**.

The impacts due to the predicted subsidence effects may include:

1. Tensile crack widths of between 20 mm and 290 mm.
2. Compressive shearing or shoving between 20 mm and 200 mm.
3. Increase of super-elevation in the road of 1% to 5%.
4. Cracking of culverts and fill embankments.
5. Erosion and slope instability of fill embankments.

11.13.2 Impact Management Strategies

A Built Features Management Plan would be prepared for Sheppeard Drive in consultation with Cessnock City Council as a component of the Extraction Plan process and may include impact management strategies for the road such as:

(i) Pre-mining condition survey of road and drainage infrastructure prior to commencement of second workings.

(ii) Installation of subsidence monitoring lines along one side of road to review measured impacts and predictions.

(iii) Remediation of pavement and drainage impacts by Donaldson Coal using normal road maintenance techniques.

(iv) On-going consultation with Cessnock City Council during and following mining, including notification of mine subsidence results.

(iii) A Trigger Action Response Plan for unanticipated mining related impacts.

11.14 Principal Residences

11.14.1 Potential Impacts

There are three residences located above the proposed pillar extraction panels.
As described in **Section 5.2** it is intended to leave sufficient first workings only zones (i.e. Level 3 SCZs) below and around the residences to limit the potential subsidence impacts to safe, serviceable and repairable. Based on reference to **Table 4A** and the conditions at each house site, it is recommended that a minimum set-back distance to second workings limits be set at 26.5^o AoD (i.e. 0.5 times the cover depth) from the corners of each principal residence.

The predicted subsidence effect contours around the Principal Residences are presented in **Figures 31a** to **31d**. The contours indicate that the maximum subsidence at the Principal Residences within the SCZ is likely to be < 20 mm, with tilts < 5 mm/m, curvature < 0.2 km^{-1}, and tensile strains < 2 mm/m.

The above SCZs will also reduce impacts to the existing water tanks and on-site effluent disposal areas adjacent to the principal residences. To-date the AoD to 20 mm subsidence contour has ranged between 1^o and 23^o around Panels 1 to 4 at the Abel Mine.

Some of the property fences, dams and access roads from Sheppeard Drive that are outside the SCZs are likely to be impacted by mine subsidence. Management of subsidence impacts to these features will be included in Property Subsidence Management Plans.

11.14.2 Impact Management Strategies

As previously discussed, all residences and associated machinery sheds, in-ground tanks and pipes within the proposed mining area will be protected from significant damage by the SCZs. The maximum subsidence is estimated to be < 20 mm for minimum set back distances of 26.5 degrees for the proposed SCZ beneath the principal residences. Any damage to Principal residences should not be greater than Category 0 to 2 Damage Classification categories (i.e. "Negligible" to "Slight" in accordance with **AS2870, 1996**). Further impact reduction may be achieved by increasing the set-back distances, and will depend upon the tolerance limits to movement of the structure(s) being protected.

The proposed management strategies required to minimise impact to the principal residences due to subsidence are:

1. Installation of monitoring pins or pegs around each structure and conduct base line subsidence, peg location and strain measurements prior to undermining.

2. In addition to the pre-mining inspections of the properties by representatives of Donaldson Coal, an inspection of the above properties to be made by the Mine Subsidence Board (MSB) before and after second workings in the vicinity of the site are undertaken.

3. Structure surveys and visual inspections should be completed not before one month after second workings of a panel has been completed.

4. Any minor repair works to internal/externals cracking or re-levelling of Principal (and non-Principal) structures should be implemented as soon as mining related movements have ceased.

5. If impacts to Principal Residences exceed a Category 2 damage classification in accordance with **AS2870, 1996** or "Moderate" damage, then is it will necessary to review the SCZ set back distance in regards to applying them to other Principal Residences.

Appropriate management strategies for the existing N*on-Principal Residences and Other Structures* that may be impacted by mine subsidence, should include and address the following issues in consultation between the stakeholders and the MSB:

1. A Property Subsidence Management Plan shall be prepared and implemented for the mitigation and remediation of any damage in conjunction with the Mine Subsidence Board to include:

2. A pre- and post-mining condition survey and/or inspection of all structures within the mining lease should be made by the MSB.

3. Determine when mining impacts will occur to the buildings and vacate premises prior to any impact. Install temporary fencing to prevent site personal or general public access to any potentially unstable structures.

4. Development of a monitoring plan for the property during mine subsidence and post mine subsidence periods and safety/hazard management plan.

5. The timing of disconnection of power and water supply etc if required.

6. An inspection of mine subsidence damaged properties should be made by registered building inspectors and any repair / mitigation / remediation works to be undertaken will be related to the extent of damage experienced.

Mine subsidence is expected to develop soon after the face retreats beneath a property and would be expected to continue until the face is 1 to 2 times the cover depth past the property (see **Section 11** for more details). Subsidence movements would also be expected to ‘start again’ soon after the passing of subsequent panels, albeit at decreasing rates and magnitudes. It is considered likely that subsidence movements will affect undermined properties for periods of at least 6 to 8 weeks after each panel is extracted.

11.15 Farm Dams

11.15.1 Potential Impacts

There are no known farm dams of significance on the private properties and above the proposed pillar extraction panels based on review of aerial photography and detailed topographic data, and landholder consultation. Notwithstanding, a farm dam may be constructed prior to mining occurring.

Non-engineered farm dams and water storages will be susceptible to surface cracking and tilting (i.e. storage level changes) due to mine subsidence. The tolerable tilt and strain values for the dams would depend upon the materials used, construction techniques, foundation type and likely repair costs to re-establish the dam’s function and pre-mining storage capacity.

The expected phases of tensile and compressive strain development may result in breaching of the dam walls or water losses through the floor of the dam storage area. Loss or increase of storage areas may also occur due to the predicted tilting. Damage to fences around the dams may also occur and require repairing.

It should be noted that farm dams have been subsided by underground coal mines elsewhere in NSW and any damage has been effectively managed. The dams were reinstated in a timely manner and an alternative supply of water was provided by the mine during the interim period.

11.15.2 Impact Management Strategies

A Dam Monitoring and Management Strategy (DMMS) will be formulated for each farm dam prior to any mining occurring which will impact on the dams. The DMMS will provide for:

(i) The individual inspection of each dam by a qualified engineer for:

- current water storage level;
- current water quality (EC and pH);
- wall orientation relative to the potential cracking;
- wall size (length, width and thickness);
- construction method and soil / fill materials;
- wall status (presence of rilling / piping / erosion / vegetation cover);
- potential for safety risk to people or animals;
- downstream receptors, such as minor or major streams, roads, tracks or other farm infrastructure; and
- potential outwash effects.

(ii) Photographs of each dam will be taken prior to and after undermining, when the majority of predicted subsidence has occurred.

(iii) Dam water levels, pH and EC will be monitored prior to and after undermining to assess the baseline and post-mining dam water level and water quality in order to determine whether rehabilitation is required.

(iv) In the event that subsidence / crack development monitoring indicates a significant potential for dam wall failure, dam water will be managed in one of the following manners:

- pumped to an adjacent dam to lower the water level to a manageable height that reduces the risk of dam wall failure,
- discharged to a lower dam via existing channels if the water cannot be transferred, or not transferred if the dam water level is sufficiently low to pose a minor risk.
- An alternate water supply will be provided to the dam owner until the dam can be reinstated.

(v) In the event of subsidence damage to any dams the Company shall remediate the damage and reinstate the dam in conjunction with the MSB.

11.16 Property Fences

11.16.1 Potential Impacts

The impact of 1.0 m to 1.3 m of subsidence on fencing could include loss of tension or failure of wire strands and the possible failure of strainer posts. Swing gates could also be affected and not function properly after mine subsidence.

Failure of fencing could allow livestock to get out of paddocks and properties until remediation works are completed.

11.16.2 Impact Management Strategies

The above impacts may be managed with the rapid repair of damaged fences and gates. Relocation of livestock / animals before mining impacts occur may also be undertaken in anticipation of fence failure. A Property Subsidence Management Plan would be prepared in consultation with the landowner to address these potential issues.

11.17 Unsealed Tracks and Fire Trails

11.17.1 Potential Impacts

There are a number of unsealed tracks above the proposed pillar extraction panels, including Sugarloaf Range Road, easement access roads and forestry access roads in Heaton State Forest.

Sugarloaf Fire Trail is located above Panels 1 and 2 in the West Borehole Seam and Tasman Mine's North East Panel in the Fassifern Seam. A dormant unnamed fire trail is located in the south above Panels 19 to 22 in the West Borehole Seam. There may be small dams and excavations associated with these fire trails for fire fighting purposes.

The predicted subsidence on the fire trails is presented in **Tables 29A** and **29B**.

Table 29A - Summary of Worst-Case Subsidence Predictions for the Fire Trails without SCZs

Panels	Cover Depth (m)	Final Maximum Subsidence S_{max} (m)	Final Maximum Tilt T_{max} (mm/m)	Final Maximum Tensile Strain* (mm/m)	Final Maximum Compressive Strain* (mm/m)	Final Horizontal Displacement (mm)
Fire Trail No. 1						
1	165	0.93 - 1.13	15 - 22	6 - 9	7 - 11	150 - 220
2	185	0.90 - 1.11	14 - 21	6 - 9	7 - 11	140 - 210
NE (Tasman)	80	0.10 - 0.15	2 - 5	0.5 - 1.5	1 - 2	20 - 50
Fire Trail No. 2						
19	100	1.04 - 1.23	20 - 31	9 - 13	11 - 16	200 - 310
20	125	0.9 - 1.11	14 - 21	6 - 9	7 - 11	140 - 210
21	290	0.57 - 0.72	5 - 8	6 - 10	7 - 10	130 - 190
22	330	0.20 - 0.30	2 - 5	0.5 - 1.5	1 - 2	20 - 50

* - Tensile and compressive strains may increase 2 to 4 times occasionally due to crack development.

Table 29B - Summary of Worst-Case Subsidence Predictions for the Fire Trails with SCZs

Panels	Cover Depth (m)	Final Maximum Subsidence S_{max} (m)	Final Maximum Tilt T_{max} (mm/m)	Final Maximum Tensile Strain* (mm/m)	Final Maximum Compressive Strain* (mm/m)	Final Horizontal Displacement (mm)
Fire Trail No. 1						
1	165	0.10 - 0.15	2-5	0.5 - 1.5	1 - 2	20 - 50
2	185	0.10 - 0.15	2-5	0.5 - 1.5	1 - 2	20 - 50
NE (Tasman)	80	0.10 - 0.15	2-5	0.5 - 1.5	1 - 2	20 - 50
Fire Trail No. 2						
19	100	1.04 - 1.23	20 -31	9 - 13	11 - 16	200 - 310
20	125	0.6 - 0.8	14 - 21	6 - 9	7 - 11	140 - 210
21	290	0.10 - 0.15	5 - 8	6 - 10	7 - 10	130 - 190
22	330	0.10 - 0.15	2 - 5	0.5 - 1.5	1 - 2	20 - 50

* - Tensile and compressive strains may increase 2 to 4 times occasionally due to crack development.

The impacts due to the predicted subsidence effects may include:

1. Tensile crack widths of between 20 mm and 130 mm above total extraction panels (cracking unlikely above SCZs).
2. Compressive shearing or shoving between 20 mm and 160 mm above total extraction panels (shear failures unlikely above SCZs).
3. Increase of super-elevation in the road of 0.3% to 3% above total extraction panels with erosion impact likely to occur (erosion unlikely above SCZs).

11.17.2 Impact Management Strategies

Similar to the management measures implemented at the Tasman Mine, Trigger Action Response Plans and remediation strategies would be developed for unsealed track and fire trails and outlined in Extraction Plans. This would include:

(i) Pre-mining condition survey of tracks prior to commencement of second workings.

(ii) Visual monitoring during mining and maintenance of appropriate warning signs.

(iii) Remediation of surface cracks or loss of storage in dams by Donaldson Coal, for example using excavation, fill and grading.

(iv) On-going consultation with relevant stakeholder (Office of Environment and Heritage, Forests NSW, Rural Fire Service) during and following mining, including notification of mine subsidence results.

11.18 Proposed Re-Development of TransGrid Land for Sub-Station

11.18.1 Predicted Impacts

It is understood that TransGrid are planning to develop a substation on Lot 15 at some time in the future and that there is to be no residual subsidence risk remaining beneath the site after mining has ceased.

The proposed pillar extraction panels will be > 200 m east of the Lot Boundary on Sheppeard Drive and will be > 3.5 times the cover depth of 55 m away (i.e. an AoD of 74^o). It is assessed that the site is well outside the AoD and any movements due to mine subsidence development will be immeasurable and impacts very likely to be ‘negligible’.

11.18.2 Impact Management Strategies

The impact management strategies for the TransGrid Site would be addressed through the preparation of a Property Subsidence Management Plan developed in consultation with TransGrid, which would address monitoring requirements for any potential issues that may arise.

11.19 Orica Research and Testing Facility and ANE Plant

The proposed pillar extraction panels will be over 200 m east of the proposed ANE plant buildings (under construction), which is over 3.5 times the cover depth of 55 m (i.e. an AoD of 74°). The Research and Testing Facility is located further away from the pillar extraction panels. It is assessed that the buildings on Orica land are well outside the AoD and any movements due to mine subsidence development will be immeasurable and impacts very likely to be ‘negligible’.

11.19.1 Impact Management Strategies

No impact strategies are required based on our understanding of the Orica Site at this stage.

11.20 George Booth Drive

11.20.1 Potential Impacts

George Booth Drive is located 680 m to 2100 m from the proposed mining areas. Based on cover depths of 60 m to 100 m, the road is well outside the AoD with distances > 6.8 times the cover depth). Far-field horizontal displacements and strains towards the mining area are very unlikely to exceed survey accuracy limits and impacts to the road will be negligible.

11.20.2 Impact Management Strategies

It is not considered necessary to monitor absolute displacements due to far-field movements along George Booth Drive.

It is however, considered reasonable to conduct visual inspections along the roads during subsidence development and prepare an impact management response strategy to deal with mining impacts if they do occur.

A series of far-field monitoring stations that monitor total horizontal displacement and strain may be established at strategic points around the mining lease to further define appropriate set-back distances from sensitive items of infrastructure that may exist elsewhere within the mining lease.

11.21 Hunter Expressway

11.21.1 Potential Impacts

The Hunter Expressway is located > 1000 m from the proposed mining areas. Based on cover depths of 60 m to 100 m, the freeway is well outside the AoD with distances > 10 times the cover depth). Far-field horizontal displacements and strains towards the mining area are very unlikely to exceed survey accuracy limits and impacts to the freeway will be negligible.

11.21.2 Impact Management Strategies

It is not considered necessary to monitor absolute displacements due to far-field movements along the Hunter Expressway.

It is however, considered reasonable to conduct visual inspections along the freeway during subsidence development and prepare an impact management response strategy to deal with mining impacts if they do occur.

A series of far-field monitoring stations that monitor total horizontal displacement and strain may be established at strategic points around the mining lease to further define appropriate set-back distances from sensitive items of infrastructure that may exist elsewhere within the mining lease.

11.22 Monitoring Requirements

11.22.1 Subsidence Development

The development of subsidence above a pillar extraction panel generally consists of two phases that are defined as 'primary' and 'residual' subsidence.

Primary subsidence is referred to the subsidence that is directly related to the retreating pillar extraction face.

Residual subsidence, due to re-consolidation of goaf, represents approximately 5 to 10% of maximum final subsidence and will be on-going for several months after primary subsidence ceases.

Maximum subsidence above a panel generally does not start to occur until the retreating extraction face has moved at least a distance equal to the width of the panel, and is referred to as the 'square' position.

Approximately 90% to 95% of mine subsidence development will occur within 4 to 6 weeks after undermining occurs. On-going residual settlements of up to 50 mm due to goaf reconsolidation may continue for a period of up to 1 year, however, these movements are unlikely to result in further impact occurring to the surface.

Reference to **ACARP, 2003** and local data for the Abel Mine panels indicate that primary subsidence is likely to commence at a given location above the panel centreline when the pillar extraction face is a distance of about 0.5 times the cover depth ahead of the point. The subsidence will then start to accelerate up to rates from 50 to 100 mm/day when the face is 0.5 to 1 times the cover depth past of the point, and then decrease to < 2 mm/day when the face is > 2 times the cover depth past it (see **Figure 46a**).

A summary of the subsidence magnitude and rate of development at several locations above the first two pillar extraction panels at Abel is presented in **Tables 30A** and **30B**.

Table 30A - Summary of Maximum Subsidence Development above Panels 1 and 2 Centrelines at the Abel Mine

Panel (Peg#)	Cover Depth H (m)	Panel Width W (m)	W/H	Start of Subsidence, d (distance to face)			End of Subsidence*, d (distance to face)		
				d_{start} (m)	d_{start}/H (m/m)	time (weeks)	d_{finish} (m)	d_{finish}/H (m/m)	time (weeks)
1 (47)	97	120	1.24	*-50*	*-0.5*	*-1.1*	175	1.8	3.7
2 (231)	70	160	2.29	*-16*	*-0.2*	*-0.5*	175	2.5	5.7

italics - Negative distances indicate face has not reached point on centreline.
* - d_{finish} = face distance past point where subsidence development rate has decreased to < 2mm/day.

Table 30B - Summary of Maximum Subsidence Rate Development above Panels 1 and 2 at the Abel Mine

Panel (Peg#)	Cover Depth H (m)	Panel Width W (m)	Face Retreat Rate [mean] (m/week)	Peak Subsidence Development Rate (mm/day)	Location of Peak Subsidence, d (distance to face)		
					d_{peak} (m)	d_{peak}/H (m/m)	time to peak (weeks)
1 (47)	97	120	30 - 59 [37]	77	74	0.8	1.9
2 (231)	70	150	25 - 50 [32]	101	101	49	1.9

The development of subsidence is also affected by the velocity of the retreating extraction face. The measured rates of retreat for the first four Abel Mine panels (Panels 1 to 4) have ranged between <10 m/week to 50 m/week with an average of approximately 30 m/week (see Panel 1 and 2 retreat rates in **Figures 46b** and **46c**).

Predictions of subsidence development curves for 10 m/week, 30 m/week and 50m/week have been derived using the dynamic subsidence analysis module provided in the SDPS® program, and are presented in **Figures 46a** to **46c**.

The default value of the time coefficient in the SDPS® model has been adopted to provide a conservative estimate of effective rate of residual subsidence development after the primary subsidence phase has finished.

Further subsidence is also expected to develop when adjacent panels are subsequently extracted and will be due to the compression of barrier pillars when subject to increasing abutment loads. The development and magnitude of these movements will be similar to the residual subsidence movements.

11.23 Surface Monitoring Plans

11.23.1 Monitoring Program

Based on the surface topography and surface infrastructure present above the proposed pillar extraction panels, the following subsidence and strain-monitoring program is suggested to provide adequate information to monitor and implement appropriate subsidence impact management plans and provide pillar stability and performance data.

The following general monitoring program activities are suggested:

- A minimum of one transverse subsidence line across the pillar extraction panels. The lines should be installed to at least the middle of the next adjacent panel before undermining occurs. The final transverse surveys for each panel should include the previous panels to capture chain pillar subsidence as it develops.

- A longitudinal line extending in-bye and out-bye from each panels starting and finishing points, for a minimum distance equal to the cover depth (i.e. to an AoD of 45^o).

- A survey line along and across the banks of Surveyors Creek (refer to Surface Water Assessment).

- Depending on location of a principal residence, either one or two survey lines to measure AoD over the proposed first workings areas running parallel and transverse to the panel centreline.

- A minimum of 4 pegs spaced 10 m apart adjacent to or around any feature of interest (e.g. TransGrid tower, archaeological sites) to measure subsidence, tilt and strain.

- The panel survey pegs should be spaced at a minimum of 10 m and a maximum of 20 m apart. For the first two or three panels it is recommended that the pegs are spaced 10 m apart along full crosslines and centrelines.

- As more survey data is obtained it is envisaged that the peg spacing may be widened at non-critical locations (eg the central sections of the panel centrelines) or deleted altogether.

- A minimum of two baseline surveys of subsidence and strain is recommended before mine subsidence occurs to establish survey accuracy.

- Survey frequency will be dependent upon mine management requirements for subsidence development data in order to implement subsidence and mine operation management plans.

- Visual inspections and mapping of damage to be conducted before, during, and after mining.

- The location of the extraction face should be recorded with each survey.

Further site or stakeholder specific monitoring may also be required.

11.23.2 Survey Accuracy

Subsidence and strains may be determined using total station or spirit levelling and steel tape techniques, depending on the survey accuracy requirements.

The accuracy of total station traverse techniques from a terrestrial base line is normally expected to be within +/- 10 mm for level and +/- 10 to 20 mm for horizontal displacement (i.e. a strain measurement accuracy of +/- 1 to 2 mm/m over a 10 m bay-length).

The accuracy of level measurements using spirit level should give subsidence to within +/- 3 mm. Strain measurements using the steel tape techniques would be expected to have an accuracy of +/- 2 mm (or 0.2 mm/m strain over 10 m).

It is recommended that total station techniques are used only for locating and monitoring of absolute X and Y displacements were possible and spirit levelling be used to measure all vertical movements. Steel tape measurements would be the preferred method for measuring strain.

11.24 Sub-Surface Monitoring

Monitoring of sub-surface fracture heights above pillar extraction panels may be necessary within the mining area to confirm the predictions of potential areas of connective surface cracking.

Two deep borehole extensometers have been installed in the middle of Abel Mine’s Panel 1 and 2 to monitor heights of sub-surface fracturing due to the caving or goafing process during mining. Two deep boreholes above the barrier pillars between the panels have been instrumented with vibrating wire piezometers to monitor groundwater impacts.
The details and results of the monitoring have now been successfully collated and indicate that the height of continuous fracturing is within the predicted ranges. Monitoring of sub-surface fracture heights (through installation of extensometers and piezometers) above the West Borehole Seam would occur during the Project as part of the Extraction Plans.

Inspections and monitoring of underground workings stability, groundwater makes and goaf air entry should continue to be recorded and included with subsidence monitoring data. In particular, the presence of faults between panels has the potential to create perched water tables and delayed inflow responses into extracted panels.

12.0 Conclusions

The maximum first and final subsidence predictions for the proposed 160.5 m wide total extraction Panels 1 to 32 and 105 m wide main headings panels (M1 to M3) range from 0.58 m to 1.27 m below the flatter areas of the mining lease with cover depths of 55 m to 185 m. Below the ridges of the Sugarloaf Range where cover depths range from 155 m to 350 m, maximum subsidence is estimated to range from 0.10 m to 1.12 m.

The predicted subsidence represents 5% to 58% of the effective mining height of 2.2 m. The proposed 19.5 m wide barrier pillars are likely to go into yield at depths > 150 m.

Predictions of final maximum tilt values for the pillar extraction panels below the flatter areas range from 13 mm/m to 60 mm/m and from 3 mm/m to 19 mm/m below the ridges. Maximum horizontal displacements are estimated to range from 130 mm to 600 mm below the flatter areas from 30 mm to 190 mm below the ridges.

Predictions of final maximum hogging curvature values for the pillar extraction panels below the flatter areas range from 0.55 km^{-1} to 2.91 km^{-1} with maximum tensile strains estimated to range from 5 to 29 mm/m. Final maximum hogging curvature values for the pillar extraction panels below the ridges range from 0.20 km^{-1} to 0.79 km^{-1} with maximum tensile strains estimated to range from 2 to 8 mm/m.

Predictions of final maximum sagging curvature values for the pillar extraction panels below the flatter areas range from 0.70 km^{-1} to 3.69 km^{-1} with maximum tensile strains estimated to range from 7 to 37 mm/m. Final maximum sagging curvature values for the pillar extraction panels below the ridges range from 0.25 km^{-1} to 1.00 km^{-1} with maximum compressive strains estimated to range from 3 to 10 mm/m.

The predicted maximum panel subsidence magnitudes are likely to result in surface cracks developing within the limits of the extracted panels (without SCZs). Surface cracks are not expected to develop where the proposed SCZs are left in place.

Connective sub-surface cracking to the surface is considered ‘likely’ to ‘possible’ for cover depths < 80 m above total extraction panels. The height of direct hydraulic connection is expected to decrease to below 60 m for partial pillar extraction panels with stable remnant pillars.

It is assessed that the use of partial pillar extraction areas beneath the watercourses and GDE areas above the proposed mining layout will provide a high level of protection from continuous fracturing from surface to seam.

Discontinuous fracturing may interact with surface cracks above total pillar extraction zones where cover depths are < 200 m, however, this will be decreased to < 80 m above partial pillar extraction panels. Discontinuous fractures occur where subsidence causes the strata to bedding partings to ‘open’ or dilate, which increases the storage capacity of the overburden in this zone and may cause a temporary lowering of groundwater tables. Temporary runoff diversion may also occur if surface cracks develop.

The rate of groundwater recovery will depend on prevailing climatic conditions after mining impacts and has been numerically modelled as part of a Groundwater Assessment by RPS Aquaterra.

Subsidence Control Zones (SCZ) have been proposed to limit impacts to within tolerable levels at the following features:

- 3rd Order stream sections along Surveyors Creek No. 2
- Ephemeral 1st and 2nd Order Tributaries sections where cover depth is < 80 m (to avoid connective cracking to mine workings).
- Principal Residences on Private Land holdings (3 only at this stage but could be more required).
- Groundwater Dependent Ecosystems (GDEs) associated with sensitive Lowland Rainforest and Alluvial Tall Moist Forest Endangered Ecological Communities (EECs).
- Riparian vegetation associated with the Hunter Lowland Redgum Forest EEC.
- Two TransGrid Towers supporting 330 kV Cable.
- AAPT and Telstra FOCs.
- Steep Slopes > 26.5°, minor cliffs between 5 m and 10 m high and cliff lines > 10 m high.

The proposed setback distances applied for the SCZs at this stage are considered conservative; however, they will still need to be confirmed by subsidence monitoring programs and adaptive management as mining progresses.

The proposed performance criteria will be achieved in the SCZ with first workings only or a partial pillar extraction layout provided the long-term stability of remnant pillars and tolerable impacts to surface features can be demonstrated.

Other mitigation works alternatives such as the removal and re-routing of FOCs around the proposed mining area may remove the need for an SCZ beneath the Telstra and AAPT FOCs.

No Aboriginal rock shelters with PADs or grinding groove sites with moderate to high archaeological significance are located above total extraction panel areas and these sites will have a an unlikely to very unlikely cracking or toppling damage potential due to mine subsidence.

No practically measureable mine subsidence or far-field displacement movements or impacts are expected along George Booth Drive, the Hunter Expressway or the Orica site due to the proposed mining layout.

The subsidence effect and impact assessment predictions have also been validated against surface and subsurface monitoring programs at Abel and Tasman Mine sites with similar geological conditions and mining methods.

Overall, it is concluded that the assessed range of potential subsidence and far-field displacement impacts after the mining of the proposed pillar extraction panels will be manageable for the majority of the site features, based on the analysis outcomes and discussions with the stake holders to-date.

If the estimated worst-case impacts cannot be reasonably managed in the event that exceedences occur through mitigation or amelioration strategies, then it will be necessary to adjust to the mining layout further to provide a more acceptable risk to the stakeholders.

The extent of mining layout adjustment will also require further discussions (and review of monitoring data) after the completion of a given panel with stakeholder and government agencies.

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Site Photographs

General surface topography and Mount Sugarloaf in eastern area of proposed mine site (looking north-east from southern ridge)

Ausgrid 132 kV transmission line easement in north area of site

West-facing steep slopes (18^o-30^o) in north eastern area of proposed mine site

West-facing rock outcrops on steep slopes in north eastern area of proposed mine site

Transgrid 330kV power line and AAPT fibre optic cable easement in northern area of proposed mine site (looking east)

Transgrid 330kV Power Line and AAPT Fibre Optic Cable Easement in northern area of proposed mine site (looking west)

Erosion alongside access road across Transgrid easement in north area of proposed mine site

North-west facing steep slopes & ridge line west of communications towers (looking south-east from Transgrid Easement) in north area of proposed mine site

Flat & low lying terrain along private property boundary line in western area of proposed mine site

Private residence, shed & water tanks east of Sheppeard Drive (Lot 7) in western area of proposed mine site

Sheppeard Drive (looking south), Telstra copper cable on LHS (buried), Ausgrid 11 kV line, property fences & access gates to 12 properties in western area of proposed mine site

Sheppeard Drive (looking south) and north facing ridge (cliffs & steep slopes) in south western area of proposed mine site

Commercial workshop / office building (Lot 9) in western area of proposed mine site

Ausgrid 132kV & Telstra FOC (along RHS) easement and west facing ridge crest & steep slopes in south eastern area of proposed mine site

North facing sandstone cliffs & overhangs (1-3 m) in southern area of proposed mine site

North facing sandstone cliff faces in southern area of proposed mine site

East/west trending ridge crest in southern area of proposed mine site

View to north from southern ridge crest of Sheppeard Drive & low lying terrain in western area of proposed mine site

Talus slope below west-facing ridge crest in eastern area of proposed mine site

West facing cliff lines in eastern area of proposed mine site