9.0 SUBSIDENCE

A detailed and comprehensive subsidence impact assessment has been undertaken by Ditton Geotechnical Services (DGS) for the proposed Mandalong Southern Extension Project. A copy of DGS's *Subsidence Predictions and General Impact Assessment* (2013) is contained within **Appendix M**, with significant findings and recommendations summarised below.

The subsidence assessment has considered the DRE's *Guideline for Applications for Subsidence Management Approvals* (Department of Mineral Resources 2003) and has been prepared to address the DGRs (see **Section 1.7.2**). Subsidence effect and impact predictions for the proposed mine plan have been based on subsidence monitoring data from the existing Mandalong Mine operation and two empirically-based models developed for the Newcastle and United States Coalfields (referred to as ACARP 2003 and SDPS 2007, respectively).

The existing Mandalong Mine has extracted coal using longwall mining methods within longwall panels ranging between 125 and 160 metres wide. The Southern Extension Area comprises similar geological conditions to the existing Mandalong Mine, however, the target coal is deeper than in the existing Mandalong Mine, which has cover depths ranging from 150 to 370 metres. The coal extraction height in the current Mandalong Mine has ranged between 3.5 to 4.8 metres, with final maximum subsidence ranging from 0.26 to 1.24 metres (7 to 26 percent of the extraction height) (DGS 2013).

The proposed mine plan in the Southern Extension Area comprises longwall panel widths of 160 metres, 180 metres and 200 metres, with cover depths ranging from 180 metres in the north-east to 480 metres in the south-west (average of 300 metres). Longwall extraction heights will vary between 1.8 metres and 4.6 metres, depending on seam thickness. The longwall panel geometries have been designed to control mine subsidence effects to tolerable or appropriate levels in accordance with stakeholder and government agency requirements (DGS 2013).

DGS (2013) advises, based on experience from the existing Mandalong Mine and other longwall mines in the Lake Macquarie area, it is likely that the development of subsidence will be affected by the spanning potential of massive conglomerate and sandstone units that exist within the overburden. Borehole data indicates that the Southern Extension Area is situated within the Triassic Narrabeen Group and upper sequences of the Newcastle Coal Measures (see **Section 2.9**). There are numerous sandstone channel and conglomerate members within the Narrabeen Group and Newcastle Coal Measures that have reduced subsidence significantly where it has been able to span across voids left in the extracted coal seams (DGS 2013).

Statistical inference techniques have been applied by DGS (2013) to determine confidence levels for the predicted subsidence values associated with the proposed underground mining in the Southern Extension Area and allow a probabilistic assessment of the potential range of impacts to the local environment and man-made developments.

9.1 Subsidence Development Mechanism

When coal is extracted using the proposed longwall mining method (see **Section 4.6.2**), the rock strata immediately above the seam is allowed to collapse into the void that is left as the longwall face retreats. This is referred to as the "goaf" or "caving zone". The overlying strata or overburden then sags down onto the collapsed material, resulting in a subsidence trough developing at the surface. Further fracturing and bedding shear failures may also develop in the overburden above the caved zone, with the extent and severity dependent upon the mine geometry and geology.

The maximum subsidence usually occurs in the middle of the extracted longwall panel and is dependent on the extraction height, panel width, cover depth, overburden strata strength and stiffness, and bulking characteristics of the collapsed strata in the caving and fractured zones. For the case of single seam mining, such as that proposed, the maximum subsidence usually does not exceed 60 percent of the extraction height in the Newcastle Coalfields, and may be lower than this value due to the spanning or bridging capability of the strata above the collapsed ground (the goaf) (DGS 2013). The combination of the above factors determines whether a single longwall panel will be sub-critical, critical or supercritical in terms of maximum subsidence.

The surface effect of extracting several adjacent longwall panels is dependent on the stiffness of the overburden and the chain pillars left between the panels. Usually, “extra” subsidence occurs above a previously extracted panel and is caused primarily by the compression of the chain pillars and adjacent strata between the extracted longwall panels (DGS 2013).

After the development of subsidence above a longwall panel, the surface subsidence trough extends outside the limits of extraction for a distance assumed equal to half the depth of cover (or an angle of draw to the vertical of 26.5 degrees) in the Newcastle Coalfields.

Approximately 90 to 95 percent of mine subsidence development will occur within four to six weeks after undermining occurs (DGS 2013). On-going residual settlements due to goaf reconsolidation may continue for a period of up to two years, however these movements are likely to be small and unlikely to result in significant impact occurring to the surface.

9.2 Subsidence Prediction Methodology

DGS (2013) assessed the subsidence effects and potential impacts of the proposed mine plan on the surface and sub-surface features present within the Southern Extension Area, based on the following methodology:

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

(ii) Prediction of maximum subsidence effect parameters for the proposed longwalls.

(iii) Review of the subsidence data and impacts from the existing Mandalong Mine workings (specifically longwalls 1 to 12).

(iv) Prediction of first and final subsidence effect profiles and final contours and assessment of the potential impacts to existing and proposed features or developments.

(v) Prediction of post-mining surface levels.

(vi) Potential surface cracking widths and their general location.

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

(viii) Potential ponding depths.

(ix) Potential surface gradient changes and erosion and/or slope stability impacts.

(x) Valley closure and uplift potential along watercourses.

(xi) Far-field horizontal displacements and strains.

(xii) Predicted impacts and management strategies for surface infrastructure, the natural environment and heritage sites.

DGS (2013) predictions have been based on subsidence monitoring data from the existing Mandalong Mine operation and two empirically-based models developed for the Newcastle and United States Coalfields (referred to ACARP 2003 and SDPS 2007, respectively).

Studies of appropriate panel widths and set-back distances required to minimise or limit surface impacts to manageable levels were undertaken by Centennial Mandalong and DGS prior to the preparation of the subsidence impact assessment report (DGS 2013). The outcomes of the preliminary mine plan optimisation process, as outlined in **Section 5.0**, have resulted in the mining geometry and layout presented as the proposed mine plan (see **Section 4.6.3** and **Figure 21**).

Using regression analysis techniques, curves of “best fit” have been used by DGS (2013) to estimate “mean” and “credible worst-case” (upper 95 percentile confidence limits) for the subsidence effects due to the proposed longwalls. The curves are based on measured subsidence data in NSW coalfields, key mining geometry parameters (ACARP 2003) and Mandalong Mine’s experience to date.

DGS (2013) advises that the ACARP 2003 model used is likely to provide reasonably conservative subsidence impact parameter predictions for the proposed mining in the Southern Extension Area.

The prediction method and results provided by DGS (2013) has allowed other engaged specialist consultants to assess the potential range of impacts to a given feature in a probabilistic manner.

9.3 Review of Measured Subsidence from Existing Mandalong Mine

The *Cooranbong Colliery Life Extension Project Environmental Impact Statement* (Umwelt 1997) prepared for Mandalong Mine proposed longwall panels ranging in width from 150 metres to 250 metres. The subsidence assessment predicted vertical subsidence of up to 2.9 metres over the 250 metre wide longwall panels, with close to 66.7 percent of Area 1 predicted to experience less than 1 metre of vertical subsidence. The assessment predicted that:

- 50.9 percent of the tilts to be 7 mm/m and less;
- 98.3 percent of tensile strains to be 5 mm/m and less; and
- 61.3 percent of compressive strains to be 5 mm/m and less.

This translated to a predicted 27 percent of residential buildings within the proposed mining area likely to experience damage equivalent “moderate” Category 3 impact and above (as per Australian Standard AS 2870-1996).

Mandalong Mine received Development Consent DA 97/800 on 14 October 1998, with the longwall panel width set as a maximum of 250 metres. The development consent imposed conditions requiring landowner agreement if the mine’s forecast subsidence levels resulted in dwellings being impacted beyond the safe, serviceable and repairable (SSR) condition, impacts to land use and/or create a flood hazard. The definition of SSR used by the MSB is understood to mean the following:

- Residences after mining are left on a residual tilt of less than 7 mm/m.
- Residences are not subject to tensile or compressive ground strains of greater than 4 mm/m.
- Impacts to the residences due to mine subsidence is not greater than “slight” Category 2 as defined in AS2870-2011 for walls and concrete floors:
  - Cracks in walls are less than 5 millimetres wide and can be easily filled or repaired.
  - Doors and windows stick slightly.
  - Cracks in concrete floors are less than 2 millimetres wide and slab is not noticeably curved or changed in level (less than 15 millimetres offset from a 3 metre straight edge).

These consent conditions encouraged Centennial Mandalong’s decision to establish a more conservative mine design in order to ensure a balance existed between the economic viability of the mining project and the interest and demands of stakeholders.

Seedsman Geotechnics Pty Ltd (2003) identified the presence of a massive conglomerate unit in the overburden that could be used to achieve reduced surface subsidence effects. The potential for 170 metre wide longwall panels was identified, with a recommendation that the initial longwalls be limited to 125 metres wide until subsidence monitoring data was available to calibrate the predictive model.

Mandalong Mine has now developed and completed 13 longwall panels (LW 1 to 13), with the first four panels (LWs 1 to 4) being limited to 125 metres wide and subsequent longwalls being increased to 160 metres wide. The extraction heights within the longwall panels ranged between 3.5 and 4.8 metres. To date, maximum subsidence above the 125 metre wide longwall panels has ranged from 0.26 and 0.60 metres in non-faulted ground, while maximum subsidence above the 160 metre wide longwall panels has ranged between 0.35 and 1.24 metres (DGS 2013).

Since the widening of longwall panels to the current 160 metres, subsidence predictions have been reviewed and subsidence monitoring indicates that actual vertical subsidence is generally within the upper bounds of the predictions. Using frequency histograms to compare actual tilts and strains against SSR criteria, and as listed in **Table 16**, 95 percent of tilts were less than 7 mm/m, 99 percent of tensile strains were below 5 mm/m and 93 percent of compressive strains were below 5 mm/m.

Table 16 – Comparison of SSR Criteria for Dwellings for Approved Longwalls 6 to 13

Longwall Panel	Frequency Histogram Summary for Approved Longwalls 6 to 13 Compared Against SSR Criteria for Dwellings		
	Tilt Less than 7mm/m	Tensile Strain Less than 5 mm/m	Compressive Strain Less than 5 mm/m
LW 6	97.7 %	99.8%	97.4%
LW 7	97.6 %	100%	97.8%
LW 8	100 %	100%	99.4%
LW 9	100 %	100%	100%
LW 10	98.8 %	100%	98.5%
LW 11	96.5 %	100%	100%
LW 12	96.4 %	100%	93.3%
LW 13	95.6 %	100%	95.6%

Figure 31 shows the difference between actual and predicted subsidence over longwalls 1 to 10, where green shading is where actual subsidence is less than predicted and red shading is where actual subsidence is greater than predicted (in metres).

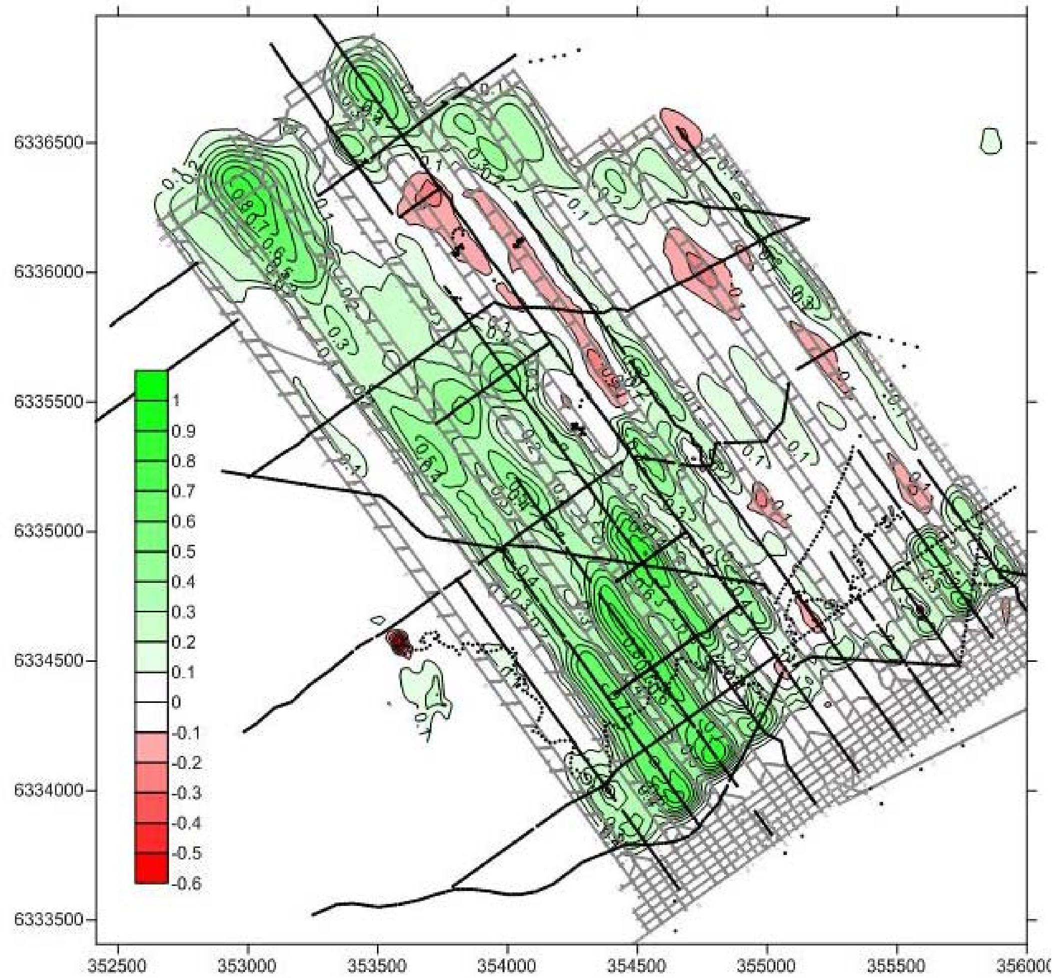


Figure 31 – Actual Versus Predicted Subsidence for Approved Longwalls 1 to 10

Subsidence monitoring during and after the completion of longwall 13 indicates that subsidence from longwalls 1 to 10 is stable. A number of subsidence lines over longwalls 1 to 4 have been removed in accordance with the approval from the Principal Subsidence Engineer.

Monitoring data indicates that although mining has impacted groundwater levels in deeper overburden rocks, there has been no long-term impact, even in faulted areas, on groundwater levels in the alluvial aquifers (Centennial Coal 2013).

The extraction of the previous 11 longwall panels has demonstrated that subsidence impact is low at Mandalong Mine. Since commencement of longwall mining in 2005, Centennial Mandalong has complied with relevant consent conditions, with all private dwellings remaining safe, serviceable and repairable. Subsidence impacts to infrastructure, including public roads and communication networks, has been managed in accordance with approved SMPs and their serviceability has not been impacted (Centennial Mandalong 2012).

9.4 Subsidence Predictions

9.4.1 Predicted Single Panel Subsidence

The maximum subsidence above a single longwall panel will depend upon its width, cover depth, extraction height and the subsidence reduction potential of the overburden.

In summary, the results of the single panel spanning assessment undertaken by DGS (2013) for the Southern Extension Area are:

- Longwall panels 160 metres wide – maximum single panel subsidence ranging between 0.08 and 0.46 metres, which is 1 to 18 percent of the extraction height;
- Longwall panels 180 metres wide – maximum single panel subsidence ranging between 0.14 and 0.87 metres, which is 2 to 29 percent of the extraction height; and
- Longwall panels 200 metres wide - maximum single panel subsidence ranging between 0.22 and 0.74 metres, which is 3 to 44 percent of the extraction height.

These single panel subsidence values have been used by DGS (2013) with the predicted chain pillar and goaf edge subsidence to estimate the multi-panel subsidence (see below).

9.4.2 Predicted Subsidence above Chain Pillars

DGS (2013) predicted the mean and credible worst-case subsidence values above the proposed chain pillars under double abutment loading conditions. The predicted first subsidence over the chain pillars is estimated to range from 0.1 metres to 0.94 metres for the range of pillar sizes and geometries proposed (and ignoring the 144 metre barrier between longwalls 38 and 61, see **Figure 21**). The final subsidence over the chain pillars after mining is completed is estimated to range from 0.12 metres to 1.1 metres, which is an overall increase of 20 percent.

9.4.3 Predicted Goaf Edge Subsidence

DGS (2013) predicts the final mean goaf edge subsidence for the proposed longwalls will range from 0.03 metres to 0.56 metres, and the credible worst-case goaf edge subsidence will range from 0.06 metres to 0.79 metres.

9.4.4 Predicted Multiple Panel Subsidence

Based on the predicted maximum single panel, chain pillar and goaf edge subsidence values derived by DGS (2013), the mean and worst-case first and final maximum subsidence predictions for multi-panels (and the associated impact parameters) have been derived. The predicted credible worst-case subsidence effect results for the proposed mine plan are summarised below:

- First maximum panel subsidence – 0.21 to 1.14 metres, with an average of 0.54 metres.
- Final maximum panel subsidence - 0.27 to 1.34 metres, with an average of 0.73 metres.
- First maximum chain pillar subsidence - 0.05 to 0.94 metres, with an average of 0.42 metres.
- Final maximum chain pillar subsidence - 0.06 to 1.1 metres, with an average of 0.49 metres.
- Maximum panel tilt - 2 to 20 mm/m, with an average of 7 mm/m.
- Maximum panel concave curvatures - 0.2 to 0.91 kilometres^{-1} (km^{-1}), with an average of 0.44 km^{-1}, or radii of curvature of 5 to 1.1 kilometres, with an average of 2.3 kilometres.
- Maximum panel convex curvatures - 0.16 to 0.72 km^{-1}, with an average of 0.35 km^{-1}, or radii of curvature 6.3 to 1.4 kilometres, with an average of 2.9 kilometres.
- Maximum panel compressive strains – 2 to 9 mm/m, with an average of 4 mm/m.
- Maximum panel tensile strains – 2 to 7 mm/m, with an average of 3.5 mm/m.

9.4.5 Practical Angle of Draw

The design of approved mining layouts have applied what are known as “practical angles of draw”, which are also referred to as “design angles of draw”. These are conservative angles of draw that will likely result in negligible surface impacts outside their limits.

In NSW, the practical angle of draw applied to sensitive features is typically 26.5 degrees and has been applied successfully to cliff lines, waterways and sensitive archaeological sites. The effectiveness of the design angle of draw of 26.5 degrees at Mandalong Mine can be demonstrated by reviewing the angles of draw to the key impact parameters of tilt, curvature and strain that have been measured to date.

The following subsidence profile limits are advised by DGS (2013) as appropriate for minimising impact to TransGrid Tension Towers and other sensitive environmental or Aboriginal heritage features:

- Subsidence - 50 to 100 millimetres.
- Tilt - 1.5 to 2 mm/m.
- Curvature - 0.06 to 0.1 km^{-1} (radius of curvature greater than 10 kilometres).
- Tensile strain - 0.5 to 1 mm/m.
- Compressive strain - 1.5 to 2 mm/m.

DGS (2013) advises that a design angle of draw of 26.5 degrees from the sides and ends of the longwall panels to sensitive surface features is unlikely to impact a given feature. The measured subsidence and tilts were within the tolerable limits defined above, however the curvatures and strains exceed the limits on occasion (may be due to survey accuracy limits).

9.4.6 Predicted Subsidence Contours

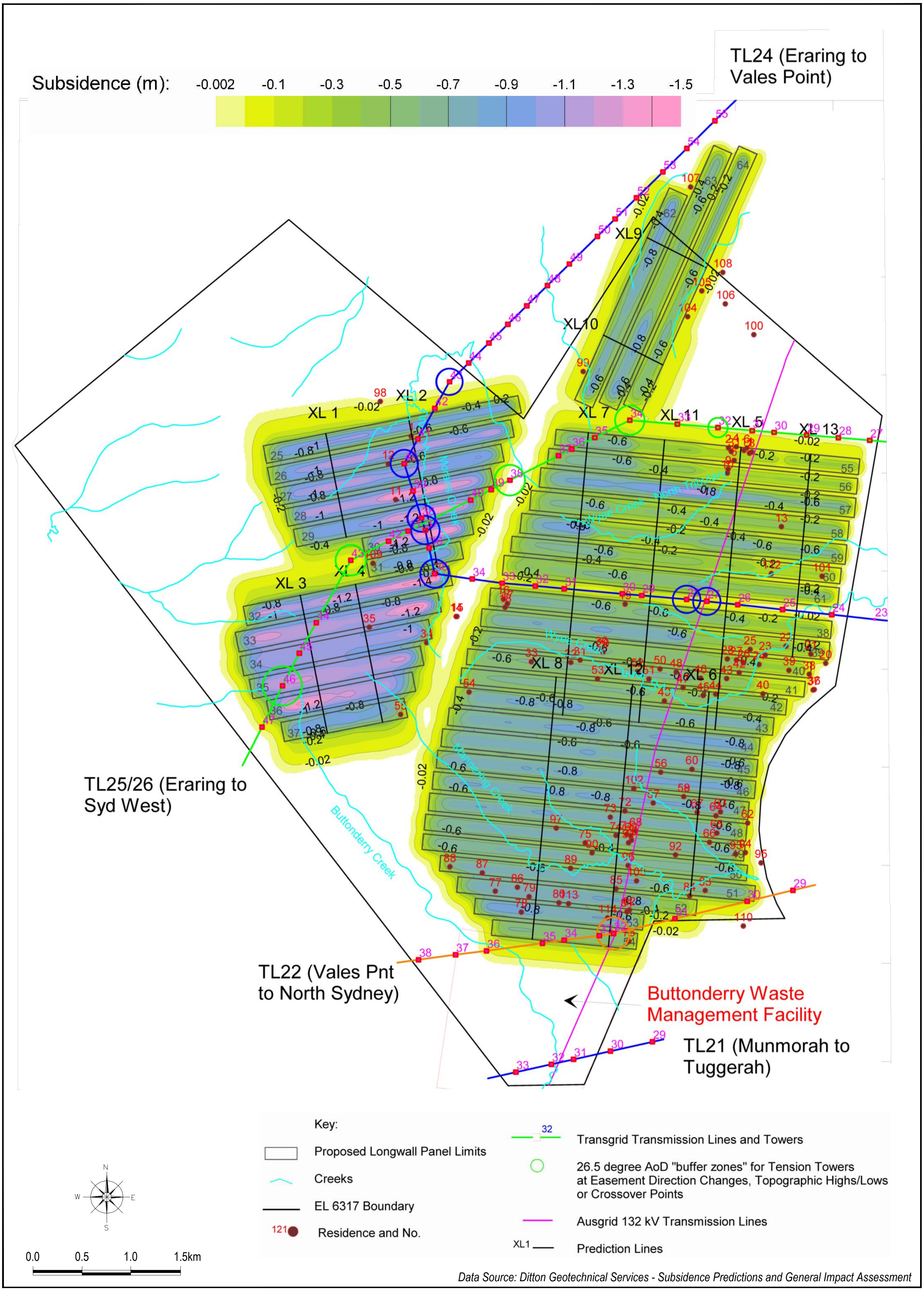
Credible worst-case subsidence contours for the proposed mine plan have been generated by DGS (2013) using SDPS® influenced function-based subsidence prediction software. The SDPS® model was calibrated to the credible worst-case subsidence profiles predicted by DGS (2013) using the ACARP 2003 empirical model. The predicted final post-mining subsidence contours within the Southern Extension Area are shown on **Figure 32**.

9.5 Subsidence Impacts

Based on the predicted maximum panel subsidence, tilt and strain values for the proposed mine plan, DGS (2013) assessed the potential for subsidence related effects, including cracking, slope instability, valley uplift and closure, and far-field displacements. A summary of the predicted effects is provided in the below sub-sections. The assessment of associated impacts on infrastructure and natural features within the Southern Extension Area, including TransGrid towers, residences, ponding and heritage sites, is provided in **Section 10.0**.

9.5.1 Surface Cracking

Based on previous experience at the existing Mandalong Mine, the predicted final maximum panel subsidence magnitudes in the Southern Extension Area (0.27 to 1.34 metres) may result in the occasional surface crack developing within the limits of the extracted panels in relatively flat terrain. Cracks may also occur outside the high sides of longwall panels beneath the steep slopes (i.e. greater than 18 degrees) in the south-west of the proposed mine plan.



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Predicted Final Subsidence Contours in Southern Extension Area

FIGURE 32

Based on the predicted maximum tensile strains (1 to 7 mm/m), crack widths are estimated to range from 10 to 70 millimetres wide where shallow rock exists within 5 metres of the surface. If alluvium or deep soil profiles exist, the strain will probably be more uniformly distributed and consist of several smaller width cracks (rather than just one single crack) or not occur at all. Where steep slopes exist, the crack widths due to the predicted subsidence could range from 150 to 320 millimetres due to rigid body rotation movements that can occur if the toe of a slope is undermined.

Surface cracking of the creek beds within the Southern Extension Area is considered "unlikely" where cover depth is greater than 180 metres. Specifically in relation to third and fourth order streams (see **Section 10.5**), surface cracking of the creek beds is considered "highly unlikely" and will be limited by longwall panel geometries and the "strain absorbing" properties of the surface alluvium.

9.5.2 Sub-Surface Cracking

DGS (2013) modelled continuous (A-Zone) and discontinuous (B-Zone) sub-surface fracturing heights and constrained zone thickness above the proposed 160 metre, 180 metre and 200 metre wide longwall panels. In summary, the predicted credible worst-case continuous cracking in the A-Zone above the proposed longwall panels range from 111 to 189 metres for cover depths of 185 to 480 metres, respectively. The depth to the height of the continuous fracturing from the surface ranges from 58 to 296 metres, and is "very unlikely" to interact with surface cracking within 15 metres of the surface.

The predicted depth of discontinuous fracturing in the B-Zone from the surface ranges from 11 to 260 metres. It is likely that the constrained zone will be limited by the presence of spanning Munmorah Conglomerate, which exists between 83 to 115 metres below the surface. It is therefore considered that the B-Zone is "very unlikely" to reach the surface zone above the proposed longwall panels.

The surface alluvium along the creeks within the Southern Extension Area is estimated to range from 5 metres to approximately 20 metres below the surface. Based on the above predictions for sub-surface cracking, it is considered "not credible" that A-Zone cracking will affect the surface alluvium beneath any of the creeks. It is also considered "unlikely" that surface watercourses will be subject to sub-surface flow re-routing due to interaction with sub-surface bed separation or discontinuous fracturing.

DGS (2013) advises that the presence of geological structures should be viewed with caution in regards to potential interaction with surface watercourses. Undermining significant faults may result in higher continuous fracture connectivity and water inflow in the mine workings.

9.5.3 Slope Instability and Erosion

Surface Gradient Changes

The proposed longwalls will cause subsidence, tilting and bending of the surface supporting rock faces and steep slopes. Worst-case subsidence predictions range from 0.6 metres to 1.2 metres above the proposed longwall panels beneath elevated ridges. The predicted post-mining surface slope gradient changes for the proposed mine plan indicate bedding dips may be increased or decreased by up 1 degree (plus or minus). The predictions of maximum tilt and strain indicate the slopes may be subject to tilts between 5 and 15 mm/m and tensile strains between 2 and 5 mm/m. Strains up to 15 mm/m may occur locally due to discontinuous movements associated with steep slopes.

Overhang Collapse and Rock Falls

The predicted subsidence and associated tilt and strains could result in cracking from bending occurring in the existing cliff faces, with the release of sandstone boulders downslope. Some existing pre-mining sandstone boulders of between 0.5 metres and 5 metres diameter have rolled for distances of up to 100 metres downhill of the cliff line crests. The boulders appear to have been stopped by trees on the densely timbered slopes or at breaks in slope.

Deep-Seated Land Sliding

The steep slopes within the Southern Extension Area in their current pre-mining condition are assessed by DGS (2013) to have a “low” sliding potential over an extreme range of climatic conditions (i.e. dry to saturated). The subsided slopes for the same climatic conditions and range of expected tilts and strains are also assessed by DGS (2013) to have “low” sliding potential during worst-case conditions, which may include unrepaired, water-filled cracks.

Shallow Translational Sliding

The potential for steep soil slope failure after mining is considered “medium” to “high” for the predicted tilts, strains and cracks. However, this may be reduced to an overall “low” to “medium” sliding potential due to the high density of trees and vegetation and assuming surface cracks are repaired.

The consequence of a shallow translational slope failure is likely to be localised and unlikely to impact on slope aesthetics. Public safety issues are addressed by way of the proposed management strategies (see **Section 9.6**).

Erosion of Slopes and Creek Beds

The potential for terrain adjustment due to erosion and deposition of soils after subsidence has also been broadly assessed by DGS (2013). The rate of soil erosion is expected to increase in areas with exposed dispersive/reactive soils and slopes greater than 18 degrees, where these slopes are subjected to the estimated tilt increases of 1 degree. Areas with slopes less than 18 degrees are expected to have low erosion rate increases, with the exception of creek channels, which would be expected to re-adjust to any changes in gradient. In general, head-cuts in creek channels would be expected to develop above chain pillars between the longwall panels and on the side where gradients increase. Sediment would be expected to accumulate where gradients decrease.

9.5.4 Valley Uplift and Closure

Due to the observed low horizontal stress regime in the Mandalong Mine workings, it is considered unlikely that significant valley uplift and closure movements will occur along the drainage gullies and in broad crested valleys above the proposed mine plan. The lack of thick, massive beds of conglomerate and sandstone units along the broad creeks and valleys at the surface will also mean the development of such movements is likely to be limited to less than 200 millimetres in the Southern Extension Area.

9.5.5 Far-Field Horizontal Displacements and Strains

Far-field displacements are horizontal movements outside the angle of draw and generally only have the potential to damage long, linear features such as pipelines (for example, Telstra and Nextgen infrastructure), bridges and dam walls. TransGrid tension towers may also be vulnerable to far-field movements and strains. This phenomenon is dependent on: (i) depth of cover to the coal seam; (ii) distance from the goaf edges; (iii) maximum subsidence over the extracted area; (iv) topographic relief and (v) horizontal stress field characteristics.

DGS (2013) assessed that far-field strains are likely to be less than 1 mm/m at 0.5 times the cover depth and less than 0.3 mm/m beyond an angle of draw of 45 degrees or a distance equal to one times the cover depth outside longwall extraction limits. Measureable horizontal displacements can extend further out than then vertical subsidence, however these are likely to be less than 20 millimetres beyond a distance of one times the cover depth. The displacements and strains are unlikely to cause damage beyond an angle of draw of 26.5 degrees to sensitive features.

9.6 Management and Monitoring

9.6.1 Management Strategies

Centennial Mandalong will continue to employ the management strategies and mitigation measures that are currently in place at Mandalong Mine to manage subsidence and mitigate associated impacts, including monitoring of surface features and infrastructure above active mining areas. Subsidence management will continue to be by mine design developed by geotechnical experts, with on-going monitoring providing the mechanism to confirm predictions and identify any impacts.

Centennial Mandalong will prepare a new Extraction Plan to manage subsidence associated with the proposed mining in the Southern Extension Area in consultation with the relevant government agencies. This will include a Public Safety Management Plan, along with a series of other subsidence management plans for each key stakeholder that will be developed with the following key elements:

- Subsidence prediction data specific to the particular item of infrastructure or feature;
- Risk assessment – damage impacts, likelihood and consequences;
- Subsidence monitoring to assess performance against predictions and action triggers; and
- TARPs and remediation strategies for each element of interest.

As recommended by DGS (2013), some specific management strategies that will be incorporated in the Extraction Plan framework to address the subsidence effects outlined above in **Section 9.4** will include:

Surface Cracking

Surface crack repair works will be implemented around affected areas and, in particular, if public roads, watercourses and steep slopes are impacted. General crack repairs in the flatter areas may involve ripping, backfilling and top dressing works, injection with polyurethane resin (PUR) or the pouring of cement-based grout or crushed rock into wider, deeper cracks. Remedial works, such as backfilling of surface cracks with durable material, will not be attempted until after the majority of active subsidence has occurred.

Consultation with relevant government agencies has indicated that natural regeneration may be favoured in some scenarios due to the likely level of disturbance caused by other remediation strategies, such as ripping and backfilling (DGS 2013). On this basis, Centennial Mandalong with consult with the relevant agencies prior to undertaking surface crack repair works.

Slope Instability and Erosion

To minimise the likelihood of slope instability and increased erosion along creeks due to cracking or changes to drainage patterns after mining, the following management strategies, as recommended by DGS (2013) are proposed as part of the Extraction Plan process:

- Monitoring will be undertaken after each longwall panel is extracted to identify any significant changes to surface slopes, such as cracking, increased erosion, seepages and drainage path adjustments.
- If and where considered necessary, signs will be placed along public access ways advising of mine subsidence impacts.
- Slopes determined to be significantly affected by erosion after mining will be repaired and protected, as considered appropriate, with mitigation works such as regrading, infilling and revegetation of exposed areas.

- If considered necessary, specialist geotechnical consultants will be engage to conduct detailed slope stability risk management assessments for vulnerable features, such as residences and public access roads located on slopes likely to be effected by mine subsidence.

Valley Uplift and Closure

Specific management strategies to address valley uplift and closure effects, as recommended by DGS (2013), include:

- Levels of upsidence and valley crest movements will be reviewed after each longwall panel is extracted to assess performance against predictions and action triggers.
- The need to repair cracking, as a result of upsidence or gully slope stabilisation works, will be assessed and, if necessary, undertaken to minimise the likelihood of long-term degradation to the environment or risk to personnel and the general public.

9.6.2 Surface Monitoring

Based on the surface topography and surface infrastructure present within then Southern Extension Area, the following subsidence and strain-monitoring program, as recommended by DGS (2013) will be implemented to provide adequate information to assess performance against predictions and action triggers. The monitoring activities will also enable appropriate management strategies to be developed, refined and implemented.

- Subject to landholder approval for access, a minimum of one transverse subsidence line across the proposed longwall panels will be established. The lines will be installed to at least the middle of the next adjacent panel before undermining occurs. The final transverse surveys for each panel will include the previous panels to capture chain pillar subsidence as it develops.
- A longitudinal line (or lines) will be installed as directed by the Principal Subsidence Engineer.
- A survey line along and across the banks of the main creeks within the Southern Extension Area will be established to the satisfaction of the NOW and DRE.
- Horizontal strain angle of draw measurements will be undertaken from the sides and ends of the first longwall panel using standardised steel tape or equivalent techniques for the purpose of assessing tensile strain predictions and the adequacy of proposed TransGrid tension tower buffer zones.
- A minimum of four pegs spaced 10 metres apart will be installed adjacent to or around any feature of interest to measure subsidence, tilt and strain at the feature in consultation with the Principal Subsidence Engineer.
- A cross-line will be established across longwall panels, with survey pegs spaced at a minimum of 10 metres and a maximum of 20 metres apart (i.e. cover depth divided by 20). For the first two or three longwall panels the pegs will be installed along full cross-lines and within the panel square end centrelines. As more survey data is obtained it is envisaged that the peg spacing may be widened at non-critical locations (for example, the central sections of the panel centrelines) or deleted altogether.
- 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 will be undertaken before, during, and after mining.
- The location of the extraction face will be recorded with each survey.

Further site and/or stakeholder specific monitoring that is considered necessary will be detailed in the Property Subsidence Management Plan prepared as part of the Extraction Plan.

All surveys will be conducted in accordance with the standards set out in the *Survey and Drafting Directions for Mining Surveyors 2013 (NSW-Coal)* in agreement with the Principal Subsidence Engineer.

9.6.3 Sub-Surface Monitoring

Monitoring of sub-surface fracture heights above longwall panels may be necessary within the Southern Extension Area to confirm the predictions of potential areas of connective surface cracking.

One deep borehole extensometer has been installed in the middle of one of Mandalong Mine's existing longwall panels (No. 5) to monitor heights of sub-surface fracturing due to the caving or goafing process during mining. The details and results of the monitoring have been successfully collated and indicate that the height of continuous fracturing is within the previously predicted ranges (DGS 2013).

Sub-surface fracture height measurements, via the installation of deep borehole extensometers and pairs of shallow stand pipe piezometers along creeks to depths ranging from 5 to 15 metres, above the proposed longwall panels will be considered (subject to a risk assessment) at representative locations as part of the TARP requirements and Extraction Plan process.

Consideration will be also given to the installation of additional deep borehole extensometers (subject to a risk assessment) in the low lying eastern areas of the Southern Extension Area to allow a more comprehensive review of groundwater interaction with the extracted longwall panels.

Inspections and monitoring of underground workings stability, groundwater makes and goaf air entry will continue to be recorded and included with subsidence monitoring data.

9.7 Conclusion

DGS (2013) concludes that the assessed range of potential subsidence and far-field displacement impacts after the mining of the proposed longwall panels within the Southern Extension Area will be manageable for the majority of the site features. Impact management strategies and TARPs will be able to be developed and implemented, in consultation with relevant stakeholders and government agencies, to assist in delivering satisfactory outcomes for the community and environment.

Centennial Mandalong will implement an adaptive management approach to subsidence, which will involve monitoring, remediation and periodic evaluation of the consequences of mining, with possible adjustment of the mining layout through the Extraction Plan process to achieve the required measure of performance.