TECHNICAL REPORT

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Report Prepared for:
Riaan Joubert

Geomech Consulting (Pty) Ltd Report No. GEOM13-2019-003

ELANDSFONTEIN COLLIERY

EXISTING UNDERGROUND WORKINGS SUBSIDENCE INVESTIGATION REPORT

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1. INTRODUCTION

At the request of Mr. R. Joubert, a rock engineering investigation has been conducted to assess the risks of surface subsidence and sinkhole formation in the Elandsfontein Colliery mining area as a result of the existing underground mine workings on the No. 1 Seam.

Underground mining has been conducted extensively at Elandsfontein to date, however, there remain significant No. 1 Seam reserve areas which may be exploited either via underground or opencast mining methods in future. The No. 1 Seam is typically overlain by the No. 2 Seam which, to date, has only be exploited via opencast mining methods due to its relatively shallow depth across the mining area as well as the weak nature of the Shale layer which typically forms the immediate roof on the No. 2 Seam.

This report serves to document the findings of the subsidence investigation report.

2. INFORMATION PROVIDED

The following information was provided by Mr. R. Joubert:

- Survey information as detailed below:
  - An electronic (.dxf) file including the following drawing layers:
  - Existing No. 1 Seam underground workings,
  - Geological borehole positions,
  - The mine boundary.
- A geological database which included information for the depth to the Two (2) seams, the thickness of the Two (2) seams and the elevation of the surface topography and mining seams at the position of most of the relevant boreholes.

3. GEOTECHNICAL INVESTIGATION

3.1 INVESTIGATION AREA

Elandsfontein Colliery is located south-west of Witbank near Clewer in the western part of Mpumalanga. The colliery owned by Anker Coal and Mineral Holdings is located in the Witbank Coalfield.

The map shown in **Figure 1** indicates Elandsfontein Colliery;' location in relation to neighbouring major roads, farms and other operations.

Figure 1 - Elandsfontein Colliery Locality Map

3.2 BOREHOLE POSITIONS

A large number of boreholes have been drilled within the Elandsfontein mining area to date most of which were drilled at least 10 years or more ago and, as a result, the quality of the borehole information / logging was found to be moderate to poor in some cases.

Due to the significant geographical extent of the area under investigation and the large number of boreholes within the area, it is not practical to plot the position of each borehole on a mine plan / in a figure. The boreholes which have been used in this investigation per area are however included in the table below.

Area I.D.	Borehole I.D.	Area I.D.	Borehole I.D.	Area I.D.	Borehole I.D.	Area I.D.	Borehole I.D.	Area I.D.	Borehole I.D.	Area I.D.	Borehole I.D.
Area 1	L04/02	**Area 4**	E04/00	**Area 7**	CM24/12		E81/96	**Area 20**	CW07/11	**Area 29**	E30/95
	L02/02		D29/02		CM83/12	**Area 11**	E43/01	**Area 21**	WE36		E41A/94
	L05/02		E07/00		CM84/12		E65/00	**Area 22**	A11/97		E32/95
	W74A/03		E06/00		CM85/12		E42/01		E30/01		E36/95
	W68A/03	**Area 5**	D19/02		CM82/12		E64/00		E29/01	**Area 30**	E21/93
	C13/02		E03/00		EL76/10		E41/01		E28/01		E17/93
	W75A/03		D29/02		CM23/12		E63/00	**Area 23**	E07/93	**Area 31**	E40/94
Area 2	L03/02		E02/00		EL09/09		E69/00		C16/02	**Area 32**	A17/97
	L08/02		D23/02		EL12/09		E78/96		A09/97		E49/94
	C26/02		E01/00		E05/00		E27/97		E70/96		E52/94
	W63A/03		D21/02		CM01/12	**Area 12**	E30/97		E69/96	**Area 33**	E05/98
Area 3	CM61/12		E36/99		CM02/12	**Area 13**	E77/96	**Area 24**	E67/95		CW12/11
	W102/03		E37/99		EL75/10	**Area 14**	E76/96		E8/93	**Area 34**	E45/99
	W53A/03		E43/99		CM03/12		E20/87	**Area 25**	E37/94		E25/80
	W57/03		D22/02		CM04/12	**Area 15**	E10/99		WE24		E03/98

	E29/02		E38/99		CM25/12		E74/96	**Area 26**	C17/02		E02/98
	D28/02	**Area 6**	D18/02		EL11/10		E12/99	**Area 27**	E66/95	**Area 35**	H04/94
	L10/02		D17/02		CM05/12	**Area 16**	E13/99		E39/95	**Area 36**	WEA33
	L07/02		D12/02		W64A/03	**Area 17**	E15/99		E40/95	**Area 37**	E04/98
	L05/02		D11/02		CM07/12		E71/96		E16/93		E28/80
	W100/03	**Area 7**	EL10/09	**Area 8**	D15/02		E14/99		CW36/10	**Area 38**	WEA34
	C28/02		A05/02		D16/02		E24/01		E38/95		E24/80
	C56/05		EL78/10	**Area 9**	D02/02	**Area 18**	E75/96	**Area 28**	E33/95	**Area 39**	E23/80
	D27/02		EL02/10		D05/02		WE37		E42/94	**Area 40**	WEA15
	L08/02		CM03/13		EL24/09		E73/96		E31/95	**Area 41**	E23/80
	D24/02		EL35/12		D14/02	**Area 19**	E72/96		E34/95		
	D25/02		CM69/12	**Area 10**	E47/01		WE38		CW18/11		
	C26/02		EL38/12		E52/01		E68/96		E45/94		
	D26/02		CM70/12		E80/96		E67/95				

Table 1 - Boreholes Identified to Occur within the Different Investigation Areas.

3.3 GENERALISED STRATIGRAPHY

Based on the available geological information, a generalised stratigraphic column for the Elandsfontein mining area has been compiled and is included in **Figure 2** below.

As can be seen from the information included in **Figure 2** below, the No. 1 Seam (underground mining seam) is usually overlain by a Sandstone layer which is typically between 1.0 m and 14 m thick and has been found based on the available borehole information as well as routine visits to the opencast mining operations at Elandsfontein Colliery over the past Three (3) years to be competent and massive. A thin Coal / Shale layer has however been observed in some areas within the Sandstone later immediately above the No. 1 Seam which could be expected to result in localised roof instability in certain areas but would not be expected to result in extensive failures of the roof across large mining spans.

The Sandstone which overlies the No. 1 Seam is typically overlain by alternating layers of Siltstone / Sandstone and Sandstone which are in turn overlain by the No. 2 Seam. Generally, competent Sandstone layers have been found to constitute between 30 % and 50 % of the No. 1 Seam's overburden within the Elandsfontein mining area.

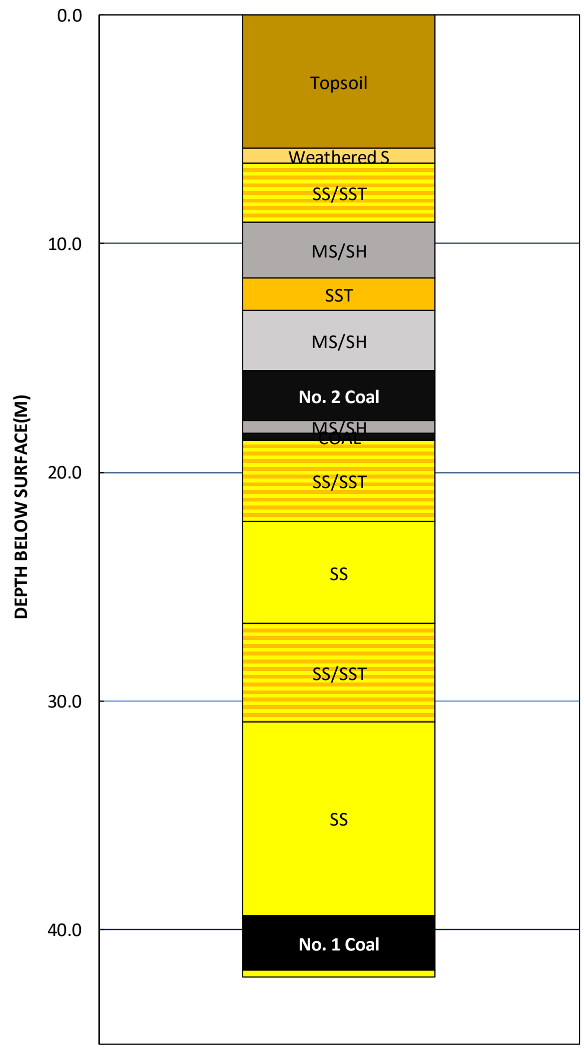

Figure 2 - Generalised Stratigraphic Column for the Elandsfontein Mining Area

The geological logs for some of the boreholes within the Elandsfontein mining area were found to be unavailable at the time of conducting this report and, as a result, these boreholes were excluded from the various investigations detailed below. Even though some of the borehole logs were not available, a large number of borehole logs were available and therefore the findings of the rock engineering investigations included in more detail below are believed to be accurate and relevant.

3.4 SURFACE ELEVATION

The surface topography within the mining right area gently varies in elevation from 1713.0 to 1777.1 metres above mean sea level (mamsl). The areas in which the surface elevation is greatest within the mining area lie towards the eastern and north-eastern mining limits.

3.5 PILLAR STABILITY

Safety Factor Calculations

For the purposes of this investigation, due to the geographical extent of the existing underground workings and the variability in pillar centres and mining depth, the existing underground workings within the Elandsfontein mining area have been sub-divided into a total of Forty-Two (42) individual areas based on the geology in each area in conjunction with the underground mining layouts (pillar and bord width dimensions). These areas are illustrated in **Figure 3** below and were generally named from South-West to North-East.

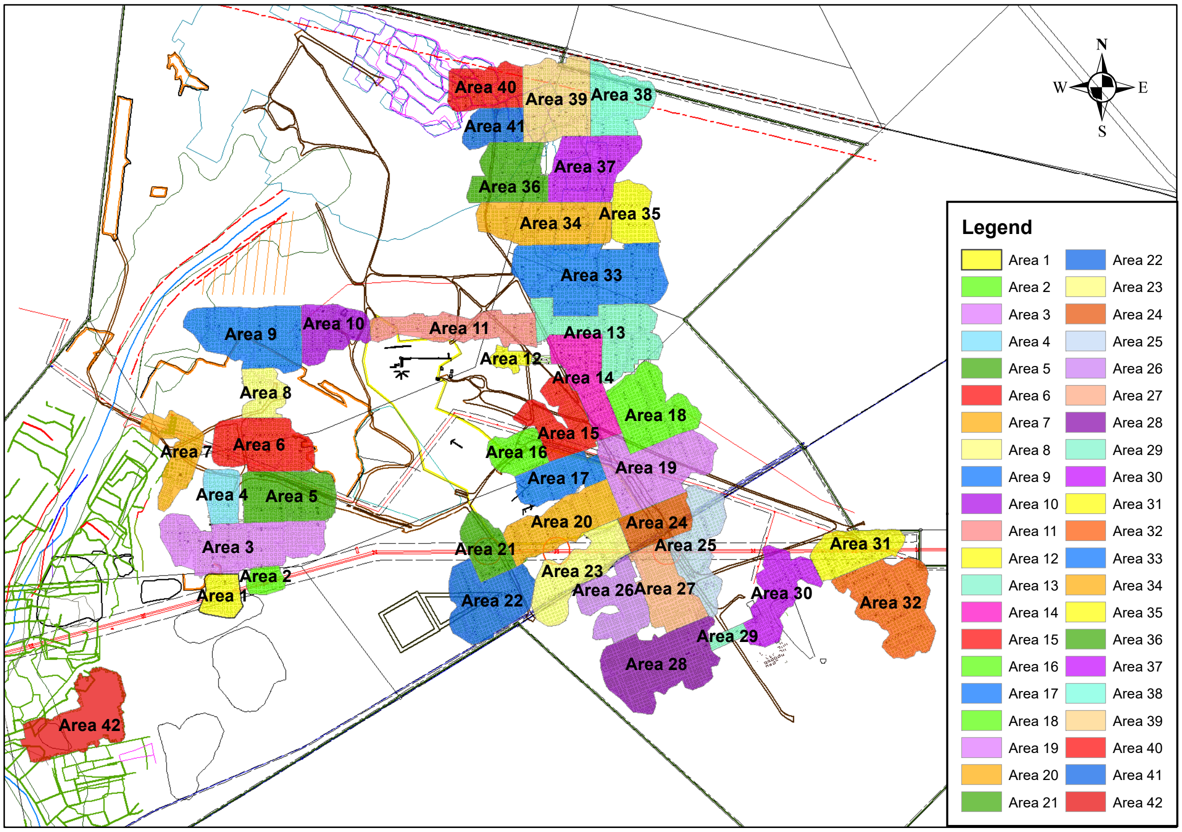

Figure 3 - Identified Investigation Areas at Elandsfontein Colliery.

Area 42 is an area in the South-Western portion of the mining area for which there was no underground survey information (mining layouts) available at the time of the assessment. The No. 1 Seam in the area is believed to have initially been mined via underground mining methods before the No. 2 Seam above it was mined via opencast mining methods. This area has been excluded from the subsequent investigations in this report due to the lack of available information for it however, given the mining depth and the apparent thickness of the No. 1 Seam in this area it is recommended that it be classified and managed as a "High Risk" area when it comes to the possibility of surface subsidence and sinkhole formation until such time as additional information has been obtained for it and these risks assessed in more detail.

The pillar stability assessment was conducted by means of strength, load and safety factor calculations documented for each of the Forty-One (41) areas detailed in **Table 4** below.

For the purpose of the investigation the pillar centres and bord widths in each of the mining areas were measured off the mining plans and averaged for the area. A total of Seven-Hundred and Seventy (770) bords widths were considered across the mining area. The mining heights were calculated from the available geological information relevant to each area.

The pillar Safety Factors were found using both the strength formulae after Salamon (1967) and the Coaltech Seam Specific strength formula. Due to the fact that mining was conducted by cut, drill and blast mining methods, the effects of blast damage considered in the strength formula were not removed.

The various pillar strengths documented in **Table 4** below have been calculated using Salamon's pillar strength formula and the Coaltech Seam Specific Strength Formula, included below:

$$Salamon\ Strength = \frac{7{,}176\ w^{0{,}46}}{h^{0{,}66}}\ \text{MPa}$$

Where:

w – Effective pillar width

h – As-mined mining height

The Seam Specific formula developed by Salamon et al in 2006 under the auspices of Coaltech 2020 is considered appropriate to use in conjunction with the Salamon pillar strength formula at Elandsfontein Colliery.

The strength (σ) of a coal pillar is given by the following power formulae:

$$\sigma = Kw^{\alpha}h^{\beta}$$

Where "*w*" and "*h*" represent the pillar width and the mining height respectively, and "*K*" and, "α" and "β" and are determined by statistical analysis.

For the conventional Salamon and Munro (1967) pillar strength formula (as detailed above):

K = 7.176

α =0.46

β = -0.66

As indicated above a revision into the coal pillar strength for South African coal seams, which includes revised values for "α" and "β" for different South African coalfields (Coal specific, Coaltech 2020), was conducted by Salamon et al (2006).

According to this revision, **Witbank No. 1, 2** and **4 Seams** coal specific properties are used to calculate the pillar safety factors for Elandsfontein Colliery, are:

K = 6.187

α =0.6721

β = -0.8682

Both formulae have been used in the pillar safety factor calculations included below.

Loading on the pillars has been calculated assuming Tributary Area Loading which is a conservative estimate of the load to which the pillars in the majority of the panels in question are subjected as the Tributary Area Loading theory usually only applies when the width of the panel in question exceeds the depth at which mining is to take place within it. Opencast mining has also been conducted to date in some of the areas above the existing No. 1 Seam underground workings and, as a result, the load on the pillars in these areas would be expected to be less than predicted by the tributary area theory due to the reduced density of the backfill material relative to the in-situ density of the typical overburden strata.

The load has however still been calculated using the following equation:

$$Load = \frac{0.025\,H\,C^2}{w^2} \text{ MPa}$$

Where:

H – Depth to the floor of the mining seam
C – As-mined pillar centers
w – Effective pillar width

Safety factors have subsequently been calculated using the following formula:

$$\text{Safety Factor} = \frac{Strength}{Load}$$

In areas where the mining depth is less than 40 meters the guidelines developed by I. Canbulat and B.J. Madden (2005) must be applied for all bord and pillar development on the advance, namely:

- Pillar width to mining height ratio should not be less than 2.2.
- Areal percentage extraction should not be greater than 75 per cent.
- The minimum pillar width should not be less than 6.5 m.
- A minimum safety factor of 2.1 should be used.

These have been considered when assessing the compliance and stability of the existing underground workings at Elandsfontein Colliery.

The table below indicates the calculated probability of failure of pillars designed with different safety factors as well as the possible number of pillar failures in a million pillars mined with each safety factor.

Safety factor	Probability of a stable geometry	No. of pillar collapses in one million
2.1	0.999999	<1
2.0	0.999994	6
1.9	0.999974	26
1.8	0.999894	106
1.7	0.999586	414
1.6	0.998468	1 532
1.5	0.9947	5 300
1.4	0.9830	17 000
1.3	0.9508	49 200
1.2	0.8748	125 200
1.1	0.7259	274 100
1.0	0.5000	500 000
0.9	0.2534	746 000
0.8	0.0799	920 100
0.7	0.0066	993 400
0.6	0.0060	999 400

Table 2 - Safety Factor, Probability of Stable Geometry and No. of Pillars Likely to Collapse in a Million Mined.

As can be seen from the information included in **Table 2** above, pillars designed with a safety factor of 2.1 have a 99.9999 % chance of having a stable geometry and less than One (1) pillar designed to a safety factor of more than 2.1 can be expected to fail in a million pillars mined.

<u>Predicting the Lifespan of Pillars</u>

Van der Merwe (2003a) analysed pillar collapses in different coal seams and areas of South Africa. He found that the majority of pillars collapsed by a process of progressive scaling. As the pillar continues to scale, it becomes progressively smaller and its load bearing capacity is reduced while its load increases. Eventually, it reaches the stage where it has to fail. By inspection of the database, he postulated that the lowest value of safety factor that a pillar can tolerate was 0.4.

He then calculated the distances that pillars in the data base of failed pillars had to scale before they reached the minimum value.

Using that distance and the known life of the pillars, he was able to indirectly deduce the rate at which pillars scaled.

The distance a pillar has to scale in order to reach the minimum safety factor, S_m, is:

$$d_c = w - [0{,}00714 S_m H h C^2]^{0{,}333} \text{ m}$$

Where:

w = pillar width,

H = depth to floor

h = mining height,

C = Pillar Center.

The rate of scaling, "R", for S_m = 0.4, was found to be:

$$R = m\left[\frac{h}{T}\right]^{x} \text{ m / year}$$

Where:

T = time since creating the pillar,

m and x are dimensionless constants.

The predicted life of the pillar is then:

$$T_L = \left[\frac{d}{mh^x}\right]^{\frac{1}{1-x}} \text{Years}$$

Different values for "m" and "x" were found for different areas and coal seams of the country, shown in Error! Reference source not found. below.

	m-Value	x-Value
Vaal Basin, Klip River and South Rand	1,3888	0,804
Witbank No 2 and 4 Seams	0,1624	0,8135

Table 3 - Values for "m" and "x" after Van der Merwe.

Using the above equations, the lifespans of the pillars formed to date at Elandsfontein Colliery, are shown in **Table 5** below.

It should be noted that the years estimated should not be taken literally but should be used as an indicator of lifespan.

In addition, the value of "w", the pillar width in the above equations should be taken conservatively as the minimum pillar width in the case of rectangular pillars.

Table 5 shows that the pillar life estimate for the No. 1 Seam pillars varies between 5.9 years in the vicinity of borehole D22/02, and 1 799 616 years in the vicinity of borehole CW07/11. The majority of the existing pillars at Elandsfontein Colliery have relatively short to extremely short, anticipated life spans as calculated using this method due to their small dimensions and relatively low width-to-height ratios. This indicates that there is in most areas an elevated level of risk of pillar instability over time.

It must be noted that not all pillars will fail due to scaling. The data base of intact pillars had predicted lives extending to several millennia. The scaling debris from the pillars will build up against the pillar sides, eventually offering sufficient resistance in the majority of cases to prevent any further scaling.

Based on the results of the pillar stability investigation, safety factor calculations (included in **Table 4** below) as well as the pillar life span calculations, the following can be stated:

- Due to the shallow mining depth generally at Elandsfontein Colliery, the pillar safety factors are relatively high in most areas.
- The following areas were found to have safety factors of less than 1.6 at the position of some of the boreholes when calculated using the Salamon and Munro strength formula taking into account the effect of blast damage on the pillars:
    - Area 7 (EL38/12).
    - Area 14 (EL76/96).
    - Area 18 (E75/96).
    - Area 23 (E69/96).
    - Area 33 (E05/98 & CW12/11).
    - Area 34 (E25/80, E03/98 & E02/98).
    - Area 35 (H04/94).
    - Area 37 (E04/98).
    - Area 39 (E23/80).
    - Area 40 (WEA15).
- As a result of the mining depth, the pillar safety factors were found in many areas to be relatively high despite the pillars being small to very small. In many areas the requirements of the shallow mining guidelines to have pillar widths of 6.5 m or more were often not complied with.
- As a result of the small size of the pillars in general, the pillar safety factor calculation is believed to be an optimistic assumption of the general pillar stability at Elandsfontein Colliery.
- The pillar life span calculations have indicated that the anticipated life spans of the pillars in the positions of a number of the boreholes are moderately to extremely low as a result of the underground mining dimensions. In general, the life spans of the pillars in the Elandsfontein mining area have been found to be variable (from extremely low to very high) highlighting the risk of pillar failure with time in some of the areas and the anticipated stability of the pillars in others.
- Pillar failure is believed to be possible over time in all areas in which the safety factors of the pillars are less than 2.1, the pillar widths are less than 6.5 m, the pillar width-to-height ratio is less than 2.2 and / or the pillar widths are less than 6.5 m over time.
- Flooding of the existing underground workings at Elandsfontein Colliery has, in some instances been found to occur. It is anticipated that some, if not most of the underground workings at Elandsfontein Colliery will become flooded over time. The flooding of the workings is however not expected to have a notable impact on the stability of the coal pillars in the existing workings.

Area	Borehole I.D.	Center 1 (m)	Center 2 (m)	Avg. Bord Width (m)	Weft (m)	Avg. Mining Height (m)	Salamon Strength (Mpa)	H (m)	Load (Mpa)	SF	Width/Height (Min)	Areal % Extraction	Coaltech Strength (Mpa)	Coaltech SF
Area 1	L04/02	14,2	14,0	6,4	7,7	3,0	8,8	30,3	2,5	3,5	2,5	70,2	9,3	3,7
	L02/02	14,2	14,0	6,4	7,7	2,8	9,3	26,2	2,2	4,2	2,7	70,2	9,9	4,5
	L05/02	14,2	14,0	6,4	7,7	4,6	6,7	23,9	2,0	3,4	**1,7**	70,2	6,5	3,2
	W74A/03	14,2	14,0	6,4	7,7	3,5	8,1	23,3	1,9	4,1	2,2	70,2	8,3	4,2
	W68A/03	14,2	14,0	6,4	6,0	2,7	8,6	28,7	2,4	3,6	2,8	70,2	8,8	3,7
	C13/02	14,2	14,0	6,4	6,0	1,6	12,0	26,5	2,2	5,4	4,8	70,2	13,8	6,2
	W75A/03	14,2	14,0	6,4	6,0	2,7	8,4	21,8	1,8	4,6	2,8	70,2	8,6	4,7
Area 2	L03/02	14,0	14,0	6,2	6,0	3,8	6,8	18,7	1,5	4,5	**2,1**	69,0	6,5	4,3
	L08/02	14,0	14,0	6,2	6,0	2,0	10,3	20,5	1,7	6,2	3,9	69,0	11,3	6,8
	C26/02	14,0	14,0	6,2	6,0	3,7	6,9	19,1	1,5	4,5	**2,1**	69,0	6,6	4,3
	W63A/03	14,0	14,0	6,2	6,0	2,2	9,8	17,2	1,4	7,0	3,6	69,0	10,4	7,5
Area 3	CM61/12	13,8	14,2	6,4	6,0	0,6	24,3	32,0	2,7	8,9	13,5	70,5	34,7	12,8
	W102/03	13,8	14,2	6,4	6,0	2,1	10,1	35,6	3,0	3,3	3,5	70,5	10,9	3,6
	W53A/03	13,8	14,2	6,4	6,0	2,6	8,7	35,0	3,0	2,9	2,8	70,5	8,9	3,0
	W57/03	13,8	14,2	6,4	6,0	2,4	9,2	33,4	2,8	3,3	3,1	70,5	9,7	3,4
	E29/02	13,8	14,2	6,4	6,0	2,2	9,7	31,1	2,6	3,7	3,4	70,5	10,4	3,9
	D28/02	13,8	14,2	6,4	5,9	3,7	6,8	27,1	2,3	3,0	**2,0**	70,5	6,5	2,8
	L10/02	13,8	14,2	6,4	5,9	2,8	8,2	25,9	2,2	3,7	2,7	70,5	8,4	3,8
	L07/02	13,8	14,2	6,4	5,9	3,9	6,6	24,4	2,1	3,2	**1,9**	70,5	6,2	3,0
	L05/02	13,8	14,2	6,4	5,9	4,6	5,9	23,9	2,0	2,9	**1,6**	70,5	5,4	2,7
	W100/03	13,8	14,2	6,4	5,9	4,1	6,4	23,4	2,0	3,2	**1,8**	70,5	6,0	3,0
	C28/02	13,8	14,2	6,4	5,9	3,1	7,7	22,1	1,9	4,1	2,4	70,5	7,6	4,1
	C56/05	13,8	14,2	6,4	5,9	2,7	8,4	31,6	2,7	3,1	2,7	70,5	8,5	3,2
	D27/02	13,8	14,2	6,4	5,9	3,1	7,7	23,9	2,0	3,8	2,4	70,5	7,6	3,7
	L08/02	13,8	14,2	6,4	5,9	2,0	10,2	20,5	1,7	5,9	3,7	70,5	11,1	6,4
	D24/02	13,8	14,2	6,4	5,9	4,6	5,9	22,3	1,9	3,1	**1,6**	70,5	5,4	2,9
	D25/02	13,8	14,2	6,4	5,2	3,3	7,0	18,7	1,6	4,4	2,3	70,5	6,7	4,2
	C26/02	13,8	14,2	6,4	5,2	3,7	6,4	19,1	1,6	4,0	**2,0**	70,5	6,0	3,7
	D26/02	13,8	14,2	6,4	5,2	3,5	6,7	22,5	1,9	3,5	**2,1**	70,5	6,3	3,3
Area 4	E04/00	14,1	14,0	6,2	5,2	3,9	6,2	29,6	2,4	2,6	**2,0**	68,8	5,7	2,4

	D29/02	14,1	14,0	6,2	5,2	2,9	7,6	21,0	1,7	4,5	2,7	68,8	7,5	4,4
	E07/00	14,1	14,0	6,2	5,3	2,7	8,1	23,9	1,9	4,2	2,9	68,8	8,1	4,2
	E06/00	14,1	14,0	6,2	5,3	1,2	13,4	26,4	2,1	6,3	6,3	68,8	15,7	7,4
Area 5	D19/02	14,1	14,1	6,7	5,3	4,1	6,1	24,7	2,2	2,7	**1,8**	72,5	5,5	2,5
	E03/00	14,1	14,1	6,7	5,3	2,6	8,3	24,7	2,2	3,7	2,9	72,5	8,4	3,7
	D29/02	14,1	14,1	6,7	5,3	2,9	7,7	21,0	1,9	4,0	2,6	72,5	7,6	4,0
	E02/00	14,1	14,1	6,7	4,4	2,5	7,8	25,8	2,3	3,3	3,0	72,5	7,7	3,3
	D23/02	14,1	14,1	6,7	4,8	2,6	7,9	22,1	2,0	3,9	2,9	72,5	7,8	3,9
	E01/00	14,1	14,1	6,7	4,8	2,1	9,0	23,0	2,1	4,3	3,5	72,5	9,3	4,4
	D21/02	14,1	14,1	6,7	4,8	4,1	5,8	24,3	2,2	2,6	**1,8**	72,5	5,2	2,3
	E36/99	14,1	14,1	6,7	4,8	2,0	9,5	22,8	2,1	4,6	3,8	72,5	9,9	4,8
	E37/99	14,1	14,1	6,7	4,9	2,6	7,9	21,1	1,9	4,1	2,8	72,5	7,8	4,0
	E43/99	14,1	14,1	6,7	4,9	2,8	7,6	21,3	1,9	3,9	2,7	72,5	7,4	3,8
	D22/02	14,1	14,1	6,7	4,7	5,7	4,6	20,8	1,9	2,4	**1,3**	72,5	3,8	2,0
	E38/99	14,1	14,1	6,7	4,7	2,9	7,3	19,8	1,8	4,0	2,6	72,5	7,0	3,9
Area 6	D18/02	14,0	14,0	6,3	4,7	2,0	9,3	26,7	2,2	4,2	3,9	69,8	9,6	4,3
	D17/02	14,0	14,0	6,3	5,1	3,5	6,6	29,2	2,4	2,8	2,2	69,8	6,2	2,6
	D12/02	14,0	14,0	6,3	5,5	3,2	7,2	29,2	2,4	3,0	2,4	69,8	7,0	2,9
	D11/02	14,0	14,0	6,3	5,0	3,5	6,6	27,5	2,3	2,9	2,2	69,8	6,2	2,7
Area 7	EL10/09	13,0	13,0	7,0	4,9	1,1	13,9	37,0	4,3	3,2	5,4	78,7	16,4	3,8
	A05/02	13,0	13,0	7,0	4,9	2,6	8,0	35,6	4,2	**1,9**	2,3	78,7	7,9	**1,9**
	EL78/10	13,0	13,0	7,0	4,9	1,6	10,9	39,2	4,6	2,4	3,8	78,7	12,0	2,6
	EL02/10	13,0	13,0	7,0	4,7	2,6	7,8	36,6	4,3	**1,8**	2,3	78,7	7,7	**1,8**
	CM03/13	13,0	13,0	7,0	4,8	1,7	10,5	38,1	4,5	2,3	3,6	78,7	11,3	2,5
	EL35/12	13,0	13,0	7,0	4,8	2,1	9,2	38,3	4,5	**2,0**	2,9	78,7	9,5	2,1
	CM69/12	13,0	13,0	7,0	4,8	0,8	17,1	37,6	4,4	3,9	7,5	78,7	21,6	4,9
	EL38/12	13,0	13,0	7,0	4,8	3,9	6,1	37,7	4,4	**1,4**	**1,6**	78,7	5,5	**1,2**
	CM70/12	13,0	13,0	7,0	4,8	2,0	9,3	37,6	4,4	2,1	3,0	78,7	9,7	2,2
	CM24/12	13,0	13,0	7,0	4,7	2,1	9,0	38,2	4,5	**2,0**	2,9	78,7	9,2	2,1
	CM83/12	13,0	13,0	7,0	4,7	2,8	7,5	37,4	4,4	**1,7**	2,2	78,7	7,3	**1,7**
	CM84/12	13,0	13,0	7,0	5,3	2,8	7,8	37,6	4,4	**1,8**	**2,1**	78,7	7,8	**1,8**
	CM85/12	13,0	13,0	7,0	5,3	1,1	14,2	37,3	4,4	3,2	5,3	78,7	16,9	3,9
	CM82/12	13,0	13,0	7,0	5,3	2,3	8,9	36,5	4,3	2,1	2,6	78,7	9,2	2,1
	EL76/10	13,0	13,0	7,0	4,8	2,4	8,2	37,6	4,4	**1,9**	2,5	78,7	8,2	**1,9**
	CM23/12	13,0	13,0	7,0	4,8	1,0	14,5	34,7	4,1	3,6	5,8	78,7	17,3	4,2
	EL09/09	13,0	13,0	7,0	5,4	1,7	11,0	35,7	4,2	2,6	3,5	78,7	12,1	2,9
	EL12/09	13,0	13,0	7,0	5,4	1,2	13,6	33,8	4,0	3,4	4,9	78,7	16,1	4,1

	E05/00	13,0	13,0	7,0	5,4	1,5	12,0	34,2	4,0	3,0	4,0	78,7	13,6	3,4
	CM01/12	13,0	13,0	7,0	4,7	2,1	8,9	35,3	4,1	2,1	2,8	78,7	9,0	2,2
	CM02/12	13,0	13,0	7,0	4,7	0,7	19,2	35,2	4,1	4,7	9,1	78,7	25,1	6,1
	EL75/10	13,0	13,0	7,0	4,7	0,6	20,5	34,1	4,0	5,1	10,0	78,7	27,3	6,8
	CM03/12	13,0	13,0	7,0	4,7	1,8	9,8	32,5	3,8	2,6	3,3	78,7	10,3	2,7
	CM04/12	13,0	13,0	7,0	4,7	0,5	22,2	30,5	3,6	6,2	11,3	78,7	30,4	8,5
	CM25/12	13,0	13,0	7,0	4,7	2,7	7,7	23,9	2,8	2,7	2,3	78,7	7,5	2,7
	EL11/10	13,0	13,0	7,0	4,7	0,7	18,5	32,0	3,8	4,9	8,6	78,7	23,9	6,3
	CM05/12	13,0	13,0	7,0	4,7	0,3	33,9	30,7	3,6	9,4	21,4	78,7	52,9	14,7
	W64A/03	13,0	13,0	7,0	4,7	4,2	5,7	21,0	2,5	2,3	1,4	78,7	5,0	2,0
	CM07/12	13,0	13,0	7,0	4,7	2,7	7,7	33,6	3,9	1,9	2,3	78,7	7,5	1,9
Area 8	D15/02	13,9	14,0	6,3	5,5	4,4	5,9	36,3	3,0	1,9	1,7	69,9	5,3	1,8
	D16/02	13,9	14,0	6,3	5,5	4,9	5,5	33,4	2,8	2,0	1,5	69,9	4,9	1,7
Area 9	D02/02	14,0	14,1	6,5	5,7	2,3	9,3	44,0	3,8	2,4	3,3	71,1	9,7	2,6
	D05/02	14,0	14,1	6,5	5,7	4,0	6,4	46,0	4,0	1,6	1,9	71,1	6,0	1,5
	EL24/09	14,0	14,1	6,5	5,6	2,0	9,9	50,0	4,3	2,3	3,7	71,1	10,6	2,4
	D14/02	14,0	14,1	6,5	7,3	1,5	13,8	39,4	3,4	4,0	5,0	71,1	16,6	4,9
Area 10	E47/01	13,9	14,0	6,4	6,6	1,4	13,8	43,4	3,7	3,7	5,4	70,7	16,6	4,5
	E52/01	13,9	14,0	6,4	6,6	2,2	10,2	41,1	3,5	2,9	3,4	70,7	11,1	3,2
	E80/96	13,9	14,0	6,4	6,6	2,8	8,6	41,3	3,5	2,4	2,6	70,7	8,9	2,5
	E81/96	13,9	14,0	6,4	6,9	1,0	17,3	31,1	2,7	6,5	7,4	70,7	22,5	8,5
Area 11	E43/01	13,9	14,0	6,3	6,9	1,5	13,2	40,0	3,3	4,0	5,0	69,9	15,7	4,7
	E65/00	13,9	14,0	6,3	6,9	1,3	14,3	44,6	3,7	3,9	5,6	69,9	17,5	4,7
	E42/01	13,9	14,0	6,3	6,9	1,0	17,2	37,1	3,1	5,6	7,5	69,9	22,3	7,2
	E64/00	13,9	14,0	6,3	7,0	1,6	13,2	44,9	3,7	3,5	4,9	69,9	15,6	4,2
	E41/01	13,9	14,0	6,3	7,0	1,0	17,3	37,1	3,1	5,6	7,5	69,9	22,5	7,3
	E63/00	13,9	14,0	6,3	7,0	1,6	12,8	33,5	2,8	4,6	4,7	69,9	15,1	5,4
	E69/00	13,9	14,0	6,3	7,0	0,5	26,1	48,1	4,0	6,5	13,8	69,9	38,4	9,6
	E78/96	13,9	14,0	6,3	7,0	1,8	11,8	34,7	2,9	4,1	4,2	69,9	13,5	4,7
	E27/97	13,9	14,0	6,3	6,5	1,4	13,7	41,5	3,5	4,0	5,5	69,9	16,5	4,8
Area 12	E30/97	12,1	12,0	6,8	7,1	1,5	13,4	38,6	5,1	2,6	3,4	81,0	16,1	3,2
Area 13	E77/96	14,0	14,0	6,9	6,8	2,4	9,6	48,9	4,8	2,0	2,9	74,3	10,4	2,2
Area 14	E76/96	12,0	12,0	6,6	6,8	2,4	9,8	56,1	6,9	1,4	2,3	79,8	10,5	1,5
	E20/87	12,0	12,0	6,6	7,1	2,2	10,7	51,3	6,3	1,7	2,5	79,8	11,9	1,9
Area 15	E10/99	12,0	12,0	5,9	7,1	1,6	13,2	25,3	2,4	5,4	3,9	74,2	15,7	6,4
	E74/96	12,0	12,0	5,9	7,0	2,0	11,2	29,4	2,8	3,9	3,1	74,2	12,6	4,4
	E12/99	12,0	12,0	5,9	7,0	2,1	10,7	42,9	4,2	2,6	2,9	74,2	11,9	2,9

Area 16	E13/99	12,0	12,0	6,0	7,0	1,9	11,7	30,6	3,1	3,8	3,2	75,0	13,3	4,4
Area 17	E15/99	12,0	12,0	6,0	7,2	2,0	11,4	42,8	4,3	2,7	3,0	75,0	12,9	3,0
	E71/96	12,0	12,0	6,0	7,2	2,6	9,5	39,0	3,9	2,5	2,3	75,0	10,3	2,6
	E14/99	12,0	12,0	6,0	7,2	2,3	10,4	40,6	4,1	2,6	2,6	75,0	11,5	2,8
	E24/01	12,0	12,0	6,0	7,0	1,8	11,9	27,3	2,7	4,4	3,3	75,0	13,7	5,0
Area 18	E75/96	12,0	13,0	6,7	6,0	2,8	8,3	55,8	6,5	1,3	1,9	78,6	8,5	1,3
	WE37	12,0	13,0	6,7	6,0	2,4	9,1	42,3	4,9	1,8	2,2	78,6	9,6	1,9
	E73/96	12,0	13,0	6,7	7,2	2,2	10,6	52,2	6,1	1,7	2,4	78,6	11,8	1,9
Area 19	E72/96	12,0	12,0	6,0	7,2	2,8	9,0	52,1	5,2	1,7	2,2	75,0	9,6	1,8
	WE38	12,0	12,0	6,0	7,3	2,3	10,5	48,3	4,8	2,2	2,7	75,0	11,6	2,4
	E68/96	12,0	12,0	6,0	7,0	3,2	8,1	48,3	4,8	1,7	1,9	75,0	8,3	1,7
	E67/95	12,0	12,0	6,0	6,7	2,9	8,5	50,2	5,0	1,7	2,1	75,0	8,8	1,8
Area 20	CW07/11	12,0	12,0	6,2	7,1	0,5	27,9	38,5	4,1	6,8	11,6	76,6	42,2	10,2
Area 21	WE36	12,0	12,0	6,2	6,0	2,0	10,3	16,9	1,8	5,7	2,9	76,6	11,2	6,2
Area 22	A11/97	12,0	12,0	6,1	6,0	1,5	12,5	13,9	1,4	8,7	3,9	75,8	14,5	10,1
	E30/01	12,0	12,0	6,1	5,9	1,4	13,0	30,1	3,1	4,2	4,2	75,8	15,2	4,9
	E29/01	12,0	12,0	6,1	5,9	1,9	10,7	27,3	2,8	3,8	3,2	75,8	11,8	4,2
	E28/01	12,0	12,0	6,1	5,7	2,0	10,2	22,5	2,3	4,4	3,0	75,8	11,1	4,8
Area 23	E07/93	12,2	12,0	7,0	5,7	2,6	8,6	38,2	5,4	1,6	2,0	82,2	8,8	1,6
	C16/02	12,2	12,0	7,0	5,9	1,3	13,5	16,9	2,4	5,7	3,8	82,2	16,0	6,7
	A09/97	12,2	12,0	7,0	5,9	2,6	8,8	37,6	5,3	1,7	2,0	82,2	9,0	1,7
	E70/96	12,2	12,0	7,0	5,9	0,5	24,4	25,5	3,6	6,8	9,3	82,2	34,8	9,7
	E69/96	12,2	12,0	7,0	5,5	2,1	9,8	44,9	6,3	1,5	2,4	82,2	10,4	1,7
Area 24	E67/95	12,1	12,0	6,0	5,5	2,9	7,8	50,2	5,0	1,6	2,1	74,8	7,7	1,6
	E8/93	12,1	12,0	6,0	5,8	2,3	9,3	46,7	4,6	2,0	2,6	74,8	9,7	2,1
Area 25	E37/94	12,0	12,0	7,0	5,5	1,7	11,3	37,0	5,3	2,1	3,0	82,6	12,6	2,4
	WE24	12,0	12,0	7,0	6,0	1,9	10,9	34,1	4,9	2,2	2,7	82,6	12,0	2,5
Area 26	C17/02	12,0	12,0	6,0	6,0	3,8	6,8	18,0	1,8	3,8	1,6	75,0	6,5	3,6
Area 27	E66/95	12,0	12,0	6,0	6,1	2,3	9,4	52,2	5,2	1,8	2,6	75,0	10,0	1,9
	E39/95	12,0	12,0	6,0	6,1	2,1	10,2	51,2	5,1	2,0	2,9	75,0	11,0	2,2
	E40/95	12,0	12,0	6,0	4,7	1,8	10,1	51,3	5,1	2,0	3,4	75,0	10,8	2,1
	E16/93	12,0	12,0	6,0	4,7	2,2	8,8	42,1	4,2	2,1	2,8	75,0	8,9	2,1
	CW36/10	12,0	12,0	6,0	4,9	1,7	10,6	50,9	5,1	2,1	3,6	75,0	11,5	2,3
	E38/95	12,0	12,0	6,0	4,9	2,0	9,4	48,6	4,9	1,9	3,0	75,0	9,9	2,0
Area 28	E33/95	12,0	12,0	6,1	4,9	2,0	9,5	53,4	5,5	1,7	3,0	75,8	9,9	1,8
	E42/94	12,0	12,0	6,1	4,9	1,8	10,3	51,3	5,3	1,9	3,4	75,8	11,1	2,1
	E31/95	12,0	12,0	6,1	4,9	1,8	10,2	48,6	5,0	2,0	3,3	75,8	10,9	2,2

	E34/95	12,0	12,0	6,1	4,7	1,3	12,2	42,8	4,4	2,7	4,5	75,8	13,8	3,1
	CW18/11	12,0	12,0	6,1	4,7	0,8	17,5	46,3	4,8	3,7	7,8	75,8	22,2	4,6
	E45/94	12,0	12,0	6,1	4,7	0,9	16,3	48,7	5,0	3,2	6,9	75,8	20,2	4,0
Area 29	E30/95	21,0	12,0	6,1	4,7	1,6	10,8	41,2	3,0	3,6	3,7	65,1	11,7	4,0
	E41A/94	21,0	12,0	6,1	4,5	1,2	13,1	40,4	2,9	4,5	5,1	65,1	15,1	5,2
	E32/95	21,0	12,0	6,1	4,5	1,8	9,8	40,7	2,9	3,4	3,3	65,1	10,4	3,6
	E36/95	21,0	12,0	6,1	4,5	0,8	16,1	37,9	2,7	5,9	7,0	65,1	19,8	7,3
Area 30	E21/93	12,0	12,0	6,1	4,8	1,2	13,4	36,1	3,7	3,6	5,1	75,8	15,6	4,2
	E17/93	12,0	12,0	6,1	4,8	0,9	16,4	31,7	3,3	5,0	6,9	75,8	20,4	6,2
Area 31	E40/94	12,0	12,0	6,7	4,8	1,0	15,0	38,5	4,9	3,0	5,4	80,5	18,1	3,7
Area 32	A17/97	12,0	12,0	6,7	4,8	1,5	11,2	40,4	5,2	2,2	3,5	80,5	12,3	2,4
	E49/94	12,0	12,0	6,7	4,8	1,6	10,9	46,2	5,9	**1,8**	3,4	80,5	11,9	**2,0**
	E52/94	12,0	12,0	6,7	4,8	1,1	13,7	42,8	5,5	2,5	4,7	80,5	16,1	2,9
Area 33	E05/98	14,0	14,1	7,7	4,8	2,1	9,2	50,7	6,2	**1,5**	3,1	79,6	9,5	**1,5**
	CW12/11	14,0	14,1	7,7	4,8	2,9	7,3	54,8	6,7	**1,1**	2,2	79,6	7,0	**1,0**
Area 34	E45/99	14,0	14,0	7,5	6,4	1,6	12,5	51,8	6,0	2,1	4,1	78,4	14,5	2,4
	E25/80	14,0	14,0	7,5	6,4	2,0	10,6	59,3	6,9	**1,5**	3,2	78,4	11,7	**1,7**
	E03/98	14,0	14,0	7,5	6,7	2,5	9,4	62,8	7,3	**1,3**	2,6	78,4	10,0	**1,4**
	E02/98	14,0	14,0	7,5	6,8	2,7	9,1	60,7	7,0	**1,3**	2,5	78,4	9,6	**1,4**
Area 35	H04/94	14,0	14,0	7,2	7,2	3,0	8,5	57,1	6,0	**1,4**	2,2	76,4	8,9	**1,5**
Area 36	WEA33	14,0	14,0	6,8	7,2	2,1	10,8	60,1	5,7	**1,9**	3,4	73,6	12,1	2,1
Area 37	E04/98	14,0	14,0	7,1	6,7	2,5	9,5	62,8	6,5	**1,5**	2,8	75,7	10,2	**1,6**
	E28/80	14,0	14,0	7,1	6,7	1,0	17,2	69,0	7,1	2,4	6,9	75,7	22,2	3,1
Area 38	WEA34	13,8	14,0	6,7	6,7	2,0	10,9	66,8	6,2	**1,8**	3,6	73,2	12,2	**2,0**
	E24/80	13,8	14,0	6,7	6,7	2,2	10,3	61,7	5,7	**1,8**	3,3	73,2	11,3	**2,0**
Area 39	E23/80	14,0	14,0	7,0	6,7	2,4	9,7	69,5	6,5	**1,5**	2,8	73,4	10,5	**1,5**
Area 40	WEA15	14,0	14,0	6,8	6,7	2,0	11,0	77,6	7,3	**1,5**	3,7	73,6	12,4	**1,7**
Area 41	E23/80	14,0	14,0	6,6	6,7	2,4	9,7	69,5	6,2	**1,6**	3,1	72,1	10,5	**1,7**

Table 4 - Calculated Pillar Safety Factors in the Forty-One (41) Areas.

Area I.D.	Borehole I.D.	Bord Widths (m)	Pillar Widths (m)	dc	TL (Years)
Area 1	L04/02	6,40	7,70	4,01	**536,31**
	L02/02	6,40	7,70	4,27	**792,26**
	L05/02	6,40	7,70	3,79	**83,25**
	W74A/03	6,40	7,70	4,17	**313,06**
	W68A/03	6,40	6,00	2,53	**595,40**
	C13/02	6,40	6,00	3,15	7123,75
	W75A/03	6,40	6,00	2,80	**589,31**
Area 2	L03/02	6,20	6,00	2,64	**139,90**
	L08/02	6,20	6,00	3,18	2588,48
	C26/02	6,20	6,00	2,62	**143,91**
	W63A/03	6,20	6,00	3,27	1826,87
Area 3	CM61/12	6,40	6,00	3,87	898076,17
	W102/03	6,40	6,00	2,58	1766,99
	W53A/03	6,40	6,00	2,33	**596,80**
	W57/03	6,40	6,00	2,50	**954,38**
	E29/02	6,40	6,00	2,67	1463,93
	D28/02	6,40	5,86	2,07	**115,03**
	L10/02	6,40	5,86	2,47	**488,43**
	L07/02	6,40	5,86	2,14	**96,80**
	L05/02	6,40	5,86	1,97	**43,20**
	W100/03	6,40	5,86	2,13	**76,65**
	C28/02	6,40	5,86	2,53	**310,38**
	C56/05	6,40	5,86	2,27	**492,73**
	D27/02	6,40	5,86	2,44	**299,73**
	L08/02	6,40	5,86	3,04	2472,84
	D24/02	6,40	5,86	2,05	**45,08**
	D25/02	6,40	5,20	2,00	**199,55**
	C26/02	6,40	5,20	1,82	**100,06**
	D26/02	6,40	5,20	1,70	**118,73**
Area 4	E04/00	6,20	5,20	1,23	**54,90**
	D29/02	6,20	5,20	1,99	**332,33**
	E07/00	6,20	5,30	2,04	**479,94**
	E06/00	6,20	5,30	2,68	17933,86
Area 5	D19/02	6,70	5,30	1,48	**51,48**
	E03/00	6,70	5,30	2,04	**566,59**
	D29/02	6,70	5,30	2,08	**347,76**
	E02/00	6,70	4,40	1,14	**383,38**
	D23/02	6,70	4,80	1,65	**451,29**
	E01/00	6,70	4,80	1,81	1192,12
	D21/02	6,70	4,80	1,00	**35,24**
	E36/99	6,70	4,80	1,89	1719,18
	E37/99	6,70	4,90	1,77	**438,72**
	E43/99	6,70	4,90	1,71	**332,00**

	D22/02	6,70	4,70	0,68	**5,68**
	E38/99	6,70	4,70	1,54	**257,61**
Area 6	D18/02	6,30	4,70	1,63	1355,76
	D17/02	6,30	5,05	1,26	**94,63**
	D12/02	6,30	5,50	1,80	**182,04**
	D11/02	6,30	5,00	1,28	**93,48**
Area 7	EL10/09	7,00	4,90	2,22	24067,42
	A05/02	7,00	4,90	1,40	**376,94**
	EL78/10	7,00	4,90	1,82	3999,25
	EL02/10	7,00	4,70	1,18	**327,70**
	CM03/13	7,00	4,80	1,70	3019,28
	EL35/12	7,00	4,80	1,48	1105,51
	CM69/12	7,00	4,80	2,38	107760,92
	EL38/12	7,00	4,80	0,74	**35,18**
	CM70/12	7,00	4,80	1,53	1270,46
	CM24/12	7,00	4,70	1,36	**912,35**
	CM83/12	7,00	4,70	1,07	**217,70**
	CM84/12	7,00	5,30	1,64	**314,98**
	CM85/12	7,00	5,30	2,59	24991,25
	CM82/12	7,00	5,30	1,91	**861,78**
	EL76/10	7,00	4,80	1,31	**466,01**
	CM23/12	7,00	4,80	2,24	33651,11
	EL09/09	7,00	5,40	2,35	3971,88
	EL12/09	7,00	5,40	2,71	18776,52
	E05/00	7,00	5,40	2,52	7568,91
	CM01/12	7,00	4,70	1,42	**880,87**
	CM02/12	7,00	4,70	2,48	259695,67
	EL75/10	7,00	4,70	2,57	408061,96
	CM03/12	7,00	4,70	1,67	1991,61
	CM04/12	7,00	4,70	2,73	743973,08
	CM25/12	7,00	4,70	1,60	**384,51**
	EL11/10	7,00	4,70	2,51	202919,62
	CM05/12	7,00	4,70	3,10	13668013,13
	W64A/03	7,00	4,70	1,25	**40,90**
	CM07/12	7,00	4,70	1,24	**296,60**
Area 8	D15/02	6,30	5,45	1,05	**27,53**
	D16/02	6,30	5,45	1,02	**16,66**
Area 9	D02/02	6,50	5,70	1,91	**898,02**
	D05/02	6,50	5,70	1,09	**45,39**
	EL24/09	6,50	5,60	1,79	1365,84
	D14/02	6,50	7,30	4,13	12386,39
Area 10	E47/01	6,40	6,60	3,42	14342,20
	E52/01	6,40	6,60	2,96	1622,99
	E80/96	6,40	6,60	2,63	**473,89**
	E81/96	6,40	6,90	4,33	70884,27
Area 11	E43/01	6,30	6,90	3,70	9889,62
	E65/00	6,30	6,90	3,72	17154,33

	E42/01	6,30	6,90	4,17	65335,98
	E64/00	6,30	7,00	3,66	9245,69
	E41/01	6,30	7,00	4,27	66903,71
	E63/00	6,30	7,00	3,92	8174,04
	E69/00	6,30	7,00	4,57	1060449,33
	E78/96	6,30	7,00	3,76	4602,33
	E27/97	6,30	6,50	3,37	14119,26
Area 12	E30/97	6,80	7,10	4,23	11649,03
Area 13	E77/96	6,90	6,80	2,80	**996,91**
Area 14	E76/96	6,60	6,80	3,05	1163,73
	E20/87	6,60	7,10	3,58	2170,29
Area 15	E10/99	5,90	7,10	4,59	11279,13
	E74/96	5,90	7,00	4,15	3602,85
	E12/99	5,90	7,00	3,70	2382,38
Area 16	E13/99	6,00	7,00	4,17	4757,52
Area 17	E15/99	6,00	7,20	3,98	3530,44
	E71/96	6,00	7,24	3,83	1047,47
	E14/99	6,00	7,24	3,92	1877,28
	E24/01	6,00	7,00	4,30	5523,85
Area 18	E75/96	6,70	6,00	1,95	**386,34**
	WE37	6,70	6,00	2,47	**894,79**
	E73/96	6,70	7,20	3,54	1939,39
Area 19	E72/96	6,00	7,20	3,34	**650,63**
	WE38	6,00	7,30	3,79	1887,06
	E68/96	6,00	7,00	3,06	**318,24**
	E67/95	6,00	6,70	2,85	**474,76**
Area 20	CW07/11	6,20	7,10	5,12	1799616,22
Area 21	WE36	6,20	6,00	3,60	2806,51
Area 22	A11/97	6,10	6,00	3,97	11573,03
	E30/01	6,10	5,90	3,34	13148,47
	E29/01	6,10	5,90	3,17	3531,94
	E28/01	6,10	5,70	3,10	2812,22
Area 23	E07/93	7,00	5,70	2,30	**662,93**
	C16/02	7,00	5,90	3,81	19399,70
	A09/97	7,00	5,90	2,52	**726,15**
	E70/96	7,00	5,90	4,12	1034343,72
	E69/96	7,00	5,50	2,17	1615,88
Area 24	E67/95	6,00	5,50	1,63	**272,75**
	E8/93	6,00	5,80	2,30	1017,91
Area 25	E37/94	7,00	5,50	2,60	5008,99
	WE24	7,00	6,00	3,07	3498,23
Area 26	C17/02	6,00	6,00	3,00	**159,02**
Area 27	E66/95	6,00	6,10	2,46	1030,49
	E39/95	6,00	6,10	2,62	1834,29
	E40/95	6,00	4,70	1,41	2098,33
	E16/93	6,00	4,70	1,39	**809,99**
	CW36/10	6,00	4,90	1,67	3044,61

	E38/95	6,00	4,90	1,52	1265,55
Area 28	E33/95	6,10	4,90	1,42	1207,83
	E42/94	6,10	4,90	1,61	2395,03
	E31/95	6,10	4,90	1,64	2215,99
	E34/95	6,10	4,70	1,88	9549,66
	CW18/11	6,10	4,70	2,28	129249,94
	E45/94	6,10	4,70	2,15	74719,11
Area 29	E30/95	6,10	4,70	1,13	2564,84
	E41A/94	6,10	4,50	1,32	12231,36
	E32/95	6,10	4,50	0,82	1161,18
	E36/95	6,10	4,50	1,69	61767,45
Area 30	E21/93	6,10	4,80	2,24	20066,64
	E17/93	6,10	4,80	2,59	89914,34
Area 31	E40/94	6,70	4,80	2,33	43451,57
Area 32	A17/97	6,70	4,80	1,90	5219,92
	E49/94	6,70	4,80	1,73	4013,95
	E52/94	6,70	4,80	2,13	22161,43
Area 33	E05/98	7,70	4,80	0,96	**703,52**
	CW12/11	7,70	4,80	0,38	**60,83**
Area 34	E45/99	7,50	6,40	2,87	6663,96
	E25/80	7,50	6,40	2,40	1906,23
	E03/98	7,50	6,70	2,31	**700,36**
	E02/98	7,50	6,80	2,38	**580,63**
Area 35	H04/94	7,20	7,20	2,67	**357,64**
Area 36	WEA33	6,80	7,20	3,10	1960,66
Area 37	E04/98	7,10	6,70	2,35	**805,48**
	E28/80	7,10	6,70	3,36	57446,68
Area 38	WEA34	6,70	6,70	2,57	2185,72
	E24/80	6,70	6,70	2,56	1459,96
Area 39	E23/80	7,00	6,70	2,24	**873,36**
Area 40	WEA15	6,80	6,70	2,37	2146,98
Area 41	E23/80	6,60	6,70	2,24	**873,36**

Table 5 - Calculated Pillar Life Spans at the Position of the Available Boreholes

3.6 POTENTIAL SURFACE SUBSIDENCE AND SINKHOLE FORMATION

The main aspects to be considered in this investigation are the risk and possible magnitude of potential surface subsidence occurring in areas above underground workings at Elandsfontein Colliery in which pillar failure occurs as well as the risk of the formation of sinkholes in areas in which the roof above individual bords / intersections on the mining horizon fail.

Surface Subsidence as a Result of Pillar Failure

According to MacCourt et. al. (1986) as referred to by van der Merwe and Madden (2010) the potential surface subsidence above failed bord and pillar workings can be estimated by multiplying the mining height by the areal percentage extraction as per the formula below:

$h_e = h \times e\%$

Where:

e – Areal percentage extraction

The potential subsidence based on this method of estimation, for each one of the existing areas under investigation has been calculated at the position of each of the relevant and available boreholes as detailed in **Table 6** below.

According to van der Merwe and Madden (2010) **Figure 4** below can be used to adjust the expected maximum amounts of subsidence based on the depth at which mining is taking place.

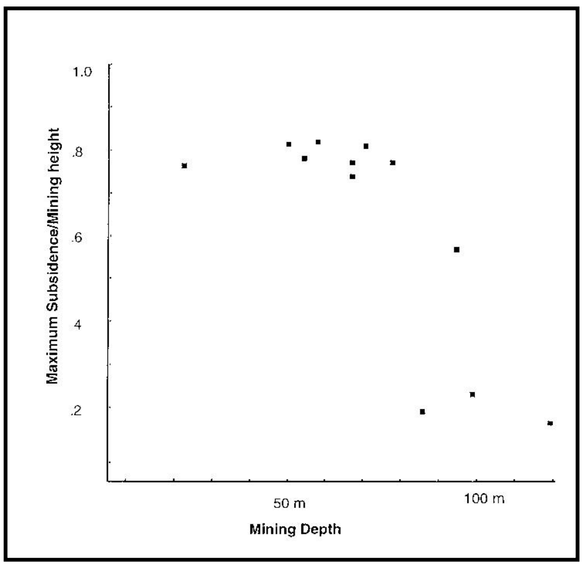

Figure 4 - Estimated Factor to be applied to the Maximum Amounts of Expected Subsidence based on Mining Depth.

In the panels under investigation mining took place close to boreholes in which the depth to the coal seam ranged from 13.9 m to 77.6 m.

Based on the work done by van der Merwe and Madden (2010) the surface subsidence has therefore been assumed to be in the region of 0.8 times the maximum potential surface subsidence calculated using the equation above.

The total amounts of potential surface subsidence have then been estimated to be in the region of the values included in **Table 6** below.

Area	Borehole No.	h (m)	b (m)	Center 1 (m)	Center 2 (m)	e %	he	Sm (m) (Max Subsidence)	H (m)	Sm / H	Sub. Class
Area 1	L04/02	3,04	6,4	14,2	14,0	70,2	2,13	1,71	30,31	0,056	D
	L02/02	2,82	6,4	14,2	14,0	70,2	1,98	1,58	26,22	0,060	E
	L05/02	4,6	6,4	14,2	14,0	70,2	3,23	2,58	23,85	0,108	E
	W74A/03	3,47	6,4	14,2	14,0	70,2	2,44	1,95	23,25	0,084	E
	W68A/03	2,67	6,4	14,2	14,0	70,2	1,87	1,50	28,72	0,052	E
	C13/02	1,59	6,4	14,2	14,0	70,2	1,12	0,89	26,45	0,034	D
	W75A/03	2,74	6,4	14,2	14,0	70,2	1,92	1,54	21,84	0,070	E
Area 2	L03/02	3,76	6,2	14,0	14,0	69,0	2,59	2,07	18,66	0,111	E
	L08/02	2,01	6,2	14,0	14,0	69,0	1,39	1,11	20,51	0,054	E
	C26/02	3,73	6,2	14,0	14,0	69,0	2,57	2,06	19,11	0,108	E
	W63A/03	2,19	6,2	14,0	14,0	69,0	1,51	1,21	17,20	0,070	E
Area 3	CM61/12	0,55	6,4	13,8	14,2	70,5	0,39	0,31	32,00	0,010	C
	W102/03	2,09	6,4	13,8	14,2	70,5	1,47	1,18	35,63	0,033	D
	W53A/03	2,62	6,4	13,8	14,2	70,5	1,85	1,48	35,02	0,042	D
	W57/03	2,39	6,4	13,8	14,2	70,5	1,69	1,35	33,37	0,040	D
	E29/02	2,2	6,4	13,8	14,2	70,5	1,55	1,24	31,13	0,040	D
	D28/02	3,72	6,4	13,8	14,2	70,5	2,62	2,10	27,10	0,077	E
	L10/02	2,78	6,4	13,8	14,2	70,5	1,96	1,57	25,90	0,061	E
	L07/02	3,9	6,4	13,8	14,2	70,5	2,75	2,20	24,41	0,090	E
	L05/02	4,6	6,4	13,8	14,2	70,5	3,25	2,60	23,85	0,109	E
	W100/03	4,11	6,4	13,8	14,2	70,5	2,90	2,32	23,35	0,099	E
	C28/02	3,1	6,4	13,8	14,2	70,5	2,19	1,75	22,11	0,079	D
	C56/05	2,72	6,4	13,8	14,2	70,5	1,92	1,54	31,62	0,049	D
	D27/02	3,1	6,4	13,8	14,2	70,5	2,19	1,75	23,90	0,073	E
	L08/02	2,01	6,4	13,8	14,2	70,5	1,42	1,13	20,51	0,055	E
	D24/02	4,6	6,4	13,8	14,2	70,5	3,25	2,60	22,30	0,116	E
	D25/02	3,25	6,4	13,8	14,2	70,5	2,29	1,83	18,74	0,098	E
	C26/02	3,73	6,4	13,8	14,2	70,5	2,63	2,11	19,11	0,110	E
	D26/02	3,53	6,4	13,8	14,2	70,5	2,49	1,99	22,49	0,089	E
Area 4	E04/00	3,91	6,2	14,1	14,0	68,8	2,69	2,15	29,60	0,073	E
	D29/02	2,89	6,2	14,1	14,0	68,8	1,99	1,59	21,00	0,076	E
	E07/00	2,67	6,2	14,1	14,0	68,8	1,84	1,47	23,94	0,061	E
	E06/00	1,24	6,2	14,1	14,0	68,8	0,85	0,68	26,44	0,026	D
Area 5	D19/02	4,14	6,7	14,1	14,1	72,5	3,00	2,40	24,70	0,097	E
	E03/00	2,57	6,7	14,1	14,1	72,5	1,86	1,49	24,72	0,060	E
	D29/02	2,89	6,7	14,1	14,1	72,5	2,09	1,68	21,00	0,080	E
	E02/00	2,46	6,7	14,1	14,1	72,5	1,78	1,43	25,76	0,055	E
	D23/02	2,58	6,7	14,1	14,1	72,5	1,87	1,50	22,12	0,068	E
	E01/00	2,11	6,7	14,1	14,1	72,5	1,53	1,22	23,03	0,053	E
	D21/02	4,13	6,7	14,1	14,1	72,5	2,99	2,39	24,32	0,098	E
	E36/99	1,96	6,7	14,1	14,1	72,5	1,42	1,14	22,78	0,050	E
	E37/99	2,64	6,7	14,1	14,1	72,5	1,91	1,53	21,14	0,072	E
	E43/99	2,79	6,7	14,1	14,1	72,5	2,02	1,62	21,30	0,076	E
	D22/02	5,74	6,7	14,1	14,1	72,5	4,16	3,33	20,80	0,160	E
	E38/99	2,89	6,7	14,1	14,1	72,5	2,09	1,68	19,84	0,084	E
Area 6	D18/02	2	6,3	14,0	14,0	69,8	1,40	1,12	26,71	0,042	D
	D17/02	3,47	6,3	14,0	14,0	69,8	2,42	1,94	29,22	0,066	E
	D12/02	3,24	6,3	14,0	14,0	69,8	2,26	1,81	29,15	0,062	E
	D11/02	3,49	6,3	14,0	14,0	69,8	2,43	1,95	27,52	0,071	E
Area 7	EL10/09	1,11	7,0	13,0	13,0	78,7	0,87	0,70	37,02	0,019	C
	A05/02	2,59	7,0	13,0	13,0	78,7	2,04	1,63	35,61	0,046	D
	EL78/10	1,6	7,0	13,0	13,0	78,7	1,26	1,01	39,23	0,026	D
	EL02/10	2,57	7,0	13,0	13,0	78,7	2,02	1,62	36,62	0,044	D
	CM03/13	1,68	7,0	13,0	13,0	78,7	1,32	1,06	38,10	0,028	D
	EL35/12	2,05	7,0	13,0	13,0	78,7	1,61	1,29	38,31	0,034	D
	CM69/12	0,8	7,0	13,0	13,0	78,7	0,63	0,50	37,60	0,013	C

	EL38/12	3,85	7,0	13,0	13,0	78,7	3,03	2,42	37,67	0,064	E
	CM70/12	2	7,0	13,0	13,0	78,7	1,57	1,26	37,60	0,033	D
	CM24/12	2,1	7,0	13,0	13,0	78,7	1,65	1,32	38,20	0,035	D
	CM83/12	2,76	7,0	13,0	13,0	78,7	2,17	1,74	37,42	0,046	D
	CM84/12	2,8	7,0	13,0	13,0	78,7	2,20	1,76	37,60	0,047	D
	CM85/12	1,14	7,0	13,0	13,0	78,7	0,90	0,72	37,30	0,019	C
	CM82/12	2,3	7,0	13,0	13,0	78,7	1,81	1,45	36,50	0,040	D
	EL76/10	2,43	7,0	13,0	13,0	78,7	1,91	1,53	37,61	0,041	D
	CM23/12	1,03	7,0	13,0	13,0	78,7	0,81	0,65	34,73	0,019	C
	EL09/09	1,7	7,0	13,0	13,0	78,7	1,34	1,07	35,70	0,030	D
	EL12/09	1,23	7,0	13,0	13,0	78,7	0,97	0,77	33,78	0,023	D
	E05/00	1,49	7,0	13,0	13,0	78,7	1,17	0,94	34,24	0,027	D
	CM01/12	2,14	7,0	13,0	13,0	78,7	1,68	1,35	35,30	0,038	D
	CM02/12	0,66	7,0	13,0	13,0	78,7	0,52	0,42	35,16	0,012	C
	EL75/10	0,6	7,0	13,0	13,0	78,7	0,47	0,38	34,05	0,011	C
	CM03/12	1,84	7,0	13,0	13,0	78,7	1,45	1,16	32,54	0,036	D
	CM04/12	0,53	7,0	13,0	13,0	78,7	0,42	0,33	30,53	0,011	C
	CM25/12	2,66	7,0	13,0	13,0	78,7	2,09	1,67	23,90	0,070	E
	EL11/10	0,7	7,0	13,0	13,0	78,7	0,55	0,44	32,04	0,014	C
	CM05/12	0,28	7,0	13,0	13,0	78,7	0,22	0,18	30,70	0,006	C
	W64A/03	4,2	7,0	13,0	13,0	78,7	3,31	2,64	21,00	0,126	E
	CM07/12	2,66	7,0	13,0	13,0	78,7	2,09	1,67	33,56	0,050	E
Area 8	D15/02	4,42	6,3	13,9	14,0	69,9	3,09	2,47	36,31	0,068	E
	D16/02	4,92	6,3	13,9	14,0	69,9	3,44	2,75	33,44	0,082	E
Area 9	D02/02	2,28	6,5	14,0	14,1	71,1	1,62	1,30	43,98	0,029	D
	D05/02	3,97	6,5	14,0	14,1	71,1	2,82	2,26	45,95	0,049	D
	EL24/09	2,04	6,5	14,0	14,1	71,1	1,45	1,16	50,02	0,023	D
	D14/02	1,49	6,5	14,0	14,1	71,1	1,06	0,85	39,40	0,022	D
Area 10	E47/01	1,38	6,4	13,9	14,0	70,7	0,98	0,78	43,44	0,018	C
	E52/01	2,2	6,4	13,9	14,0	70,7	1,56	1,24	41,05	0,030	D
	E80/96	2,84	6,4	13,9	14,0	70,7	2,01	1,61	41,28	0,039	D
	E81/96	1,01	6,4	13,9	14,0	70,7	0,71	0,57	31,07	0,018	C
Area 11	E43/01	1,53	6,3	13,9	14,0	69,9	1,07	0,86	39,98	0,021	D
	E65/00	1,35	6,3	13,9	14,0	69,9	0,94	0,76	44,55	0,017	C
	E42/01	1,02	6,3	13,9	14,0	69,9	0,71	0,57	37,10	0,015	C
	E64/00	1,55	6,3	13,9	14,0	69,9	1,08	0,87	44,90	0,019	C
	E41/01	1,02	6,3	13,9	14,0	69,9	0,71	0,57	37,10	0,015	C
	E63/00	1,62	6,3	13,9	14,0	69,9	1,13	0,91	33,50	0,027	D
	E69/00	0,55	6,3	13,9	14,0	69,9	0,38	0,31	48,05	0,006	C
	E78/96	1,83	6,3	13,9	14,0	69,9	1,28	1,02	34,71	0,029	D
	E27/97	1,38	6,3	13,9	14,0	69,9	0,97	0,77	41,53	0,019	C
Area 12	E30/97	1,52	6,8	12,1	12,0	81,0	1,23	0,99	38,58	0,026	D
Area 13	E77/96	2,43	6,9	14,0	14,0	74,3	1,81	1,44	48,90	0,030	D
Area 14	E76/96	2,39	6,6	12,0	12,0	79,8	1,91	1,52	56,06	0,027	D
	E20/87	2,15	6,6	12,0	12,0	79,8	1,71	1,37	51,27	0,027	D
Area 15	E10/99	1,56	5,9	12,0	12,0	74,2	1,16	0,93	25,32	0,037	D
	E74/96	1,98	5,9	12,0	12,0	74,2	1,47	1,17	29,39	0,040	D
	E12/99	2,12	5,9	12,0	12,0	74,2	1,57	1,26	42,91	0,029	D
Area 16	E13/99	1,86	6,0	12,0	12,0	75,0	1,40	1,12	30,56	0,037	D
Area 17	E15/99	1,97	6,0	12,0	12,0	75,0	1,48	1,18	42,84	0,028	D
	E71/96	2,58	6,0	12,0	12,0	75,0	1,94	1,55	38,95	0,040	D
	E14/99	2,27	6,0	12,0	12,0	75,0	1,70	1,36	40,56	0,034	D
	E24/01	1,81	6,0	12,0	12,0	75,0	1,36	1,09	27,26	0,040	D
Area 18	E75/96	2,78	6,7	12,0	13,0	78,6	2,18	1,75	55,76	0,031	D
	WE37	2,42	6,7	12,0	13,0	78,6	1,90	1,52	42,30	0,036	D
	E73/96	2,2	6,7	12,0	13,0	78,6	1,73	1,38	52,20	0,026	D
Area 19	E72/96	2,79	6,0	12,0	12,0	75,0	2,09	1,67	52,06	0,032	D
	WE38	2,25	6,0	12,0	12,0	75,0	1,69	1,35	48,34	0,028	D
	E68/96	3,22	6,0	12,0	12,0	75,0	2,42	1,93	48,28	0,040	D
	E67/95	2,89	6,0	12,0	12,0	75,0	2,17	1,73	50,21	0,035	D
Area 20	CW07/11	0,5	6,2	12,0	12,0	76,6	0,38	0,31	38,50	0,008	C
Area 21	WE36	2,03	6,2	12,0	12,0	76,6	1,56	1,24	16,94	0,073	E

Area 22	A11/97	1,5	6,1	12,0	12,0	75,8	1,14	0,91	13,86	0,066	E
	E30/01	1,4	6,1	12,0	12,0	75,8	1,06	0,85	30,05	0,028	D
	E29/01	1,87	6,1	12,0	12,0	75,8	1,42	1,13	27,29	0,042	D
	E28/01	1,96	6,1	12,0	12,0	75,8	1,49	1,19	22,50	0,053	E
Area 23	E07/93	2,55	7,0	12,2	12,0	82,2	2,10	1,68	38,21	0,044	D
	C16/02	1,32	7,0	12,2	12,0	82,2	1,09	0,87	16,91	0,051	E
	A09/97	2,55	7,0	12,2	12,0	82,2	2,10	1,68	37,55	0,045	D
	E70/96	0,54	7,0	12,2	12,0	82,2	0,44	0,36	25,54	0,014	C
	E69/96	2,05	7,0	12,2	12,0	82,2	1,69	1,35	44,88	0,030	D
Area 24	E67/95	2,89	6,0	12,1	12,0	74,8	2,16	1,73	50,21	0,034	D
	E8/93	2,31	6,0	12,1	12,0	74,8	1,73	1,38	46,65	0,030	D
Area 25	E37/94	1,65	7,0	12,0	12,0	82,6	1,36	1,09	36,97	0,030	D
	WE24	1,86	7,0	12,0	12,0	82,6	1,54	1,23	34,09	0,036	D
Area 26	C17/02	3,76	6,0	12,0	12,0	75,0	2,82	2,26	17,99	0,125	E
Area 27	E66/95	2,34	6,0	12,0	12,0	75,0	1,76	1,40	52,16	0,027	D
	E39/95	2,08	6,0	12,0	12,0	75,0	1,56	1,25	51,23	0,024	D
	E40/95	1,75	6,0	12,0	12,0	75,0	1,31	1,05	51,30	0,020	D
	E16/93	2,17	6,0	12,0	12,0	75,0	1,63	1,30	42,10	0,031	D
	CW36/10	1,67	6,0	12,0	12,0	75,0	1,25	1,00	50,93	0,020	D
	E38/95	2	6,0	12,0	12,0	75,0	1,50	1,20	48,60	0,025	D
Area 28	E33/95	1,99	6,1	12,0	12,0	75,8	1,51	1,21	53,40	0,023	D
	E42/94	1,75	6,1	12,0	12,0	75,8	1,33	1,06	51,33	0,021	D
	E31/95	1,79	6,1	12,0	12,0	75,8	1,36	1,09	48,63	0,022	D
	E34/95	1,32	6,1	12,0	12,0	75,8	1,00	0,80	42,83	0,019	C
	CW18/11	0,76	6,1	12,0	12,0	75,8	0,58	0,46	46,32	0,010	C
	E45/94	0,85	6,1	12,0	12,0	75,8	0,64	0,52	48,70	0,011	C
Area 29	E30/95	1,59	6,1	21,0	12,0	65,1	1,04	0,83	41,17	0,020	D
	E41A/94	1,15	6,1	21,0	12,0	65,1	0,75	0,60	40,37	0,015	C
	E32/95	1,77	6,1	21,0	12,0	65,1	1,15	0,92	40,70	0,023	D
	E36/95	0,84	6,1	21,0	12,0	65,1	0,55	0,44	37,90	0,012	C
Area 30	E21/93	1,16	6,1	12,0	12,0	75,8	0,88	0,70	36,05	0,020	D
	E17/93	0,85	6,1	12,0	12,0	75,8	0,64	0,52	31,66	0,016	C
Area 31	E40/94	0,98	6,7	12,0	12,0	80,5	0,79	0,63	38,53	0,016	C
Area 32	A17/97	1,52	6,7	12,0	12,0	80,5	1,22	0,98	40,42	0,024	D
	E49/94	1,58	6,7	12,0	12,0	80,5	1,27	1,02	46,20	0,022	D
	E52/94	1,12	6,7	12,0	12,0	80,5	0,90	0,72	42,78	0,017	C
Area 33	E05/98	2,06	7,7	14,0	14,1	79,6	1,64	1,31	50,67	0,026	D
	CW12/11	2,92	7,7	14,0	14,1	79,6	2,32	1,86	54,82	0,034	D
Area 34	E45/99	1,58	7,5	14,0	14,0	78,4	1,24	0,99	51,79	0,019	C
	E25/80	2,02	7,5	14,0	14,0	78,4	1,58	1,27	59,25	0,021	D
	E03/98	2,52	7,5	14,0	14,0	78,4	1,98	1,58	62,77	0,025	D
	E02/98	2,65	7,5	14,0	14,0	78,4	2,08	1,66	60,73	0,027	D
Area 35	H04/94	3,04	7,2	14,0	14,0	76,4	2,32	1,86	57,09	0,033	D
Area 36	WEA33	2,13	6,8	14,0	14,0	73,6	1,57	1,25	60,13	0,021	D
Area 37	E04/98	2,45	7,1	14,0	14,0	75,7	1,85	1,48	62,82	0,024	D
	E28/80	1	7,1	14,0	14,0	75,7	0,76	0,61	68,97	0,009	C
Area 38	WEA34	1,99	6,7	13,8	14,0	73,2	1,46	1,16	66,84	0,017	C
	E24/80	2,18	6,7	13,8	14,0	73,2	1,60	1,28	61,68	0,021	D
Area 39	E23/80	2,38	7,0	14,0	14,0	75,0	1,79	1,43	69,49	0,021	D
Area 40	WEA15	1,96	6,8	14,0	14,0	73,6	1,44	1,15	77,62	0,015	C
Area 41	E23/80	2,38	6,6	14,0	14,0	72,1	1,72	1,37	69,49	0,020	D

Table 6 - Anticipated Maximum Amounts of Surface Subsidence as well as the Subsidence Class Per Area.

The estimated total possible magnitude of surface subsidence can then be divided by the mining depth (H) to identify which class the subsidence in each panel is likely to fall in.

As can be noted from **Table 6**, most of the areas which have been mined at Elandsfontein Colliery to date either fall into **Class D** or **Class E** with a few panels falling into **Class C**.

The following is valid regarding the various classes:

- Class C can be described as: "*Noticeable in flat terrain, smooth, cracks 2 – 10 cm wide, compression ridges 1 to 5 cm high*."
- Class D can be described as: "*Noticeable in most terrain, visible vertical displacements across cracks, cracks 10 – 50 cm wide, compression ridges 5 to 50 cm high*."
- Class E can be described as: "*Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm high.*"

Class	Sm/H ratio	Description
A	< 0,001	Barely noticeable, smooth, continuous profile, hair-line cracks
B	0,00 – 0,005	Difficult to notice, smooth profile, cracks 1 – 2 cm wide
C	0,005 – 0,02	Noticeable in flat terrain, smooth, cracks 2 – 10 cm wide, compression ridges 1 to 5 cm high
D	0,02 – 0,05	Noticeable in most terrain, visible vertical displacements across cracks, cracks 10 – 50 cm wide, compression ridges 5 to 50 cm high
E	>0,05	Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm high

Table 7 - The Various Possible Subsidence Classes as well as the Surface Profile which they can be expected to be Associated with

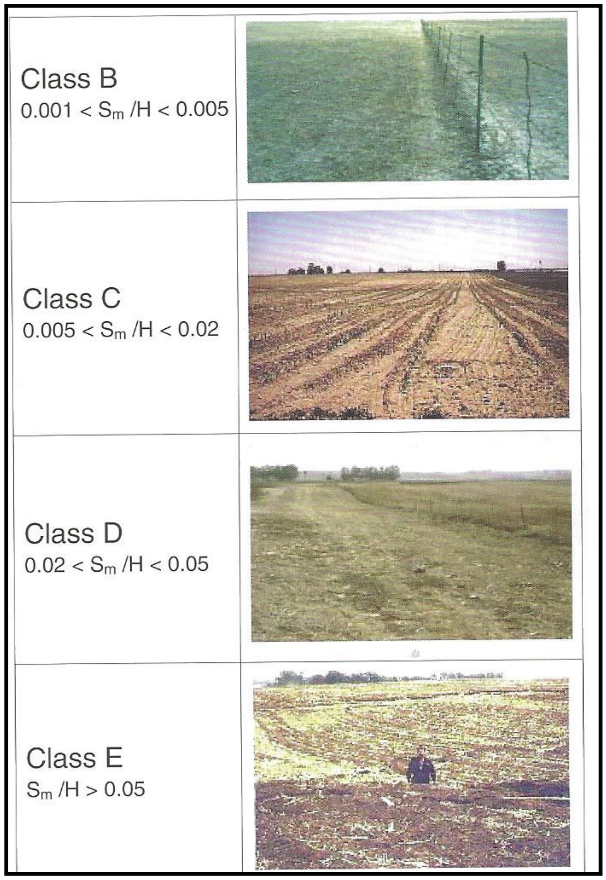

Figure 5 - Examples of the Various Possible Subsidence Classes

Anticipated remedial measures to mitigate the effects of subsidence could be to bulldoze the crack and crest area to create a more even surface profile and close any openings (cracks) which may have formed as a result of the subsidence.

<u>Sinkhole Formation</u>

Sinkhole formation has been found by Hill, R. W. (1996), to be possible when mining is conducted at depths of less than 40 m which has been found to be the case in a number of areas in which underground mining has been conducted at Elandsfontein Colliery.

Canbulat, I. and Ryder, J.A. (2002) proposed a methodology to assess the likelihood of sinkhole formation which takes into account the depth of mining, mining heights, mining dimensions as well as the overburden strata.

This methodology was adopted in this investigation and yielded the following results as included in **Table 8** below.

Roof stability assessments which have been conducted and are indicated in **Table 8** below refer to long-term stability of the roof and should they indicate possible "Roof Failure", do not imply that there is / was necessarily an immediate risk of roof failure in the underground workings.

Sinkhole Formation						
Area		h	Comp. Layer Thickness	Tensile Stress	Shear Stress	Risk
1	L05/02	4,60	5,00	Stable Roof	Stable Roof	Sinkhole Formation Likely
2	L03/02	3,80	3,50	Stable Roof	Stable Roof	Sinkhole Formation Likely
3	L05/02	4,60	2,70	Stable Roof	Stable Roof	Sinkhole Formation Likely
4	E06/00	1,20	2,80	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
5	WE36	2,00	3,00	Stable Roof	Stable Roof	Sinkhole Formation Likely
6	E28/01	2,00	8,70	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
7	E07/93	2,60	3,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
8	E67/95	2,90	3,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
9	D22/02	5,70	5,40	Stable Roof	Stable Roof	Sinkhole Formation Likely
10	D17/02	3,50	9,20	Stable Roof	Stable Roof	Sinkhole Formation Likely
11	EL12/09	1,20	3,90	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
12	D15/02	4,40	9,70	Stable Roof	Stable Roof	Sinkhole Formation Likely
13	E37/94	2,25	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
14	C17/02	3,80	6,20	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
15	CW36/10	1,70	19,80	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
16	CW18/11	0,80	17,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
17	D14/02	1,50	8,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
18	E81/96	1,00	3,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
19	E42/01	1,00	18,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
20	E30/97	1,50	17,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
21	E30/95	1,60	3,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
22	E21/93	1,20	3,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
23	E40/94	1,00	3,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
24	E49/94	1,60	3,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
25	E77/96	2,40	10,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
26	E76/96	2,40	10,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
27	E10/99	1,60	10,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
28	E13/99	1,90	10,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
29	CW12/11	2,90	1014,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
30	E02/98	2,70	15,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
31	H04/94	3,00	10,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
32	WEA33	2,20	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
33	E24/01	1,80	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
34	E75/96	2,80	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
35	E72/96	2,80	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
36	CW07/11	0,50	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
37	E04/98	3,90	8,00	Stable Roof	Stable Roof	Sinkhole Formation Likely
38	E24/80	2,20	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
39	E23/80	2,40	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
40	WEA15	2,00	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
41	E23/80	2,40	5,00	Stable Roof	Stable Roof	Sinkhole Formation Unlikely

Table 8 - Likelihood of Sinkhole Formation at Each Borehole Position based on the Methodology suggested by Canbulat, I. and Ryder, J.A. (2002).

As can be seen from the information included in **Table 8** above, the sandstone layers, which are present in the No. 1 Seam's overburden in the position of all the boreholes within the Elandsfontein Colliery mining area, are expected to remain stable in the short to medium term (not taking into account the effects of jointing / weathering) over the typical mining spans in each of the Forty-One (41) areas. In the event of failure of the overburden strata in the position of boreholes L05/02, L03/02, WE36, D22/02, D17/02, D15/02 and E04/98 and progressive caving of the overburden, the caved material would not be expected to choke the void before the caving reaches the weathered zone, which may then result in the formation of sinkholes. It is for this reason that sinkhole formation is deemed possible in these areas. As indicated above, there is expected to be a significantly thick, competent Sandstone layer in the No. 1 Seam's overburden in the Elandsfontein mining area and, as a result, although sinkhole formation is deemed to be possible in these areas were the overburden material to progressively cave, the failure of the overburden strata is deemed to be unlikely and therefore the formation of sinkholes in these areas is not thought to be likely in the short to medium term.

3.7 RISK ASSESSMENT

Based on the findings of the above investigations, a risk assessment has been conducted in an attempt to identify the areas in which the risk of pillar failure and associated surface subsidence as well as sinkhole formation is greatest in the short to medium term. This risk assessment can be used to highlight the immediate risk areas, but it must also be considered that some areas will be expected to become higher risk areas over time due to the relatively short life expectancy of the pillars in them as calculated above. The results of the risk assessment are included in **Table 10** below and illustrated on the plan included in **Figure 6** below. The matrix used in this risk assessment is illustrated in **Table 9** below.

<u>Risk Assessment Matrix</u>

ELANDSFONTEIN COLLIERY

UNDERGROUND PILLAR FAILURE, SURFACE SUBSIDENCE AND SINKHOLE FORMATION

Document No:	Rev: 0	Document Name: Issue Based Risk Assessment - Risk Matrix	Issue Date: October 2019 Revision Date: N/A

Probability of occurrence of the scenarios			
5	Likely	Almost certainly will occur	$>10^{-2}$
4	Unlikely	Probably will occur	10^{-2} to 10^{-3}
3	Very Unlikely	Possibly could occur	$10^{-3} – 10^{-4}$
2	Extremely unlikely	Probably won't occur	$10^{-4} – 10^{-5}$
1	Remote	Highliy Unlikely	$<10^{-5}$

Risk Ranking Matrix - Golfview Colliery

PROBABILITY							
5	Likely	5	10	15	20	25
4	Unlikely	4	8	12	16	20
3	Very unlikely	3	6	9	12	15
2	Extremely unlikely	2	4	6	8	10
1	Remote	1	2	3	4	5
		1	2	3	4	5
	SEVERITY					
		Moderate	Serious	Major	Catastrophic	Disastrous
		First aid	Medical / Lost time	1 Fatal	Few Fatals	Multiple fatals

Reduction Factor - Control Measures		
Control Measure	**Number allocation**	**Percentage reduction**
Elimination	1	100%
Substitution	2	50%
Engineering Control	3	30%
Administartive	4	20%
PPE	5	10%

SEVERITY LEVELS		
1	Minor, Dangerous acts and First aid	Not used
2	Moderate, Recordable injury, medical treatment	On site: No permanent effect External: no effect
3	Serious, Lost time accident	On site: permanent effects External: no permanent effects
4	Major - Fatality, permanent disability or injury. Involving population	On site: one fatality and/or several permanent invalidities External: permanent effects
5	Catastrophic - Several Fatalities	On site: many fatalitiesExternal: one fatality many physical injuries
5	Disastrous - Several Fatalities	On site: many fatalities External: several fatalities

IMPACT CATEGORIES	
Category	**Description**
S	Safety - Fatalities, Reportable injury, lost time injuries.
PD	Property damage
PL	Product loss
H	Health - HIV/AIDS, Occupational disease, hearing loss.
E	Environmental - Spillage, waste management

Table 9 - Risk Assessment Matrix

ELANDSFONTEIN COLLIERY

ELANDSFONTEIN UNDERGROUND

Document No:	Rev: 0	**Document Name: Issue Based Risk Assessment: Surface Subsidence Risk - Data Sheet**

Document No:	
Mine:	
Process:	**ISSUE BASED RISK ASSESSMENT - SURFACE SUBSIDENCE**
Sub Process:	

Legend:

Consequence		**Risk**	**Risk Reduction**	**Final Risk**
PI - Personal Injury	HI - Health Impact	S - Severity	C - Control measure	A - High Risk and Probability
PD - Property Damage	EI - Environmental Impact	P - Probability	F - Factor	B - Moderate Risk and Probability
PL - Property Loss		R - Risk rating		C - Controlled Risk

Process Activity	Ref. No	Risk Task	Hazard	Risk	Consequence					Potential Risk Value			Comments
					PI	PD	PL	HI	EI	S	P	R	
Surface Subsidence as a Result of Pillar Failure or Sinkhole Formation as a Result of Roof Failure in the Existing Underground Workings	1	Area 1	Surface Subsidence as a result of Pillar Failure in the Existing Underground Workings. Sinkhole formation as a result of Roof Failure in the Existing Underground Workings.	Damage to Surface. Damage to Structures. Damage to the Water Table and Enviroment. Injury to or death of people on Surface.	X	X	X	X	X	4	3	12	Sinkhole formation possible
	2	**Area 2**			X	X	X	X	X	5	3	15	Sinkhole formation possible. Eskom pylon on surface
	3	Area 3			X	X	X	X	X	4	3	12	Sinkhole formation possible
	4	Area 4			X	X	X	X	X	4	2	8	Pillar failure possible over time
	5	**Area 5**			X	X	X	X	X	5	3	15	Sinkhole formation possible. Road on surface
	6	Area 6			X	X	X	X	X	4	2	8	Pillar failure possible over time
	7	Area 7			X	X	X	X	X	5	1	5	
	8	**Area 8**			X	X	X	X	X	4	4	16	Pillar failure likely over time
	9	Area 9			X	X	X	X	X	4	3	12	Sinkhole formation possible
	10	Area 10			X	X	X	X	X	4	3	12	Sinkhole formation possible
	11	Area 11			X	X	X	X	X	4	1	4	
	12	Area 12			X	X	X	X	X	4	3	12	Sinkhole formation possible
	13	Area 13			X	X	X	X	X	4	1	4	
	14	Area 14			X	X	X	X	X	4	2	8	Pillar failure possible over time
	15	Area 15			X	X	X	X	X	4	1	4	
	16	Area 16			X	X	X	X	X	4	1	4	

Surface Subsidence as a Result of Pillar Failure or Sinkhole Formation as a Result of Roof Failure in the Existing Underground Workings	17	Area 17	Surface Subsidence as a result of Pillar Failure in the Existing Underground Workings. Sinkhole formation as a result of Roof Failure in the Existing Underground Workings.	Damage to Surface. Damage to Structures. Damage to the Water Table and Enviroment. Injury to or death of people on Surface.	X	X	X	X	X	4	1	4	
	18	Area 18			X	X	X	X	X	4	2	8	Pillar failure possible over time
	19	Area 19			X	X	X	X	X	4	2	8	Pillar failure possible over time
	20	Area 20			X	X	X	X	X	4	1	4	
	21	Area 21			X	X	X	X	X	5	1	5	Eskom pylon on surface
	22	Area 22			X	X	X	X	X	5	1	5	Pipeline on surface
	23	Area 23			X	X	X	X	X	5	2	10	Pillar failure possible over time. Pipeline on surface
	24	Area 24			X	X	X	X	X	5	2	10	Pillar failure possible over time. Pipeline on surface
	25	Area 25			X	X	X	X	X	4	1	4	
	26	**Area 26**			X	X	X	X	X	5	3	15	Pillar failure likely over time. Pipeline on surface
	27	Area 27			X	X	X	X	X	4	2	8	Pillar failure possible over time
	28	Area 28			X	X	X	X	X	4	2	8	Pillar failure possible over time
	29	Area 29			X	X	X	X	X	4	1	4	
	30	Area 30			X	X	X	X	X	4	1	4	
	31	Area 31			X	X	X	X	X	5	1	5	Eskom pylon on surface
	32	Area 32			X	X	X	X	X	4	2	8	Pillar failure possible over time
	33	**Area 33**			X	X	X	X	X	4	4	16	Pillar failure likely over time
	34	**Area 34**			X	X	X	X	X	4	4	16	Pillar failure likely over time
	35	**Area 35**			X	X	X	X	X	4	4	16	Pillar failure likely over time
	36	Area 36			X	X	X	X	X	4	2	8	Pillar failure possible over time
	37	**Area 37**			X	X	X	X	X	4	4	16	Pillar failure and sinkhole formation possible over time
	38	Area 38			X	X	X	X	X	5	2	10	Pillar failure possible over time. Railw ay line next to area on surface
	39	**Area 39**			X	X	X	X	X	5	4	20	Pillar failure likely over time. Railw ay line next to area on surface
	40	**Area 40**			X	X	X	X	X	4	4	16	Pillar failure likely over time
	41	Area 41			X	X	X	X	X	4	2	8	Pillar failure possible over time

Table 10 - Results of the Surface Subsidence and Sinkhole Formation Risk Assessment which has been Conducted at Elandsfontein Colliery.

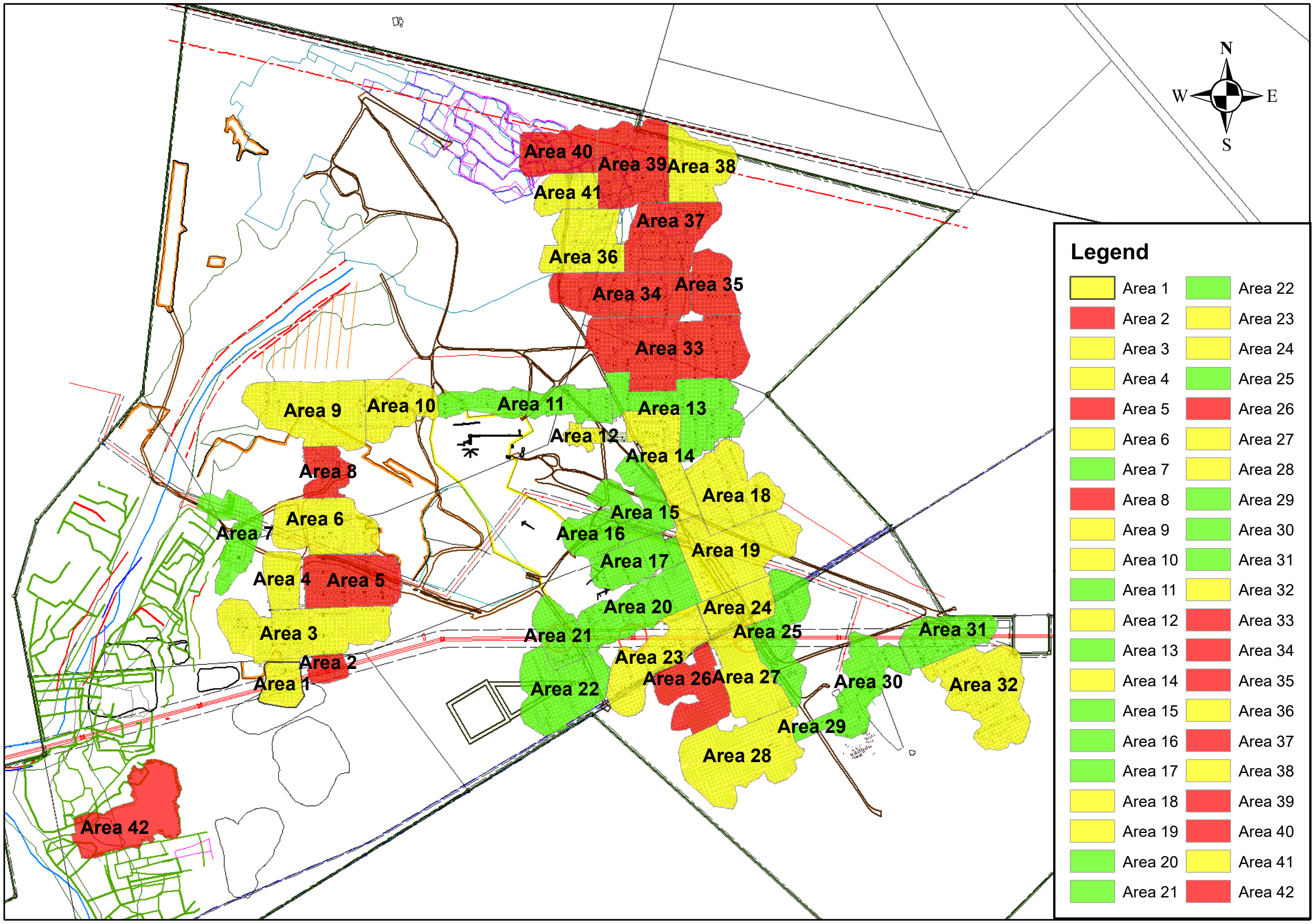

Figure 6 - Illustration of the Calculated Risk Per Investigation Area.

3.8 FUTURE UNDERGROUND MINING AREAS

Underground mining typically poses Two (2) primary Rock Engineering related risks to surface and the associated structures / features i.e. pillar instability and roof instability.

The collapse of the pillars usually occurs over the width of a panel, while the failure of the roof usually occurs in individual bords or intersections.

In the latter case if the roof was to fail in One (1) area, and the failure was to propagate through the overburden to within the weathered zone near surface, a sinkhole would be likely to form. If this were found to occur in one area, additional sinkholes would be likely to form in other areas over time.

To prevent underground mining from influencing surface in the future mining areas it would be important to consider these Two (2) primary risks in the overall mine design and layouts.

Because the No. 1 Seam at Elandsfontein Colliery often occurs at depths of less than 40 m below surface, the risks to surface associated with underground mining are considerably higher.

At least the following design guidelines will typically have to be applied at Elandsfontein Colliery when mining the No. 1 Seam via underground mining methods in future to ensure that the risks to surface are as far as possible limited:

- The following minimum pillar Safety Factors must be complied with at all times:
    - Main developments: 2.0
    - Production panels: 1.6
- In areas in which mining will be conducted within a horizontal distance of 100 m of a surface structure or feature, including an environmental restriction, an application to mine within the identified area should be submitted along with a Geotechnical Risk Assessment.
- In such a Risk Assessment, all the relevant design guidelines would be documented but the following minimum pillar Safety Factors can be considered as a guideline:
    - Buildings where people congregate: 2.5.
    - Provincial Roads: 2.5.
    - Power Lines: 2.0.
    - Pans: 2.0.
    - Farm Dams: 2.0.
    - Areas in which sensitive environmental ecosystems / wetlands / rivers occur on surface: 2.5.
- In areas in which mining is to take place at depths of less than 40 m, the following revised Shallow Mining Guidelines must at least be complied with in addition to the criteria listed above:
    - Pillar width to mining height ratio should not be less than 2.2.
    - Areal percentage extraction should not be greater than 75 %.
    - The minimum pillar width should not be less than 6.5 m.
    - A minimum safety factor of 2.1 should be used.
- In areas in which mining is to take place at depths of less than 40 m a Rock Engineering risk assessment must also be conducted into the risks of sinkhole formation which must detail measures to be put in place to prevent such features from forming.

To date the previous underground mining at Elandsfontein Colliery has not been found to have had any impact on surface in the form of subsidence or sinkhole formation and the pillars as well as the No. 1 Seam's overburden, in the existing underground workings (where accessible / visible) have been found to remain stable.

Based on the observations made to date and provided that at least the above recommended minimum guidelines are complied with at all times in future underground mining areas on the No. 1 Seam at Elandsfontein Colliery, and that a Competent Rock Engineer is involved in the mine planning and operation of the mine, it is believed to be highly unlikely that future underground mining on the No. 1 Seam will have an impact on any surface structures / features at Elandsfontein Colliery in the long term.

4. CONCLUSIONS AND SUGGESTIONS

The following conclusions and suggestions are made, based on the investigations which have been conducted into the possibility and risk of surface subsidence as a result of failure of the existing pillars in the underground workings and / or potential sinkhole formation as a result of failure of the overburden / roof above the existing underground voids on the No. 1 Seam at Elandsfontein Colliery:

- At the request of Mr. R. Joubert, a rock engineering investigation has been conducted to assess the risks of surface subsidence and sinkhole formation within the Elandsfontein mining area as a result of possible pillar failure in the existing workings on the No. 1 Seam.
- For the purposes of the risk assessment, the existing underground workings were sub-divided into Forty-Two (2) different areas.
- Area 42 is located in the south-western portion of the mining area and, at the time of the investigation, there were no underground mining layouts available for this area. The area has therefore been excluded from the investigations conducted in this report however it is recommended that, based on the depth to the No. 1 Seam in this area and the apparent thickness of the No. 1 Seam, the area be classified and managed as a "High Risk" area until further investigations into the risks of sinkhole formation and surface subsidence have been conducted for it.
- The stability of the existing pillars on the No. 1 Seam as well as the likelihood of sinkhole formation were assessed in the remaining Forty-One (41) areas.
- This was done in the following manner:
    - Surface subsidence - By calculating the as mined pillar safety factors, width-to-height ratios and pillar widths and comparing them with the recommended mine design guidelines to assess their probability of failure.
    - Sinkhole formation – By using the mining parameters (i.e. pillar centers, bord widths, mining heights and mining depths) as well as the overburden strata, in each of the areas, to assess the likelihood of failure of the roof taking place underground and it potentially propagating to surface over time.
- The anticipated life spans of the pillars in the position of each of the boreholes within the project area was subsequently calculated, to assess the anticipated long-term stability / life of the existing pillars.

- Due to the variable nature of the No. 1 Seam (undulations in the floor horizon / depth and significant variations in seam thickness) in each of the Forty-One (41) areas, the worst-case scenario was assumed for this investigation based on the available borehole information for each area.
- Based on the findings of these investigations, the following can be stated:
  - Due to the shallow mining depth generally at Elandsfontein Colliery, the pillar safety factors are relatively high in most areas.
  - The following areas were found to have safety factors of less than 1.6 in the position of some of the boreholes within the area:
    - Area 7 (EL38/12).
    - Area 14 (EL76/96).
    - Area 18 (E75/96).
    - Area 23 (E69/96).
    - Area 33 (E05/98 & CW12/11).
    - Area 34 (E25/80, E03/98 & E02/98).
    - Area 35 (H04/94).
    - Area 37 (E04/98).
    - Area 39 (E23/80).
    - Area 40 (WEA15).
  - As a result of the mining depth, the pillar safety factors were found in many areas to be relatively high despite the pillars being small to very small. In many areas the requirements of the shallow mining guidelines to have pillar widths of 6.5 m or more were not complied with.
  - As a result of the small size of the pillars in general, the pillar safety factor calculation is believed to be an optimistic assumption of the general pillar stability at Elandsfontein Colliery.
  - The pillar life span calculations have indicated that the anticipated life spans of the pillars in the positions of a number of the boreholes are moderately to extremely low as a result of the underground mining dimensions. In general, the life spans of the pillars in the Elandsfontein mining area have been found to be variable (from very low to very high) highlighting the risk of pillar failure with time in some of the areas and indicating anticipated stability of the pillars in others.
  - Pillar failure is believed to be possible in all areas in which the safety factors of the pillars are less than 2.1, the pillar widths are less than 6.5 m, the pillar width-to-height ratio is less than 2.2 and / or the pillar widths are less than 6.5 m over time.
  - While it is likely that many if not most of the existing underground workings at Elandsfontein Colliery will become flooded over time, the flooding of the workings is not expected to have a significant impact on the stability of the coal pillars.
- In addition to the assessment of the anticipated stability of the existing pillars on the No. 1 Seam, the expected magnitude of surface subsidence which may manifest were pillar failure to occur as well as the risk of sinkhole formation in each of the Forty-One (41) areas have been assessed.
- Based on the findings of the surface subsidence investigation and, as a result of the fact that mining took place on the No. 1 Seam at Elandsfontein Colliery at relatively shallow mining

depths as well as the mining height and dimensions of the pillars, the magnitude and effect of the possible surface subsidence has been found to be “Moderate to Severe”.

- The investigation into the risk of the formation of sinkholes in each of the Forty-One (41) mining areas found that sinkhole formation is possible in Eight (8) of the Forty-One (41) areas which are listed below:
  - Area 1,
  - Area 2,
  - Area 3,
  - Area 5,
  - Area 9,
  - Area 10,
  - Area 12,
  - Area 37.
- While sinkhole formation is deemed to be possible in these areas as a result of the thickness of the overburden and the mining height in the underground workings (based on the borehole information) in all of the Eight (8) areas it is not deemed to be likely in the short to medium term as a result of the competency of the overburden which occurs above the No. 1 Seam within the Elandsfontein mining area.
- Taking into consideration the findings of the above investigations, a risk assessment has been conducted to identify the areas which are most at risk when it comes to pillar failure, surface subsidence and sinkhole formation in the short to medium term. These areas have been illustrated on plan and correlate directly with areas in which the pillars have been found to have low safety factors / width-to-height ratios; the No. 1 Seam was significantly thick; there is not expected to be a massive Sandstone layer in the No. 1 Seam’s overburden and / or the No. 1 Seam was mined at very shallow depths. A higher risk rating (consequence) has also been applied to areas in which significant infrastructure occurs on surface (i.e. Eskom pylons and / or the railway line) which would be at risk of surface subsidence were to occur / sinkholes were to form.
- A list of design guidelines has also been included in this report which must be complied with in all areas in which underground mining is conducted at Elandsfontein Colliery in the future.
- Provided that, at least the recommended guidelines are complied with, it is highly unlikely that future underground mining at Elandsfontein Colliery will have an impact on the surface structures / features in those areas over the long term.

Should you have any further queries please feel free to contact myself at the following locations: Cell. (082) 413 2641, or Email. duncan@geomech.co.za.

Yours Sincerely

Geomech Consulting (Pty) Ltd

Per: **Duncan Lees** (Senior Rock Engineer)

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