ROCK ENGINEERING RISK ASSESSMENT
OF DELMAS COAL’S
WESTERN AND SOUTHERN EXTENSION

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EXECUTIVE SUMMARY

The primary objective of this report is to assess the stability of the existing and proposed underground workings directly beneath the river/streams and possible effects on the water table in the mining area as part of Delmas Coal’s application for a water use licence from the Department of Water Affairs and Forestry (DWAF).

The overall interburden between the No. 5 Seam and the No.4 Seam consists of interbedded sandstones/siltstones, No. 4A Seam, interbedded siltstone/sandstone with gritty base, No. 4 Upper Seam underlain by the carbonaceous shale/mudstone parting between the No. 4 Upper and No. 4 Lower Seam. This interburden thickness varies across the mining area but is on average 25m thick.

The overburden consists of a ±30m thick dolerite sill intrusion in places within the No. 4 Seam overburden. The total depth of the sill below ground and up to the sill floor level is ±50m. Where this dolerite sill exists within the No. 4 Seam overburden, it is considered a positive factor in protecting the surface features above the underground mining areas.

Geotechnical Point load strength tests were conducted by Saxum Mining in 2013 on the overburden strata, from approximately 20m above the No. 4 Lower Seam roof horizon. The test results can be grouped into low values of up to a maximum of \(20\text{MPa}\) for the weak formations, moderate strength values ranging from \(20\text{MPa}\) to \(50\text{MPa}\) for the moderate formations and the more competent formations with higher strength values ranging from \(50\text{MPa}\) to \(80\text{MPa}\).

The areas undermining the rivers/streams were subdivided into four (4) areas namely: Area A, Area B, Area C and Area D and stability analysis carried out where pillar factor of safety (FOS), probability of survival and width to height (w:h) ratios were used as indicators of pillar stability. The Coaltech (coal seam specific power formula) was used to estimate the stability of the mined pillars. The No. 2 Seam pillars were mined by conventional methods within the Southern Extension area (Area D), but have not been developed in the other areas.

Based on the general pillar design philosophy at Delmas Coal’s No. 4 Seam workings and analysis of the mined areas in the No. 4 Seam, the risk ratings for the areas undermining the water courses was found to be low. Historical mining of the No. 2 Seam results in one medium risk area, but the thick dolerite sill on surface serves to mitigate this risk.

The general pillar design philosophy for Delmas Coal’s No. 4 Seam workings is to maintain safety factors of 2.0, 1.8 and 1.6 for primary, secondary and tertiary development areas respectively and to design pillar centres based on these safety factors. The designed width to height (w:h) ratios range between 2.2 and 2.6.

The D/2.7 rule is also applied at Delmas Coal wherever the undermining of structures like power lines, roads and rivers is carried out. In general pillar design under such structures is such that their FOS is at least 2 for a distance of D/2.7 all round.
INTRODUCTION

Delmas Coal (Pty) Ltd requested Saxum Mining (Saxum) to conduct a rock engineering stability risk assessment of its underground workings undermining the Wilge River and Steenkoolspruit in the Western and Southern Extension areas of the reserve.

The primary objective of this report is to determine the stability of Delmas Coal’s No. 2 and No. 4 Seam underground workings directly beneath the river/streams and possible effects on the water table in the mining area as part of Delmas Coal’s application for a water use licence from the Department of Water Affairs and Forestry (DWAF).

GOVERNING LEGISLATION

The Mine Health and Safety Act (MHSA) Regulation 17(7) restricts mining operations within a horizontal distance of 100m (one hundred metres) from reserve land, buildings, roads, railways, dams, waste dumps, or any other structure whatsoever including such structures beyond the mining boundaries, or any surface which may be necessary to protect in order to prevent any significant risk, unless a lesser distance has been determined by risk assessment and all restrictions and conditions determined in terms of the risk assessment are complied with.

Sections 11(1) and 11(2) of the same Act require the employer to assess and respond to risk and to determine all measures, including changing the organisation of work and the design of safe systems of work necessary to:

- Eliminate any recorded risk;
- Control the risk at source;
- Minimize the risk; and
- In so far as the risk remains, institute a programme to monitor the risk to which employees may be exposed.

Exemptions by the DMR are issued in accordance with the Minerals Act (Act 50 of 1991) and Schedule 4 of the Mine Health and Safety Act, 1996 (Act 29 of 1996), specifically by Regulations 5.3.1 and 5.3.2. Exemption issued by the DMR stipulates that written consent must be obtained from the DWAF in terms of the National Water Act and Government Notice 704 before such mining can commence (Handley, R.J., 2005).

The Mining and Related Activity Regulations (Government Notice 704), states in Regulation 4(b), inter alia, that:

- no person in control of a mine or activity may, except in relation to a matter contemplated in regulation 10, carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, whichever is the greatest.

Should a mine wish to undermine a watercourse, exemption from the requirements of Regulation 4(b) must be applied for. Exemption from the regulation grants the applicant a relaxation (in terms of distance) from the restriction, but not permission to mine anywhere within the...
restricted area (Schwab, 2004). An exemption application is authorised at a regional level by the Director of Waste Discharge and Disposal. The requirements are at the discretion of the regional office.

Section 21(c) and (l) of the National Water Act (Act 36 of 1998) addresses impeding or diverting the flow of water in a watercourse and altering the bed, banks, course or characteristics of a watercourse. If it is found that the undermining of a watercourse would have the above consequences, then the undermining must be authorised by a Water Use Licence or other authorisation granted in terms of the National Water Act. An exemption application is subservient to a Water Use Licence.

A further stipulation by the DWAF is that approval for the undermining project is always subject to the provision that the mine concerned will be prepared to assume full responsibility for the undermining of the watercourse and to take the necessary steps to rectify the situation should problems arise as a result of the mining operation.

It is against this background that a rock engineering risk assessment is being conducted on the workings. The outcome of this risk assessment will be used to apply for the Delmas Coal Southern Extension and Western Extension mining areas water use licence.

3 GEOLOGY AND MINING BACKGROUND

3.1 Locality

Delmas Coal is situated along the R50 regional road, approximately 20km from the town of Delmas and 10km north-east of Devon in Mpumalanga, as shown in Figure 3–1. The mine forms part of the old Delmas Colliery operation under Billiton’s Ingwe Coal Corporation, sold to Kuyasa Mining and hence known as Delmas Coal.

As the original coal-reserves available to Delmas Coal became depleted, additional reserves were bought from BECSA to the west and south. These areas, referred to as the Western Extension and Southern Extension commenced mining in 2012 and 2013 respectively. To date, Section 42 is mining panel D16 B&P NE3, in the southern portion of the northern block within the Western Extension area. Section 43 is currently mining panel C17 B&P SW1 South of the Western Extension.

Mining the No. 4 Seam in the Southern Extension commenced in mid-2013 where the Southern Extension panel (South Main Development) is currently mining in Section 41 and Section 44 is mining to the west of the Southern Extension.
Figure 3–1 Delmas Coal Locality Map

Figure 3–2 shows the underground workings in question outlined as blocks and mining sections. The blocks/areas; marked A, B, C and D delineate the four (4) areas of focus in this report. Three (3) of these areas, namely A, B and C are in the Western Extension Area, and one area, namely Area D is located in the Southern Extension area.

Some Western Extension production sections are undermining the Wilge River and its tributaries, which are crossing the mined and planned future mining panels in the southern portion of the northern block within the Western Extension in Area B. Parts of the Southern Extension are undermining the Steenkoolspruit and its tributaries which cross the Southern Extension reserves in Area D and are draining from the Western Extension in Area C.
Figure 3–2  Delmas Coal Mining Plan
3.2 Local Geology

The coal seams were deposited in a glacial basin sculpted by a continental ice sheet in the Highveld Witbank Coal fields. The floors of the coal seams are relatively flat, dipping at 1° towards the south and east, except in areas adjacent to palaeo hills or ridges. The coal is thickest within the glacial basin, which thins out towards the palaeo hills and ridges.

A typical stratigraphic sequence within the Delmas Coal resource is shown in Figure 3–4. The main economic coal seams are the No. 4 and No. 2 Seams. The No. 4 Seam occurs higher up in the succession. The two seams are separated by a series of sandstones, shales and mudstones. Since commencement of the mine, mining activity has been initially concentrated in the No.2 Seam with the latter mining activity concentrated on extracting the No.4 Lower Coal Seam.

The No. 4 Seam Coal zone consists of the No. 4 Upper and No. 4 Lower Seams separated by a shale layer. The No. 4 Upper Seam is shaley and of poor quality with a high sulphur content, it is discontinuous and therefore not considered for economic extraction.
A selected horizon of the lower section of No.4 Lower Seam is mined. The seam thicknesses range from 2.2m to 2.8m with an average mining thickness of 2.5m. The seam depth ranges from 50m to 140m deep, averaging a depth of approximately 90m.

<table>
<thead>
<tr>
<th>Description</th>
<th>Thickness</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weathered zone: loose material, clay, shale, sandstone composition</td>
<td>±8.39</td>
<td></td>
</tr>
<tr>
<td>Sandstone: massive sandstone interbedded with laminated sandstone</td>
<td>±11m</td>
<td></td>
</tr>
<tr>
<td>Dolerite zone: The sill splits into 2 to 3 layers</td>
<td>±38.12m</td>
<td></td>
</tr>
<tr>
<td>Laminated Sandstone</td>
<td>±20.14</td>
<td></td>
</tr>
<tr>
<td>Coal No.5 Seam</td>
<td>±6.67</td>
<td></td>
</tr>
<tr>
<td>Inter-bedded Sandstone/Siltstone</td>
<td>±10.03m</td>
<td></td>
</tr>
<tr>
<td>Coal No. 4 A Seam</td>
<td>±1.22m</td>
<td></td>
</tr>
<tr>
<td>Inter-bedded Sandstone/Siltstone, with gritty base</td>
<td>±9.51m</td>
<td></td>
</tr>
<tr>
<td>Coal No. 4 Upper Seam</td>
<td>±1.560m</td>
<td></td>
</tr>
<tr>
<td>Shale, Carbonaceous</td>
<td>±1.07m</td>
<td></td>
</tr>
<tr>
<td>Coal No. 4 Lower Seam</td>
<td>2.4-2.7m</td>
<td></td>
</tr>
<tr>
<td>Interlaminated /interbedded sandstone/siltstone/shales</td>
<td>±21.8m</td>
<td></td>
</tr>
<tr>
<td>Coal No. 2 Seam</td>
<td>±3.71m</td>
<td></td>
</tr>
<tr>
<td>Basement Rocks (dolerite, tillite, sandstones)</td>
<td>±11.35m</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3–4  Delmas General Stratigraphy
3.2.1 Structures

The geological structures intersecting the No. 4 Seam have been identified from drill hole data, airborne magnetometer and the mining of the No. 2 Seam. The main structures recognized are:

- **B4 Dolerite Sill**: The B4 dolerite sill occurs as a flat dipping transgressive sill-like body that reaches a maximum thickness of approximately 30m. The sill generally occurs above the No. 4 Seam horizon, except in the eastern and north-western portions of the area where it cuts through the coal horizons and defines the resource boundary for the No.4 Seam. Where present, the dolerite sill is seen as a positive factor in protecting the water table above areas where pillars could be prone to partial failure. This dolerite sill varies in thickness and relative position in the overburden. Although not currently reflected in the geological model, the sill is not always a single stratigraphic member, but tends to split up into two or even three layers in places.

- **Dolerite Dykes**: Mining of the No. 2 Seam has exposed the presence of two principal dolerite dykes that also intersect the No. 4 Seam. These dykes vary in thickness from 1m to 2m and are normally vertical or steeply dipping, with little or no displacement associated with them. A number of minor dykes were also intersected in the No. 2 Seam workings and many of these are likely to also affect the No. 4 Seam.

- **Fault**: One major fault zone has been identified during the mining of the No. 2 Seam. The fault is relatively minor, with displacement in the order of 0.5m to 3m. This fault zone is also anticipated to affect the No. 4 Seam.

3.3 Delmas Coal Underground Workings Beneath The Rivers/Streams

The Wilge River flows in a north-eastern direction from Delmas towards Witbank. The Wilge River and its tributaries flow from the north-west in the Delmas Coal mining area and over the Western Extensions mining area. The Steenkoolspruit and its tributaries drain roughly from south-west of the Delmas Coal mining area (Southern Extension), flow northwards and then joins with the Wilge River north-east of the Delmas Coal North Shaft.

Much of the Western Extension and Southern Extension areas underlie the Wilge River and the Steenkoolspruit and their flood plains /wetlands as shown in Figure 3–2. The spatial extent of the Delmas Coal mining area and topography indicating both the Wilge River and Steenkoolspruit is shown in Figure 3–5. As can be seen, the topography gently slopes SSW to NNE.
3.4 Geotechnical Background

The report entitled *Geotechnical Report for Delmas Coal’s New Western and Southern Extension*, compiled by F. Chiramba and J.J. van Vuuren, dated January 2013, contains the results of the geotechnical logging and point load test results conducted on the rock material in Delmas Coal’s Western and Southern Extension mining areas. Figure 3–6 is extracted from this report, detailing the various relevant parameters of the rock material.

The overall interburden between the No. 5 Seam and the No.4 Seam as shown in the generalised stratigraphic column in Figure 3–4, consists of interbedded sandstones /siltstones, No. 4A Seam, interbedded siltstone/sandstone with gritty base, No.4 Upper Seam underlain by the carbonaceous shale /mudstone parting between No. 4 Upper and No. 4 Lower Seams. This interburden is approximately 25m, but varies across the mining area.

The immediate roof of the No. 4 Seam Lower is made up of fractured mudstone/siltstone overlain by the No. 4 Upper Seam. The point load tests were conducted from approximately 20m above the No. 4 Lower Seam roof strata overburden. The immediate No. 4 Seam roof values are mostly excluded from point load testing because it was not possible to sample the relatively weak horizon.

The graph below indicates that the point load strength for the roof rock can be grouped into low values of up to a maximum of 20MPa for the weak formations, the moderate strength formations with recorded values of between 20MPa and 50MPa and the more competent formations with higher values of between 50MPa and 80MPa.
The overburden consists of a ±30m thick dolerite sill intrusion in places within the No. 4 Seam overburden. The total depth of the sill below ground and up to the sill floor level is ±50m. Where this dolerite sill exists within the No. 4 Seam overburden, it is considered a positive factor in protecting the water table above the mining areas.

Considering the thick dolerite sill intrusion and the rock material properties in Figure 3–6, the intact overburden material is considered to be fairly competent.

![Figure 3–6 Point Load Strength Assessment Results](image)

4 METHODOLOGY USED FOR STABILITY ANALYSIS

All the mine design and panel layouts at Delmas have taken the below mentioned principle rock engineering guidelines and factors into consideration. In terms of defining the pillar risk assessment, these are the primary factors in determining the specific risk for a particular area.

4.1 Pillar Stability

According to Bakker, 1992, the design of pillars beneath surface structures and features should be conducted according to the minimum Safety Factors included in Table 4–1 below.
<table>
<thead>
<tr>
<th>Surface Structure</th>
<th>Safety Factor (Minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings where people sleep or congregate</td>
<td>2.5</td>
</tr>
<tr>
<td>Dams Pans and reservoirs</td>
<td>2.0</td>
</tr>
<tr>
<td>Rivers, Streams, water courses</td>
<td>2.0 (Zone of influence (D/2.7) to be calculated from 50yr flood level line)</td>
</tr>
<tr>
<td>Water borehole</td>
<td>Solid pillar of not less than 5m diameter to be left under borehole</td>
</tr>
</tbody>
</table>

Table 4–1  Minimum Safety Factors Required per Structure/Feature Type

4.2 Pillar Load

Pillar load is determined through applying the cover load or Tributary Area Theory (TAT), where each individual pillar is assumed to carry the weight of the overburden immediately above it. This assumption applies where the pillars are of uniform size and the panel width is larger than the depth to the seam. These conditions are fulfilled by the majority of bord and pillar panels in the No. 4 Seam workings of Delmas Colliery.

The pillar load \( q \) for square pillars can be calculated from the formula;

\[
q = \gamma H C^2 w^{-2}
\]

- Where \( \gamma \) is the average specific weight of the overburden rock =0.02488 MPa/m.
- \( H \) is the Depth to the seam floor in metres.
- \( C \) is the coal pillar centre distances in metres.
- \( w \) is the coal pillar width in metres.

4.3 Pillar Strength

A revision of the pillar safety factor calculation for the Witbank/Highveld No’s. 1, 2 and 4 Seams, where Delmas Coal is located, was conducted by Salamon et al (2006). According to this revision, pillar strength \( \sigma \) is given by the following power formula:

\[
\sigma = Kw^\alpha h^\beta
\]

- Where \( w \) and \( h \) represent the pillar width and mining height respectively, in metres.
- \( K, \alpha \) and \( \beta \) were determined by statistical analysis.
- For the Witbank/Highveld coalfield:
  \( K=6.187 \) MPa,
  \( \alpha=0.6721 \) and
  \( \beta=0.8682 \).

4.4 Pillar Width to Height Ratio

The strength of a coal pillar was said to depend on the material strength as well as the pillar’s volume and shape. The shape effect was said to be a result of constraints imposed on the pillar through friction or cohesion by the roof and floor.
Based on the shape of the pillar, the width of the pillar in relation to its height, i.e. the width to height ratio \((w:h)\), is one of the most critical parameters in determining the overall pillar stability. Tall, slender pillars cannot contain discontinuities as effectively and tend to be soft under loading. For the same height, the wider the pillar, the higher the value of the confining stress and thus the strength and stiffness of the pillar increases.

According to Rusnak & Mark (2000), pillar failure can be divided into three categories depending on the w:h ratio:

- **Slender pillars \((w:h<3)\)** which are subject to sudden collapse in a violent uncontrolled fashion with little residual strength in the pillar. They are prone to massive collapse when used over a large area in the absence of barrier pillars.

- **Intermediate pillars \((3<w:h<10)\)** in which pillar failure is slow and controlled and can occur over an extended period of time. They have a high residual strength.

- **Squat pillars \((w:h>10)\)**. These pillars are virtually indestructible due to their strain hardening characteristics.

### 4.5 Pillar Factor of Safety (FOS)

MacCourt et al. (1986) found that the calculation of the safety factor for a pillar yields a good indication of the stability of the pillar. However, anomalies occur especially in shallow areas with weak roof strata.

The failed pillar database for the Witbank-Highveld Coalfield suggests that a well-designed pillar with a safety factor of at least 1.6 and a width-to-height ratio greater than 2 should not fail, be it under a watercourse or not, as the database covers collapses in all mining areas (Handley, 2005).

The pillar safety factor is defined as:

\[
SF = \frac{\text{Pillar strength}}{\text{Pillar load}}
\]

Therefore the pillar factor of safety (FOS) can be calculated using the formula: 

\[
FOS = \frac{\sigma}{q}
\]

The factor of safety (FOS) represents the probability of a panel of pillars failing: the higher the FOS, the lower the probability of failure.

Salamon (1967) reasoned that the majority of mining engineers arrived at an acceptable compromise between safety and economic mining, with the optimum safety factor lying in the range where 50 percent of the stable cases are most densely concentrated. For the cases studied, this occurs between safety factors of 1.3 to 1.9 with the mean being 1.6. It is this mean value of 1.6 that was recommended for the design of production pillars in South African bord...
and pillar workings. Table 4–2 shows the relationship between probability of failure and factor of safety (FOS).

<table>
<thead>
<tr>
<th>FOS</th>
<th>0.5</th>
<th>1.0</th>
<th>1.25</th>
<th>1.5</th>
<th>1.6</th>
<th>1.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of Stability</td>
<td>0%</td>
<td>50%</td>
<td>92%</td>
<td>99.5%</td>
<td>99.85%</td>
<td>99.99%</td>
</tr>
<tr>
<td>Pillar failures per Million</td>
<td>1 000 000</td>
<td>500 000</td>
<td>79 681</td>
<td>5 300</td>
<td>1 532</td>
<td>106</td>
</tr>
</tbody>
</table>

Table 4–2  Probability of Failure

For the Witbank and Highveld coalfields, pillars where the in-situ coal strength is ±7.2MPa, with an observed minimum pillar safety factor of 0.5, have a 100 percent probability of failure (Vander Merwe, 1998).

When consequences of failure are serious, a reduced probability of failure needs to be adopted in order to achieve the acceptable level of risk.

As part of this risk assessment, the more critical areas in the No. 4 Seam were identified and the No. 2 Seam stability beneath these workings assessed for stability where it has been mined.

4.6 Multi-seam Consideration

The generally accepted guideline for multiple seam mining states that when the vertical distance between seams is more than 0.75 to 1 x centre distance, the alternating stress influence of bord and pillars becomes less of an influence (Salamon & Oravecz, 1976 and Bradbury & Lear, 1984, cited by Hill, R.W. 2006).

The following basic guidelines were drafted for multi-seam mining:

i. If the parting > 1.5 x pillar centre distance, then no superimposition of barriers is necessary. Pillar Safety Factor = 1.6.

ii. If the parting >0.75 x centre distance, but <1.5 C, then only the barrier pillars are superimposed Pillar Safety Factor = 1.6.

iii. If the parting > 2 x bord width, then the pillars must be superimposed and designed to a Safety Factor of 1.7.

iv. If the parting < 2 x bord width then panel pillars must be superimposed. The Safety Factor of the pillar must be 1.8 with a combined Safety Factor of 1.4.

Bradbury and Lear (1984) indicated in their work that this limiting distance (0.75C or 75% of the centre distance), at which the stresses above or below bord and pillar workings return to primitive stress values, decreases with depth and also with increased pillar size.
It is reported by Chekan & Matetic (1988) in the case of rectangular pillars, that the interactive distance is controlled by the least width of the pillar. In general, rectangular pillars transfer less load over a shorter distance than square pillars of equal load carrying capacity.

Ehgartner (1982, cited by Hill, R.W. 2006) evaluated stress due to pillar loading using photo-elastic models and found that the distance the stress was transferred depended on the nature of the rock above and below the pillar. In particular, it was found that low modulus, stratified materials (Shales) tended to increase the distance through which stress is transferred, while stiff isotropic materials (Sandstone) had the opposite effect.

Therefore, the points stated above can be summarized into guidelines for determining risk, i.e. regarding pillar and panel stability.

- The superimposing of the No. 4 Seam pillars with the No. 2 Seam pillars, if the total parting width is less than 75% of the size of the pillar centres in the No. 2 Seam, determines the initial risk of pillar stability in both the No.4 and No. 2 Seams.
- If the overall mining depth increases, the risk of pillars not superimposed for a parting in the region of 75% of the centre distance, can be reduced.
- For rectangular pillars this risk can be further reduced.
- In the presence of a significant and competent sandstone layer within the parting, the risk is further reduced.

### 4.7 Risk Matrix

Two primary potentially significant risks resulting from undermining of the watercourses are envisaged and these are:

- Pillar failure and associated surface subsidence and
- Intersection failure and associated sinkhole formation.

Both risks can lead to possible alteration of the water courses on surface and possible disruption of the water table with possible negative impact to the ecosystems thereby negatively impacting on water flow, both upstream and downstream.

In order to simplify the risk assessment process, the area of interest was subdivided into four different blocks namely: Area A, Area B, Area C and Area D. The simplified risk matrix shown in Table 4-3 is used to quantify the risk for each individual block. The subsequent section and subparagraphs briefly state the risks per block and provides a risk rating for the specific areas.
### Table 4-3 Risk Matrix

<table>
<thead>
<tr>
<th>RISK RATING</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>&gt;24</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>12 to 24</td>
</tr>
<tr>
<td>LOW</td>
<td>&lt;12</td>
</tr>
</tbody>
</table>

5 PILLAR STABILITY ASSESSMENT

The assessment of the Western and Southern Extension areas for stability undermining surface water was divided into four different areas:

- Area A: the northern portion of northern block within the Western Extension area,
- Area B: the southern portion of northern block within the Western Extension area,
- Area C: the southern block within the Western Extension area and
- Area D: the Southern Extension area

The areas were analysed for the stability of the workings undermining the surface water features, Wilge River and Steenkoolspuit. The stability analysis involved the computation of planned mining pillar safety factor for stable extraction of the No.4 Seam, using the Delmas Coal geological database grid files obtained from Gemecs (Pty) Ltd (Gemecs).
The recommended safety factor for design of stable production pillars in South Africa is 1.6 for tertiary development panels while the recommended safety factors for main development and secondary development panels are 2.0 and 1.8 respectively.

In order to promote the stability of the No. 4 Seam workings, the following summary of design parameters for Delmas (Table 5–1) as outlined in the COP (Code of Practice to combat roof fall accidents in underground coal mines) will be adhered to.

<table>
<thead>
<tr>
<th>DELMAS COAL GROUND CONTROL DISTRICT A, B and C PANEL DESIGN PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal and Shale roof</td>
</tr>
<tr>
<td>Minimum Safety Factor:</td>
</tr>
<tr>
<td>- Main (Primary) Development.</td>
</tr>
<tr>
<td>- Secondary Development.</td>
</tr>
<tr>
<td>- Tertiary Panels.</td>
</tr>
<tr>
<td>Minimum Width/Height Ratio of Pillars:</td>
</tr>
<tr>
<td>- Main (Primary) Development.</td>
</tr>
<tr>
<td>- Secondary Development.</td>
</tr>
<tr>
<td>- Panels.</td>
</tr>
</tbody>
</table>

| General:                                                      |
| Maximum average bord width.                                   | 6.8m                           |
| Pillar superposition required.                                | Where #2 to #4 Seam parting < 0.75C. Main development roadways will be assessed by rock engineer for applicability of superimposing of pillars. |
| Maximum face advance beyond last row of permanent support.    | 12m                            |
| Support requirements                                          | Recommended Systematic support and supplementary support on discontinuities |

Table 5–1 Delmas Coal Panel Design Parameters

In cases where seam dip is less than 20 degrees, it is common to define the restricted mining area with the formula: “within a horizontal distance of D/2.7”. In this formula, D is the vertical depth to the floor of the workings beneath the natural surface of the ground, and the horizontal distance is to be measured from the sides of the object to be protected (Bakker, 1992).

It is based on the assumption that the angle of draw; from the point in the underground workings at which failure is initiated, is equal to 20° off the vertical. Therefore that the horizontal distance, on surface, which may be affected by such failure in the form of subsidence is equal to the Depth (D) / Tan 90°minus angle of Draw- (i.e 90°-20°=70°) and therefore is equal to D/Tan70° or D/2.7.

The D/2.7 rule is applied at Delmas Coal wherever the undermining of structures, including perennial watercourses is carried out. In general, pillar design under such structures is such that their FOS is at least 2 for a distance of D/2.7 all round.

The depth to the No. 4 Seam floor as shown in Figure 5–1 reveals a south-west to north-east decrease in depth trend. This follows the general river flow with the shallowest depth to the
No. 4 Seam found in the area underneath the river/water features. This is due to the river valley that erodes the surface topography. The estimated average depth is between 90m and 100m.

The variation in the No. 4 Seam thickness is shown in Figure 5–2. The general thickness in the No. 4 Seam ranges from 2m to 3m. In the northern portion within the Western Extension (Area A) and the southern portion of the northern block within the Western Extension (Area B), the No. 4 Seam is relatively thicker than in the southern block within the Western Extension (Area C) and the Southern Extension (Area D).

The above information was used to compute pillar centres which will result in a safety factor of at least 1.8 in the No. 4 Seam using the seam specific pillar safety factor calculation method. The results of this calculation are shown in Figure 5–3.

The three pillar centre ranges recommended in the mining areas are:

- 14m-16m pillar centres,
- 16m-18m pillar centres and
- the larger 18m-20m pillar centres, distributed as shown in Figure 5–3.

In the Western Extension, the smallest pillars plot around Area B, then increase northwards in Area A and southwards in Area B. The pillar centres also increase southwards in the Southern...
However, the largest pillar centres in Area D (Southern Extension) range from 16m to 18m.

Figure 5–2 Contour Plan Showing No. 4 Seam Thickness
5.1 Area A: Northern Portion Of The Northern Block Within The Western Extension

The selected boreholes for Area A are shown in Table 5–2 and their locations shown in Figure 5–4. Mining activity in this area took place in panel D16 B&P NW2, where the Old Section 41 was mined in an east to west direction, mining the No. 4 Lower Seam. The significant geological structures in this area are three (3) dykes of which two are striking NW-SE, north and south of the panel while the third dyke is striking NE-SW across the area.

<table>
<thead>
<tr>
<th>BH. ID</th>
<th>GPS ELEVATION</th>
<th>Upper Dolerite Thickness (m)</th>
<th>Lower Dolerite Thickness (m)</th>
<th>EOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB36</td>
<td>1607.3</td>
<td>24.84</td>
<td>N/A</td>
<td>140.10</td>
</tr>
<tr>
<td>EN30104</td>
<td>1595.1</td>
<td>27.13</td>
<td>N/A</td>
<td>139.50</td>
</tr>
<tr>
<td>EN30105</td>
<td>1629.4</td>
<td>07.95</td>
<td>16.80</td>
<td>162.00</td>
</tr>
<tr>
<td>EN30162</td>
<td>1627.9</td>
<td>08.36</td>
<td>18.82</td>
<td>112.14</td>
</tr>
<tr>
<td>EN301110</td>
<td>1587.9</td>
<td>18.80</td>
<td>12.65</td>
<td>173.00</td>
</tr>
<tr>
<td>EN301111</td>
<td>1641.5</td>
<td>26.60</td>
<td>21.98</td>
<td>121.10</td>
</tr>
</tbody>
</table>

Table 5–2 Area A: Representative Boreholes
Information obtained from the selected boreholes shows that there is a dolerite sill intrusion in the overburden above the No. 5 Seam. The sill splits into two (2) layers, namely Upper Dolerite sill and Lower Dolerite sill in this report. The Upper Sill, intruding at depths from 0m-50m from the surface, has thickness values ranging between 8m and 27m, with an average thickness of approximately 18m.

The depth to the No. 4 Seam floor in Area A ranges from 70m to 140m, and increases towards the northern boundary of the Western Extension. The No. 2 Seam is not developed. In order to achieve a pillar FOS of at least 1.8, the recommended pillar centres in the No.4 seam in this area are between 15 and 20m. The mining parameters for this area are summarised in Table 5–3.

<table>
<thead>
<tr>
<th>AREA A</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining Depth (m)</td>
<td>70-140</td>
</tr>
<tr>
<td>Dolerite sill (m)</td>
<td>8 to 27</td>
</tr>
<tr>
<td>Mining Height (m)</td>
<td>2.7</td>
</tr>
<tr>
<td>Pillar Centre (m)</td>
<td>15-20</td>
</tr>
<tr>
<td>Pillar Width (m)</td>
<td>8.2-13.2</td>
</tr>
<tr>
<td>Bord Width</td>
<td>6.8</td>
</tr>
<tr>
<td>w:h</td>
<td>3.0-4.8</td>
</tr>
<tr>
<td>Minimum Factor of Safety</td>
<td>1.8</td>
</tr>
<tr>
<td>Probability of Survival</td>
<td>0.999</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5–3  Area A: Pillar Design, Mining Parameters and Risk Rating

The minimum design FOS of 1.8 and the significantly thick dolerite sill above the workings combine to lower the risk rating in Area A.
5.2 Area B: The Southern Portion of The Northern Block Within The Western Extension.

In Area B, Section 42 is mining in the western panel, namely panel C17 B&P NE3, in a north-western direction. The geotechnical hazard plan in Figure 5–5 shows the Wilge River in relation to the old mining panel C17 B&P North, the planned panels, boreholes and the geological information in relation to the southern portion of the northern block within the Western Extension for Area B.
The No.4 Seam workings, where the river crosses the panel **C17 B&P North**, experienced a zone of increased jointing across the panel and undulating seam floor. The joints in the panel strike almost parallel to the river. Another geological structure observed in this area is a dyke striking NW-SE to Area B.

Geological boreholes selected in this area revealed a dolerite sill intruding the No. 5 Seam overburden. The depth to roof of the sill ranges from 18m to 33m. However, in borehole **EB40** (north of river) and **EN301109** (south of the river) the sill intrudes at relatively shallow depths of 4.74m and 9.41m respectively. The average thickness of the sill is approximately 27m with the
values ranging from 25.4m to 29.5m. The relevant boreholes with dolerite thickness are shown in Table 5–4.

<table>
<thead>
<tr>
<th>BH. ID</th>
<th>GPS ELEVATION</th>
<th>Upper Dolerite Thickness (m)</th>
<th>Lower Dolerite Thickness (m)</th>
<th>EOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB18</td>
<td>1586.0</td>
<td>25.92</td>
<td>N/A</td>
<td>117.04</td>
</tr>
<tr>
<td>EB19</td>
<td>1601.9</td>
<td>29.54</td>
<td>N/A</td>
<td>134.11</td>
</tr>
<tr>
<td>EB40</td>
<td>1580.0</td>
<td>28.87</td>
<td>N/A</td>
<td>110.20</td>
</tr>
<tr>
<td>EN301104</td>
<td>1599.7</td>
<td>25.46</td>
<td>N/A</td>
<td>136.16</td>
</tr>
<tr>
<td>EN301108</td>
<td>1608.0</td>
<td>28.28</td>
<td>N/A</td>
<td>112.14</td>
</tr>
<tr>
<td>EN301109</td>
<td>1583.0</td>
<td>28.23</td>
<td>N/A</td>
<td>17.68</td>
</tr>
</tbody>
</table>

Table 5–4  Area B: Representative Boreholes

The mining parameters for Area B are summarised in Table 5–5. This area is the middle of the Western Extension. The depth to the No. 4 Seam is shallowest in this area, relative to the rest of the Western Extension mining area. The average depth to No. 4 Seam floor is approximately 80m, while the pillar centres for a minimum FOS of 1.8, range from 15 to 18m.

<table>
<thead>
<tr>
<th>AREA B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining Depth (m)</td>
<td>60-100</td>
</tr>
<tr>
<td>Mining Height (m)</td>
<td>2.7</td>
</tr>
<tr>
<td>Pillar Centre (m)</td>
<td>15-18</td>
</tr>
<tr>
<td>Pillar Width (m)</td>
<td>8.2-11.2</td>
</tr>
<tr>
<td>Bord Width</td>
<td>6.8</td>
</tr>
<tr>
<td>w:h</td>
<td>3.0-4.1</td>
</tr>
<tr>
<td>Minimum Factor of Safety</td>
<td>1.8</td>
</tr>
<tr>
<td>Probability of Survival</td>
<td>0.998</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 (Low)</td>
</tr>
</tbody>
</table>

Table 5–5  Area B: Pillar Design, Mining Parameters and Risk Rating
In light of the above discussion, the risk rating for Area B is a low. In the unlikely event of a wide spread pillar collapse the dolerite thickness of average 27m would bridge the workings and prevent subsidence or sinkhole formation on surface.

5.3 Area C: The Southern Block Within The Western Extension

Area C, located south of the Western Extension Area is currently mining Section 43 in panel C17 B&P SW3 in a western direction. Figure 5–6 show Area C in relation to the mining panels and the selected boreholes. Workings in panel C17 B&P SE1 were stopped due to the intersection of multiple joint/slips zones sympathetic to a fault striking NE-SW to the panel. The other old mining panel is C17 B&P SW4, which has reached the end of the planned layout.

Table 5–6 summarizes some selected boreholes, together with the dolerite sill thicknesses in this area. The information obtained from the boreholes show that the dolerite splits into two layers in borehole EB22 and EN301105. The minimum lower sill layer thickness in these
boreholes is 3m. The minimum upper sill thickness is approximately 16m, therefore the combined sill thickness values range from 4.9m to 34.7m.

<table>
<thead>
<tr>
<th>BH. ID</th>
<th>GPS Elevation</th>
<th>Upper Dolerite Thickness (m)</th>
<th>Lower Dolerite Thickness (m)</th>
<th>EOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB22</td>
<td>1621.1</td>
<td>30.66</td>
<td>4.17</td>
<td></td>
</tr>
<tr>
<td>EN30128</td>
<td>1617.3</td>
<td>4.9</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>EN30129</td>
<td>1599.5</td>
<td>23.69</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>EN30165</td>
<td>1606.9</td>
<td>26.49</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>EN301105</td>
<td>1635.0</td>
<td>16.19</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5–6 Area C: Representative Boreholes**

The southern block within the Western Extension, Area C, is characterised by an increase in the depth to the No. 4 Seam. The pillar centres ranges from 16m to 20m. The pillar centres increase southwards, relative to the increase in cover depth. The summary of the mining parameters in this area is presented in **Table 5–7**.

**Area C**

<table>
<thead>
<tr>
<th>Mining Depth (m)</th>
<th>80-140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining Height (m)</td>
<td>2.7</td>
</tr>
<tr>
<td>Pillar Centre (m)</td>
<td>16-20</td>
</tr>
<tr>
<td>Pillar Width (m)</td>
<td>9.2-13.2</td>
</tr>
<tr>
<td>Bord Width</td>
<td>6.8</td>
</tr>
<tr>
<td>w:h</td>
<td>3.4-4.8</td>
</tr>
<tr>
<td>Factor of Safety</td>
<td>1.9</td>
</tr>
<tr>
<td>Probability of Survival</td>
<td>0.999</td>
</tr>
</tbody>
</table>

**Table 5–7 Area C: Pillar Centre Distance Contour Plan and Mining Parameters**

The risk rating is low due to the presence of a thick dolerite sill and relatively high designed safety factors for the pillars.
5.4 Area D: The Southern Extension

Area D is located to the north of the Southern Extension and the No. 2 Seam coal was mined by conventional methods. Mining activity is currently on the north-western area on the No. 4 Lower Seam. Section 41 is in production in this area, mining the Southern Extension Main Development and Section 44 is mining west in tertiary panel F19 B&P SW2.

![Diagram of Area D: Geotechnical Hazard Plan](image)

**Figure 5–7  Area D: Geotechnical Hazard Plan**

**Figure 5–7** shows the Steenkoolspruit in relation to the underground mining area and the selected boreholes in this area. **Table 5–8** presents the summary of the selected boreholes. Section 41 has recently undermined a dyke striking NE-SW and is currently undermining the Steenkoolspruit. The section is experiencing multi-directional striking and dipping slips/joints with low to moderate water seepage along the slips plains.

Section 44 is mining westwards towards the Southern Extension’s western mining boundary, marked by a NNE-SSW trending fault. The fault structure was taken as the dividing line between the Western and Southern Extension reserves.

The dolerite sill thickness was estimated from the selected boreholes. The average sill thickness is approximately 27m and ranges from 18m to 34m.
5.4.1 Area D: No. 4 Seam Workings Stability Assessment

The mining parameters of the Southern Extension No. 4 Seam are summarised in Table 5–9. The cover depth ranges from 60m to 120m, with a southward increase in the cover depth and pillar centre sizes that follow the same trend. The pillar centres range from 14m to 18m and have a 1.8 factor of safety.

<table>
<thead>
<tr>
<th>BH. ID</th>
<th>GPS ELEVATION</th>
<th>Upper Dolerite Thickness (m)</th>
<th>Lower Dolerite Thickness (m)</th>
<th>EOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB21</td>
<td>1602.3</td>
<td>34.83</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>EN301103</td>
<td>25.37</td>
<td>N/A</td>
<td>106.10</td>
<td></td>
</tr>
<tr>
<td>S30245</td>
<td>1577.2</td>
<td>18.31</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>S30280</td>
<td>1591.8</td>
<td>31.9</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Table 5–8 Area D: Representative Boreholes

5.4.2 Area D: No. 2 Seam Workings Stability Assessment

The memorandum entitled Overmining Main Development on No. 2 Seam by the No. 4 Seam Workings, compiled by D. Neal and J.J. van Wijk, dated 16 September 2001 (Ingwe Rock Engineering), contains the No. 2 Seam pillar width, mining height, the No. 2 Seam
bord widths and underground measurements as is shown in Table 5–12. Depth to the No. 2 Seam floor and the parting thickness between the No. 2 Seam and No. 4 Seam were extracted from the geological data base obtained from Gemecs (Pty) Ltd (Gemecs).

The depth to No. 2 Seam ranges between 80m and 140m. Figure 5–8 shows that the No. 2 Seam depth range is distributed. The depth to floor is shallower underneath the Steenkoolspuit with depths ranging from 80m to 90m. It then increases generally westwards and eastwards away from the stream. This is expected of the river valley.

![Figure 5–8 Contour Plan Showing No. 2 Seam Depth to Floor](image)

The parting thickness distribution between the No. 2 Seam roof and No.4 Seam floor is shown in Figure 5–9. The parting is relatively thin in the north-eastern area of Area D, ranging from 16m to 20m. The thickness of the parting increases in the south-easterly, south-westerly and north-westerly direction within Area D. It should be noted that the parting thickness reported here excludes the coal that is left in the No. 2 Seam roof. The average No. 2 Seam thickness is ±5m.
Figure 5–9  Contour Plan Showing Parting Thickness between No. 4 and No. 2 Seam in Area D

Table 5–10 and Table 5–11 are formulated based on the multi-seam mining guidelines to determine which conditions of the guidelines does the workings fall under and to determine whether the No. 4 Seam pillars require to be superimposed on the No. 2 Seam pillars or not.

The parting thickness underneath the stream ranges from 16 to 20m, at the determined thickness range.

<table>
<thead>
<tr>
<th>Pillar Centre (m)</th>
<th>Parting thickness (m)</th>
<th>1.5 x centre distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guideline (i)</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Guideline (i)</td>
<td>17</td>
<td>20</td>
</tr>
</tbody>
</table>

0.75 x centre distance

| Guideline (ii)    | 17                    | 16                    | 12.7                  |
| Guideline (ii)    | 17                    | 20                    | 12.7                  |

Table 5–10  Multi-Seam Mining Guideline 1 and 2 in Relation to Pillar Centres

<table>
<thead>
<tr>
<th>Bord width (m)</th>
<th>Parting thickness (m)</th>
<th>2 x bord width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guideline (iii)</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>Guideline (iii)</td>
<td>7</td>
<td>20</td>
</tr>
</tbody>
</table>

2 x bord width

| Guideline (iv)   | 7                     | 16             | 14                  |
| Guideline (iv)   | 7                     | 20             | 14                  |

Table 5–11  Multi-Seam Mining Guidelines 3 and 4 in Relation to Bord Widths
The calculations show that there is no need for superimposition of in panel pillars on the No. 2 Seam and No. 4 Seam, however based on the multi-seam mining guidelines, superimposition of the barrier pillars on the two mining seams under investigation is required.

The No. 2 Seam safety factors were calculated using the Coaltech (coal seam specific power formula) and the results are shown in Figure 5–10. The safety factors determined range from 1.2 to 1.9. This shows that most of the No. 2 Seam was mined at low safety factors, except in the area located northeast of the Area D, where the area is undermining the stream, the safety factors ranges from 1.6 to 1.9. This is due to the decrease in the cover depth caused by erosion. It should be noted that this is a relatively small area.

The overall risk in the No. 2 Seam is considered medium to high with an increase in risk due to the multi-seam mining. The summarised mining parameters and risk ratings are shown in Table 5–12.

Figure 5–10 Contour Plan Showing No. 2 Seam Safety Factor in Area D
Area D – No. 2 Seam

<table>
<thead>
<tr>
<th>Mining Depth (m)</th>
<th>80-140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining Height (m)</td>
<td>3</td>
</tr>
<tr>
<td>Pillar Centre (m)</td>
<td>17</td>
</tr>
<tr>
<td>Pillar Width (m)</td>
<td>10</td>
</tr>
<tr>
<td>Bord Width</td>
<td>7 (6.75)</td>
</tr>
<tr>
<td>w:h</td>
<td>2.6-4.1</td>
</tr>
<tr>
<td>Parting Thickness</td>
<td>16m to 20m</td>
</tr>
<tr>
<td>Factor of Safety</td>
<td>1.2-1.9</td>
</tr>
<tr>
<td>Probability of Survival</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Table 5–12  Area D: No. 2 Seam Pillar Design, Mining Parameters and Risk Rating

The assessment shows a medium to high risk rating in the No. 2 Seam workings however, with a dolerite sill thickness of 27m, any pillar collapse in the No. 2 Seam workings is not likely to propagate to surface due to the stiffness of the dolerite.

5.5 Risk of Sinkhole Formation

The depth to No. 4 Seam in the area under investigation ranges between 60m and 120m with illustration of the depth distribution shown in Figure 5–1. Sinkhole formation is highly unlikely in areas where mining takes place at depths greater than 40m, which is the case in the areas under investigation.

The No. 4 Seam overburden contains an approximately 11m thick, massive sandstone layer, underlain by ± 30m thick dolerite sill, therefore the risk of sinkhole formation is considered to be low.
5.6 Dolerite Effect on the Pillar Load

The overburden consists of a ±30m thick dolerite sill intrusion in the No. 4 Seam overburden with ±50m depth to floor of the sill. Where this dolerite sill exists within the No. 4 Seam overburden it is seen as a positive factor in protecting the water table above the mining areas and a contributing factor in prevention of sinkhole formation.

Influence of the dolerite thickness in the pillar load and subsequently on the pillar safety factor is examined using Salomon and Munro equation and the graphical representation of the outcome is shown in Figure 5–11.

The safety factor is calculated using 17m x 17m pillar centres, the depth to No. 4 Seam Floor is between 60m and 100m. The increase in the dolerite thickness with increasing depth will results in lower safety factors, however increasing pillar centres in the area affected will result in an increase in the pillar safety factors as shown in Figure 5–12.

![Figure 5–11 No. 4 Seam FOS with Dolerite on 17m x 17m Pillar Centres](image)
Summary of Risk Ratings

The No. 4 Seam risk ratings in the respective focus areas, Area A, Area B, Area C and Area D are summarised in Table 5–13. These ratings are within the low risk category. The No. 2 Seam stability ratings for Area D are medium to high due to low safety factors in the No. 2 Seam workings.

Based on the findings of this investigation, to maintain stability in the relatively shallow areas underneath the rivers/river valley, the minimum recommended pillar centres for the No. 4 Seam pillars beneath the rivers/river valley needs to be restricted to 15m. Such pillars have a w:h ratio of 3. The pillar FOS calculation is shown in Figure 5–13.

The result of pillar instability on the No. 2 Seam is already identified as a risk factor, but should mining of the No. 4 Seam be conducted according to the recommendations included in this report, no significant increase of this identified risk is foreseen.
### Table 5–13 Risk Rating Summary

<table>
<thead>
<tr>
<th>Area</th>
<th>Pillar FOS</th>
<th>Prob. of survival</th>
<th>Risk Rating</th>
<th>Specific Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (4Seam)</td>
<td>1.8</td>
<td>0.99</td>
<td>1</td>
<td>Considered to be relatively stable</td>
</tr>
<tr>
<td>B (4 Seam)</td>
<td>1.8</td>
<td>0.99</td>
<td>1</td>
<td>Wilge River flows above the area</td>
</tr>
<tr>
<td>C (4 Seam)</td>
<td>1.8</td>
<td>0.99</td>
<td>1</td>
<td>Considered to be relatively stable</td>
</tr>
<tr>
<td>D (4 Seam)</td>
<td>1.8</td>
<td>0.99</td>
<td>6</td>
<td>Steenkoolspruit flows above the area</td>
</tr>
<tr>
<td>D (2 Seam)</td>
<td>1.2 to 1.9</td>
<td></td>
<td>24</td>
<td>Steenkoolspruit flows above the area, Some No. 2 seam pillars have FOS &lt;1.6</td>
</tr>
</tbody>
</table>

![Table 5–13 Risk Rating Summary](image)

**Figure 5–13** No. 4 Lower Seam Pillar Safety Factor Calculations on 15m C
6 CONCLUSIONS

1. A rock engineering related risk assessment was successfully conducted for the underground workings beneath the Wilge River and Steenkoolspruit at Delmas Coal.

2. The information pertaining to the mining parameters was obtained from the Delmas Coal Underground General Plan, borehole information and geological data from Geofox and Gemecs and the Saxum database of Delmas Coal Underground geotechnical hazards.

3. The overburden consists of a ±30m thick dolerite sill intrusion, in the No.4 Seam overburden with ±50m depth to floor of the sill. Where this dolerite sill is present it is seen as a positive factor in protecting the water table above the mining areas and is also seen to contribute in the prevention of sinkhole formation.

4. The No. 2 Seam and No. 4 Seam are the economically viable coal seams at Delmas Coal. The No.2 Seam was mined in the southern extension, but operations have ceased and were sealed. The No. 2 Seam is not currently mined elsewhere in the area of interest. Mining activity is currently taking place in the No. 4 Seam in both the Western and Southern Extensions.

5. The area undermining the rivers/streams was subdivided into four (4) parts namely Area A, Area B, Area C and Area D and stability assessed, where pillar FOS, probability of survival and width to height ratios were used as indicators of pillar stability.

6. The general pillar design philosophy for Delmas Coal’s No. 4 Seam workings is to maintain safety factors of 2.0, 1.8 and 1.6 for primary, secondary and tertiary development areas respectively and to design pillar centres based on these safety factors. The designed width to height (w:h) ratios range between 2.2 and 2.6.

7. The D/2.7 rule is also applied at Delmas wherever the undermining of structures like power lines, roads and rivers is carried out. In general pillar design under such structures is such that their FOS is at least 2 for a distance of D/2.7 all round.

8. The equivalent distance of D/2.7 from the river/stream was found to range from 23m to 30m based on the depth ranging from 60m to 80m, obtained from the depth contours. It is therefore recommended that the minimum design pillar safety factor be not less than 2.0 for a distance of ±23m all round measured from the edge of the streams/rivers for a mining depth of 60m and 30m for a mining depth of 80m.

9. The Coaltech (coal seam specific power formula) was used to estimate the stability of the No. 2 Seam workings which were mined by conventional methods within the southern extension area (Area D).
10. The overall No. 4 Seam pillar centres range from 14m to 20m pillar centres at 1.8-safety factor (Coaltech). The increase in safety factor is directly proportional to the increase in cover depth.

11. The pillar centres in the areas directly underlying the rivers/streams must be increased from 14m pillar centres at 1.8 pillar safety factor to the recommended minimum pillars centre distance of 15m resulting in a square pillar of 8.2, w:h of 3.0, factor of safety of 2.1 and a pillars survival probability of 0.9999.
7 BIBLIOGRAPHY


6. Handley ,R.J.,2005. *Undermining of watercourses: Detailed investigation of pillars left under surface streams*. COALTECH 2020 task 2.2.1


