MANNERING COLLIERY

ENVIRONMENTAL ASSESSMENT

APPENDIX G

SUBSIDENCE IMPACT ASSESSMENT

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SUBSIDENCE PREDICTIONS
FOR LONG-TERM MINE PLAN

Mannering 24 DECEMBER 2006

EXECUTIVE SUMMARY

The proposed layout for Mannering Colliery involves first workings in 7 headings forming pillars on 30m centres. It is understood that the basis of the mine planning was the requirement for vertical subsidence in all areas to be less than 20mm.

The mining will be conducted in the Fassifern Seam in areas where the Great Northern Seam has not been extracted. The Fassifern Seam has no records of unpredicted subsidence behaviour related to roof and floor strata. Similar mining layouts have been used in the Fassifern Seam at Mannering Colliery over the last 2 years and at Myuna Colliery without any reported onset of subsidence impacts or pillar failure.

The pillar dimensions are such that the layout has very high levels of stability that are compatible with long-term serviceability. At Mannering Colliery, the Awaba Tuff immediately above the Fassifern Seam is a high strength unit and does not represent a hazard in terms of pillar stability. The width of the roadways with respect to the depth of cover means that chimney failures and hence surface subsidence above the extracted roadways and intersections is not a credible mechanism.

Without the presence of wide spans of extracted coal, any surface subsidence will be related only to the elastic deformations of the roof, floor and pillar system. There are a number of thin, low strength and low modulus claystone bands in the Fassifern Seam that will contribute to the level of vertical subsidence. The maximum vertical subsidence from all mechanisms is predicted to be less than 20mm – 20mm is conventionally taken as the onset of mining induced movement or subsidence.

Both stability and deformation criteria are indicative of a “no subsidence” layout. When the mine is flooded, which will occur some time after abandonment, the stability of the system will increase due to the buoyancy effect of the water reducing pillar stresses and as a result the vertical subsidence will tend to reduce.

Suitable monitoring strategies for this layout would involve annual monitoring of a limited number of subsidence lines for a period of no more than 3 years after mining has been completed within 500m of the survey points.

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1 Introduction

Mannering Colliery is preparing a Part 3A submission for the long-term mining of the lease. A conceptual mine plan has been developed in order to define possible mining areas so as to provide a basis for quantitative predictions of environmental impacts. The conceptual mine plan is based on the same pillar and roadway dimensions currently being used at Mannering.

Seedsman Geotechnics Pty Ltd (SGPL) has been associated with the Mannering layout since operations commenced and has been commissioned to prepare a subsidence assessment of the conceptual mine plan.

The surface above the proposed mining consists of wetlands, low lying foreshore areas, ridge topography with elevations to a maximum of about 45m, and residential areas (Figures 1 and 2).

Figure 1 Air photo of site with outline of mine plan

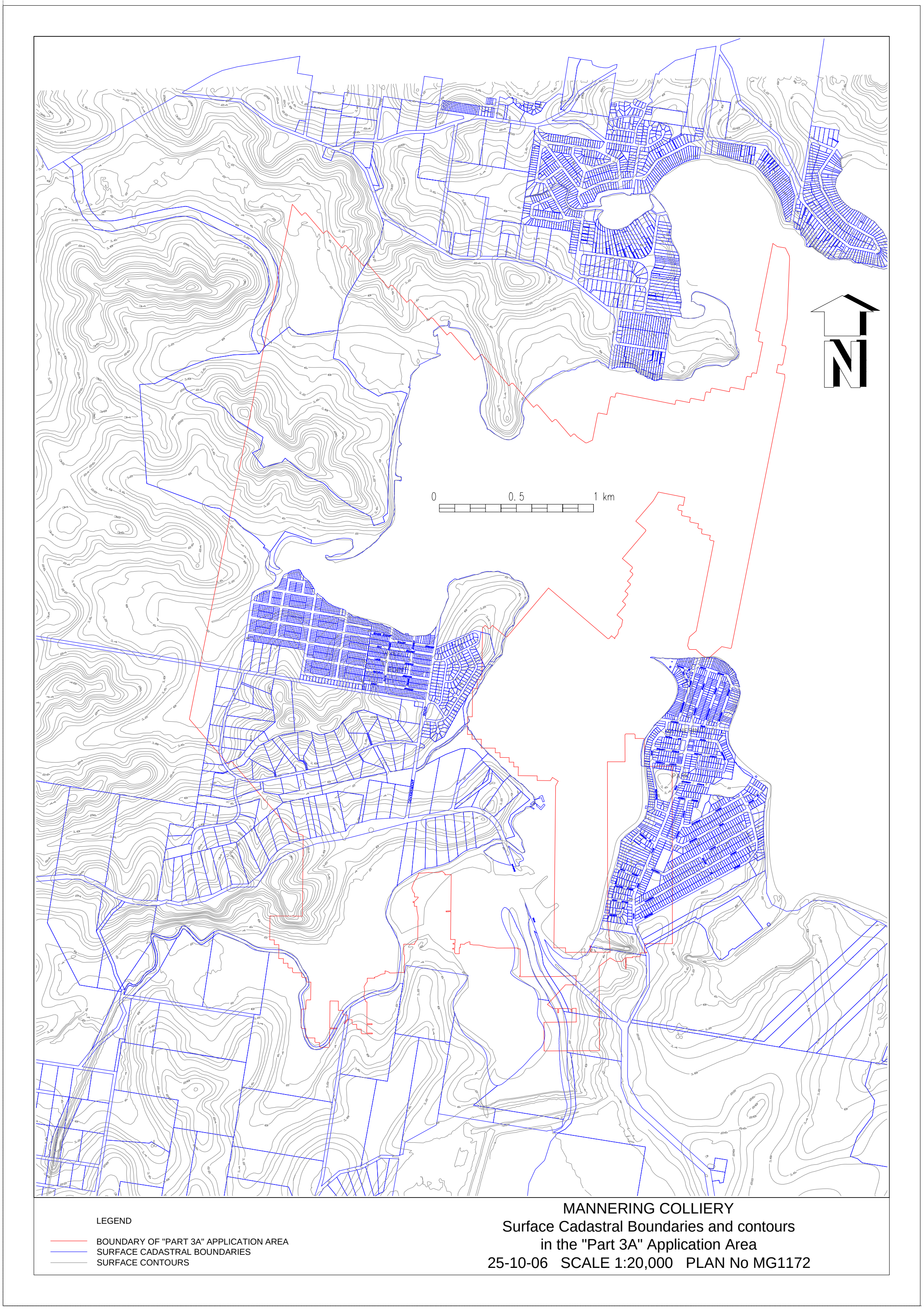

Figure 2 Surface topography and cadastral boundaries

5.1 Mine plan

The target seam is the Fassifern Seam. It is understood that in the area of interest other seams in the Newcastle Coal Measures, such as the Wallarah and Great Northern Seams, are not currently considered to be economic targets.

The proposed mining method is based on what are called ‘first workings’ where roadways are driven to form large pillars and where the pillars are not subsequently extracted. This method extracts less coal than other methods and has the advantage that the subsidence of the surface is negligible[1].

It is understood that continuous miner systems will be used in panels with 7 headings and associated cutthroughs defining pillars on 30m centres (Figure 3). The panels will be separated by barrier pillars of 54m width. Roadways will be 5.5m wide and 2.9m high. At Mannering, there are similar workings in the Fassifern Seam that have been developed since January 2005.

5.2 Data provided

A large amount of information has been provided on the overburden sequence at Mannering: 3 recent core holes (WC0, 02,03) with associated rock strength testing, an ACIRL report dated 1991, and also the work by Forster and Enever (1992). In addition there are logs from holes drilled in the 1950s to 1970s.

Mannering also provided the following plans:

Plan showing proposed workings (MG1163)
Fassifern Seam depth of cover (MG1164)
Fassifern Seam working thickness (MG1165)
Great Northern Seam working thickness (MG1166)
Great Northern to Fassifern Seam thickness (MG1167)

[1] *For the purposes of this report, subsidence is defined as mining-induced movements and deformations at the ground surface where the vertical downward surface movements are greater than 20mm*

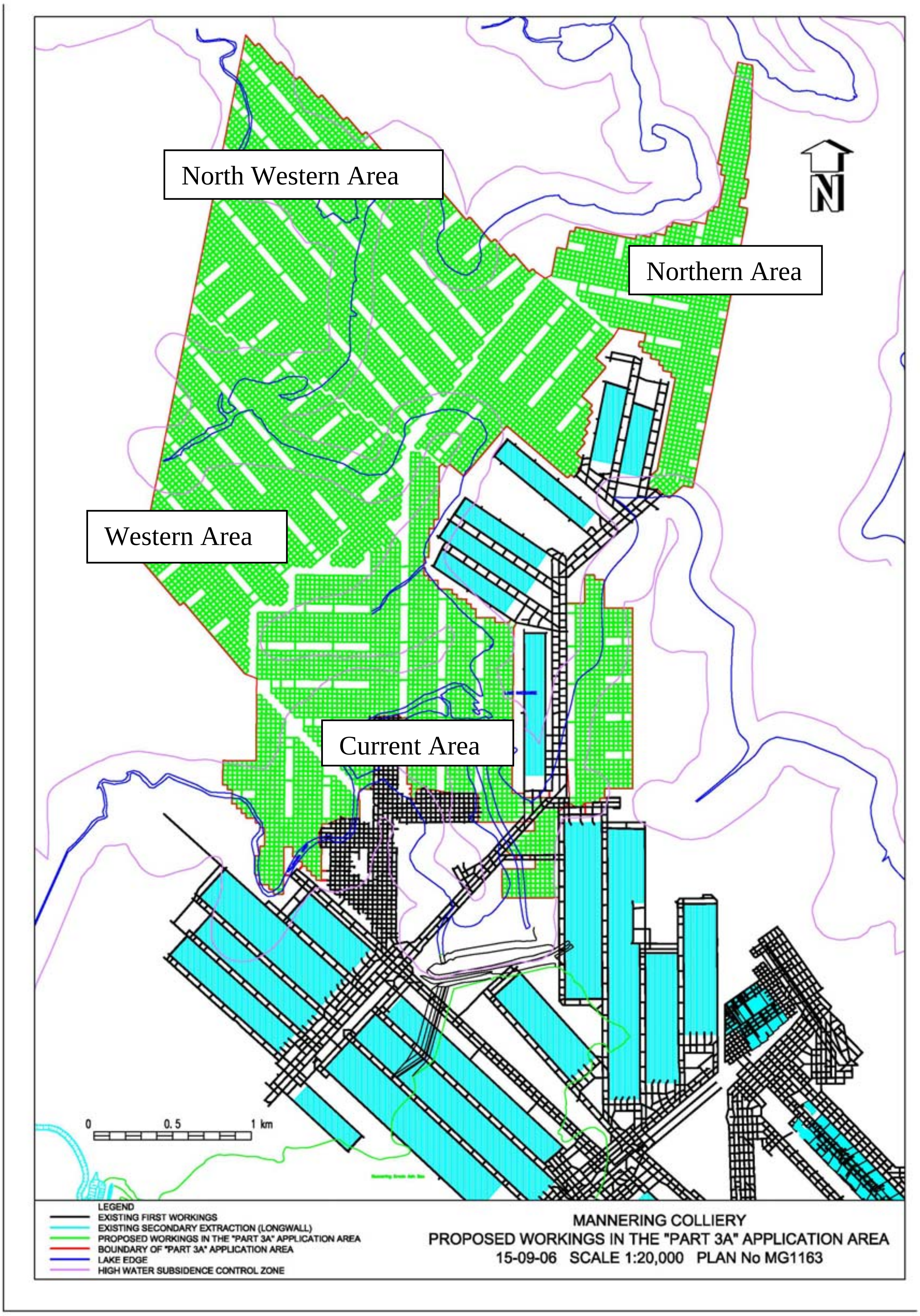

Figure 3 Conceptual mine plan for the Fassifern Seam (green) and existing Fassifern longwall extraction (blue)

2 Geological conditions

The Fassifern Seam is part of the Newcastle Coal Measures. In the area of interest, the Fassifern Seam lies at 150m to 205m depth (Figure 3). Overlying the Fassifern Seam are the Great Northern and Wallarah Seams and their associated conglomerates and tuffs, and the Dooralong Shale/Munmorah Conglomerate of the Narrabeen Group.

Table 1 compares aspects of the geometry of the current mining area with the areas proposed to be mined in the long-term plan. It can be seen that the overall geometry of the Fassifern Seam is similar throughout the lease.

Table 1 Geometry of the Fassifern Seam

	Current area	North western	Northern	Eastern
Depth (m)	185	150	190	190
Fassifern working section (m)	3.5	3.5	4.0	3.25
Great Northern working section (m)	2.4	0.2	0.4	2.2
Interburden (m)	30	60	80	15

The geological logs from the proposed mining areas describe a Fassifern Seam that is identical to that in holes taken from the current working area. In addition, the Awaba Tuff, which is the stone roof of the Fassifern Seam, is described as hard, moderately hard, or medium hard – the same term as used in the reference holes from the current area.

The Fassifern Seam at Wyee is a typical occurrence of the seam and is about 6.5m thick. The proposed working section is 2.9m thick with a maximum thickness of 3.5m to 3.75m (Figure 5). The FA and FB coal plies are to be left as top coal – their aggregate thickness is approximately 1.2m to 1.4m. The floor of the working section is about 0.5m to 1m of coal, leaving another 1.7m of banded coal and claystone.

Uniaxial compressive strength testing of the Fassifern Seam by ACIRL has given values of 30MPa - 38MPa, with modulus values of 4.1 GPa - 4.9 GPa.

The FBR and FCR stone bands are typically 9cm-15cm and 6cm-10cm thick and vary little in thickness. They are typically logged as soft – see below.

The floor of the working section consists of claystones and interbedded shale/mudstone/coal. The thickness of the bands varies from 5mm to 260mm with one outlier at 0.38m (Figure 6). Knowledge of the strength of the claystone bands is drawn from the old logging of boreholes – the material in the holes included in the 1991 ACIRL report and in 2004 had already been sent to the laboratory for incorporation in the coal plies. The old logging uses terms such as "soft", "moderately soft" and "very soft" which are not defined. A similar problem was encountered at adjacent mines and based on a review of mine experiences it was concluded that very soft can be interpreted as 1 MPa, soft as 5 MPa and moderately soft greater than 5 MPa.

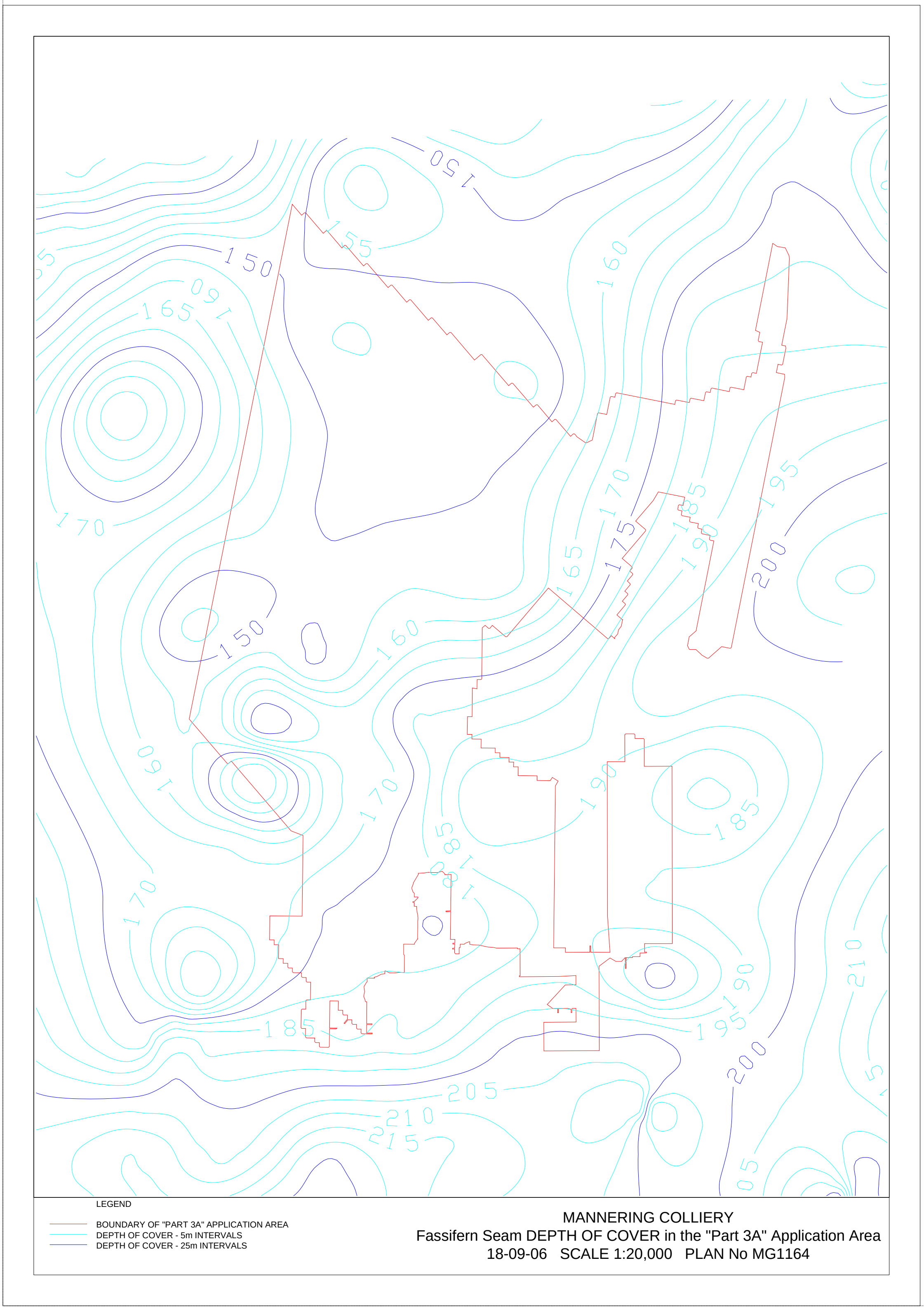

Figure 4 Fassifern Seam – depth of cover

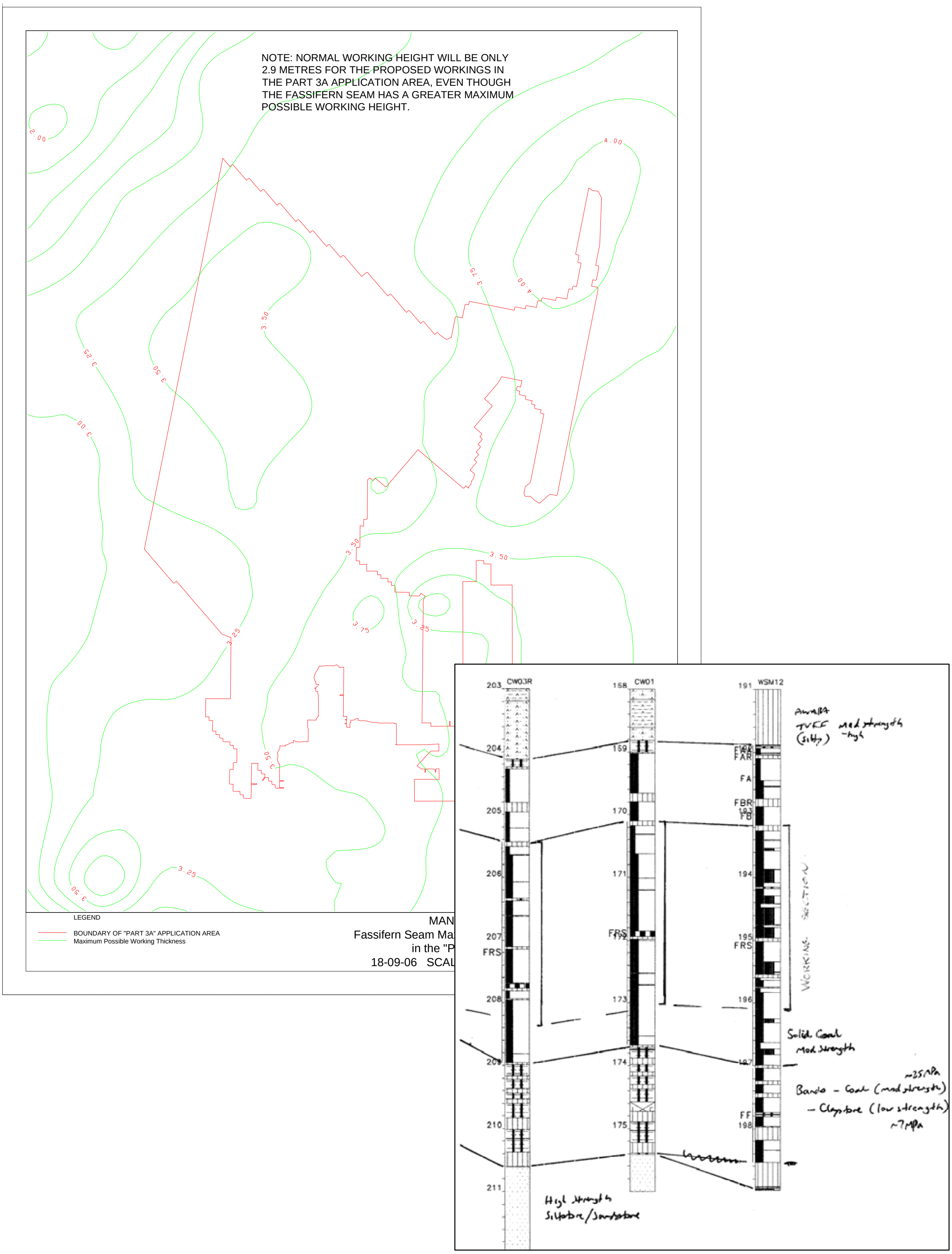

Figure 5 Typical Fassifern Seam sections and working section

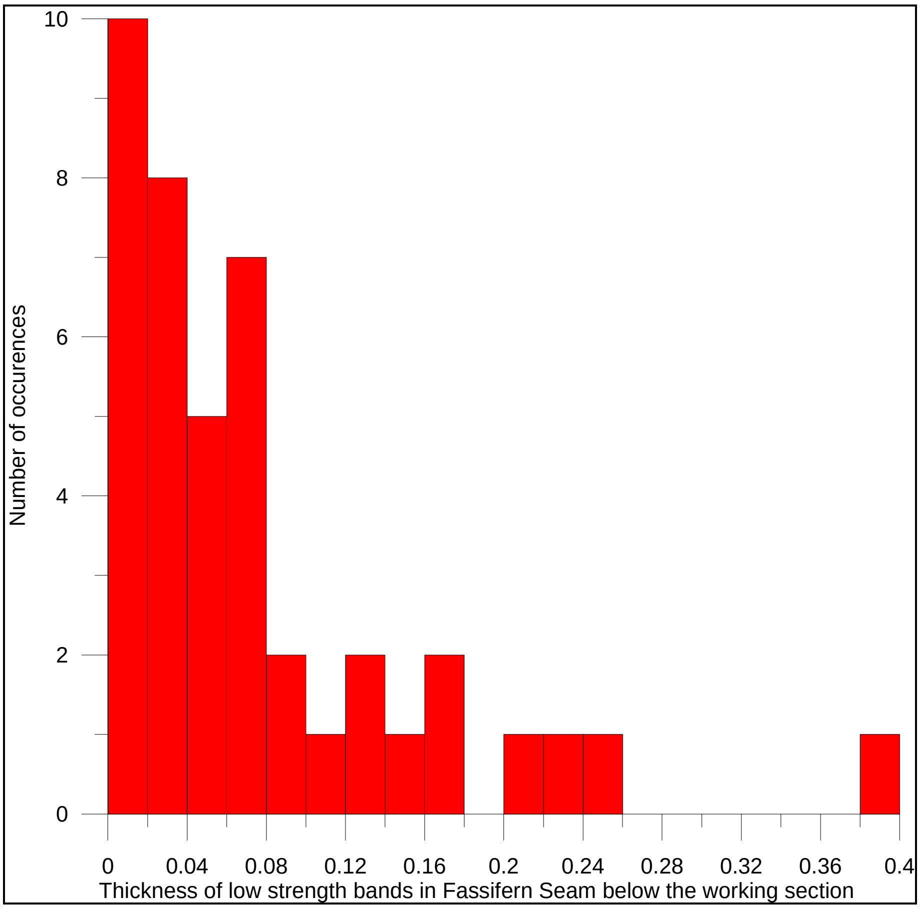

Figure 6 Histogram of thickness of claystone bands in the floor of the working section of the Fassifern Seam

The rocks below the Fassifern Seam are high strength sandstones – 90 MPa with a modulus of 16 GPa

The Fassifern to Great Northern interval ranges between 15 m and 80 m in thickness, the lower portion of which is the Awaba Tuff and the upper portion of which is a conglomerate/coarse-grained sandstone unit. The Awaba Tuff presents as a massive rock (sometimes logged as tuffite to distinguish it from low strength claystone) with measured UCS values of 10.5 MPa -38 MPa in the recent program and 40 MPa to 100 MPa in the 1991 program. The lower values in the 2004 program relate to the presence of healed joints in the samples such that the measured UCS is not representative of the substance strength. The conglomerate/sandstone unit has UCS values of 64 MPa and a modulus of 23 GPa.

The Great Northern Seam has been extracted in the immediate vicinity (Figure 7). The proposed Fassifern Seam workings are located so that they are not under any of the Great Northern extraction areas. Some of the proposed workings are located under first workings in the Great Northern Seam. In Figure 7 it can also be seen that above the proposed Fassifern Seam workings the Great Northern Seam is less than approximately 1m thick.

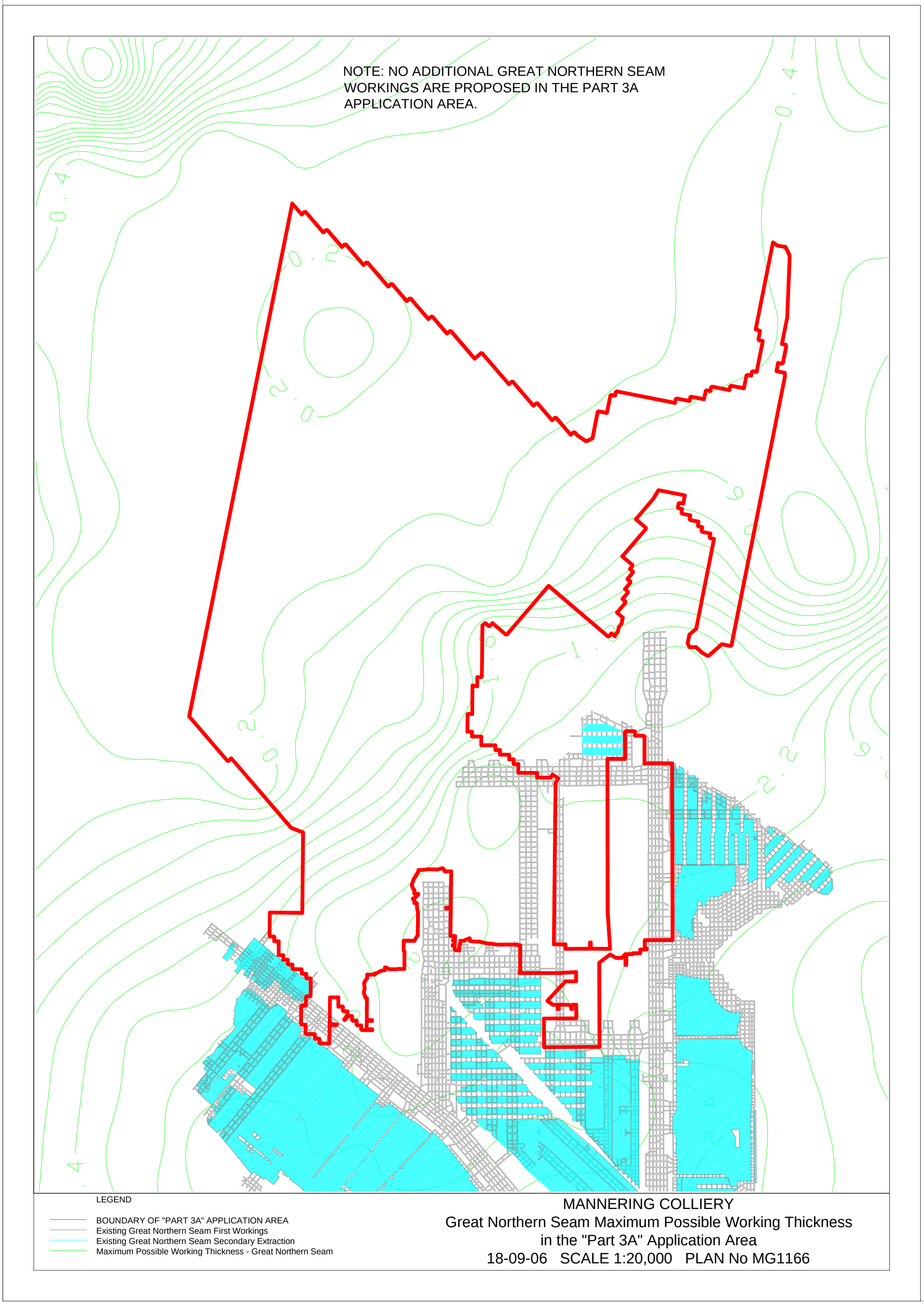

Figure 7 Proposed mining area with respect to Great Northern extraction

There are no recognised aquifers in the sequence except for the coal seams themselves.

3 Subsidence predictions – prediction method, previous subsidence

Given the nature of the surface, long-term stability of the mine workings and negligible vertical subsidence is required so that there will be no measurable change in the flood hazard or tidal reach and that surface infrastructure are not adversely impacted. The requirement regarding flood hazard and tidal reach is more stringent than damage to surface infrastructure. As mentioned previously, Centennial Mannering has determined that the vertical subsidence is required to be less than 20mm.

This requirement for both stability and serviceability is similar to that applied to many civil geotechnical designs in foundation engineering. The only difference is that in this mining application we need to consider the stability and deformation of not only the floor foundation but also the coal pillar and the roof.

3.1 Geotechnical model

To allow analysis of the stability and deformation of the proposed mining system, it is necessary to establish a geotechnical model that includes consideration of the material properties in and around the openings. The section is based on previous assessments conducted for Mannering Colliery.

The strength of the coal will be assumed to be 25 MPa, although it is emphasised that coal strength is not an input to coal pillar strength calculations. At 25 MPa, the Fassifern Seam is at the high end of Australian coal strengths, so the use of the University of NSW empirical strength formula is conservative (i.e. coal pillar strength will not be underestimated).

There is a need to consider the possible onset of a bearing capacity failure in the thickest/weakest of the claystone horizons. Based on the available information, an appropriate conservative model is 0.26m of “very soft” material – UCS of 1 MPa.

For consideration of compression of the coal in the pillar and the coal plies in the roof, a Young’s modulus of 4 GPa will be used.

For consideration of compression of the claystone materials, and based on the core descriptions and our experiences with similar materials, the claystones will be assumed to have a strength of 2 MPa, and a modulus of 270 MPa in long term (drained) and 500 MPa in short term (undrained). The total thickness of claystone in the Fassifern Seam system will be assumed to be 0.8m.

The floor of the Fassifern Seam will be assumed to have a strength of 90 MPa, with a rock mass modulus of 16 GPa. The Awaba Tuff in the roof of the seam has a strength of 40 MPa, and a rock mass modulus of 12.5 GPa.

All modulus values have been reduced by a factor of 0.73 to account for the properties of the rock mass compared to the laboratory scale. This reduction is based on the use of a GSI (Geological Strength Index) value of 70.

Roadways will be assumed to be 2.9m high with a width of 5.5m. Depth of cover will be assumed to be 185m.

3.2 Stability

Current coal pillar design utilises empirical methods, with the strength of the pillar being related to the geometry of the pillar. This report will use the empirically-derived University of NSW pillar strength equation. The database used by the method was created from the as-mined dimensions of pillars. Failed pillars in the database have width to height ratios mostly less than 5 (only 1 at a greater ratio of 8), and pillar widths are less than 22m.

The University of NSW method provides a relationship between factor of safety and probability of failure. It is noted that in the University of NSW method, a factor of safety of 2.23 is associated with a 1:1,000,000 probability of failure. However, this probability of failure only applies to pillars with a width to height ratio less than 8. A rigorous application of the pillar failure database leads to the observation that the probability of failure of a pillar with a width to height ratio greater than 8 is zero.

Any collapse of the stone roof is not considered to be a major issue in the application of the method. The higher strength and modulus of the stone will continue to provide the constraint to the coal (which is what provides the coal pillar strength) even if there is a collapse in the roadways. Furthermore, such collapse is intrinsic in the pillar failure data base.

<u>Coal</u>

The stability of the coal pillar itself can be assessed using the University of NSW pillar strength equation and the vertical stresses estimated using tributary area concepts.

For the proposed 7 headings at 30m centres at these depths, tributary area loading is the appropriate (and maximum) loading assumption.

The vertical stresses (MPa) are calculated as follows:

$$1/(1-e) * (\text{vertical depth} * \text{overburden density} - \text{water height} * 0.01)$$

where e= extraction ratio, depth is in metres, overburden density = 0.025 kN/m^3, and water height with respect to seam level is in metres. The pillar stresses are in the order of 6MPa-7 MPa for the proposed layout.

During mining, the water height is zero at seam level, but when the mine is flooded the water height will increase to be equivalent to depth of cover. On flooding, the pillar stresses will reduce by approximately 40%.

Figure 8 shows how the factor of safety of the pillars increases with increasing centre dimensions. At the proposed centre dimension of 30m, the factor of safety of pillars at 2.9m high is 2.65. With a worst case assumption that a fall of coal roof increases the pillar height in direct proportion, and that the fall debris does not provide restraint to the pillar, the factor of safety of pillars on 30m centres decreases to 1.91.

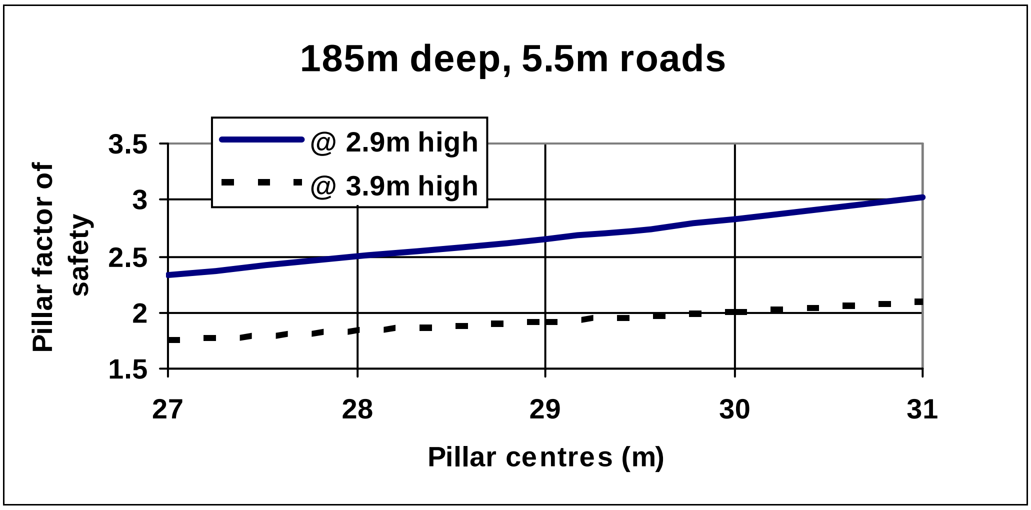

Figure 8 Pillar stability

It is assessed that the proposed pillars have adequate stability.

The design of the barrier pillars has been assessed assuming that the 30m centre pillars collapse and provide no restraint to the roof. The following calculation uses the University of NSW squat pillar equation, minimum pillar width, and the ALPS/ALTS loading regime based on a 21^{o} of draw. The 54.5m wide barriers have a factor of safety of 3.45 for a 3.9m height, and 2.38 under the 4.7m fallen roof scenario. The respective width/height ratios are 14.0 and 11.6. These levels are assessed to be adequate.

Floor

There have been no reports of floor failures in the Fassifern Seam. Importantly, there have been no occurrences of floor heave or associated pillar punching at either Mannering or Myuna Colliery. The geometry of the mining (first workings only) and the fact that the Fassifern Seam is mined means that a different geotechnical environment is present compared to other reported floor failures.

Newvale, Newvale No2 and Munmorah had unpredicted subsidence events above second workings in the Great Northern Seam. Typically, these mines developed first workings at about 180m depth, using pillars on 40m centres. Pillar extraction was based on taking a row and leaving a row such that rows of pillars of 35m width alternated with extraction panels of 45m. The unplanned subsidence events developed after a wide area of such extraction was conducted. The overriding consensus is that the pillars “punched” into low strength layers in the top of the Awaba Tuff.

There have been a number of reported floor failures in the Great Northern Seam at Cooranbong Colliery that have been associated with higher than expected levels of subsidence. Here, the floor was better characterised and there was the ability to relate the onset of floor heave/subsidence to the bearing failure of low strength claystones in the top of the Awaba Tuff floor.

SGPL have successfully used civil engineering bearing capacity methods to assess if the onset of floor failures limits the application of the empirical pillar design methods. They have been used particularly in the Great Northern Seam.

The bearing capacity of the low strength layers is given by the equation:

$$UCS/2 * (3.14159 + 1 + w/2t),$$

where UCS refers to the strength of the layer, w is pillar width and t is thickness of the low strength unit. Based on work at Cooranbong and more recently at Awaba, a minimum factor of safety of 2.5 should be used when pillar stresses are estimated from tributary area concepts. It is important to note that the lowest bearing capacity is developed in the undrained loading state immediately after pillar formation. Over time, the stability of the floor increases and increases further when the mine floods and the pillar stresses are reduced.

Figure 9 presents the results of the analysis of bearing capacity. The factors of safety are very high, well above the 2.5 value used elsewhere. For pillars on 30m centres, the factor of safety against a bearing failure in the floor is 3.77. It is assessed that there is not a credible hazard of floor failure.

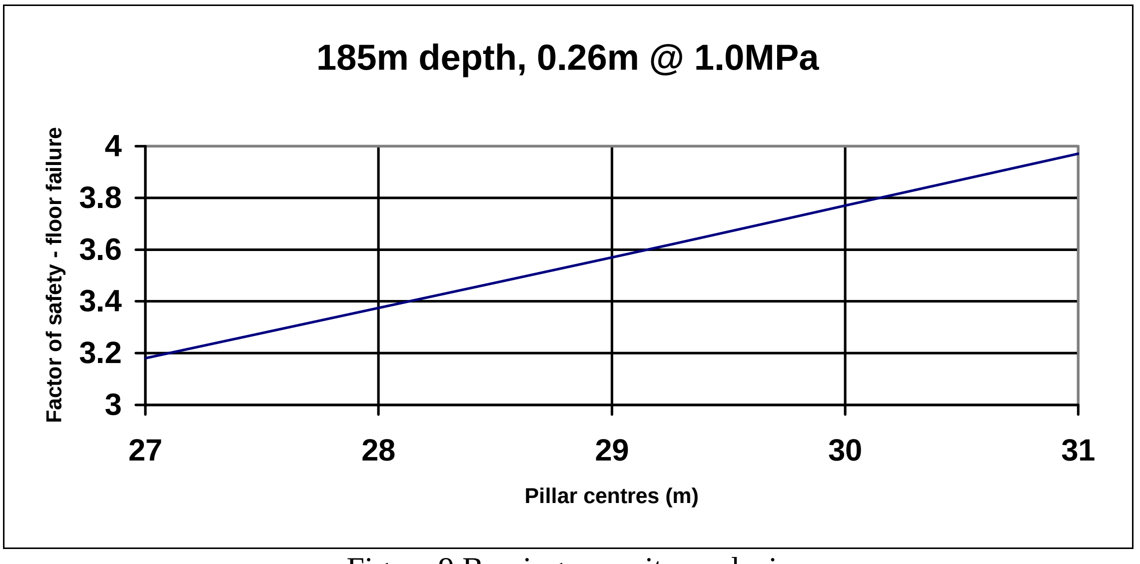

Figure 9 Bearing capacity analysis

3.3 Deformation and surface subsidence

Plug collapse is not a credible subsidence mechanism – the ratio of roadway width to depth of cover is 5.5/185 or only 3 %, and typically plug collapse is expected at ratios greater than approximately 20%. Furthermore, in the international mining literature no plug collapses above roadways or intersections have been recorded at depths greater than about 50m.

The vertical subsidence that will develop above the pillar layout will be a direct translation of deformations that develop about the openings in the coal seam. These deformations develop in response to the increased pillar stresses that result from the extraction of the roadways. These increased stresses on the pillar cause compression of the pillar and also the roof and floor.

The deformation of the coal is based on the full thickness of the coal seam and assuming uniaxial loading. The equation is:

stress change/modulus * coal thickness.

For the Mannering conditions the result is 4mm.

A similar analysis as used for the coal has been applied to the claystone horizons. The result is a compression of 11 mm over an extended period of time. Immediately after mining the compression is estimated to be 2mm.

The compression of the stone in the roof and floor is calculated using the Poulos and Davis (1976) method, and this gives 3mm in the roof and 2 mm in the floor.

Thus the maximum compression of the pillar system is less than 20mm and hence this is the maximum predicted subsidence. At these levels of subsidence the maximum tilts will be of the order of 1mm/m and maximum strains of the order of 0.3mm/m.

3.4 Flooding of the mine

In terms of long term stability of the workings, another issue that needs to be considered is the impact of the inevitable flooding of the workings when the mine is abandoned.

As presented earlier, the vertical pillar stresses decrease by approximately 40 % as a result of buoyancy.

The claystone horizons under the roadway may swell due to the presence of water. Consideration of the stress gradients that are acting under the pillars leads to the conclusion that there will be negligible movement of water into the claystones and hence negligible loss of strength.

The engineering considerations of flooding the mine lead to the conclusion that the pillars and the floor will become more stable over time.

3.5 Reliability of predictions

The reliability of subsidence predictions can be discussed in two frameworks – firstly a comparison between prediction and outcomes, and secondly in terms of the robustness of the geotechnical model.

Comparison to outcomes

The surface subsidence surveys conducted on 5 June 2006 along the line of the conveyor belt (Figure 10) indicate that the maximum vertical subsidence to date is 10mm (Figure 11). The precision of this survey, related to meteorological effects and measurement errors, would appears to be +/-2mm.

This result is consistent with the prediction for vertical subsidence to be less than 20mm.

Robustness of the geotechnical model

In geotechnical engineering, predictive models can be assessed in the context of parameter uncertainty and model uncertainty.

Parameter uncertainty relates to the geological assumptions that are made. In this context, the Fassifern Seam is known to be a remarkably uniform sequence, with the plys and bands having the same dimensions over very broad areas. In addition, there has been a large amount of drilling in the area. The good correspondence to between predictions and outcomes to date also demonstrates that the parameters have been appropriately selected.

In terms of model uncertainty, the prediction of subsidence is based on the application of elastic deformation theory to stable pillars and footings. This method has been used in other projects, but it is important to note that there has not been any validation of the approach because the predicted subsidence has been less than the resolution of survey techniques.

An examination of the components of the predictive model is needed to assess the model uncertainty.

1. Compression of the pillar/roof/floor system leads to surface subsidence. This is a reasonable assumption for a wide expanse of pillars such as the 7 headings being proposed.
2. Pillar compression can be simply estimated from the uniformly distributed load (derived from tributary area concepts) and the Young's Modulus of coal. The aspect ratio of the coal pillars (width/height) is such this will result in an over-prediction of the pillar compression. The "constrained modulus" should be used, which is about 60% greater than the Young's Modulus for a material with a Poisson's Ratio of 0.35. A similar correction should be applied to the compression of thin clay horizons
3. The largest component of the compression is derived from the low strength claystone horizons. An estimate of the modulus of this material is required, and given the inability to collect suitable samples for laboratory testing, there is a need to use a constant ratio of modulus/UCS and an estimate of the UCS. Given their low strength,

testing of these claystone materials is subject to extreme sample disturbance. Such disturbance can occur before sampling (softening in the roadways due to stress relief) and during coring (exposure to water).

4. The ratio of drained modulus to UCS is assumed to be 135. The technical literature gives very little guidance as to what is a valid presumed value for this ratio. The only information we have been able to find is a table that presents data for various clay-shales in North America.

4 Subsidence impacts

HansenBailey has provided the following list of surface features that need to be assessed:

- Lake Macquarie
- Pourmalong Creek
- Wetlands
- Residential areas
- Morisset Hospital
- 330 kV power lines
- Roads
- Coal conveyor

Since the predicted subsidence is less than 20mm, with tilts less than 1 mm/m and strains less than 0.3mm/m, there are no predicted adverse impacts on any of these features.

5 Monitoring

5.1 Confirmation to date

As discussed above, monitoring of subsidence in the current area has been conducted by a subsidence survey line along the conveyor (Figure 10). The results show that the vertical subsidence has been less than 12mm (Figure 11) with the associated tilts less than 0.2mm/m over a 50m bay length.

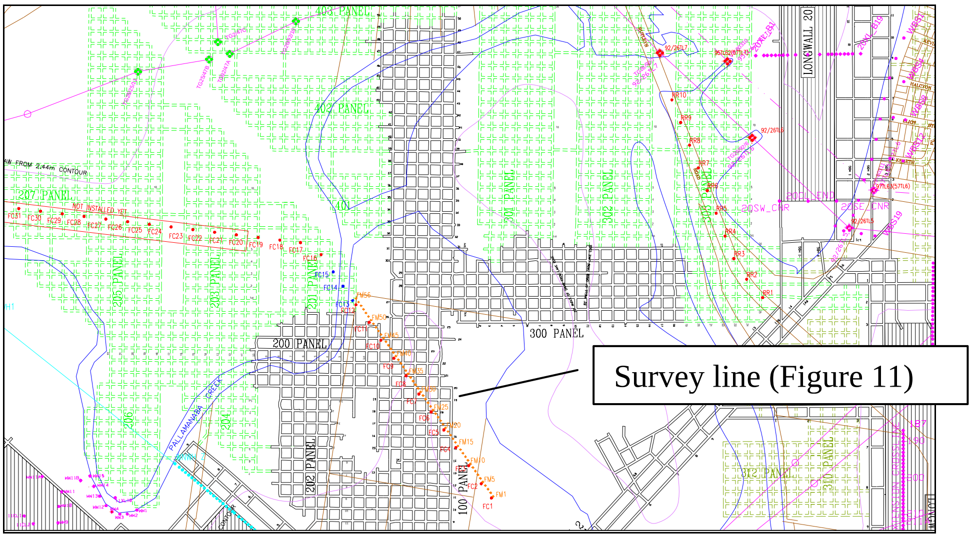

Figure 10 Location of survey

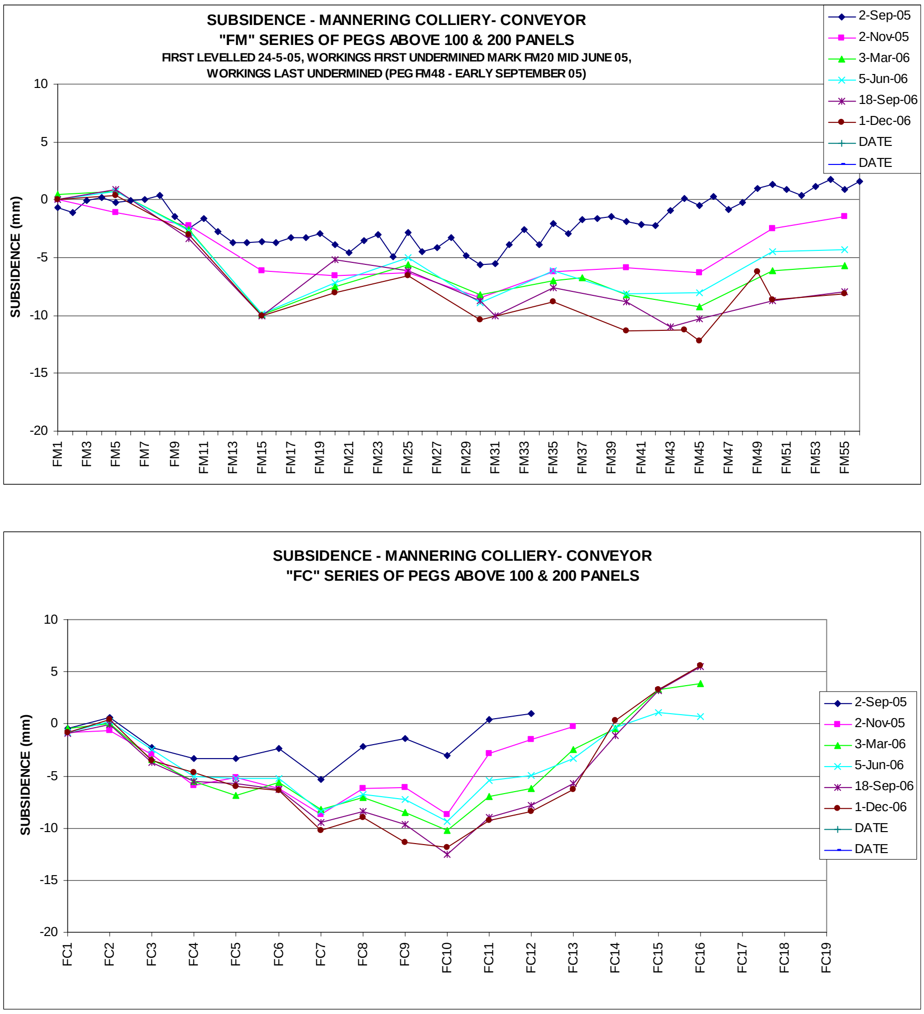

Figure 11 Vertical subsidence along both side of conveyor belt

5.2 Future monitoring

Suitable monitoring strategies for this layout should involve annual monitoring of a limited number of subsidence lines for a period of no more than 3 years after mining has been completed within 500m of the survey points. The design of the survey lines should have pegs spaced at nominally 1/20 of depth and either horizontal movement or horizontal strain should be recorded. It is noted that annual surveys represent a low frequency but it is considered that there is more value in intensive infrequent surveys than frequent surveys of only vertical subsidence. The fact that the lines have been established means that they can be reoccupied at any time if there is a specific concern about adverse impacts.