DRAFT V1 REPORT TO

BMA Coal

on the

Surface Subsidence Prediction for the Red Hill Mine (RHM)

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1 EXECUTIVE SUMMARY

This report provides an assessment of the predicted subsidence due to underground longwall coal and longwall top coal caving mining at the proposed Red Hill Mine (RHM) longwall project.

Two separate scenarios required subsidence predictions as follows:

- ***Scenario 1 – "Mitigated Case":*** In areas not overlain by the Isaac River or significant faults a longwall extraction thickness of 9.6m is modelled based on Longwall Top Coal Caving (LTCC). In areas where the Isaac river overlies the longwall panels at surface (with a buffer zone either side), and where there are significant fault impacts as determined by BMA, extraction is modeled at 3.9m. This is with a view to minimising subsidence impacts on the river flow, together with minimising the potential impacts of subsidence associated with fault zones.
- ***Scenario 2 – "Worse Case":*** 10m extraction height for all longwall panels throughout. This represents the "worst case", or most significant vertical subsidence that would occur across the mine layout at close to full seam extraction based on Longwall Top Coal Caving (LTCC).

Longwall mining involves the extraction of "panels" of coal which are separated by narrow "chain pillars" of coal which are left in place for support. When coal has been extracted from panel areas each mined out panel area is described as a "goaf".

When coal is extracted by the longwall mining method, the roof above the seam is allowed to collapse into the void that is created as a result of extraction. This collapsed area is referred to as the goaf. Creation of this goaf area results in fracturing and settlement of the overlying strata, commonly referred to as the overburden strata. There is an overall downwards movement of overburden strata as a result of longwall goaf formation, which also results in sagging and bending of the land surface overlying the extracted longwall panels. The overall process of deformation to both the overburden and overlying land surface as a result of underlying longwall extraction and goaf formation is called subsidence.

IMC Mining Group Pty Ltd (IMC) at this stage has been asked to provide predictions of the likely surface subsidence effects due to coal extraction of the target Goonyella Middle Seam (GMS). The nature and extent of strata of surface subsidence impacts and cracking at the surface have also been predicted. This is based largely on IMC experience in similar mining environments, together with empirical industry experience.

Predictions have been made based on geological model data and interpretation of the overburden strata. They have also been checked against centerline line and cross line survey subsidence measurement profiles at Broadmeadow.

IMC have utilised Surface Deformation Prediction Software (SDPS) to model and predict the magnitude and impact of longwall extraction on the overlying land surface. This modelling has allowed for a prediction of the total vertical subsidence, as well as strains, tilts and curvature of the overlying land surface.

Modelled maximum vertical subsidence for scenarios 1 and 2 are summarised as follows:

- Scenario 1 – 6.1m in areas being extracted at 9.6m thickness (64% of extraction thickness). In areas where seam extraction thickness is reduced to 3.9m, the maximum predicted vertical subsidence is 2.5m (also 64% of the extracted thickness).
- Scenario 2 – 6.4m (64% of extraction thickness at a 10m extraction height).

Figures showing contours of predicted Smax to illustrate the variation across the mining area are provided in the report. IMC have also provided predictions of maximum strains, tilts and curvatures based on SDPS subsidence model outcomes. As with Smax, these predictions vary dependent on the mining extraction height and cover depths. These parameters are commonly quoted in subsidence assessments as they are relevant in providing inputs for assessment of the nature and style of surface deformation and cracking. Contoured figures showing predictions of strain, tilt and curvature across the mining area are provided in the report.

The worst case manifestation of subsidence on surface land deformation is anticipated to be similar for scenario 1 (maximum extraction of 9.6m) as it is for scenario 2 (10m extraction). Based on subsidence prediction modelling, the zone of rehabilitation over surface tension cracking following scenario 1 and 2 seam undermining is anticipated over the chain pillars and to extend some 35m either side into the panels. Rehabilitation of the resultant tensile cracks will be required and cracks in the order of a maximum width of 0.5m and a maximum depth of 10m are anticipated in the worst case instances. Surface crack rehabilitation is likely to require remedial earthworks and the use of sealants.

Compressive strains are predicted over the central parts of the longwall panels. The surface manifestation of compression / humping is also considered likely to minor remedial earthworks.

Maximum tilts developed to around 6.4% in limited areas will also require careful management. The impacts on surface drainage and any other sensitive surface landscape features will require consideration and management through subsidence management strategies.

This is largely based on observation and experience at nearby Goonyella Middle Seam longwall operations. In most cases subsidence cracking at the surface due to tensile strain is anticipated to be less severe than this. Rehabilitation recommendations are beyond the scope of IMC's work and would require assessment by environmental scientists.

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2 INTRODUCTION

2.1 Work Scope

IMC Mining Group Pty Ltd (IMC) was requested by Andrew Swiericzuk (BMA) to undertake a subsidence assessment based on the most recent mine layout, which was updated in September 2011. The target mining seam is the Goonyella Middle Seam (GMS).

Work undertaken and outlined in this report includes:

An explanation of the subsidence prediction methodology including key assumptions and limitations;

- A general description of the nature of the surface subsidence predictions – vertical subsidence, stains, tilts and curvatures.
- A description of the nature and extent of predicted surface cracking, including comparisons with experience from other similar longwall mines.

2.2 Overview of Longwall Mining and Subsidence

Longwall mining involves the progressive extraction of blocks of coal in "panels". These longwall panels are created by driving a set of gate roadways, commonly referred to as entries, from the main heading roadways in the mine. The gate roadways are separated by solid coal, referred to as longwall gate roadway pillars. When the entries have been driven to a predetermined length, they are connected and a rectangular longwall block is formed. Figure 2-1 illustrates the formation of longwall panels.

The longwall face is then installed and as mining continues into the panel, back to the original main headings development, the entries are allowed to collapse behind the face line to form part of the "goaf". Longwall panel widths (the distance between adjacent gate roadways) for proposed workings at the RHM project are typically 320m. IMC have been asked to consider two extraction scenarios as follows:

- ***Scenario 1 – "Mitigated Case":*** In areas not overlain by the Isaac River or significant faults a longwall extraction thickness of 9.6m is modelled based on Longwall Top Coal Caving (LTCC). In areas where the Isaac river overlies the longwall panels at surface (with a buffer zone either side), and where there are significant fault impacts as determined by BMA, extraction is modeled at 3.9m (Figure 2-2). This is with a view to minimising subsidence impacts on the river flow, together with minimising the potential impacts of subsidence associated with fault zones.
- ***Scenario 2 – "Worse Case":*** 10m extraction height for all longwall panels throughout. This represents the "worst case", or most significant vertical subsidence that would occur across the mine layout at close to full seam extraction based on LTCC (Figure 2-3).

Coal is mechanically extracted from longwall panels using a shearer which cuts out a block of coal to a specified height, typically in 1m increments or "web passes". As mining progresses the longwall face gradually retreats back to the main headings.

Coal is collected onto a longwall armoured face conveyor (AFC), and transported from the longwall face via the gate roadway entries and main mine drifts out of the mine. In the case of Longwall Top Coal Caving which is being considered in scenario 1, a separate back AFC will be installed to recover the “top coal” over and above the height of the initial first cut.

The area immediately in front of the coal face is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata and provide a working space for the shearing machinery and face conveyor. After each slice of coal is removed, the hydraulic roof supports, the face conveyor and the shearing machinery are moved forward.

Figure 2-4 shows a cross section from a typical longwall face, illustrating the formation of goaf as a block of coal is cut by a longwall shearer. When coal is extracted by the longwall mining method, the roof above the seam is allowed to collapse into the void that is created as a result of extraction. This collapsed area is referred to as the goaf.

Creation of this goaf area results in fracturing and settlement of the overlying strata, commonly referred to as the overburden strata. There is an overall downwards movement of overburden strata as a result of longwall goaf formation, which also results in sagging and bending of the land surface overlying the extracted longwall panels. The overall process of deformation to both the overburden and overlying land surface as a result of underlying longwall extraction and goaf formation is called subsidence.

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The majority of the subsidence at the ground surface occurs over the centre of the longwall and tapers off around the perimeter of the longwall adjacent to and over the gate roadway pillars.

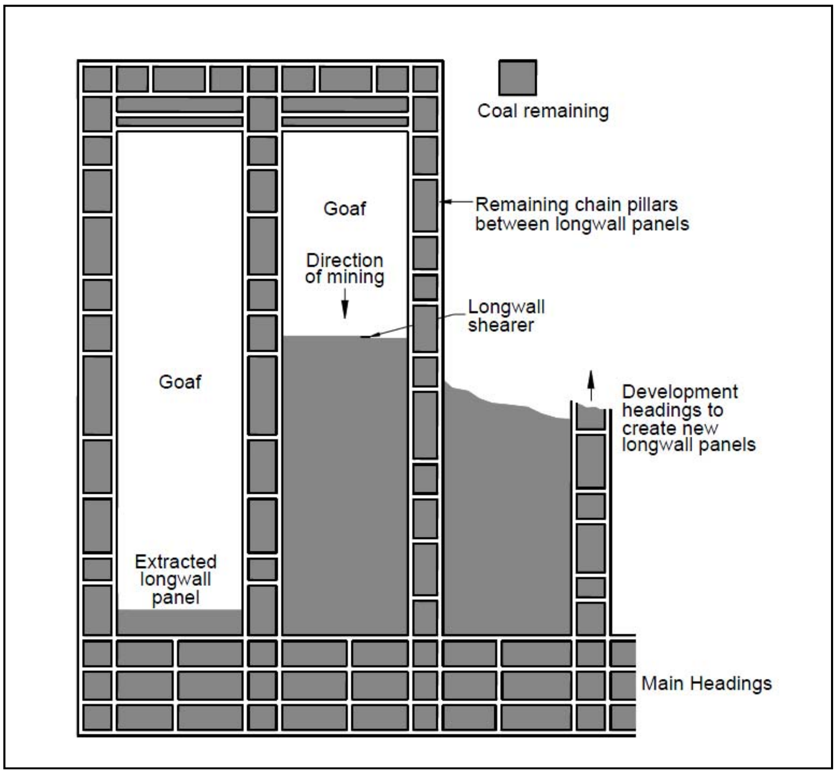

Figure 2-1 : Typical Plan View of a Series of Longwall Panels *(From "Introduction to Longwall Mining and Subsidence – Mine Subsidence Engineering Consultants, 2007).*

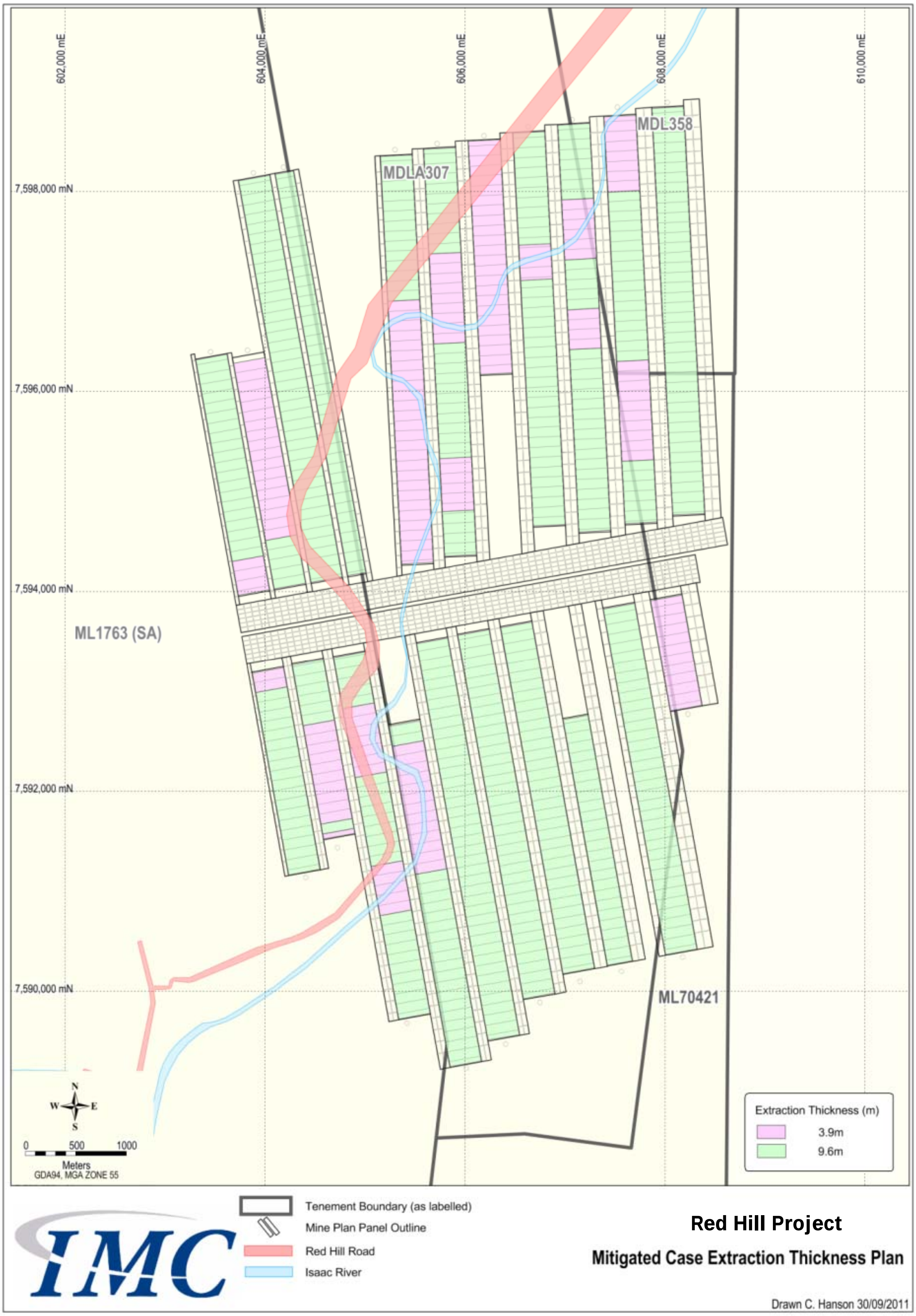

Figure 2-2 : Extraction Thickness for Scenario 1 – Mitigated Case

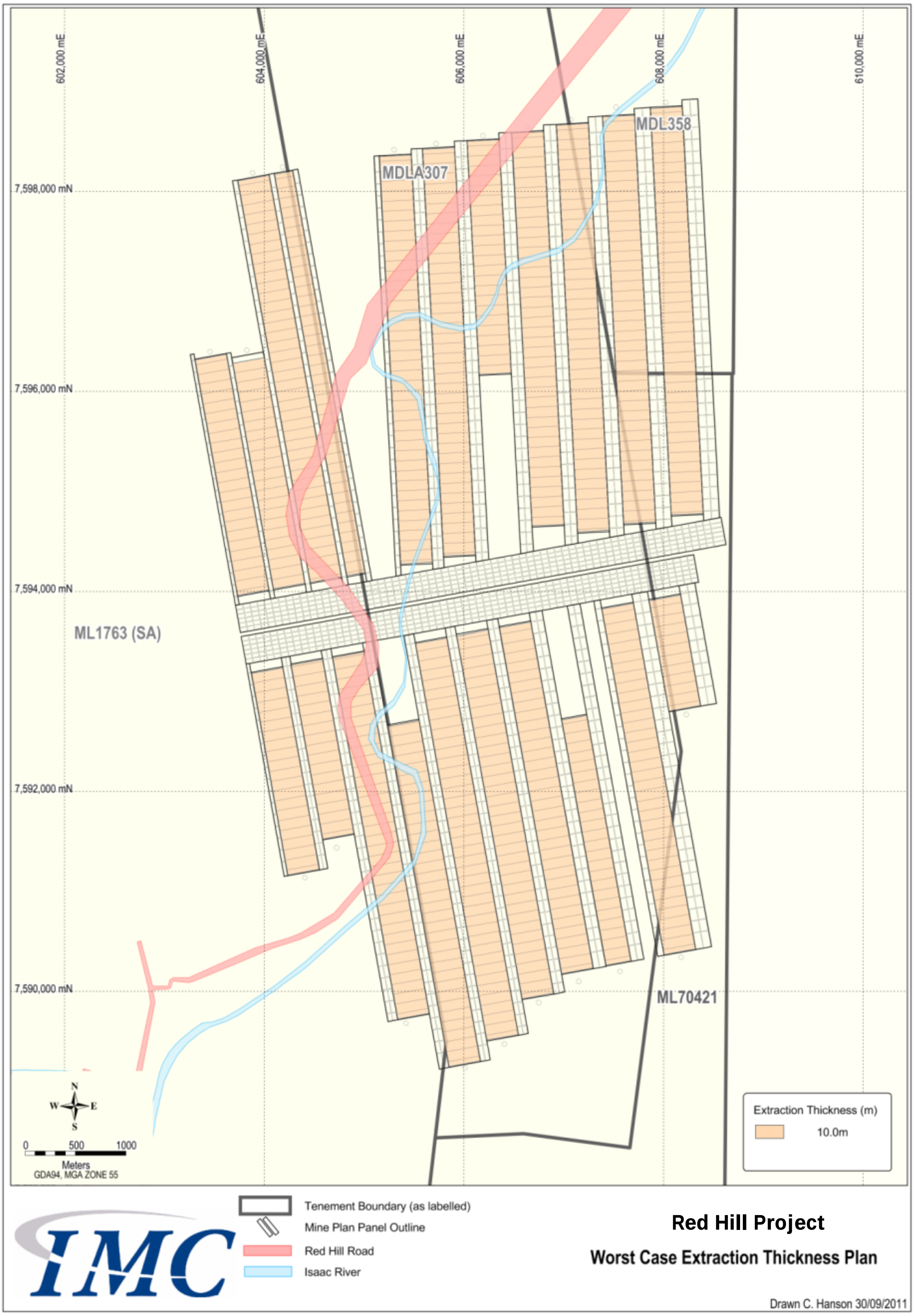

Figure 2-3 : Extraction Thickness for Scenario 2 – Worst Case

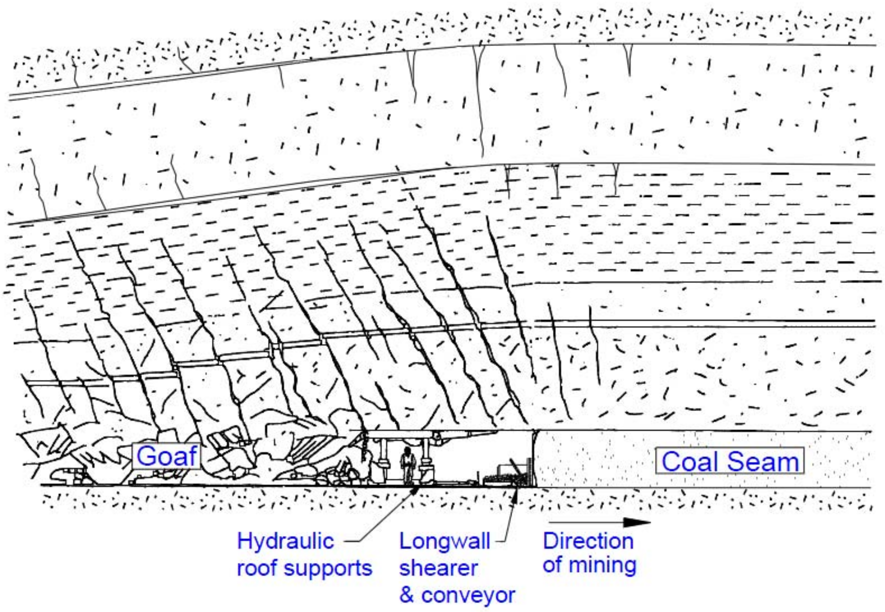

Figure 2-4 : Cross Section of a Typical Longwall Face *(From "Introduction to Longwall Mining and Subsidence – Mine Subsidence Engineering Consultants, 2007).*

3 RESOURCE CHARACTERISTICS

Target economic coal seams are contained in the Late Permian Moranbah Coal Measures (MCM) which are generally 200m - 300m thick. The Moranbah Coal Measures are overlain by the Fort Cooper Coal Measures (FCCM), Rangal Coal Measures (RCM) and the Late Permian to Early Triassic Rewan Group. Figure 3-1 details the regional stratigraphy of the North Bowen Basin.

The MCM comprise mainly volcanic lithic sandstones, with lesser siltstone, mudstones and coal. Quartz clasts form up to 20%, but more commonly less than 10% of the sandstones. The transition between the MCM and the overlying FCCM is difficult to identify with precision, and is usually seen by the absence of tuffaceous coaly bands in the MCM, and the presence of more lithic sandstones. Approximately 20m of coal is present over the northern section of the MCM, and is generally concentrated into four or five coal seams which show extensive splitting and coalescing.

The FCCM comprise typically tuffaceous sandstones, siltstones, mudstones and coal seams. The transition between the FCCM and the RCM is generally clearly marked by the Yarrabee Tuff - a basin-wide marker bed comprised of weak, brown tuffaceous claystone.

The RCM comprise light grey, cross-bedded, fine to medium grained sandstones, grey siltstones, mudstones and coal seams. Cemented sections are common in the sandstones. The transition from the RCM to the Rewan Formation is generally difficult to define and is often based on the change from the green-grey colour of the Rewan sandstones to the blue-grey colour of the RCM sandstones. The transition between the formations is 15 to 60m above the first major seam in the RCM, the Leichardt Seam.

Coal within the MCM occurs in four distinct horizons: Goonyella Upper seam zone (GUS), P seams zone, Goonyella Middle Seam zone (GMS) and Goonyella Lower Seam zone (GLS).

Coal of a suitable thickness and quality to be mined by underground methods is confined to the GUS (GU0), GMS (GM0, GM1 and GM4) and GLS (GL0, GL1, GL6 and GL7). These coal seams are consistent over large areas but are prone to occasional splitting and coalescence.

The overlying FCCM comprise a typically weak sequence of tuffaceous sandstones and siltstones and several thick, high ash coaly horizons.

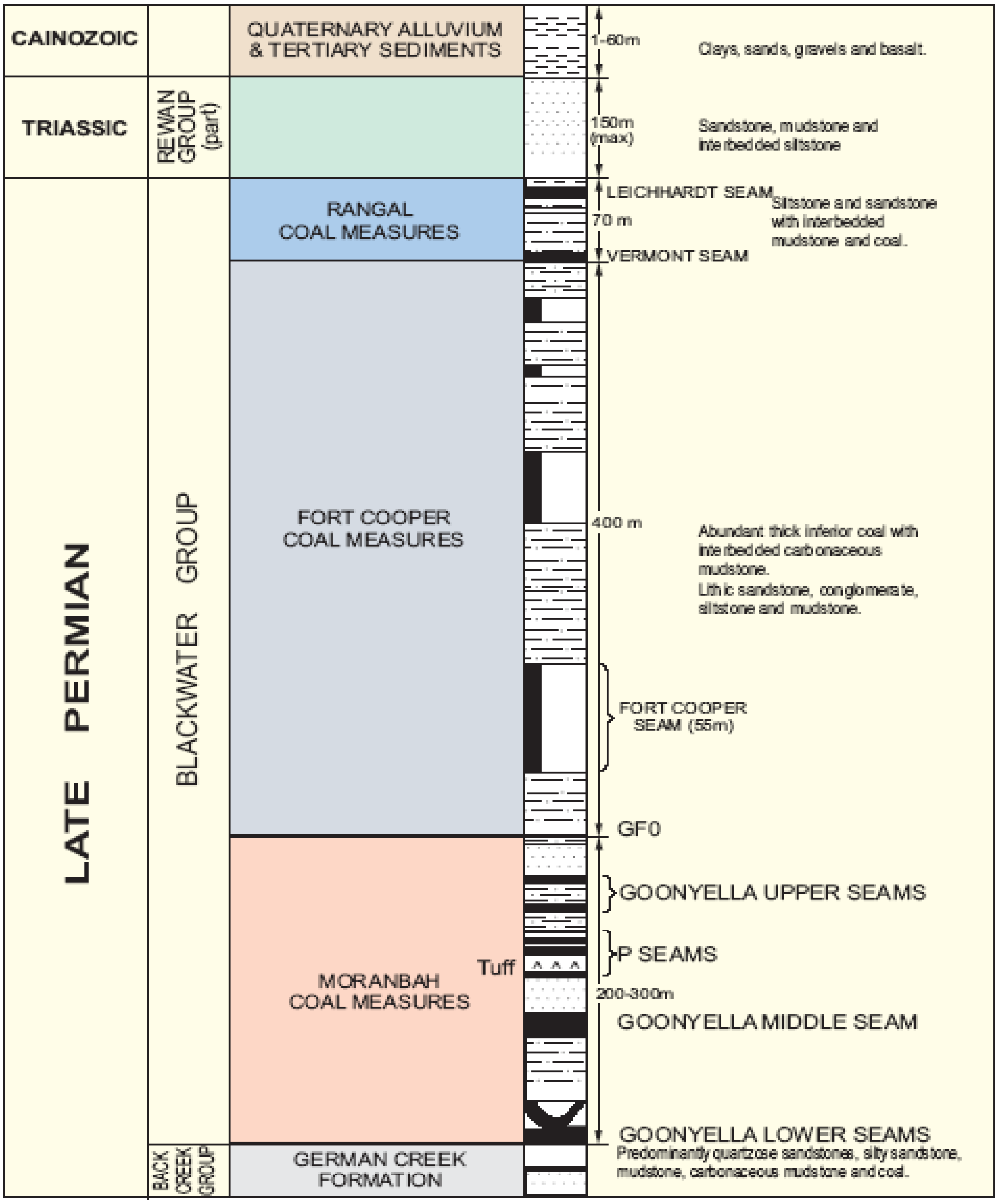

Figure 3-1 : Regional Stratigraphical Sequence

Topographical contours are shown in Figure 3-3. Topography is relatively gentle with a slight increase to the west and east either side of the Isaac River.

Depth to the base of Tertiary is shown in Figure 3-4. Quaternary sediments are relatively thin, with the base of Tertiary typically ranging from around 2 – 17m.

Depth to the base of weathering over the resource area ranges from around 20m to 30m averaging as illustrated in Figure 3-5. From a subsidence perspective therefore, the majority of the overburden strata to the GMS is formed from fresh rock material. However, with the exception of some thicker sandstone sequences (referred to as GM41 and GM42), the overburden units to the GMS comprising the Fort Copper, Rangal and Rewan sequences are known to be relatively low strength and cave easily during subsidence and following extraction.

3.1.1 Target Seam Characteristics

The GMS is the target seam for the RHM project. The thickness of the GMS over the RHM project area is shown in Figure 3-7.

To the north of the thick seam mining (TSM) (longwall top coal caving) project area a number of combined seams, termed the GM0, are consistently 9-10 metres thick. Within the current Broadmeadow underground area the GM0 splits into the lower GM1 seam and an upper GM2 Rider seam split. The average thickness of this GM1 seam throughout most of the TSM project area is around 6 – 7m. In the southern end of the TSM project area the GM3 seam splits away resulting in a thinner combined section of coal plies termed the GM4.

Figure 3-2 shows the GMS ply and seam code schematic as it relates to the RHM project area and adjacent areas. The GMS is very consistent, with four plies being recognised. As shown in Figure 3-2, through the RHM project area the seam is represented by all plies and is unaffected by seam splits. The upper ply (J) is the only GMS ply that contains significant stone banding and as such is the lowest quality ply. Plies K and L are relatively homogeneous and of a similar quality. The base of ply L is a prominent stone band that is traceable across the lease and forms a good marker band. The basal ply (M) is made up of bright banded coal but with a prominent stone band in the centre.

Thickness of the GMS through the RHM mine plan is shown in Figure 3-6. Thicknesses are typically between 7.5m to a maximum of around 9.5m. For the purposes of mine planning, BMA are assuming a recovered coal total extraction thickness of 7.5m.

- Cover depth to the GMS roof is shown in Figure 3-7. Mains panels are developed over a range from approximately 230m to 520m. Proposed longwall panels are developed from approximately 210m through to a maximum of around 350m Cover depth to the upper target HCU seam through the resource area ranges from 250m in the west to around 530m in the north east as shown in Figure 3-7.

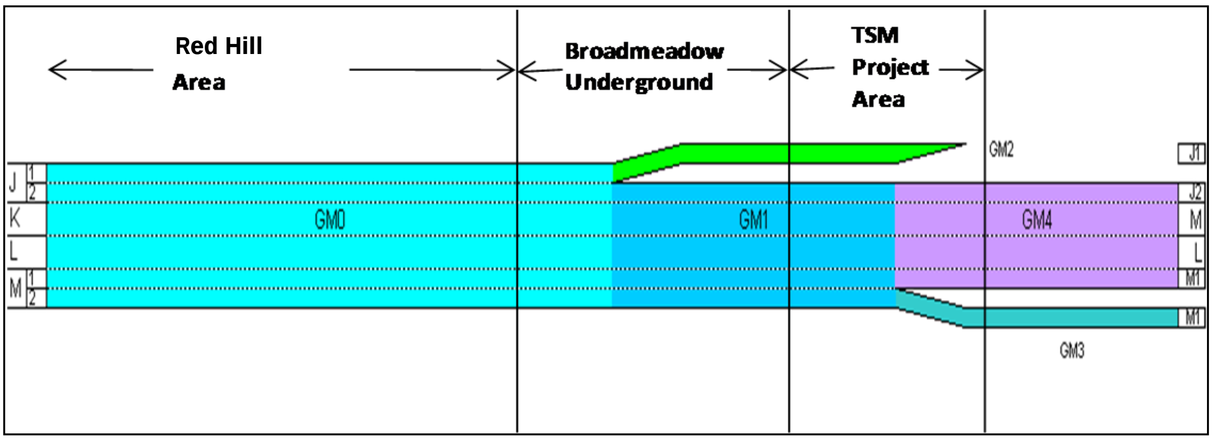

Figure 3-2 : GMS Ply and Seam Code Schematic

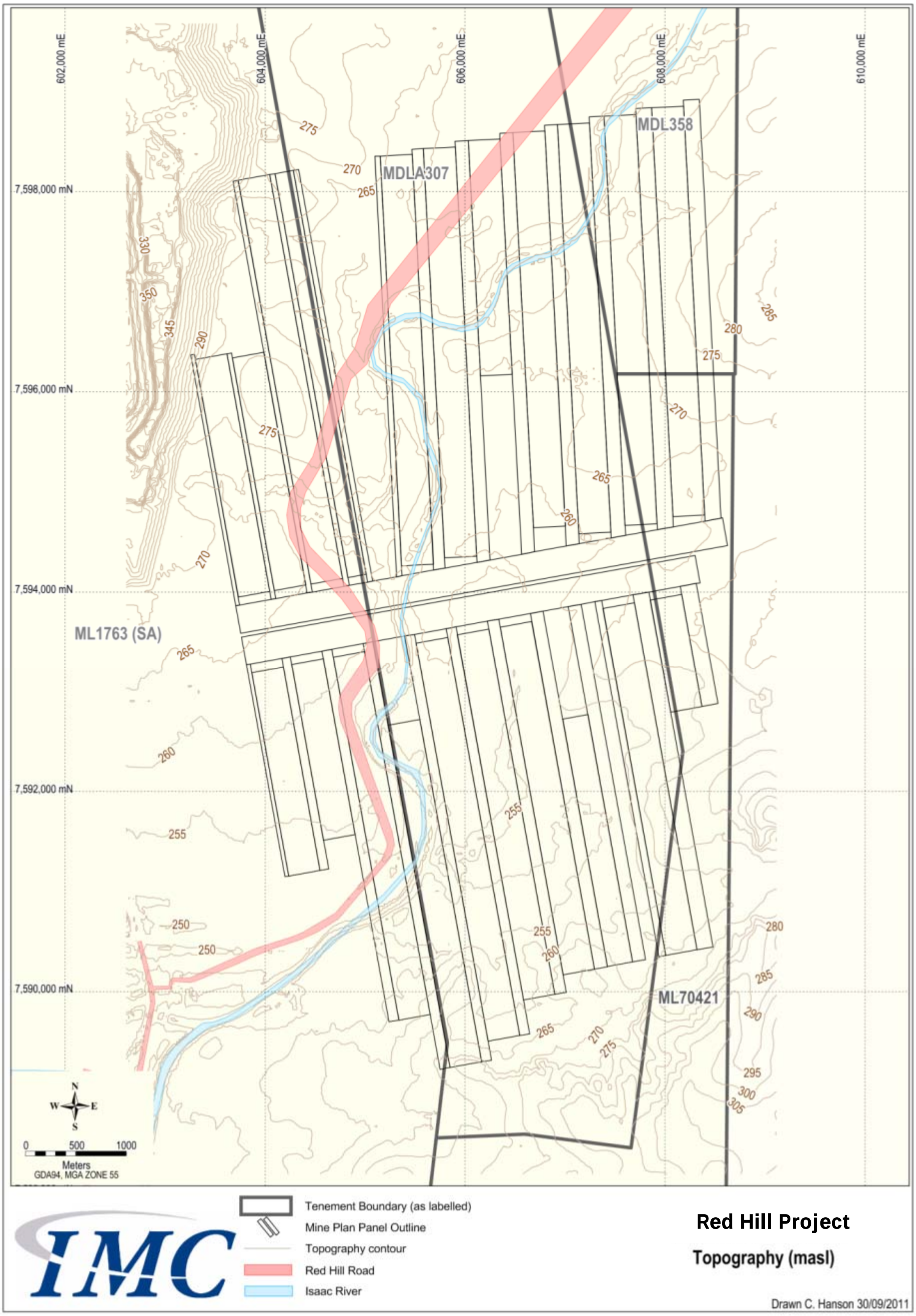

Figure 3-3 : Topography Contours (masl)

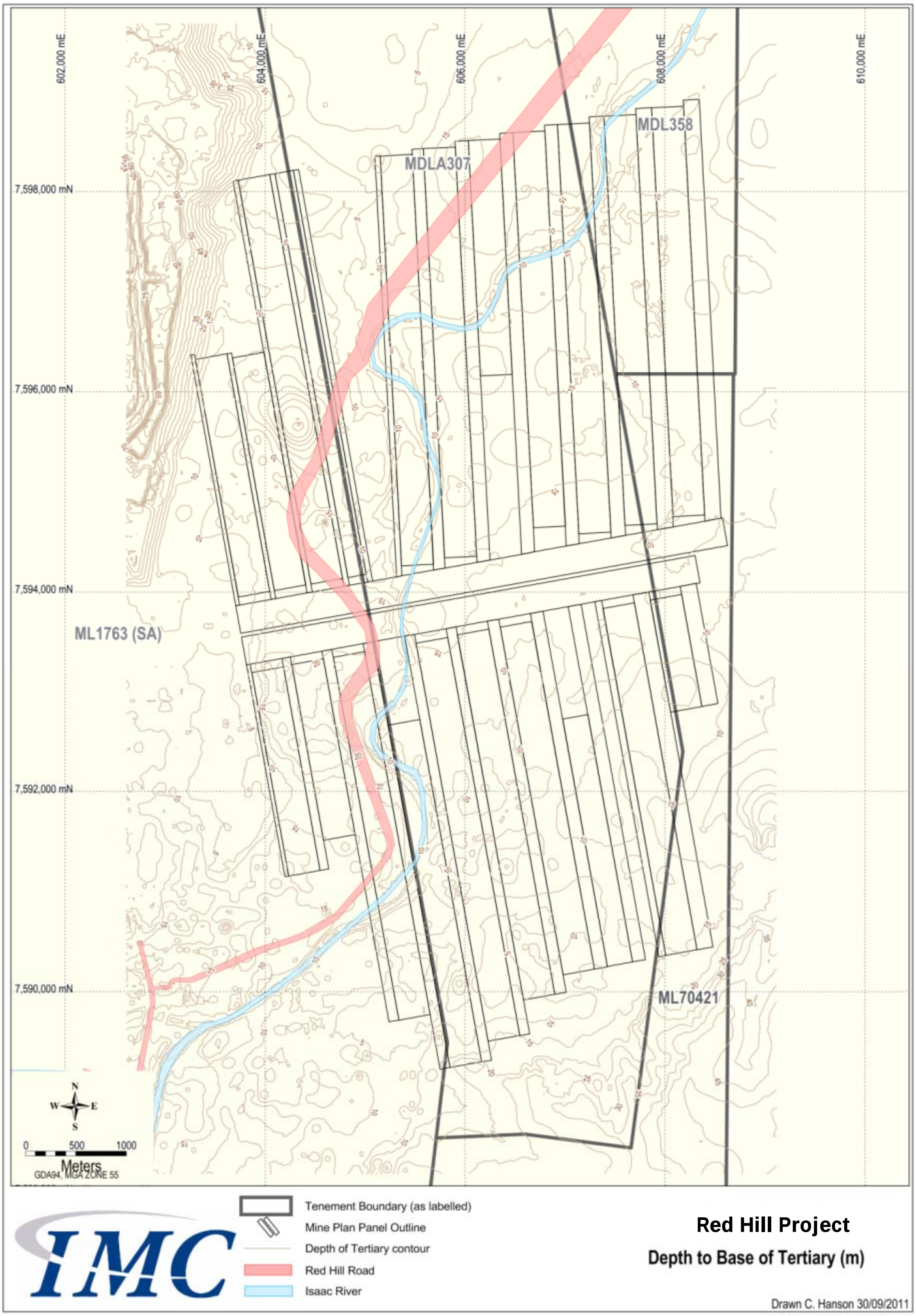

Figure 3-4 : Depth to Base of Tertiary (m)

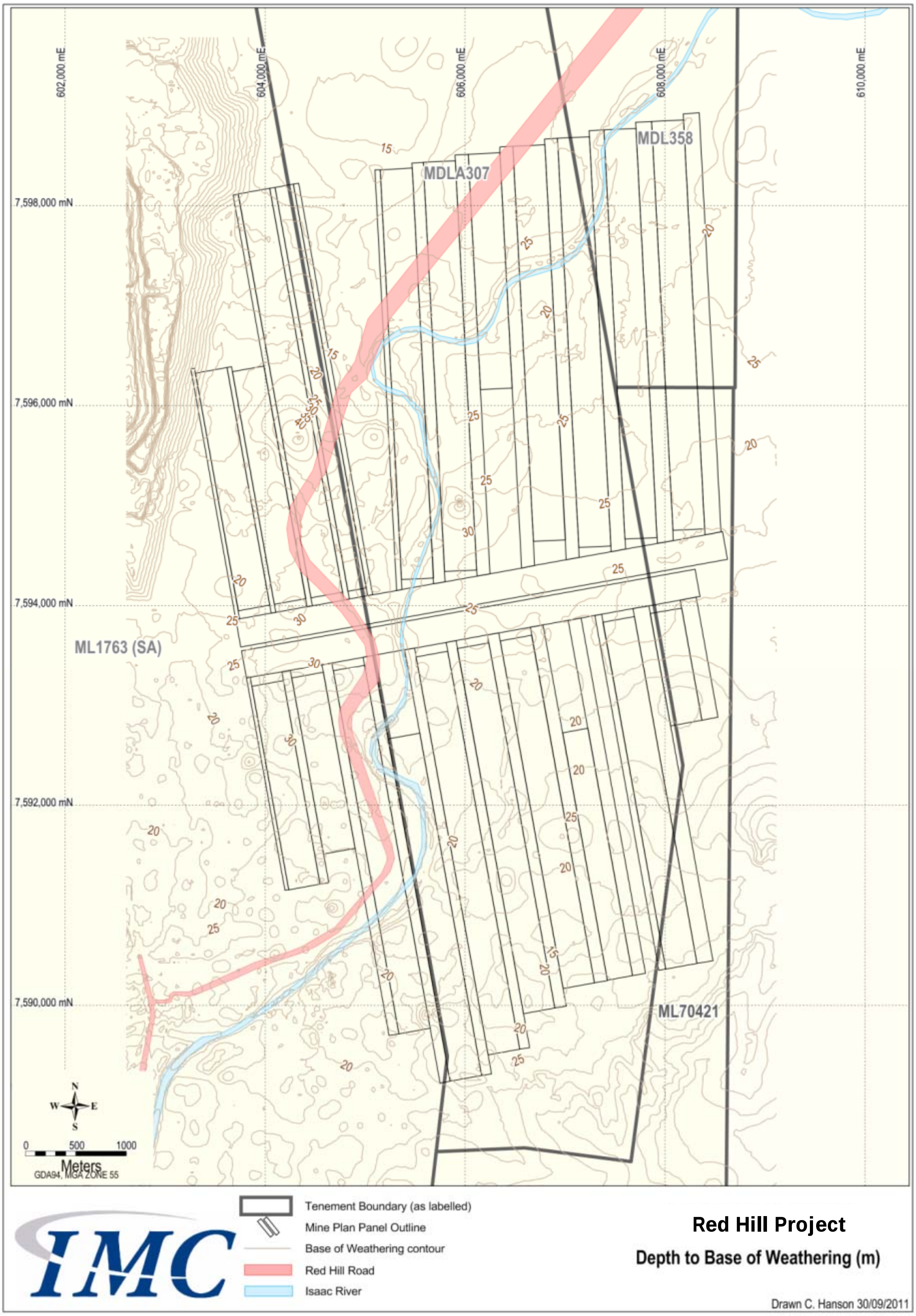

Figure 3-5 : Depth to Base of Weathering (m)

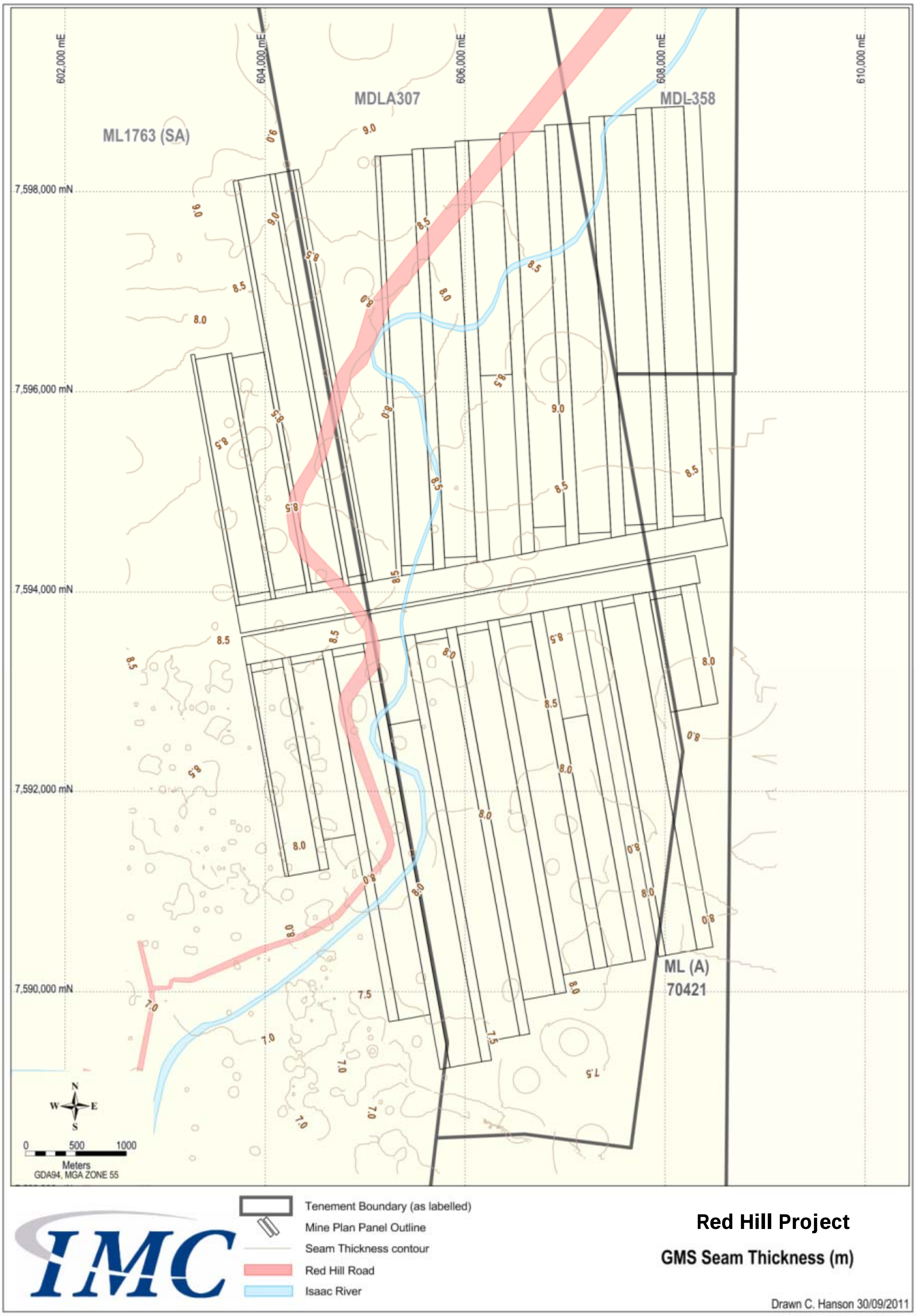

Figure 3-6 : GMS Thickness Contours

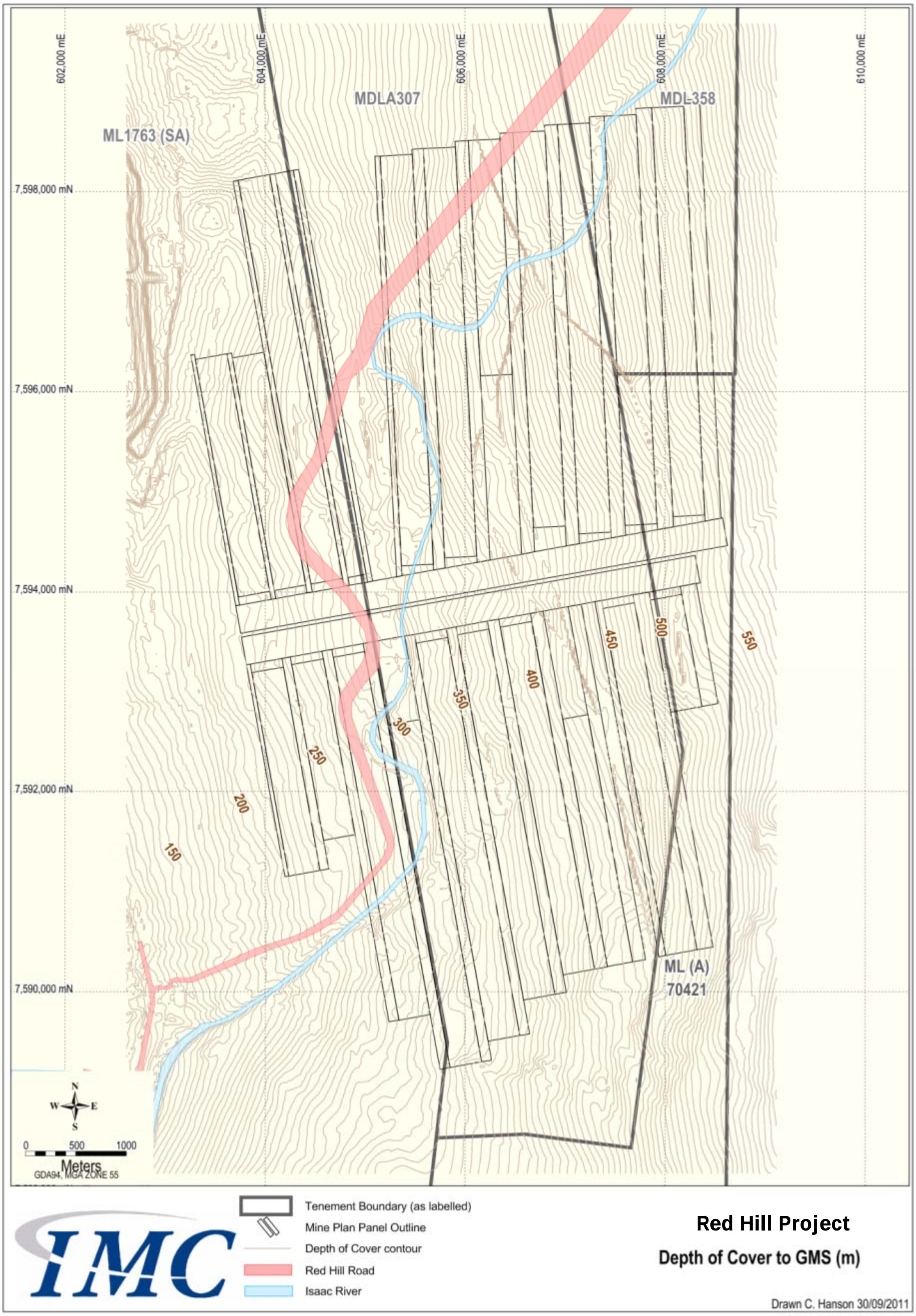

Figure 3-7 : GMS Cover Depth Contours

3.2 Subsidence Prediction Methodology

Surface Deformation Prediction Software (SDPS) has been used for subsidence prediction for the RHM mine plan. SDPS is a software package that implements the Influence Function method (Karmis et al, 1990), to calculate a number of surface deformation indices based on a digitised mine plan and, in this case, digitised cover depth contours. Depth of cover to each of the target mining seams was provided as 1m interval contours as 3D (X,Y,Z) strings from the latest RHM geological model.

The functionality provided by SDPS using a regional subsidence modelling approach is considered suitable and sufficiently accurate for Greenfield sites such as the RHM project, for the purposes of an EIS. It has been used extensively for Queensland and New South Wales underground coal mine EISs.

The SDPS subsidence predictions when correlated to actual measurements in the Bowen Basin at a number of sites have been reasonably accurate. IMC have incorporated recent relevant and documented industry experience, empirical research and data / measurements from Broadmeadow to calibrate the subsidence model and provide what are considered to be credible subsidence estimates based on the current state of knowledge (described in detail in Section 3-3).

3.3 Limitations

SDPS is a recognised credible method for predicting surface subsidence due to longwall mining. However, as with any predictive model the method does have some limitations. In a general sense these limitations are considered unlikely to present a material difference to the outcomes or impacts predicted.

Specific limitations associated with the Influence function / SDPS approach are summarised as follows.

- SDPS utilises a single mathematical formula and therefore makes the assumption that all panels are symmetrical. In this instance, and since all the undermined panels are similar in width, this will not have a material effect on the accuracy of the subsidence predictions.
- The applied modelling technique is limited in its capability to provide and combine contoured outputs across areas with variable resource characteristics. In most instances single specific assumptions and calibrated outputs are incorporated and apply to the whole resource area based on the mining panel outline and a limited number of additional parameters and variations (usually cover depth and topography). In this instance IMC have based subsidence predictions for the RHM mine plan area based on a basic assessment of the overburden and interburden to target mining seams utilising a hard rock factor which has been reduced in extracted interburdens to reflect the increased fracturing which is considered inevitable. Assumptions regarding the percentage of hard rock within the overburden and apply across the entire resource area. Nonetheless this is considered reasonable, based on both calibrations with subsidence measurements elsewhere in similar circumstances and the level of confidence and accuracy generally required for an EIS.

- Dynamic / incremental subsidence effects have not been modelled in this approach. This is not considered to have a significant material impact in that the assessment of subsidence predictions for the purpose of the EIS are based on either final subsidence magnitudes following the completion of mining in each seam or at selected points in time during the overall mining schedule. The final subsidence impacts as modelled will generally be greater than associated incremental impacts.
- The model does not account for anomalous effects of subsidence including in the vicinity of faulting or impacts of other significant geological variations. It should be emphasised that based on experience at similar Bowen Basin longwall mine sites, the impacts of subsidence associated with faulting are generally very localised and can usually be easily rehabilitated or managed on a case by case basis.

4 SDPS SUBSIDENCE MODEL CONSTRUCTION AND APPLIED PARAMETERS

The SDPS Incremental Profile Method of prediction is based upon predicting the incremental subsidence profiles for each longwall individually. IMC have calculated maximum subsidence based on cover depth contours provided by BMA at 0.5m increments. Predicted Smax (maximum subsidence) is calculated for the Influence Profile for each extracted seam at discreet locations along the lines of the cover depth contours. These (Smax Prediction) points have further been contoured in Mapinfo Discover utilising a smoothed Kriging function to provide graphical contoured outputs of Smax. Through estimating discreet points in the transverse and longitudinal directions tilts, systematic curvatures and strains can be predicted at any point on the surface above a series of longwalls.

The SDPS Influence Function Module allows for the shape of a subsided surface to be modelled using a Gaussian (bell shaped) curve that is centred on the point of inflexion of a subsidence profile. The empirical SDPS package is based on several empirical relationships (including some correlations) developed through statistical analysis of data from a number of case studies including:

- A correlation between the maximum subsidence factor with the width to depth ratio of a panel and the percent hard rock (%HR) in the overburden (or interburden in the case of multiple extracted seams);
- A correlation of the distance of the inflection point from the rib of the panel, with respect to the width to depth ratio of the panel;
- A regional value for the tangent of the influence angle (tan β), and the radius of influence;
- A regional value for the horizontal strain coefficient.

The following parameters have been defined for subsidence modelling at the RHM project based (in part) on IMC knowledge of subsidence measurements at similar operations and environments.

4.1.1 Maximum subsidence factor (Smax / m)

The Maximum Subsidence Factor (SF) required for SDPS modelling is a function of the width-to-depth ratio and the estimated percentage hardrock in the overburden. Smax refers to the maximum vertical subsidence of the profile. SDPS incorporates the maximum subsidence as a function of the width-to-depth ratio, and the percentage hardrock in the overburden as shown in Figure 4-1.

Hard Rock Factors of between 25% to 35% have been assumed for the subsidence models based on a generic assessment and IMC knowledge of overburden characteristics.

	Percent Hardrock in the Overburden							
W/h	10%	20%	30%	40%	50%	60%	70%	80%
0.6	0.64	0.59	0.51	0.42	0.34	0.26	0.21	0.16
0.7	0.69	0.63	0.55	0.46	0.36	0.28	0.22	0.18
0.8	0.71	0.65	0.57	0.47	0.38	0.29	0.23	0.18
0.9	0.72	0.66	0.58	0.48	0.38	0.30	0.23	0.19
1.0	0.73	0.67	0.58	0.49	0.39	0.30	0.24	0.19
1.1	0.74	0.68	0.59	0.49	0.39	0.31	0.24	0.19
1.2	0.74	0.68	0.59	0.49	0.39	0.31	0.24	0.19
1.3	0.74	0.68	0.60	0.49	0.40	0.31	0.24	0.19
1.4	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.5	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.6	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.7	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.8	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.9	0.76	0.69	0.60	0.50	0.40	0.31	0.24	0.19
2.0	0.76	0.69	0.60	0.50	0.40	0.31	0.24	0.19

Figure 4-1 : Calculation of maximum subsidence factors (Smax/m) for longwall panels

4.1.2 Critical Width Concepts

Based on cover depth and panel extraction width, a longwall panel may be classified as being of sub-critical, critical or super-critical width. Panel critical width is defined as the panel width for which maximum possible subsidence for a given extraction height is developed. The critical width represents the cross-over point from a "wide and \ or shallow" longwall panel to a "narrow and / or deep" longwall panel, the width and depth being determined relative to one another. The magnitude of the critical width depends upon the geological characteristics of the overburden and can range from 1.4 to 2 times the mining depth. The geometry of these three cases is illustrated in Figure 4-2 below.

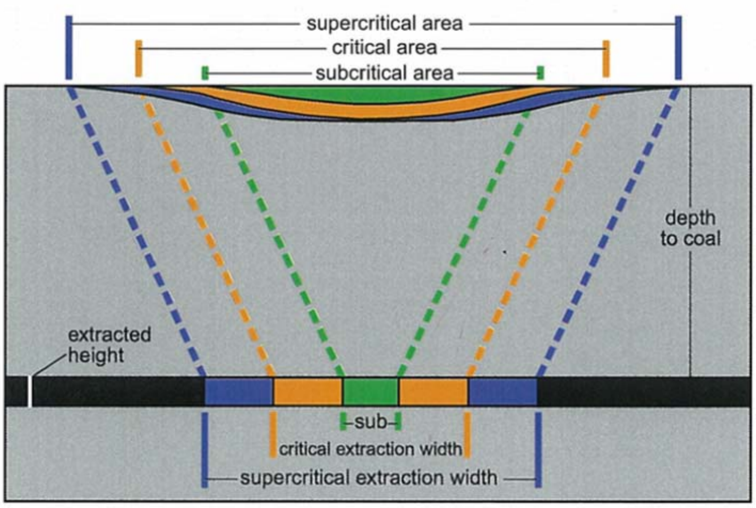

Figure 4-2 : The Development of Surface Subsidence based on Critical Width Concepts (after New South Wales Coal Association 1989)

The extraction of coal removes support from the overlying strata causing them to sag into the void space created. The sag is propagated upward to the surface, and, it follows, that the maximum surface subsidence can be no greater than the thickness of the coal bed mined. However, the lateral extent of subsidence at the surface is greater than the extent of underground mining.

The surface position of the boundary between areas of subsidence and no subsidence which is often used to describe the “limit of mining influence” is defined by the "angle of draw." This is the angle between a vertical line drawn upward to the surface from the edge of the underground opening and a line drawn from the edge of the opening to the point of zero surface subsidence. The angle of draw varies from 25° to 35° degrees in most instances. The larger the angle of draw the wider will be the zone on the surface in which subsidence should occur.

Super-critical (wide and \ or shallow) extractions result in flat-bottomed subsidence troughs as illustrated in Figure 4-2. Sub-critical (narrow and / or deep) subsidence troughs are shallower than supercritical troughs with more gentle bending of the strata towards the centre of the panels and less steep sided, high differential subsidence strains adjacent to the chain pillar edges.

For SDPS subsidence modeling a panel is considered supercritical for W/h greater than 1.2. Due to numerical approximations there may be slight variations to the supercritical subsidence factors determined as a result of critical width assessments although these are anticipated to be minor. For the RHM mine layout, all earlier western panels are supercritical with basin supercritical profiles. Critical width is reached around half way through the planned mine life, at around 270m cover depth based on the width of most of the longwall panels at 320m. Beyond critical width, the later eastern panels develop subcritical profiles and these are reflected in the subsidence prediction profiles and figures.

4.1.3 Inflection point

The inflection point corresponds to S = Smax / 2 on the subsidence profile, or the point of zero curvature – i.e. the transition point from positive to negative curvature as shown in Figure 4-3. It is, therefore, the point at which the subsidence profile changes from concave to convex. The inflection point is estimated with respect to overburden depth (d/h) and can be estimated based on empirical curves.

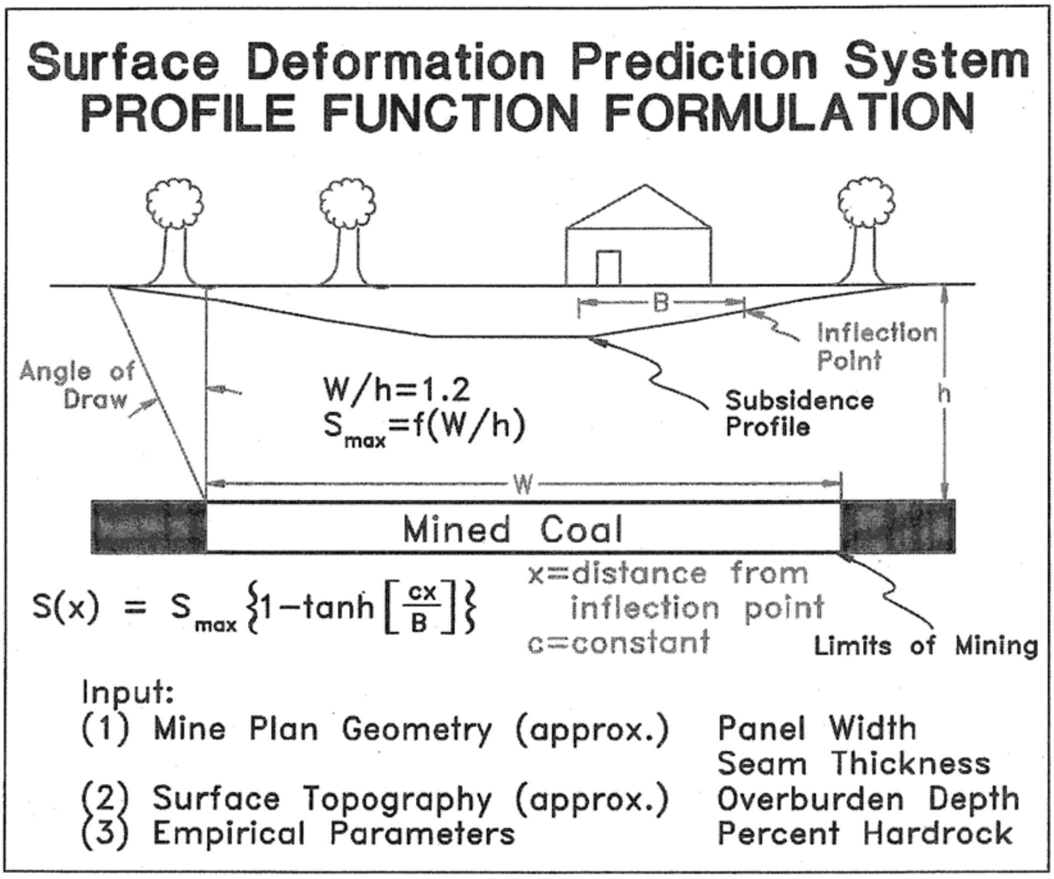

Figure 4-3 : Illustrating Profile Function Parameters in SDPS

4.1.4 Angle of Influence (β)

This is the angle between the horizontal and the line connecting the projection of the inflection point position of the subsidence trough, at the seam level, with the surface point of "zero influence" i.e. where subsidence is about 0.6 percent of the maximum subsidence value (VPI&SU 1987). This is one of the basic parameters used in the Influence Function method of subsidence prediction. The Angle of Influence is related to the Radius of Influence by the equation:

$\tan\beta = h/r$

Where:

h = the overburden depth

r = the radius of influence

Based primarily on experience at adjacent operations IMC have set the angle of influence (Beta) - at 56 degrees (or Tangent of influence angle of 1.48 for model input). Whilst recognised that this angle may be a little higher (up to 65°) for shallower more supercritical panels, IMC consider a generic angle of 56° is more likely to be typical of the overall resource for the RHM mine layout. Sensitivities associated with the range of (considered) probable angles (56° to 65°) are not considered to be of major significance with respect to resultant associated zones of surface strains.

4.1.5 Horizontal Strain Factor (Bs)

This value is directly related to the magnitude of calculated strains and curvatures over an undermined area and can be empirically calculated by the average ratio of strain and curvature over a set of surface points. The higher the value for this coefficient, the larger the predicted strains and displacements. IMC have used the default SDPS strain coefficient of 0.35 in the absence of more detailed subsidence data.

5 SURFACE SUBSIDENCE PREDICTIONS

SDPS modelled subsidence predictions are shown in Figure 5-2 to Figure 5-9. The following section provides commentary on the interpretation of these predictions.

5.1 Differential Surface Subsidence

In addition to the estimate of the maximum vertical subsidence magnitude, it is important to have an understanding of the parameters relating to longwall extraction and subsidence for the RHM mine layout as illustrated in Figure 5-1 namely:

- Maximum tensile and compressive ground strains ($+E_{max}$ and $-E_{max}$); and
- Maximum Tilt (T_{max}).
- Maximum Curvature (K_{max}).

The tilt of the ground surface between two points is found by dividing the difference in subsidence at the two points by the distance between them. The maximum tilt occurs at the point of inflection where the subsidence is roughly equal to half of Smax. The curvature is concave towards the centre of the longwall panel and convex over the margin and chain pillars. Horizontal strain is the change in length per unit of original length of the ground surface and is critical in the context of pipeline design and impacts.

Both strain and tilt are directly proportional to Smax and inversely proportional to the cover depth. The change in the horizontal stress field caused by mining has the potential to generate movement along the bedding planes in the overburden. This movement need not be confined to the strata directly above an extraction panel and may extend well outside the extraction panel (and the angle of draw).

Strain profiles across sub-critical panels are smooth, with a distinct tensile peak over the edge of the extraction panel and a compressive peak over the central part of the panel. It will tend to be more variable under more rugged surface topography. This is reflected by modelled zones of tensile strain at the pillar edges, with compression towards the centre of the extracted longwall panels.

5.2 Limit of Measurable Subsidence (LOMS)

The Limit of Measurable Subsidence (LOMS) is typically used to define a boundary outside of mine workings beyond which no measurable subsidence (equal or less than 20mm) is predicted. Precedence in NSW indicates that an angle of draw of 26.5° is normally accepted as the LOMS outside any type of mine workings.

On this basis IMC have defined an LOMS for the RHM mine layout longwall panels based on the above criteria. The boundary line defining both the LOMS has been incorporated and applied to visual subsidence plans as illustrated in Figure 5-2 to Figure 5-9.

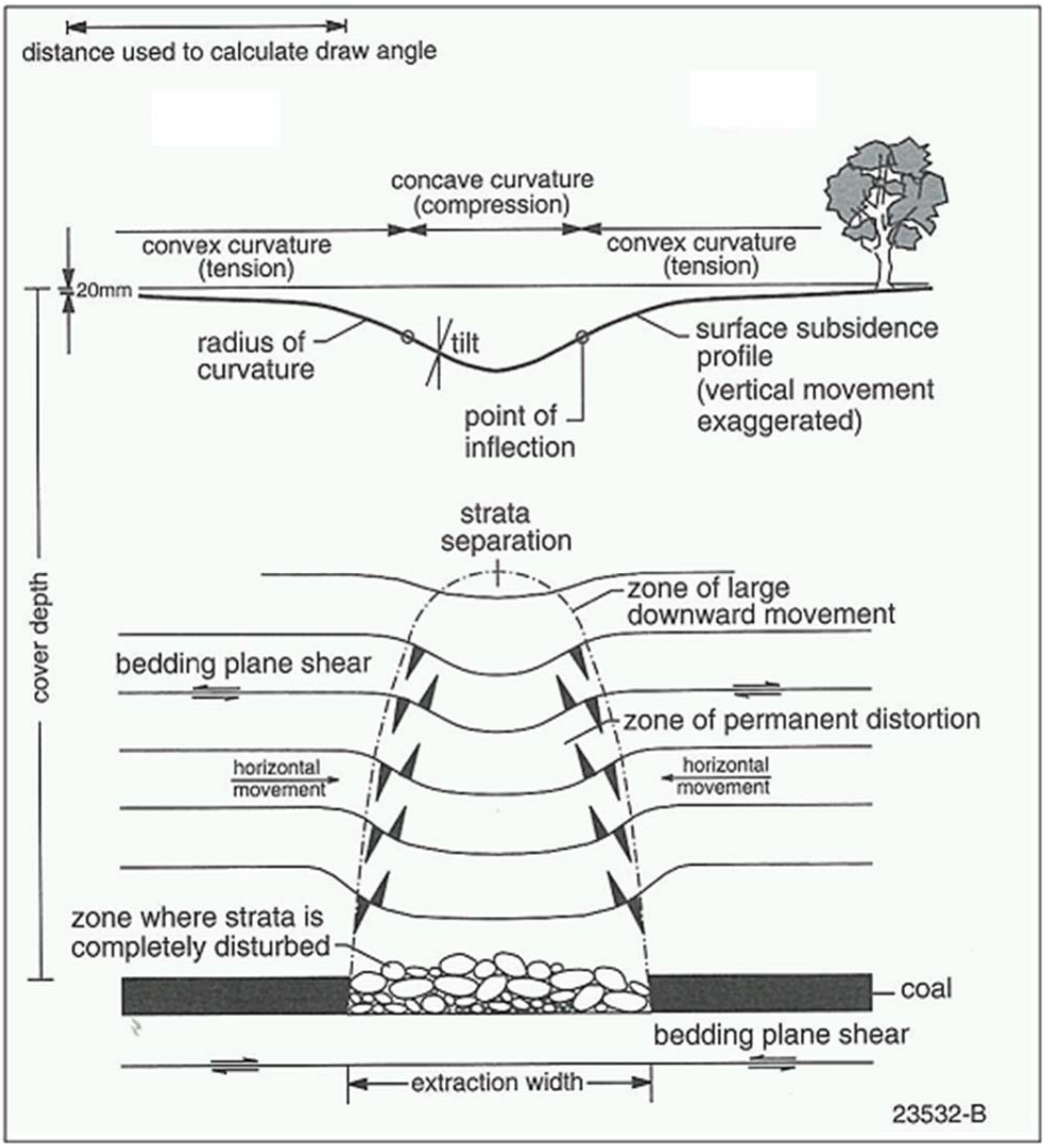

Figure 5-1 : Formation of a Subsidence Trough above an Extraction Panel

(Holla and Barclay, 2000)

5.3 Maximum Vertical Subsidence Predictions

5.3.1 Scenario 1

Maximum vertical subsidence predictions for scenario 1 are shown in Figure 5-2. In areas <u>where reduced extraction to 3.9m</u> is planned, the maximum predicted subsidence in the shallower supercritical panels of around 2.5m is evident in the centre of the basin panel profiles. This equates to around 64% of the extracted thickness.

As the cover depth increases to the east, the maximum subsidence in areas extracted at 3.9m in the deeper subcritical panels to the east reaches around 2.3m in the centre of the panel trough profiles (a little less than the shallower supercritical panels). This equates to around 59% of the extracted thickness in these areas.

For areas where there are no significant constraints on mining extraction and extraction is planned at 9.6m, the maximum predicted subsidence in the shallower supercritical panels of around 6.1m is evident in the centre of the basin panel profiles. This equates to around 64% of the extracted thickness.

As the cover depth increases to the east, the maximum subsidence in areas extracted at 9.6m in the deeper subcritical panels to the east reaches around 5.5m in the centre of the panel trough profiles (a little less than the shallower supercritical panels). This equates to around 57% of the extracted thickness in these areas.

5.3.2 Scenario 2

Predicted maximum vertical subsidence (SMax) contours for extraction based on scenario 2 is shown in Figure 5-2 and for scenario 2 in Figure 5-3.

Vertical subsidence following GMS extraction in scenario 1 (worst case) is predicted to reach a maximum of 6.4m. This is equivalent to 64% of the extraction thickness of 10m in this worst case scenario. These higher maximum values are evident in the shallower supercritical basin shaped longwall panels in the west of the mine layout, with more limited areas through the central portions of the subcritical panels to the east.

The wide / shallow subcritical longwall panels represent the areas where cover depth to workings is less than the critical width. These are characterised by high strains, tilts and curvatures at the longwall panel / chain pillar edges, and by reaching and maintaining the maximum subsidence over a greater proportion of the longwall panel width. This style of subsidence is clearly illustrated in the prediction contours as shown in Figure 5-2.

Beyond the critical width (at around 270m cover depth for 320m wide longwall panels), subcritical subsidence profiles are evident for the “narrow / deep” panels as shown by the eastern panels. As shown in Figure 5-2, these eastern panels are characterised by similar maximum vertical subsidence predictions in comparison with shallower supercritical panels at around 6 to 6.4mm, however this maximum vertical subsidence is spread over a smaller proportion of panel with and length in comparison with the shallower supercritical panels to the west.

5.4 Maximum Strain Predictions

Maximum strain (measured in mm/m or millistrains – divide by 100 to obtain result) following extraction of the GMS for scenario 1 is shown in Figure 5-4 (mitigated case) and for scenario 2 (worst case) in Figure 5-5. Strain is caused by differential horizontal movement.

Areas of maximum indicated tensile strains for scenario 1 are associated with the longwall panel edge / chain pillar interface and are predicted to reach a maximum of around 23 mm/m. These maximum values are located, as would be anticipated, around the edges of the shallower western subcritical panels in areas where the seam is extracted to 9.6m, as illustrated in Figure 5-4. Elsewhere, maximum predicted tensile strains of around 10 - 15mm/m are typical for Scenario 1.

Predicted compressive strain reaches a maximum of around -38 mm/m and varies in its location as shown in Figure 5-4. Higher levels of compressive strain are also predicted in the narrower panel areas (for example the narrow northern fourth sequential panel along to the east).

Elsewhere, maximum compressive strains are typically predicted in the order of -15 to -20mm/m. These maximum compressive strains are developed into the longwall panels away from the panel edges in the shallower supercritical panels, developing towards the centre of the panels in the deeper subcritical panels to the east. It should be emphasised that compressive strain does not equate to positive subsidence or "upsidence" over these areas. There is likely to be an overall lowering of the surface profile throughout as indicated by the predicted Smax in Figure 5-4.

Areas of maximum indicated tensile strains for scenario 2 (worst case) are predicted to reach a maximum of around 25 mm/m as illustrated in Figure 5-5. Elsewhere, maximum tensile strains of around 15mm/m are predicted for Scenario 2.

Typical maximum compression in the panels for scenario 2 is up to -39mm/m and varies in its location, as shown in Figure 5-5. These maximum compressive strains are developed in the narrow northern longwall (fourth sequential panel along to the east). Elsewhere, maximum compressive strains are typically predicted in the order of -15 mm/m.

5.5 Maximum Tilt Predictions

Maximum tilts reflect the difference in subsidence at two points divided by the distance between them. Both tilts and curvature of course reflect the maximum strains predicted at longwall panel edge / chain pillar interfaces. The maximum tilt tends to occur at the point of inflection where the subsidence is roughly equal to one half of Smax. This is illustrated schematically in Figure 4-1.

Maximum predicted tilt (Tm - %) for scenario 1 are shown in Figure 5-6 and reach an absolute maximum of around 6.4%. This maximum tilt is apparent in the first northern and southern longwall panels being mined in the shallow, western supercritical panels, in areas of 9.6m seam extraction.

Elsewhere, typical maximum predicted tilts around the perimeter of longwall panels are predicted at around 3% to 4%. Reduced tilt magnitudes (up to around 1%) are predicted in the deeper extraction areas and at increased depths in the eastern subcritical scenario 1 longwall panels, consistent with critical width concepts.

Maximum predicted tilt (Tm - %) for scenario 2 are shown in Figure 5-7, as for scenario 1, and reach an absolute maximum of around 6.4% the first northern and southern longwall panels being mined in the shallow, western supercritical panels.

Elsewhere, typical maximum predicted tilts around the perimeter of longwall panels are predicted 3% to 4%. Reduced tilt magnitudes (up to around 1 – 1.5%) are predicted in the deeper extraction areas and at increased depths in the eastern subcritical scenario 1 longwall panels, consistent with critical width concepts.

5.6 Maximum Curvature Predictions

Maximum curvature reflects the rate of change of tilt and is therefore calculated from the tilt profile.

Maximum predicted curvature (Km - 1/R hundreds of ppm) for scenario 1 are shown in Figure 5-8 and reach a maximum of around 8 to 12 hundreds of ppm apparent in the first northern and southern longwall panels being mined in the shallow, western supercritical panels, in areas of 9.6m seam extraction.

Elsewhere, typical maximum predicted curvatures around the perimeter of longwall panels for scenario 1 are predicted at around 2 - 4 hundreds of ppm. As with tilts, the highest curvatures are generally predicted in the high strain zones adjacent to chain pillar / longwall panel edges. Figure 5-8 clearly illustrates (as expected) a reduction in both positive (convex) and negative (concave) curvature magnitudes in the deeper subcritical panels.

Maximum predicted curvature (Km - 1/R hundreds of ppm) for scenario 2 are shown in Figure 5-9 and reach a maximum of around 10 to 12 hundreds of ppm in the shallow, western supercritical panels. Elsewhere, typical maximum predicted curvatures around the perimeter of longwall panels are predicted at around 2 – 4 hundreds of ppm.

Figure 5-2 : Predicted Maximum Subsidence (Smax) in metres for RHM Mine Layout Scenario 1

Figure 5-3 : Predicted Maximum Subsidence (Smax) in metres for RHM Mine Layout Scenario 2

Figure 5-4 : Predicted Maximum Strain (Emax) in mm/m for RHM Mine Layout Scenario 1

Figure 5-5 : Predicted Maximum Strain (Emax) in mm/m for RHM Mine Layout Scenario 2

Figure 5-6 : Predicted Maximum Tilt % (Tmax) for RHM Mine Layout Scenario 1

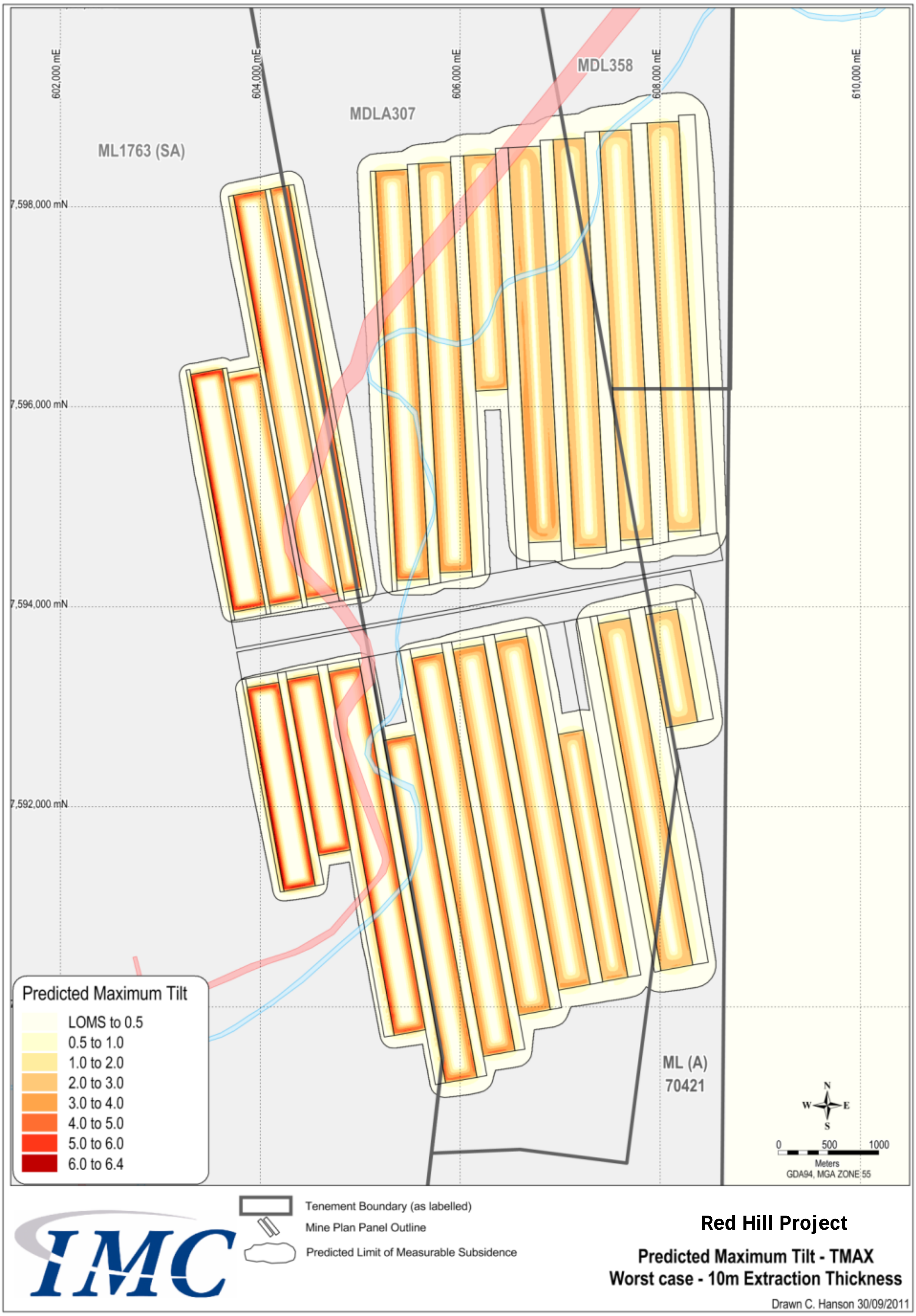

Figure 5-7 : Predicted Maximum Tilt % (Tmax) for RHM Mine Layout Scenario 2

Figure 5-8 : Predicted Maximum Curvature (Kmax) in 1/R hundreds of ppm for RHM Mine Layout Scenario 1

Figure 5-9 : Predicted Maximum Curvature (Kmax) in 1/R hundreds of ppm for RHM Mine Layout Scenario 2

6 ANTICIPATED SURFACE IMPACTS OF SUBSIDENCE

Maximum total vertical subsidence (Smax) for scenario 1 is predicted at 6.1m (or 64% of the maximum 9.6m recovered thickness. Maximum tensile strains to 23 mm/m are anticipated at the chain pillar edges with compressive strains towards the central parts of longwall panels developed to a maximum of around -38mm/m.

Maximum total vertical subsidence (Smax) for scenario 2 is predicted at 6.4m (or 64% of 10m extraction thickness). Maximum tensile strains to 25 mm/m are anticipated at the chain pillar edges with compressive strains towards the central parts of longwall panels developed to an absolute maximum of around -39mm/m.

These levels of predicted Smax, strains and tilts will of course have impacts on the overlying landscape.

The following summary assesses broadly the impacts on the surface landscape based on modelled seam subsidence prediction for scenarios 1 and 2.

6.1 Surface Subsidence Impacts for Scenario 1 and 2 Seam Extraction

The worst case manifestation of subsidence on surface land deformation is anticipated to be similar for scenario 1 (maximum extraction of 9.6m) as it is for scenario 2 (10m extraction). Based on subsidence prediction modelling, the zone of rehabilitation over surface tension cracking following scenario 1 and 2 seam undermining is anticipated over the chain pillars and to extend some 35m either side into the panels. Rehabilitation of the resultant tensile cracks will be required and cracks in the order of a maximum width of 0.5m and a maximum depth of 10m are anticipated in the worst case instances. Surface crack rehabilitation is likely to require remedial earthworks and the use of sealants.

Compressive strains are predicted over the central parts of the longwall panels. The surface manifestation of compression / humping is also considered likely to require minor remedial earthworks.

Maximum tilts developed to around 6.4% in limited areas will also require careful management. The impacts on surface drainage and any other sensitive surface landscape features will require consideration and management through subsidence management strategies.

This is largely based on observation and experience at nearby Goonyella Middle Seam longwall operations. In most cases subsidence cracking at the surface due to tensile strain is anticipated to be less severe than this. Rehabilitation recommendations are beyond the scope of IMC's work and would require assessment by environmental scientists.

7 REFERENCES

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