

3 Case study: Sarafina Dolomite Stability Investigation

Based on the definition and structure of a dolomite stability investigation (DSI) as described and refined in section 2 of this document, the following study was conducted in Sarafina, Potchefstroom. The practical application of the study will be used to compile and evaluate the decision support system in section 4 of this document.

3.1 Introduction

3.1.1 Background

This case study is based on a dolomite stability investigation (DSI) which was conducted by AGES (Pty) Ltd for the Tlokwe City Council in the Sarafina Extension. This project was initiated as part of the Regional Dolomite Risk Management Strategy for the Tlokwe City Council. AGES (Pty) Ltd has been appointed by the Tlokwe City Council to conduct the Regional Dolomite Risk Management Strategy (DRMS) in 2009/2010 (AGES, 2010a). This DRMS includes the following phases:

- Regional Dolomite Assessment – based on existing information, regional mapping and regional risk determination
- Detail research process – based on dolomite stability investigations of various identified critical zones
- Management and monitoring – including geohydrological, geotechnical, land use and human activity and development management and monitoring.

The case study used in this report, Dolomite Stability Investigation in Focus Area 4 – Sarafina, Ikageng (AGES, 2012), forms part of the detailed research process as mentioned above. This case study is the implementation of a DSI as described in section 2 of this document. This will then be used as a framework to a decision support system, which will be discussed in section 4 of this document.

During the Preliminary Geo-Environmental Assessment of Dolomitic Land in Potchefstroom (AGES, 2010b) priority focus areas were identified according to the level of risk ratings (i.e. high, medium or low) and the status of the infrastructure (Figure 3). Risk ratings were assigned to the areas with an indicated risk based on the probable occurrence of dolomite and incompetent wet infrastructure. When an area was on both a high-risk dolomite area and an area with old water infrastructure, it became a high-risk area that should receive priority when intervention measures were formulated.

With the event of the Sarafina Sinkhole, reported on 16 May 2011 (-26.737708 S; 27.02139 E), it was decided to elevate the priority of this focus area and immediately investigate this area in order to manage the possible disaster.

AGES (Pty) Ltd was therefore appointed to conduct a DSI for Focus Area 4 in Ikageng,

Potchefstroom, North West Province. This section details the process and findings of the risk of expected dolomite instability events with regard to the risk management and mitigation of Council infrastructure. It must be noted that this investigation was not conducted for township establishment purposes.

Priority Focus Areas

29 March 2010

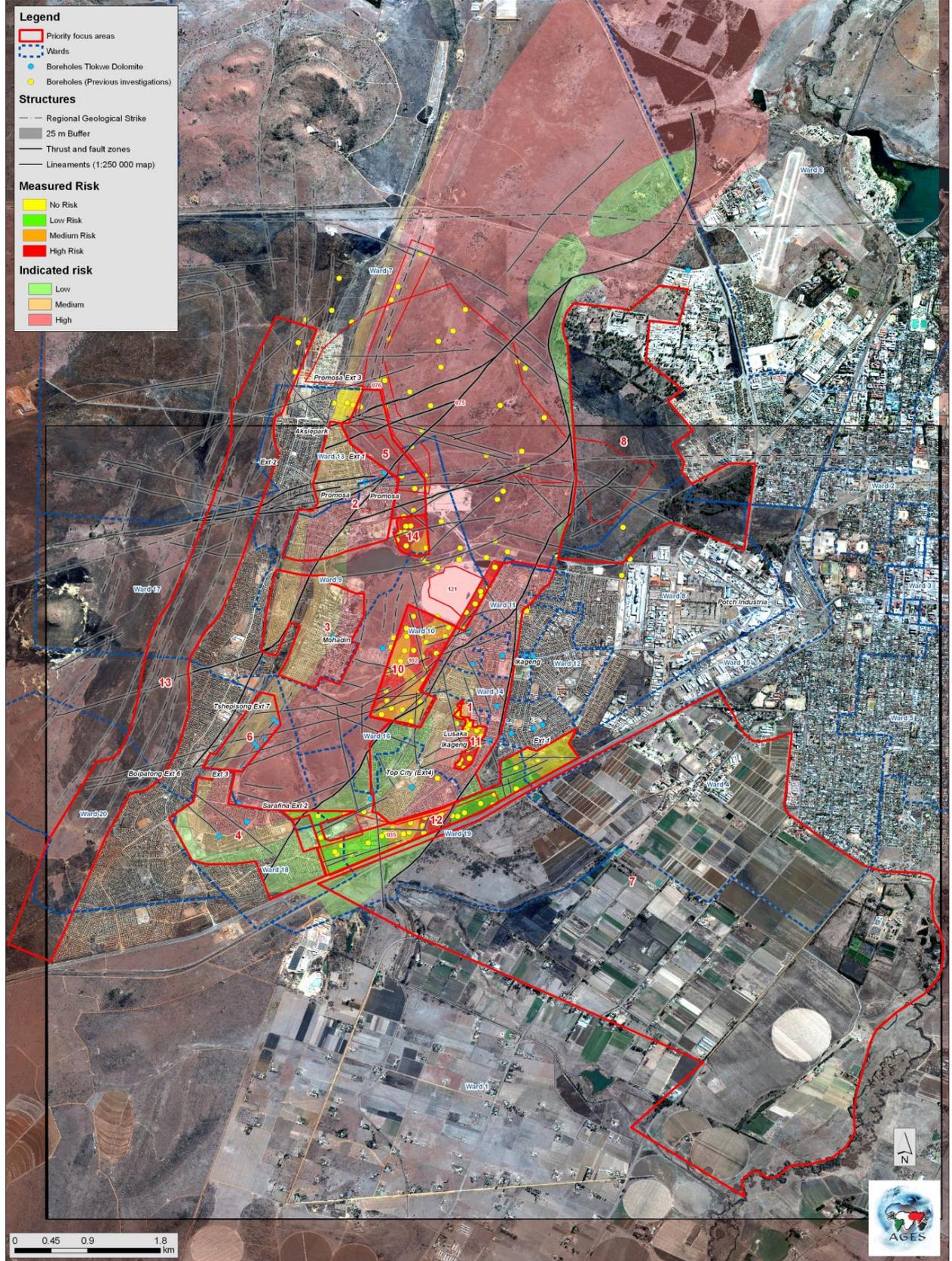


Figure 3: Priority focus areas (Source: AGES, 2010)

3.1.2 Terms of reference

The investigation was requested by the Tlokwe City Council. The investigation was conducted according to:

- GFSH-2 guidelines of the National Department of Housing (2002);
- Consultants guide for the approach to sites on dolomite land by the Council for Geoscience (2007);
- South African National Standard SANS 1936 Parts 1 – 4 (In Draft);
- South African National Standard SANS 633: 2009 – Edition 1 (in Draft);
- Council for Geoscience/South African Institute of Engineering and Environmental Geologists (2003) Guideline for engineering-geological characterisation and development of dolomitic land. Council of Geoscience Publication;
- Geoscience Amendment Act, Act no. 16 of 2010;
- National Home Builders Registration Council: Home Building Manual Part 1 & 2. Revision No: 1. February 1999;
- Buttrick, D. B., Van Schalkwyk, A., Kleywegt, R. J. & Watermeyer, R. B. 2001. Proposed method for dolomite land hazard and risk assessment in South Africa. *Journal of the South African institute of civil engineering*, 43(2):27-36;
- Buttrick, D. B., Trollip, N. Y. G., Watermeyer, R. B., Pieterse, N. D. & Gerber, A. A. 2011. A performance base approach to dolomite risk management. *Environ Earth Sci* (2011):64:1127-1138.

3.1.3 Scope of the investigation

The investigation had the following aims:

- 1) To determine and evaluate the geological and geohydrological character of the study area;
- 2) To assess the risk of the formation of karst-related instability features at the surface;
- 3) To assess the possible size of these surface instability features;
- 4) To characterise the hazard potential in various zones;
- 5) To recommend suitable precautionary and risk mitigation measures to be implemented in the various zones as determined based on above mentioned guidelines and standards.

3.1.4 Information sources

The following information sources were utilised during this study:

Geological maps:

- Geological map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland, 1:1 000 000 (Johnson *et al.*, 2006).
- The 1:250 000 geological map 2626 Wes-Rand (Wilkinson, 1986).
- The Potchefstroom Dorp en Dorpsgronde Geologiese Kaart. 1: 50 000 (Bisschoff, 1992).
- Unpublished field maps from the Council for Geoscience:
- LOMBAARD, B. 1935. KF588 Area to West of Potchefstroom. 1:35 000 (500yds to 1"). Council of Geoscience.
- MELLOW, E.T. 1934. KF589 Map of Potchefstroom – Showing fifteen mile radius. Council of Geoscience.
- TRUTER, F.C. 1936. KF587 2627C. Approximately 1: 75 000. Council of Geoscience.

Geohydrological maps:

- Hydrogeological map Johannesburg 2526 Scale 1:500 000 (Barnard, 1999)
- Explanation of the Hydrogeological map (Barnard, 2000)

Topographical map:

- 2627 CA POTCHEFSTROOM; scale 1 : 50 000 (digital copy)

Aerial photographs:

- Job 1064 Klerksdorp; Strip 010; Photograph 3215 to 3218; scale 1: 50 000
- Chief Directorate: National Geo-Spatial Information; Photograph 2627CA 16 to 22; scale 1 : 10 000; Enlargement factor: 3 times
- Quickbird Satellite Image, June 2008 (GISCOE)
- Google earth, 2008

3.2 *Geo-environmental setting*

3.2.1 Location of the study area

The study area, Focus Area 4 (Figure 4), includes the greater part of Sarafina, with the N12 as a boundary in the south. The study area falls within the Tlokwe Local City Council's area of jurisdiction, which forms part of the Dr Kenneth Kaunda District Municipality. The study area covers a total surface area of approximately 129 ha formalised township development characterised by low-income housing. The size of residential stands in the study area are $\pm 200 \text{ m}^2$, resulting in about 40 houses per hectare, with a population density of ± 180 people per hectare.

The center point of the project area is roughly defined by the following coordinates (WGS84):

- Latitude: -26.741731°S
- Longitude: 27.022547°E

3.2.2 Existing infrastructure

In the greater part of the study area, no appropriate storm water drainage systems have been installed and most of the roads are gravel roads. The areas that have storm water infrastructure and paved roads have been indicated in Figure 5. All the areas do however have active water infrastructure with an average age of about 20 years.

3.2.3 Topography

The study area is located at an elevation of approximately 1 375 metres above mean sea level (mamsl), with an average slope of less than 1.5 % to the south-east. The slope increases to the north of the study area.

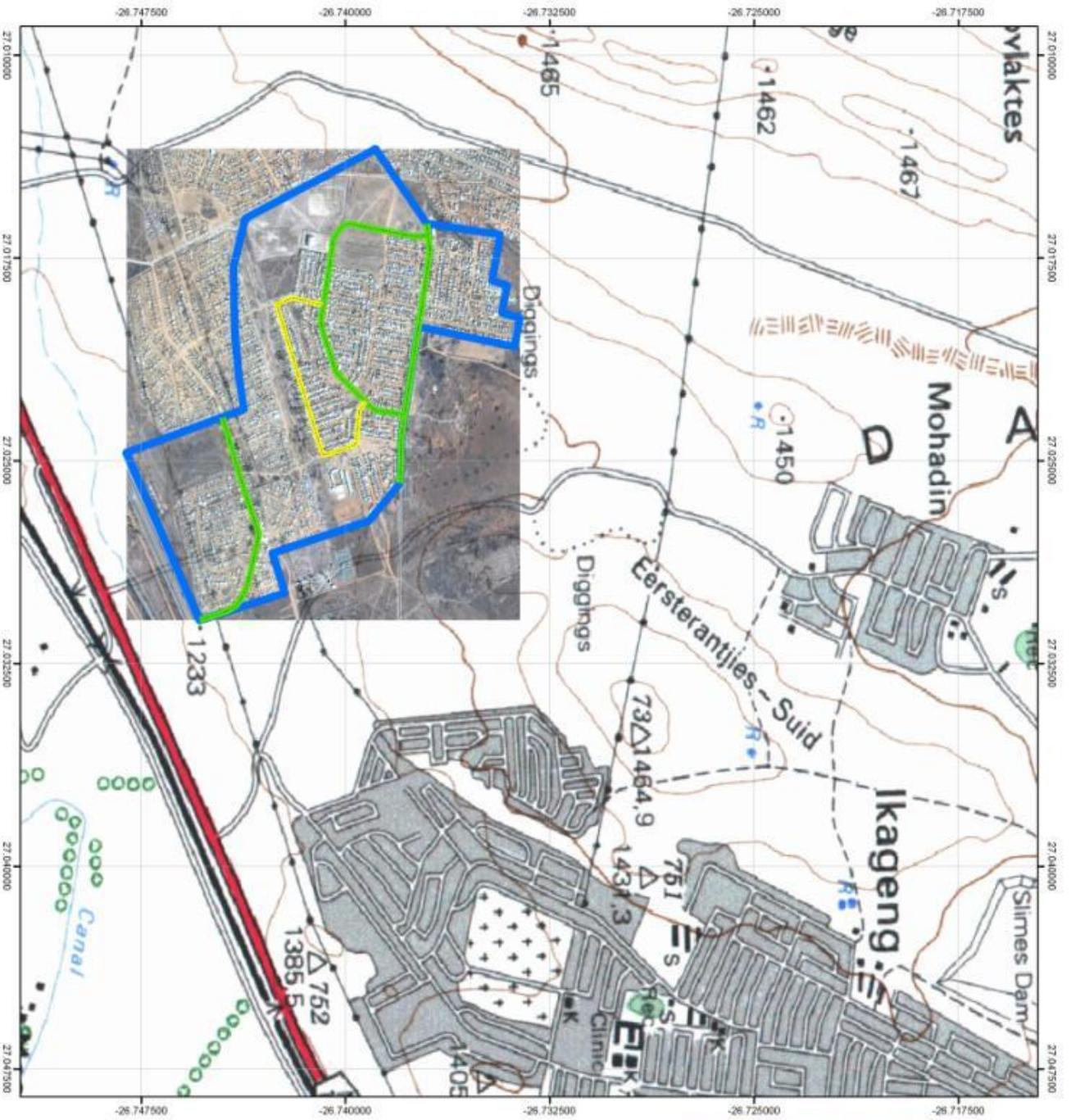
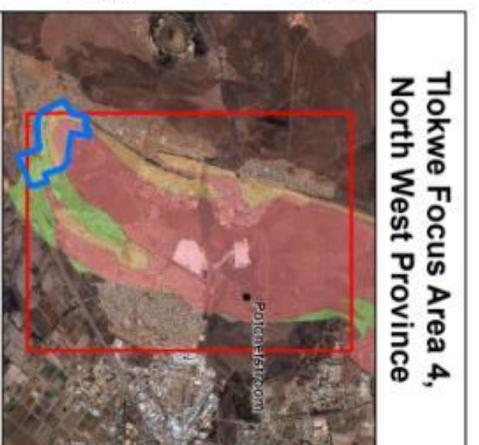


Figure 4: Locality Map



- Legend**
- Focus Area 4
 - Paved Road with stormwater infrastructure
 - Tarred Road with stormwater infrastructure



NORTH WEST OFFICE
 76 Steve Biko Avenue
 Potchefstroom 2531
 Tel: +27 18 297 6588
 Fax: +27 18 297 4813

Source: AGES, 2012



Coordinate system: WGS 1984

3.2.4 Drainage

Due to the slope of the study area, surface drainage occurs in a south-eastern direction, with a decreasing flow rate to the south. Due to the lack of storm water drainage systems, the storm water runoff takes place in the unpaved roads (ENPAT, 2001).

3.2.5 Climate

The study area is located in the Summer Rainfall Zone of the Republic of South Africa in the quaternary catchment C23L within the Vaal Catchment Management area. The area is expected to receive a mean annual precipitation of approximately 610 mm (ENPAT, 2001).

3.2.6 Vegetation

The natural vegetation region within which the study area is situated is classified as Cymbopogan-Themeda Veldt (Sandy), but due to the extent of the urban development, very little of the original vegetation still remains.

3.2.7 Regional seismic risk

According to Fernandez *et al.* (1979) the regional seismic hazard in the project area can be defined as follows:

The area exhibits a 90 % probability of the occurrence of a seismic event not exceeding Class VI-intensity [Strong] (i.e.: equivalent to a seismic event registering 4.9 to 5.4 on the Richter Scale) within a period of 100 years.

The area exhibits a 90 % probability of the occurrence of a seismic event not exceeding Class VII-intensity¹ [Very strong] (i.e.: equivalent to a seismic event registering 5.5 to 6.1 on the Richter scale) within a period of 500 years.

The project area is characterised as a zone where induced seismicity takes place. Estimates of the hazards of these zones are not shown due to the unpredictability of such events that are the result of underground mining activities in the vicinity.

¹ The effects of a Class VII-intensity event (categorized as rather strong) can be summarized as follows:

- Difficult to stand
- Noticed by drivers of motorcars
- Hanging objects quiver
- Furniture broken
- Damage to weak materials (such as adobe: poor mortar; low standards of workmanship; weak horizontally) including cracks
- Weak chimneys broken at roof line
- Fall of plaster, loose bricks, stones, tiles, cornices, unbraced parapets and architectural ornaments
- Some cracks in ordinary workmanship and mortar
- Small slides and caving-in along sand or gravel banks and concrete irrigation ditches will be damaged

Taking the above mentioned information into consideration, the seismic risk of the study area can be classified as SLIGHT, and as such requires that Masonry Class B design and construction measures be implemented, incorporating good workmanship and reinforced mortar work, but specific design and construction measures to resist the effect of lateral forces on the proposed development is not deemed necessary (Fernandez *et al*, 1979).

3.3 Nature of the investigation

3.3.1 Desk study

The investigation commenced with the conducting of the following actions:

- The collation and evaluation of all available geological and geotechnical information from the study area;
- The compilation of base map showing the regional geological setting and morphological character;
- The planning of field work actions.

3.3.2 Field work

The following field work actions were conducted during the study:

- Surface mapping

Surface mapping was done in order to differentiate between the various surface features in the study area. The surface geology was then used to increase the accuracy of the interpolation between the various geological units and to evaluate the condition of the underlying material. The main geological units identified in the study area were dolomite, shale, diabase and quartzite. Below are photos taken of shale and diabase outcrops within the study area:



Photo 1: Shale and diabase outcrops in study area

Source: Own Photograph (2012)

- Geophysical surveys

A detailed gravity survey was conducted across the entire study area to characterise the bedrock morphology (Figure 5). The survey was conducted in August of 2011 by Messrs. Engineering & Exploration Geophysical Services CC utilizing a 30 m-grid spacing. The 1374 stations were laid out and measured by means of a Leica Differential GPS system, and ScintrexAutograv was employed to observe changes in gravity.

All the field observations were reduced to relative Bouguer values using an elevation correction of 0,189 and a theoretical gravity gradient of 0,00065mGals per metre. The final data set was adjusted in order to generate a residual gravity map. The residual gravity map was then used to correlate depth to hard rock dolomite bedrock for the entire study area.

From the residual gravity map, well defined anomalies occur in the north-western third of the site. The strike of these anomalies changes from south-west to south-east to east from north to south. From the drilling it was evident that these anomalies represent stratigraphical changes across the study area.

- Rotary percussion drilling

A total of 45 boreholes have been drilled by Messrs. Hennie Erwee Drilling in Focus Area 4. All boreholes were drilled using rotary percussion techniques (Figure 5). The borehole logs were compiled in LogPlotter and are available from AGES North West. The most relevant drilling logs are attached in Appendix A.

The geophysical and available geological data was used in determining the exact drilling positions. The drilling results were then used to interpret the subsurface properties of the underlying rocks, i.e. geology, rock competency, possible receptacles and water strikes and levels and to assess the precise geological character of the prominent gravity anomalies.

- Drilling specifications:

Drilling was done with air pressure of 19 bar and air capacity of 27.6 m³/s whilst using a 165 mm diameter button drill bit. According to current practice, the boreholes were drilled to a depth of 60 meters or until at least 6 meters of competent dolomite bedrock has been penetrated. The following data was recorded during the drilling: (1) penetration rates per meter drilled, using an electronic stopwatch, (2) depth of groundwater strike, (3) hammer rate, (4) sample loss per meter and (5) air loss per meter.

- Sampling:

Chip samples were collected per meter drilled and described according to the current industry standards (SANS 633). All samples were filed sequentially in plastic sleeves, with tags included. The tags of each sample record the borehole number, sample depth and penetration rate. Below is a photo of the drilling rig in action (Photo 2).



Photo 2: Drilling in study area

Source: Own Photograph

3.3.3 Data evaluation

All geophysical, geological, geohydrological and drilling data was then evaluated and processed. The focus of this was to evaluate and characterise all dolomite instability features within the study area.

3.3.4 Reporting

The investigation concluded with the compilation of a technical report detailing all methodology utilized during the study and all results obtained. That report includes an assessment of the risk of the formation of karst-related surface instability features based on the results from the gravity surveys and percussion drilling, with delineation of the study area into hazard zones according to the industry-standard methods. The development potential of each zone has been defined according to the relevant guidelines, and recommendations given on the design, construction and upgrading of structures and services within each zone.

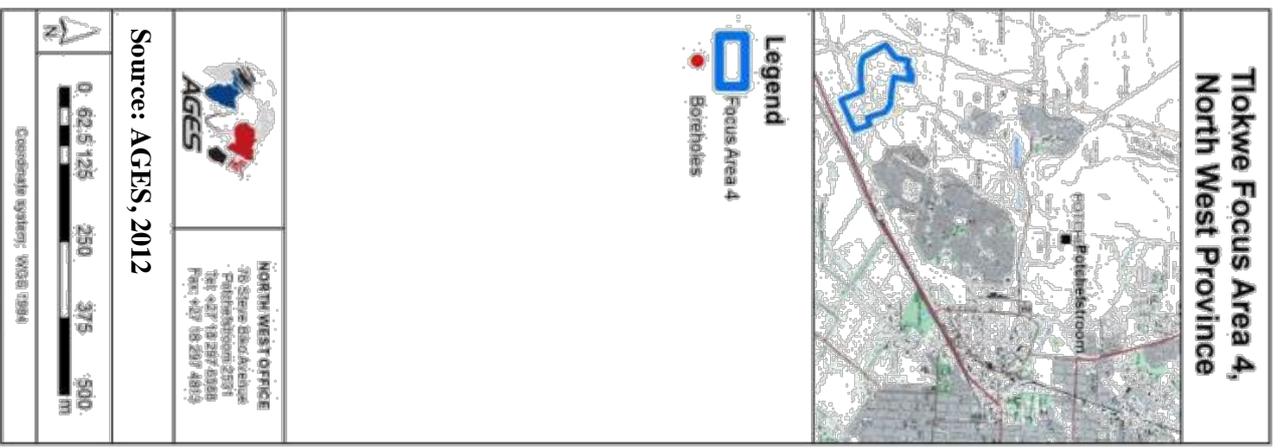
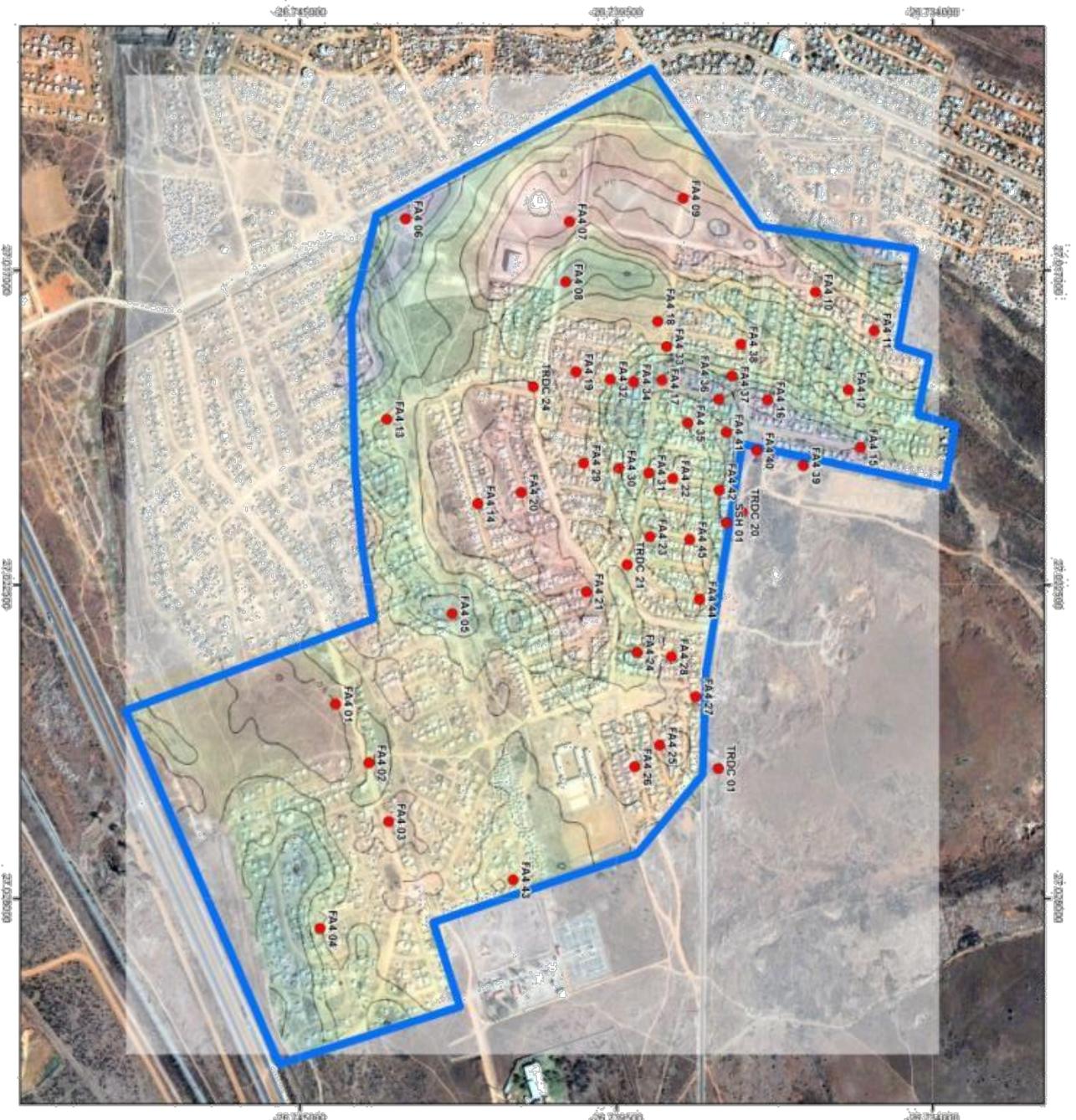


Figure 5: Drilled borehole localities

3.4 Geological Assessment

3.4.1 Regional geological setting

According to the available geological information, the study area is underlain by material from the Transvaal Supergroup, specifically from the Pretoria and Chuniespoort groups.

Table 9: Transvaal sequence

STRATIGRAPHIC UNITS				
SUPERGROUP	GROUP	SUBGROUP	FORMATION	Description
TRANVAAL SEQUENCE	Pretoria		Silwerton	Shale
			Daspoort	Quartzite
			Strubenkop	Shale and iron-rich shale
			Hekpoort	Andesite
			Boshoek	Quartzite
			Timeball Hill	Quartzite, shale and conglomerate
	Chuniespoort	Malmani	Frisco	
			Eccles	Dominant in study area
			Lyttleton	
			Monte Christo	
			Oaktree	
Black Reef			Quartzite	

Source: AGES, 2012

- The Transvaal Sequence

The Transvaal Sequence represents a late Archaean to early Proterozoic basin on the Kaapvaal Craton of Southern Africa. The Transvaal Sequence overlays the Ventersdorp Supergroup in general and is on a more regional scale influenced by the intrusion of the 2060 Ma Bushveld Complex (Eriksson *et al.*, 2001). The Transvaal Sequence represents one of the world's earliest carbonate platform successions recording early history of life on earth (Beukes, 1987; Altermann and Wotherspoon, 1995), representing a geological time frame in the order of 640 Ma (2714 to 2050 Ma). It contains a sequence of rocks deposited to a maximum of 15 000 m thickness (Eriksson *et al.*, 2001), but measured in the Potchefstroom–Fochville area to a total thickness of only 3900m (Jansen, 1967).

- Vredefort Dome

The study area forms part of the outer boundary of a multi-ring regional structure reflecting in the geology around Vredefort as seen in Figure 7. Together with strata belonging to the Witwatersrand (2970 – 2914 Ma), Ventersdorp (2714 Ma) and other, the Transvaal Sequence is part of a conspicuous set of spatially, chronologically and genetic related, concentrically arranged structural elements forming the greater Vredefort Structure (Brink *et al.*, 2000). This represents exposure of the rocks and structures found on the floor of a large impact crater reflecting the greatest single energy release event that occurred on the surface of the earth due to a meteorite impact with age 2023 Ma (Brink *et al.*, 2005).

The occurrence of geological structures related to the development of the greater Vredefort structure is of specific importance in the study area (and this report) as the Potchefstroom Fault, a major dislocation situated in the rim synclinorium of the Vredefort Dome (van der Merwe *et al.*, 1988), is developed in the study area. This results in major dis-homogeneity in geology that may contribute to potential dolomite instability within the study area.

- Regional Structures

Many faults and fractures were identified in the dolomite in and around Potchefstroom. From the nature of the displacements it was pointed out that more than one fault plane is normally developed giving rise to a zone of faulting comprising a number of parallel dislocations and not a simple break (Brink, 1996). The reactivation of these zones gave rise to intense faulting and fracturing within the dolomite. The deformation as evident in the Transvaal Sequence is associated with major regional geological events including the 2060 Ma Bushveld Intrusion (Trustwell, 1970) and the 2023 Ma Vredefort Meteoric Impact (Brink *et al.*, 2005)

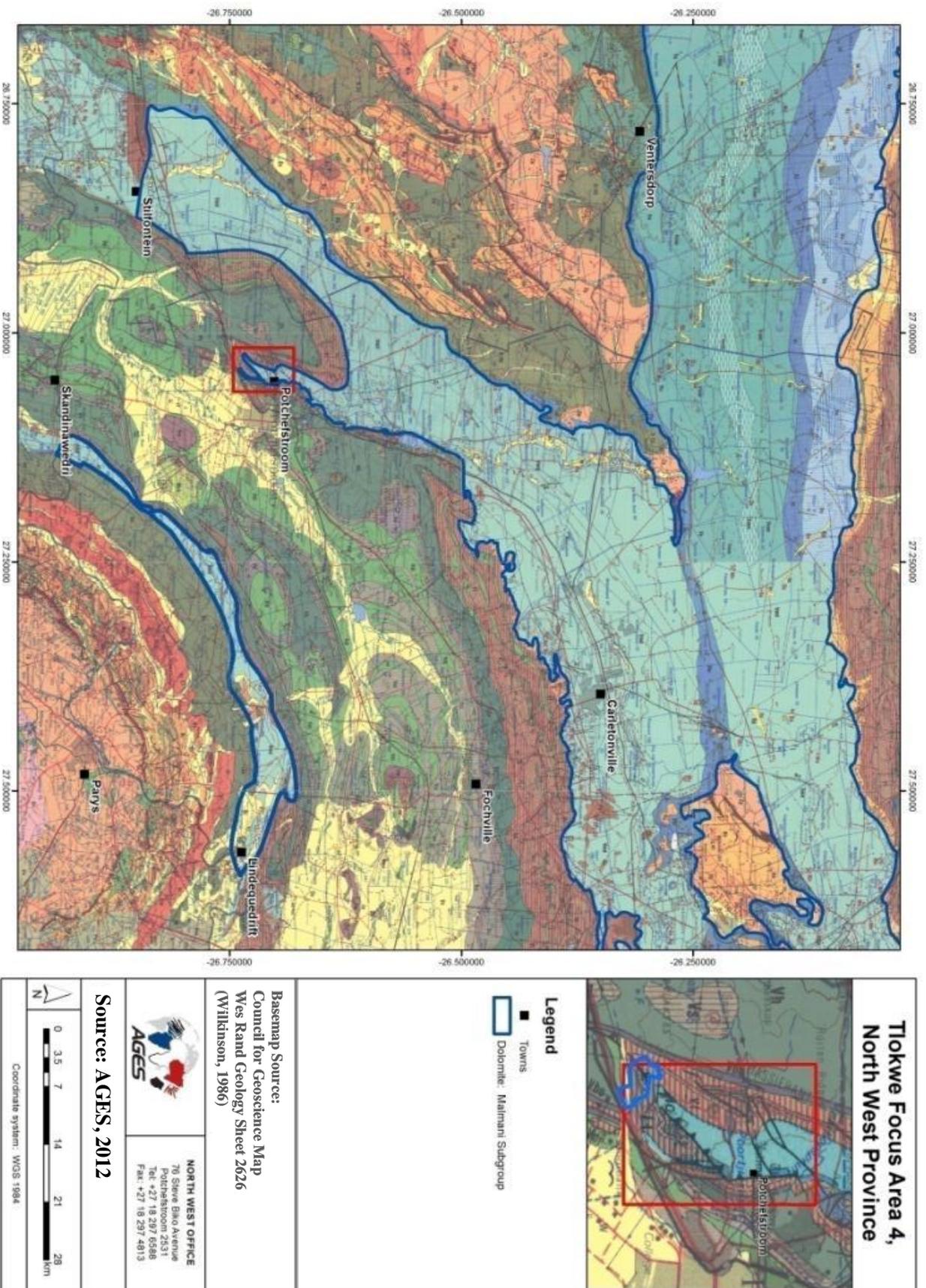


Figure 6: Regional Geology

3.4.2 Local geological setting

From the regional geological setting, geological mapping and percussion drilling data, it was determined that the study area is underlain by two stratigraphic formations, namely the Timeball Hill Formation (quartzite and shale) in the Pretoria Group and formation of concern, the Eccles Formation (dolomite and interlayered chert) from the Malmani Group. The Timeball Hill Formation has been intruded by diabase sills prior to deformation (Photo 3).

The geological succession strikes south-west in the north-western part of the study area, but the strike changes to south-east and then east from north to south across the study area. From the geophysical and geological data it was derived that the geology in the study area is defined by an anticline plunging to the south-west with a core of dolomite, enclosed by layers of shale and diabase. Figure 8 is a cross section across the stratigraphical sequence in the study area.

- Depth to dolomite

The depth to the dolomite bedrock increases from the outcropping dolomite in the north-east of the study area, to the south-west (Figure 8) at an angle of about 7°. This implies that the 60 m below surface line is in a range of around 500 m from the outcropping dolomite. The most southern part of the study area is therefore underlain by dolomite at a depth of around 150 m.

The dolomite is sequentially overlain by shale and diabase, with the overburden thickness increasing to the south-west, and is only exposed in the eastern most section of the study area.

- Pretoria Group - Timeball Hill Formation

The Pretoria Group in general consists of a 6 - 7 km thick sequence comprising mostly of mudrocks alternating with quartzitic sandstones, significant interbedded basaltic-andesitic lavas, subordinate conglomerates, diamictites and carbonate rocks, all of which have been subjected to low-grade metamorphism (Eriksson *et al.*, 2001).

The Timeball Hill Formation is the only Pretoria Group Formation found within the study area. The Timeball Hill Formation in the regional area is described as ferruginous shale, hornfels and ferruginous quartzite on a regional basis (Wilkinson, 1986). Within the study area, Bischoff (1992) distinguished between Timeball Hill Shale 1, Timeball Hill Quartzite, and Timeball Hill Shale 2. The Timeball Hill Quartzite can clearly be seen within the study area as a prominent hill with a strike $\pm 15^\circ$ west of north (Photo 3):

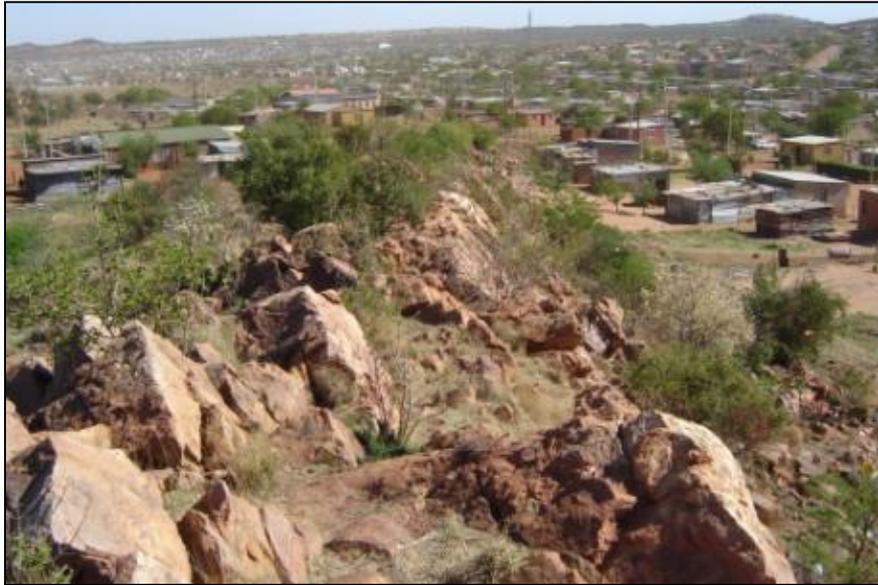


Photo 3: Outcropping Timeball Hill Quartzite

Source: Own Photograph

- Malmani Dolomite- Eccles Formation

The dolomite within the study area is part of the Chuniespoort Group, consisting predominantly of the Eccles Formation (Wilkinson, 1986). Together with other formations as seen outside the study area (Oaktree, Monte Christo, Lyttelton, and Frisco Formation), these rock types represent the deposition of carbonates from bicarbonate and silica rich water through chemical and organic (algal) precipitation. This is recognised in the stromatolitic structures within the dolomite as seen in the study area. Limestone is considered to have been the original precipitate with dolomite and chert as secondary replacement of the limestone (Brink, 1996). The chert is a replacement product formed as a result of the interaction of acidic meteoric water and alkaline brines (Truswell, 1977; Fourie, 1984).

During geological time, the karst topography of the area was developed and broken down several times after the original formation of the dolomite – and this contributes to the dis-homogeneity within the strata as seen today (Button, 1972).

The Eccles Formation is in general comprised of cherty dolomite of up to 600m thick and includes a series of erosion breccias (Eriksson *et al.*, 2001). The erosion breccias within the Eccles Formation may be gold bearing due to the intense heat that remobilised the fluids during the Bushveld Complex intrusion (Tyler & Tyler, 1996).

The Eccles Formation is furthermore characterised by sedimentary stratification (horizontally stratified to wavy laminated, rippled and cross-stratified layers) and the occurrences of chert bands, lenses and breccias with varying thicknesses and densities.

3.4.3 Local Geological Structures

The development of extensional faults and thrust faults occur in the study area and is seen as part of the Foch-related trusting and dislocations associated with and developed concentrically around the Vredefort Dome (Brink *et al.*, 2000; van der Merwe *et al.*, 1988).

In order to evaluate all geological results and do a final spatial assessment of the associated risk, the structural geology from all existing maps were re-evaluated. In addition all lineal structures within the study area were identified by means of a structural aerial photo interpretation according to methodology described by Lattman and Ray (1965) (Figure 7).

The following aerial photographs were used in this interpretation:

- Job 1064 Klerksdorp; Strip 010; Photograph 3215 to 3218; scale 1 : 50 000;
- Chief Directorate: National Geo-Spatial Information; Photograph 2627CA 16 to 22; scale 1 : 10 000; Enlargement factor: 3 times;
- Google earth, 2010.

3.4.4 Geological map compilation

The local geological map was compiled based on mapping results (Table 10) and the drilling results. The results were then evaluated together with the available geophysical information.

Table 10: Mapping results

Nom	Latitude	Longitude	Lithology	Description	Strike
1	-26.73469	27.03222	Dolomite	Roundish large boulders of grey elephant-skin textured dolomite with dark grey and brown chert inclusions.	
2	-26.73648	27.03045	Quartzite	Reddish fine grained quartzite	
3	-26.73659	27.03116	Quartzite	Reddish fine grained quartzite	
4	-26.73744	27.03202	Quartzite	Reddish fine grained quartzite	
5	-26.73781	27.03220	Quartzite	Reddish fine grained quartzite	
6	-26.73772	27.03251	Quartzite	Reddish fine grained quartzite	
7	-26.73719	27.03218	Quartzite	Reddish fine grained quartzite	
8	-26.73698	27.03125	Quartzite	Reddish fine grained quartzite	
9	-26.73692	27.03028	Quartzite	Reddish fine grained quartzite	
10	-26.73196	27.01860	Quartzite	Quartzite	
11	-26.73208	27.01867	Quartzite	Quartzite - Diabase transition	65
12	-26.73223	27.01881	Diabase	Diabase escarp	
13	-26.73245	27.01905	Transition	Diabase - shale transition	
14	-26.73482	27.01637	Quartzite	Quartzite outcrop north-east	
15	-26.73528	27.01706	Quartzite	Quartzite outcrop south-east	
16	-26.73703	27.01554	Quartzite	Quartzite outcrop far south-east	

17	-26.73712	27.01521	Quartzite	Quartzite outcrop far south-east fault	
18	-26.73776	27.01487	Quartzite	Quartzite outcrop far south-east fault	
19	-26.74194	27.01832	Quartzite	Loose quartzite boulders (100mX40m)	113
20	-26.73310	27.01981	Shale	Shale Escarpment	
21	-26.73305	27.01999	Transition	Shale -diabase (quarter of escarp)	
22	-26.73493	27.02186	Dolomite	Dolomitic chert breccia	
23	-26.73414	27.02194	Shale	Highly weathered shale	65
24	-26.73640	27.01726	Shale	Light brown thinly layered rather soft shale (In road)	
25	-26.73612	27.01777	Shale	Hard dark grey weathered reddish brown thickly layered shale on escarpment	
26	-26.73549	27.01794	Shale	Shale - in small pathway	
27	-26.73803	27.01614	Transition	Large property: South - Quartzite; East - Shale	
28	-26.74136	27.02135	Shale	Shale like quartzite	A
29	-26.74136	27.01992	Quartzite	White quartzite	B
30	-26.74062	27.01879	Shale	Shale with prominent strike	
31	-26.74062	27.01870	Shale		

Source: AGES, 2012



Figure 7 : Local geology

**Tlokwe Focus Area 4,
North West Province**

POTCHFSTROOM

- Legend**
- Boreholes
 - Focus Area 4
 - Cross-section
 - Faults
 - Residual Gravity
 - Dolomite
 - Shale
 - Diabase
 - Quartzite

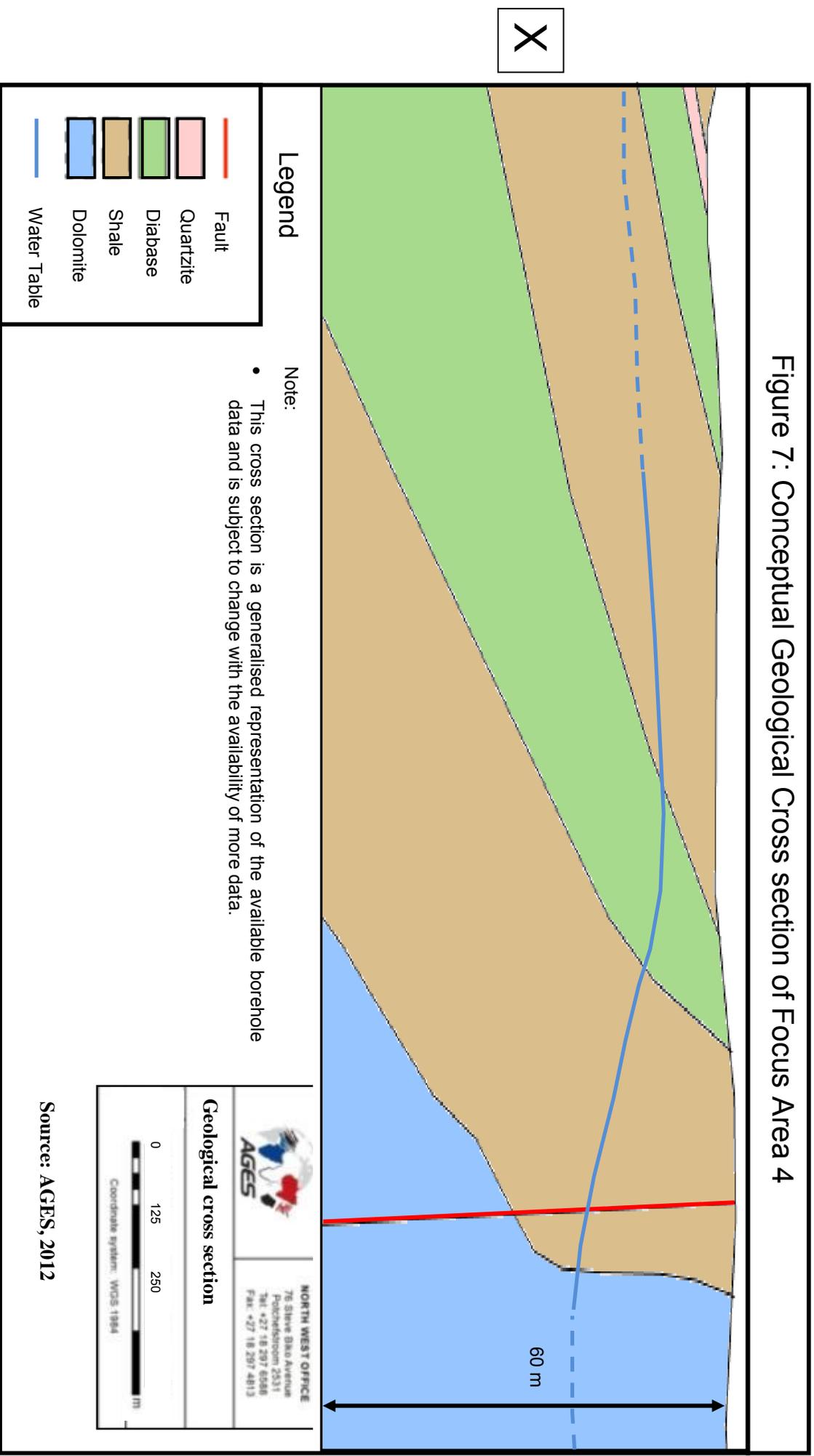
NORTH WEST OFFICE
 76 Steve Biko Avenue
 Potchefstroom 2531
 Tel: +27 18 297 6588
 Fax: +27 18 297 4913

Source: AGES, 2012

0 70 140 280 420 560 m

Coordinate system: WGS 1984

Figure 7: Conceptual Geological Cross section of Focus Area 4



Source: AGES, 2012

3.4.5 Existing karst-related instability features

A sinkhole (Photo 4) was reported on Erf 7081 in Sarafina Road, Sarafina. A total of 25 Dynamic Cone Penetrometer (DCP) tests were conducted in and around the house and a borehole was also drilled at the sinkhole (Borehole number: SSH 01). The inspectors from the City Council regularly inspect the house for any signs of further settlement or collapse.



Photo 4: Sinkhole at Erf 7081

Source: AGES, 2012

3.4.6 Important geological factors

- Geological history of the study area

According to Johnson *et al.* (2006), the Eccles Formation is the fourth highest formation within the Chuniespoort Group. Within the top formations of the Chuniespoort, an unconformity was identified. The Timeball Hill Formation is the second lowest Formation within the Pretoria Group, underlain by the Rooihogte formation. The Timeball Hill and Eccles Formations are therefore supposed to be separated by at least 2 000 m of other formations. But in the study area, this is not the case. It is therefore evident that a long period of erosion took place before the Timeball Hill Shale's were deposited on the dolomite of the Eccles Formation.

The geological history of the study area is reconstructed as follows:

- The Malmani Dolomite sequence was deposited;
- A period of deposition and erosion took place (± 150 Ma);
- The uppermost part of the Chuniespoort Group is deposited, separated by a major unconformity;
- The Rooihogte Formation is deposited, followed by the Timeball Hill Formation;
- The area is deformed and fractured by the Bushveld Complex, followed by the Vredefort Meteorite Impact.

The period elapsed between the deposition of the dolomite and the overlying shale is important in that it resulted in an unconform contact zone. This is the reason for the non-homogeneous character of the dolomite in the study area.

- General geological character

The geological assessment has been conducted to determine what the general geological characteristic of the study area is. This includes delineating the possible shallow dolomite bedrock areas, the character of the material overlying the dolomite and to determine, in conjunction with the residual gravity data, where the geotechnical drilling should commence. The following can be derived from the geological assessment:

- The study area is underlain by dolomite of varying depth and character;
- The depth of dolomite increases to the south of the study area (Figure 7 and 8);
- The dolomite is covered by Timeball Hill shale and intrusive diabase;
- The area has been subjected to various faults and folds;
- A major fault runs through the study area with a north east, south west trending strike;
- Several smaller east west trending faults were also identified in the study area;

- All structural geological observations from previous maps, (dip and strike) as well as new field observation were used in compiling the final geological map (Figure 7);
- The structures, as presented in Figure 8, are important in that it indicates dis-homogeneity in geology and also acts as preferential pathways for groundwater flow and this increases the possible risk associated with the study area.

3.5 Geohydrology

3.5.1 Regional geohydrological setting

The study area is situated in the C23L (1 211 km²) Quaternary Catchment (Figure 9). This is a sub-catchment of the Mooi River Catchment, and forms the westernmost boundary of the Upper Vaal Water Management Area (DWAF, 2004).

The study area is furthermore located within the Welgegund Dolomite Compartment, with the Turffontein Dolomite Compartment upstream, and the KOSH Dolomite Compartment downstream. Water abstraction from either of these compartments may have an influence on the geohydrological conditions of the Welgegund Dolomite Compartment.

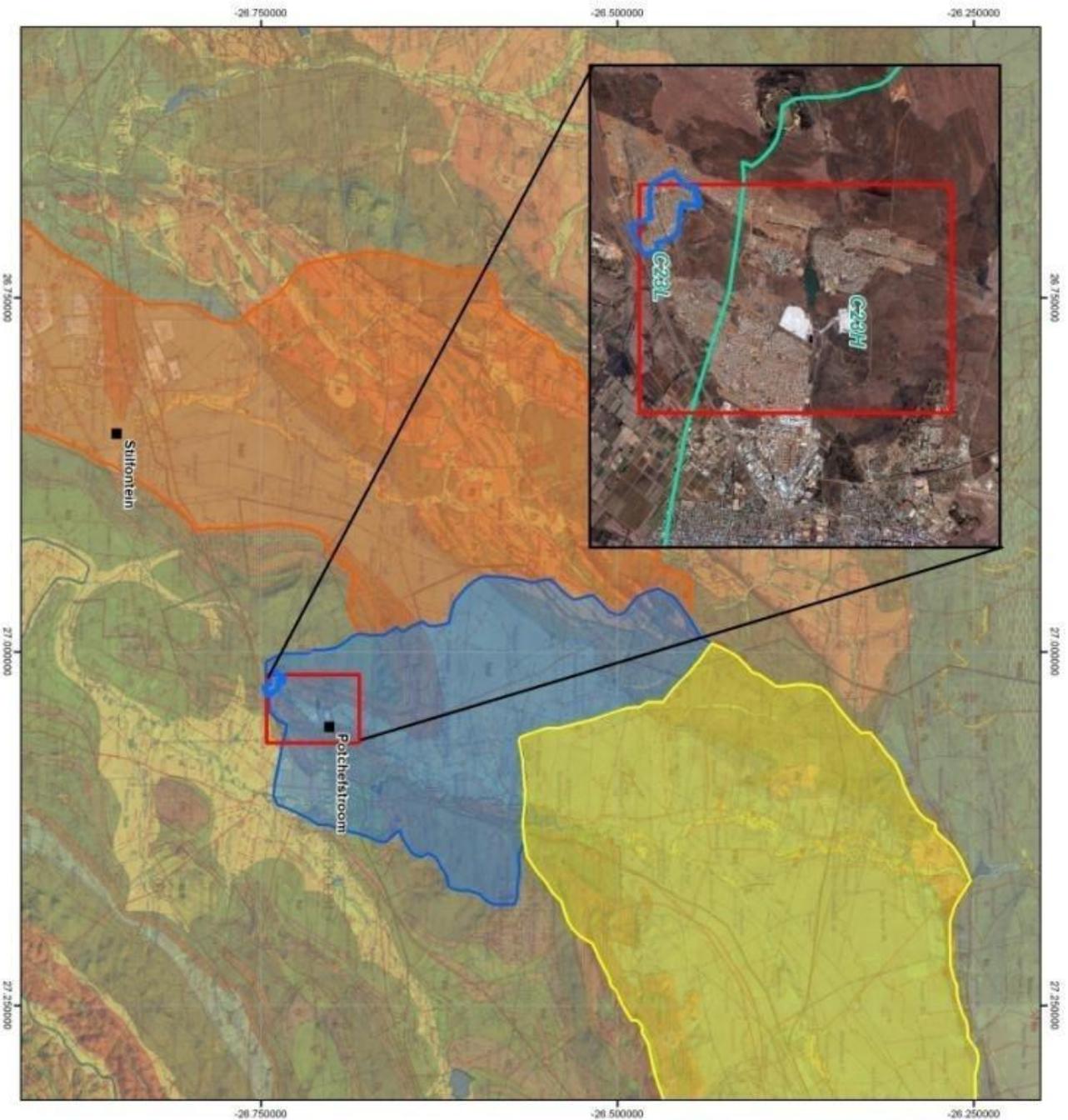
3.5.2 Aquifer types

Based on the underlying geology of the study area, two main aquifer types can be distinguished:

- A Karst Type aquifer located in the dolomitic rock due to dissolution cavities (karsts) in the dolomite; and,
- An Intergranular and Fractured Type aquifer in the clastic sedimentary and intrusive igneous rocks (quartzite, shale and diabase).

The hydraulic properties vary greatly for these two aquifer types due to the nature of the rock matrix. Water occurs within dissolution cavities within the otherwise impermeable dolomite and depending on the size and extent of the cavities, may have significant groundwater potential with very high transmissivity and storativity values.

Inside the clastic sedimentary rocks water occurs in between the individual grains (intergranular) depending on the porosity of the matrix, but is mainly transported along preferred pathways created by structures like faults and joints. The contacts with intrusive bodies like dykes and sills also fracture the surrounding rock to create preferred pathways.



<p>Tlokwe Focus Area 4, North West Province</p>	
<p>Legend</p> <ul style="list-style-type: none"> ■ Towns □ Focus Area 4 □ Regional project area □ Turffontein GRU □ Weigegund GRU □ KOSH Area GRU □ Quaternary Catchment 	
<p>Basemap Source: Council for Geoscience Map Wes Rand Geology Sheet 2626 (Wilkinson, 1986)</p>	
<p>NORTH WEST OFFICE 76 Steve Biko Avenue Potcheitstroom, 2331 Tel. +27 18 297 6588 Fax. +27 18 297 4813</p>	
<p>AGES</p>	
<p>Source: AGES, 2012</p>	
<p>0 2.5 5 10 15 20 km</p> <p>Coordinate system: WGS 1984</p>	

Figure 9: Quaternary Catchment

3.5.3 Water uses

There are currently no registered water use taking place in the study area, and no regional deep mine dewatering is currently in process in the dolomitic compartment in which the study area is situated. Water fluctuation in the study area may be possible due to the water abstraction for irrigation to the south of the study area.

3.5.4 Infrastructure and drainage

The surface topography gently slopes to the south east of the study area, but this slope increases to the north of the study area. The general orientations of the roads in the study area are north-south or east-west. Surface water runoff will therefore flow in a southerly direction in the north-south orientated roads, but ponding may take place in the east-west orientated roads. This ponding may increase the ingress of surface water, which may pose a possible risk of hazard formation acceleration.

3.5.5 Ground water levels

During the drilling of the 45 geotechnical boreholes in the study area, water strikes were noted and groundwater rest levels were recorded after the drilling took place. The water strike levels are summarized in Table 11:

Table 11: Groundwater levels and strikes

Borehole Nr	Water level	Lithological occurrences	Water strikes	Lithological occurrence	Lithological Contact	Depth of contact
FA4 01	2,3	Shale	17;40	Shale, Diabase	-	-
FA4 02	2,6	Diabase	13	Diabase	-	-
FA4 03	2,2	Shale	24	-	Shale - Black shale	24
FA4 04	1,9	Diabase	30	Shale	-	-
FA4 05	Blocked	-	34	Clay	Clay - Diabase	36
FA4 06	9,8	Diabase	38	-	Diabase - Shale	36
FA4 07	12,1	Diabase	25	Diabase	-	-
FA4 08	Blocked	-	55	-	Shale - Black shale	56
FA4 09	Blocked	-	28	-	Shale - Diabase	31
FA4 10	Blocked	-	35	-	Shale - Diabase	36
FA4 11	18,3	Shale	41	-	Shale - Black shale	45
FA4 12	20,7	Shale	47	Shale	-	-
FA4 13	5,3	Shale	40	-	Shale - Black shale	40
FA4 14	4,5	Quartzite	22;31	-	Quartz - Diabase	31
FA4 15	20,6	Diabase	32	-	Diabase - Shale	35
FA4 16	22,3	Diabase	55	Shale	-	-

FA4 17	13,2	Shale	33	-	Shale - Black shale	36
FA4 18	Blocked	-	45;50	-	Shale - Diabase	53
FA4 19	9,3	Shale	35	Shale	-	-
FA4 20	Blocked	-	36	Diabase	-	-
FA4 21	7,1	Diabase	30	Diabase	-	-
FA4 22	17,2	Shale	-	-	-	-
FA4 23	13,5	Diabase	31	Shale	-	-
FA4 24	22,3	Shale	21	Shale	-	-
FA4 25	9,9	Shale	37	-	Shale - Black shale	41
FA4 26	7,4	Shale	35	-	Shale - Black shale	36
FA4 27	7,6	Shale	20	-	Shale - Wad (ToC)	20
FA4 28	7,0	Shale	30	Shale	-	-
FA4 29	9,3	Shale	35	Diabase	-	-
FA4 30	10,7	Diabase	Dry	-	-	-
FA4 31	Blocked	-	28	Shale	-	-
FA4 32	11,1	H-D	41	-	Diabase - Shale	40
FA4 33	17,2	Shale	26;42	-	S-D,D-S	26,44
FA4 34	12,1	Diabase	20;33	Diabase, shale	-	-
FA4 35	15,0	Shale	38	-	Shale - Dolomite	39
FA4 36	Blocked	-	38	Shale	-	-
FA4 37	17,8	Diabase	24	Diabase	-	-
FA4 38	16,0	Shale	37	Shale	-	-
FA4 39	Mud	-	-	-	-	-
FA4 40	17,8	Shale	38	Dolomite	-	-
FA4 41	18,1	Shale	42	Dolomite	-	-
FA4 42	16,3	Diabase	33	Dolomite	-	-
FA4 43	4,8	Shale	42	Shale	-	-
FA4 44	21,3	Shale	18	Shale	-	-
FA4 45	28,1	Shale	35	Dolomite	-	-
SSH 01	Not measured	-	19	Wad	-	-
TRDC 01	Not measured	-	17	Shale	-	-
TRDC 20	Not measured	-	25;31	Shale	Shale - Dolomite	25,31
TRDC 21	Not measured	-	23;35;52	Shale, Diabase, shale	-	-
TRDC 24	Not measured	-	20;25	Diabase	-	-

Source: AGES, 2012

From the close correlation between the water strikes and the depth of lithological contact, it is evident that the geohydrological conditions and the geological and structural geological conditions present on site are closely related. Water strikes were generally encountered on the

contact zones between the various lithological units, especially the contact between shale and diabase. This is indicative of the diabase therefore acting as an aquiclude, decreasing water ingress and acting as a possible buffer for mobilisation agencies.

Most of the groundwater levels were measured before the holes were sealed according to the current practice and regulations. These levels are summarized in Table 11. These levels were modelled in relation to the depth to dolomite. From the model it is evident that the depth of the water table below ground level increases to the north of the study area. It is also important to note that the water level is below the dolomite bedrock at the location of the sinkhole that fell in Erf 7081.

3.5.6 Fault zones

Due to the transmissivity along the fault zones, these zones are characterised as having higher mobilizing properties. They must therefore be regarded as areas with a higher inherent susceptibility for mobilisation from an ingress of water perspective (Buttrick, 2012).

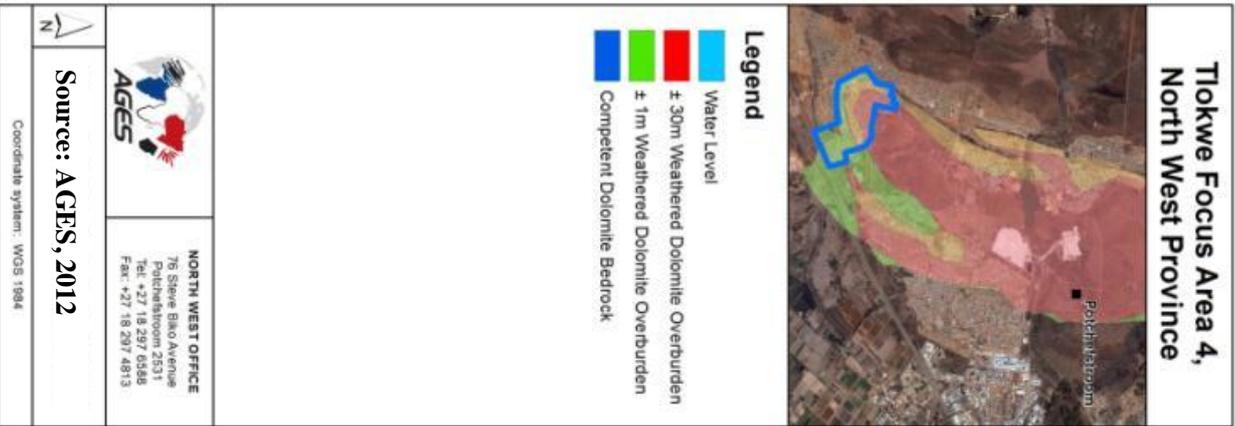
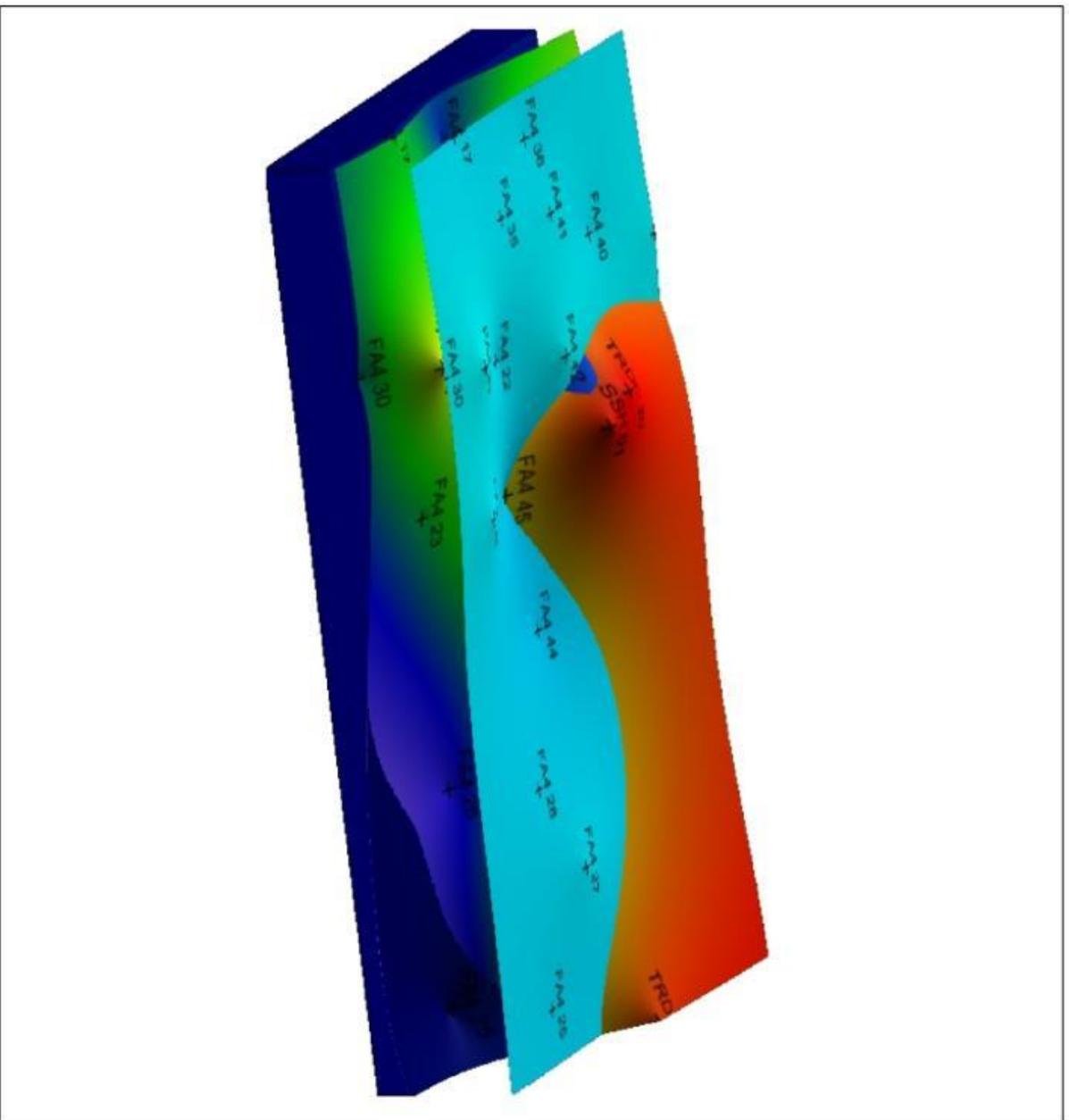


Figure 10: Water level model

3.6 Hazard characterisation and evaluation procedures

Each of the factors considered in this section is related to a specific criteria based legend. This evaluative criteria is used as a mediator to compare the character of each of the zones to one another.

3.6.1 Gathering of existing data

All available reports and field maps from previous dolomite stability investigations and field mapping projects in Ikageng were obtained and reviewed. These reports and maps were studied to obtain a more detailed perspective of the geological character of the region in which the study area is located.

The following papers have been regarded as very important in the hazard characterisation and evaluation procedures:

- Buttrick, D. B., Van Schalkwyk, A., Kleywegt, R. J. & Watermeyer, R. B. 2001. Proposed method for dolomite land hazard and risk assessment in South Africa. *Journal of the South African institute of civil engineering*, 43(2):27-36;
- Consultants guide for the approach to sites on dolomite land by the Council for Geoscience (2007);
- Buttrick, D. B., Trollip, N. Y. G., Watermeyer, R. B., Pieterse, N. D. & Gerber, A. A. 2011. A performance base approach to dolomite risk management. *Environ Earth Sci* (2011):64:1127-1138;
- South African National Standard SANS 1936 Parts 1 – 4 (In draft and subject to ratification).

3.6.2 Evaluation factors

A legend is applied to each of the evaluation factors. This is to increase the comparability of the various layers, and is based on the actual parameters encountered on site. The following evaluation factors were considered in the process of hazard evaluation:

- **A** - Receptacle development;
- **B** - Mobilisation agencies;
- **C** - Potential sinkhole development space;
- **D** - Nature of the blanketing layer;
- **E** - Mobilisation potential of the blanketing layer;
- **F** - Bedrock morphology;
- **G** - Gravity.

These factors will now be discussed in terms of their influence on the hazard characterisation and evaluation procedure.

3.6.3 A - Receptacle development

Receptacles or disseminated receptacles are voids or cavities that have developed in either the dolomite bedrock or overlying material. These receptacles are able to receive mobilised material from the overlying horizons.

Even though the size of the receptacle will determine to what extent the overburden may be accepted, there are no effective techniques available at present to fully determine the volume of the receptacles. The following assumptions are therefore made:

- A1 - High penetration rates, air loss, sample recovery and hammer tempo are all considered in determining the possibility of receptacles in the material above the dolomite bedrock;
- A2 - Receptacles are present within the dolomite bedrock (penetration rates >3 min/m);
- A3 - All receptacles are of such a size that all mobilised material from the overlying horizons may be accommodated.

3.6.4 B - Mobilisation agencies

All potential current and future mobilisation agents have to be identified, and the following mechanisms are deemed to represent localized mobilisation agents that may contribute to the mobilisation of the overburden material:

- B1 - Water ingress from leaking wet services (i.e.: buried water- and sewerage pipes);
- B2 - Water ingress from ponding storm water at the surface in those areas exhibiting limited surface drainage (i.e.: next to structures, along access roads and within unsealed excavations);
- B3 - Water ingress from ponding storm water at the surface in areas where the natural drainage paths have been disturbed;
- B4 - Collapse of overburden into cavities due to the extraction of water from voids or cavities.
- B5 - Groundwater level fluctuations resulting in the ravelling of overburden material and weathered bedrock into water-filled cavities due to changes in the phreatic groundwater pressure;

In order to do a final hazard characterisation and evaluation, it must be assumed that all material within the blanketing layer may be mobilized, and that an adequate and sustained mobilizing agency is present.

3.6.5 C - Potential surface manifestation development space

The potential development space of a surface manifestation (sinkhole or subsidence) refers to the maximum possible size of a feature in the event that the feature does occur. This is based on:

- Drilling data from each borehole;
- C2 - The estimated depth below the ground surface to the potential throat of either the receptacle or disseminated receptacle (i.e.: the thickness of the blanketing layer);
- C3 - The thickness of each layer constituting the blanketing above a possible receptacle;
- C4 - The estimated angle of draw in the various horizons of the blanketing layer (calculated from the horizontal to the assumed sinkhole sidewalls). These values are based on *at least* the following parameters:
 - The shape, size cohesion, grading and density of the material in each layer;
 - Possible pockets or variations within each layer;
 - Penetration rate, hammer tempo, air loss and sample recovery within each layer;
 - Possible groundwater level fluctuation within each layer;
 - The presence of wad within each layer, and;
 - The mobilisation potential of each layer.

C1 - The possible size of a feature (sinkhole or subsidence) is then categorized in terms of Table 8 in this document, Feature size classification (Buttrick & van Schalkwyk, 1995).

3.6.6 D/E - Nature and mobilisation potential of the blanketing layer

The nature and mobilisation potential of the blanketing layers are determined by evaluation of an array of soil/ ground/ rock attributes. Based on these attributes and the specific results from the geotechnical drilling, the following attributes have been identified and must be rated to determine the actual mobilisation potential (D3) of each layer:

D1 - Drilling properties:

- Penetration rates
- Hammer tempo
- Air loss
- Sample recovery
- Water added

D2 - Material properties:

- Lithology
- Effective weathering
- Internal size
- Possible shape
- Layering
- Cohesion
- Sorting/ grading
- Density
- Possible pockets
- Internal movement
- Internal consistency
- Hardness
- Possible groundwater movement
- Presence of wad

3.6.7 F - Bedrock morphology:

All possible variances in the bedrock morphology must be considered as an integral part of the evaluation and 'built' in to the risk evaluation.

The following features may act as preferred pathways for mobilisation agents, with sudden variances in the nature of the material.

- F1 – Faults;
- F2 – Joints;
- F3 – Fractures;
- F4 – Ringstructures;
- F5 – Breccias.

Sinkholes have been known to occur along fault systems (NHBRC, 1999). Fault systems must therefore be incorporated in all zone designations.

3.6.8 Inherent hazard characterisation

In the light of above mentioned, the following factors are evaluated in order to determine the Inherent Hazard Class of each borehole profile:

- F - The gravity anomaly in which the borehole is located;
- D - The nature and thickness of each layer comprising the total thickness of the blanketing layer;
- C2 - The depth to dolomite bedrock or to a possible receptacle;
- E - The dolomite bedrock morphology;
- B5 - The groundwater level in relation to the various layers within the profile.

In order to classify each profile in terms of the Inherent Hazard Class, the following assumptions have to be made:

- The profile is subject to exploitation and mobilisation under the influence of a mobilizing agency;
- The site is, or will be subject to inappropriate land use;
- The area is subject to poor management of storm water and water-bearing infrastructure, and;
- The area is or will be subjected to dewatering.

As described in section 2.7.6 of this document, the inherent hazard classification is a reflection of the geotechnical characteristics of the material in the blanketing layer represented as the susceptibility of the material to an event (sinkhole or subsidence formation) of a certain size forming. The susceptibility of the blanketing layer to mobilisation is expressed as low, medium or high.

The Inherent Hazard Class (IHC) rating is the potential of a sinkhole or subsidence occurring as well as the likely size (diameter) of this feature (Buttrick *et al.*, 2011). This is represented in Table 6 of this document.

The IHC Class rating is represented as a rating from one to eight and is defined in terms of ingress of water and water level drawdown. This is reflected by two IHC designations separated by a double forward slash:

Inherent Hazard Class (Ingress water) // Inherent Hazard Class (groundwater level drawdown)

In zonal designation, there may be a predominant characterisation and a characterisation of anticipated pockets or small subareas within the zone. The primary Inherent Hazard Class designation will describe the primary characteristic, and the suffix (in brackets) describes the anticipated pockets. For instance, Inherent Hazard Class 6(2) will indicate that the area predominantly displays a high inherent susceptibility for a medium-size feature forming with anticipated pockets or sub-areas indicating a medium inherent susceptibility for a small-size feature forming.

In the event that the groundwater level is drawn down, the inherent susceptibility of the overlying material may be altered. This may have a direct effect on the Inherent Hazard designation with respect to ingress of water, and a dewatered scenario must therefore also be commented on.

3.7 Dolomite Area Designation

In order to establish appropriate development on dolomite land, certain establishment requirements have to be adhered to. The Dolomite Area Designation as follows in Table 12 is defined in Table 9, Section 2, Part 1 of the NHBRC Home Building Manual, Part 1 and 2, Revision 1, dated February 1999, as well as SANS 1936 Part I (in draft). The ‘D’ designation is a function of inherent risk in combination with the proposed development type, and is contained in the SANS 1936 (in draft and subject to ratification) as follows:

Table 12: Dolomite Area Designation

Dolomite area designation	Description
D1	No precautionary measures are required to support development
D2	Only general precautionary measures that are intended to prevent the concentrated ingress of water into the ground in accordance with the requirements of SANS 1936-3, are required to support development.
D3	<p>Precautionary measures in addition to those pertaining to the prevention of concentrated ingress of water into the ground are required to support development in accordance with the relevant requirements of SANS 1936-3. These may include the following:</p> <ul style="list-style-type: none"> • Selection of pipe materials and joint type that minimizes joints, is impact resistant and flexible • Wet services placed above ground • Limitation on wet service entries to buildings • Provision of water tight services in the vicinity of buildings • Design of buildings in which people congregate, work or sleep to enable safe evacuation in the event of sinkhole formation
D4	<p>Precautionary measures cannot normally achieve a tolerable hazard rating and are considered as uneconomical or impractical. But in the event that development must proceed, development may only be considered under the following conditions:</p> <ul style="list-style-type: none"> • Site characterisation, analysis and design, specification of precautionary measures, supervision of implementation and formulation of dolomite risk management plan shall be undertaken by a Competence Level 4 geo-professional; • The foundation design, precautionary measures and dolomite risk management plan shall specifically address and effectively mitigate the

	<p>dolomite risks present on the site;</p> <ul style="list-style-type: none"> • The site characterisation, foundation design, design of structures, precautionary measures and dolomite risk management requirements shall be reviewed and approved by independent Competence Level 4 professionals and geo-professionals; • All aspects of the development proposal shall be reviewed and approved by the Authority who may request a further review by an Authority-designated Competence Level 4 peer if required; and • The responsible Local Authority must be committed to maintaining dolomite risk management principles in accordance with SANS 1936-4.
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Source: NHBRC, 1999

3.8 Appropriate land use and infrastructure development

The following tables (Table 13 – Appropriate land use and Table 14 – Appropriate infrastructure) are guidelines for permissible land usage and infrastructure development based on the eight Inherent Risk Classes as summarised from Table 2, SANS 1936 Part I (in draft and subject to ratification):

Table 13: Permissible land usage based on Inherent Risk Classes

Table 1 (SANS 1936-1:2009) - Permissible land usage based on inherent risk class and dolomite area designation and footprint investigations									
Land usage		Inherent risk class (SANS 1936-2)							
Designation	Description	1 L/A	2 M/S	3 M/ M	4 M/ L	5 H/S	6 H/M	7 H/ L	8 H/V L
Agricultural, recreational and private public open spaces									
A1	Agriculture that requires intensive irrigation excluding flood irrigation.		D2			D3			D3/D4
A2	Agriculture that requires limited irrigation; Botanical gardens, sports fields, driving ranges, golf courses, parkland and public open spaces.		D2			D3			D3/D4
A3	Agriculture that does not require irrigation in any form or the storage of water. Parkland and public open spaces that are not irrigated and grazing pastures.					D1/D2			
Commercial and miscellaneous non-residential usages									
C1	Places of detention, police stations, hospitals, hostels, hotels and institutional homes for the handicapped or aged with populations not exceeding those calculated in accordance with Regulation A21 of the National Building Regulations.					D3 + FPI			D4

C2	Railway stations, shops, wholesale stores, offices.	D2 + FPI	D3 + FPI		D4
C3	Places of worship, theatrical, indoor sports or public assembly venues, other institutional land uses, such as universities, schools, colleges, libraries, exhibition halls and museums.	D2 + FPI	D3 + FPI		D4
C4	High rise commercial developments with populations not exceeding those calculated in accordance with Regulation A21 of the National Building Regulations.	D2 + FPI	D3 + FPI		D4
C5	Light (dry) industrial developments, dry manufacturing, commercial uses such as warehousing, packaging, etc.	D2 + FPI	D3 + FPI		D4
C6	Fuel depots, processing plants or any other areas for the storage of liquids.	D2 + FPI/ D3 + FPI	D3 + FPI		D4
C7	Outdoor storage facilities, stock yards, container depots, etc.	D2 + FPI	D3 + FPI		D4
C8	Waste sites, cemeteries, slimes dams, etc.	D2 + FPI	D3 + FPI in dry areas with deep groundwater levels	D4	
C9	Parking areas.	D2/D3	D3		D4
C10	Parking garages	D2/D3	D3 + FPI		D4
Low rise dwelling units					
RL1	≤ 3 storeys with 80 to 120 units per hectare evenly distributed and a population not exceeding 600 people per hectare.	D2 + FPI/ D3 + FPI	D4		
RL2	≤ 3 storeys with 40 to 80 units per hectare evenly distributed and a population not exceeding 400 people per hectare.	D2 + FPI/ D3 + FPI	D3 + FPI		D4
RL3	≤ 3 storeys with less than 40 units per hectare evenly distributed and a population of ≤ 200 people per hectare.	D2 + FPI	D3 + FPI		D4
Dwelling houses					
RN1	26 to 60 dwelling houses per hectare with stands larger than 150 m ² , and a population of ≤ 300 people per hectare.	D2/D3	D3	D4	
RN2	10 to 25 dwelling houses per hectare with stands no smaller than 300 m ² , and a population of ≤ 200 people per hectare.	D2/D3	D3	D4	D3

RN3	2 to 10 stands per hectare with 1 000 to 4 000 m ² stands, and a population of ≤ 60 people per hectare.	D2/D3	D3	D3 + FPI/ D4	D4
RN4	Small holdings, < 2 stands per hectare with stands > 4 000 m ² , and a population of ≤ 25 people per hectare.	D2/D3	D3	D3 + FPI/ D4	D4
High rise dwelling units					
RH1	> 3 storeys with a population of ≤ 1 500 people per hectare.	D2 + FPI/ D3 + FPI	D4		
RH2	> 3 storeys with a coverage ratio of ≤ 0,4, no higher than 10 storeys, and a population of ≤ 800 people per hectare.	D2 + FPI/ D3 + FPI	D3 + FPI (preferably with basement)	D3 + FPI/ D4	D4
RH3	> 3 storeys with a coverage ratio of ≤ 0,3, no higher than 10 storeys, and a population of ≤ 600 people per hectare.	D2 + FPI	D3 + FPI (preferably with basement)	D3 + FPI/ D4	D4
FPI = a footprint investigation conducted in accordance with the requirements of SANS 1936-2.					

Source: SANS 1936, Part IV

Table 14: Appropriate infrastructure development

Table 2 (SANS 1936-1:2009) - Permissible infrastructure type based on inherent risk class and dolomite area designations										
Infrastructure and Social Facilities		Inherent risk class determined in accordance with the requirements of SANS 1936-2								
Designation	Description	1	2	3	4	5	6	7	8	
IN1	Trunk roads (national and regional roads which facilitate intercity travel) and primary distributor roads (major arterial roads forming the primary network for an urban area as a whole), railway lines, power lines and runways.	D2	D3				D4		D4	
IN2	Bulk pipelines, including water, sewer, fuel and gas lines.	D2	D3			D4				
IN3	Reservoirs and public swimming pools, water care works.	D3				D4				
IN4	Attenuation and retention ponds for storm water management and artificial lakes, cemeteries.	D3				D4				
IN5	Dams and slimes dams.	D3	D4							
IN6	Waste disposal facilities.	D3						D4		

Source: SANS 1936, Part IV

3.9 Monitoring guidelines

According to SANS 1936 Part 4 (in draft) Monitoring Designations must be identified and delineated according to the Inherent Hazard characterisation of the site and knowledge of problems which could impact on the infrastructure on site. The generic Monitoring Activities considered appropriate for dolomite sites are as follows:

Table 15: Monitoring Activities and Activity Reactions

Area designation components of the risk reduction measures			
Annotation	Monitoring activity	Reaction	Purpose
A	Visual inspection of ground, structures and above-ground infrastructure (e.g. Roads, storm water canals, ditches)	Any evidence of cracking or ground settlement should immediately be reported and investigated	Monitor, control and prevention of concentrated ingress of water
B	Visual inspection of storm water systems for blockages	Any evidence of blockages should be reported and cleared immediately	
C	Testing of wet services for leaks.	Any leaks to be reported and repaired immediately	
D	Monitoring of structures and ground levels.	Any evidence of movement shall be reported and investigated.	Monitor the effects of concentrated ingress of water or groundwater level drawdown
E	Monitoring of the groundwater levels.	Evidence of lowering shall be reported to the Local Authority and the Department of Water Affairs.	Monitor, control and prevention of groundwater level drawdown

Source: SANS 1936, Part IV

Table 16: Activity Frequency

Annotation	frequency of activities
DAILY	Activities to be undertaken daily.
WEEKLY	Activities to be undertaken weekly.
1	Activities to be undertaken once a month.
3	Activities to be undertaken quarterly.
6	Activities to be undertaken bi-annually
12	Activities to be undertaken annually.
24	Activities to be undertaken once every two years.
0	NO ACTION REQUIRED
TBD	TO BE DETERMINED

Source: SANS 1936, Part IV

The monitoring area designation in terms of the risk reduction measures and the frequency of activities as follows:

Monitoring area designation = Monitoring Activity (Table 15) + Frequency designation (Table 16) e.g. (A)DAILY or (E)24

Areas of no dolomite hazard require no monitoring at all from a dolomite risk management perspective. For example areas on Witwatersrand Supergroup rocks may be designated as (ABCDE)0, indicating that no action is required to lower the risk of dolomite related instability.

Areas of low susceptibility, such as IHC 1 areas, are assigned a low priority and require basic monitoring and maintenance activities at long intervals. For example areas on thick Karoo Supergroup rocks (in excess of 30 m) may be designated as (ABC)24D0E12 indicating that all identified activities which control ingress water need only be undertaken once every two years with precision structure and ground leveling and monitoring not being required and groundwater level monitoring being required annually.

However, where such rocks overlie dolomite residuum below the original level, a designation of (ABC)24 D0E1 might apply, indication that activities which control the ingress of concentrated water remain necessary once every two years, but level monitoring is critical and should be undertaken once a month. Within an already de-watered compartment, such monitoring should only commence once mining has ceased and the level is allowed to recover.

Areas of high susceptibility, for example IHC 5, and therefore high priority in terms of monitoring and maintenance, should receive attention more frequently. These areas require more stringent monitoring and maintenance activities at short intervals.

Such areas are typically characterised by:

- Metastable subsurface conditions or latent sinkhole formation;
- High Inherent Hazard conditions;
- Poor subsurface conditions e.g. cavities, sample or air loss;
- Previous sinkhole or subsidence formation;
- Palaeo-sinkhole or palaeo-subsidence structures;
- Geological contact areas;
- Fault zones;
- Anticipated ground settlement; or
- Ponding of water, etc.

For example, an area in which various sinkholes have already been reported and where the

area is designated as high hazard or even medium to high hazard from an ingress of water perspective a (ABCE)³E⁰ or even (AB)^{DAILY}D³E⁰ designation may apply, indicating the need to undertake activities controlling ingress of water quarterly, or even daily.

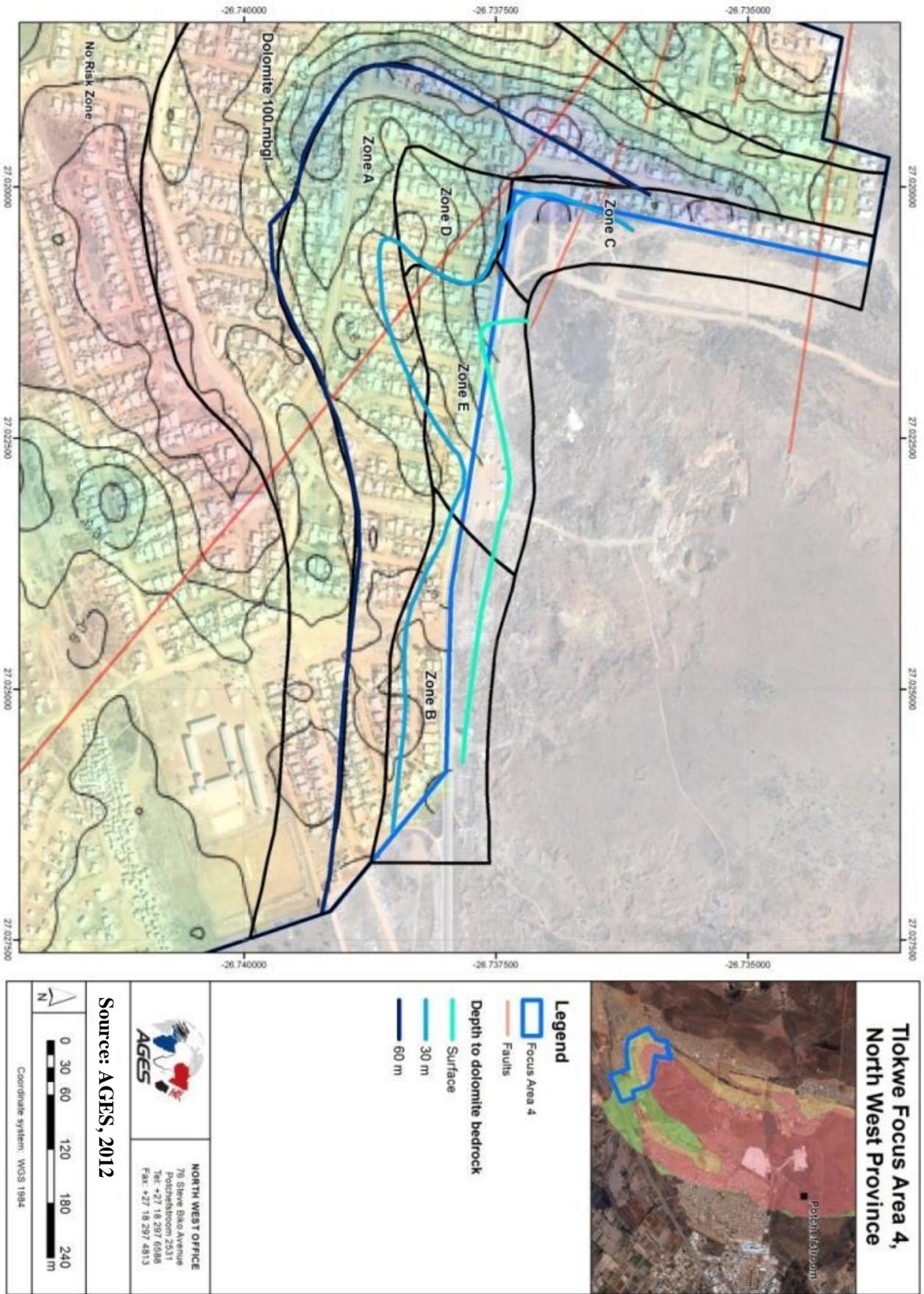


Figure 11: Zone identification map

3.10 Dolomite Hazard Characterisation of the site

The following zones have been identified in the study area in accordance with above mentioned methodologies and standards. Figure 11 was used in the process of zone identification and characterisation.

3.10.1 Nature and mobilisation potential of the blanketing layer

The different materials comprising the overburden in Focus Area 4 are assumed to exhibit the following characteristics:

- The *transported topsoil* is deemed to be highly permeable and moderately cohesive, with a resultant moderate mobilisation potential;
- The *shale* grades from a highly weathered silty powder, to a very hard and massive solid unit, with a corresponding mobilisation potential of moderate to low;
- The *highly weathered diabase* has been broken down in to clayey sand, and the *moderately weathered diabase* is seen as broken down rock fragments. Both of these result in a moderate mobilisation potential. The *slightly weathered diabase* is a massive solid rock, resulting in a low mobilisation potential;
- The *chert* grades from a highly weathered fragmented rock with occasional air loss and some traces of wad, to a slightly weathered massive solid rock, with a corresponding high to low mobilisation potential;
- The *dolomite* grades from a highly weathered dolomite residuum with some larger boulders, to a slightly weathered dolomite bedrock, with a corresponding high to low mobilisation potential;
- Both the *chert-rich and chert-poor dolomite residuum* are deemed composed of coarse particles moderately densely- to densely packed in a moderately cohesive clayey matrix, but the recording of irregular hammer rates in some places within these materials during drilling is indicative of the occasional occurrence of less densely packed pockets, resulting in an assumed moderate to high mobilisation potential;

In order to determine the mobilisation potential of each of the layers, the material within each of the borehole profiles was evaluated based on section 3.6.6 of this document. From the possible mobilisation potential, the effective angles of draw (calculated from the horizontal to the assumed sinkhole sidewalls) were determined (see section 2.7.6 for details):

Table 17: Angles of draw for Focus Area 4

Lithology:	Weathering		
	Highly	Moderately	Slightly
Top soil	80°	-	-
Shale	80°	85°	90°
Diabase	80°	80°	90°
Chert	70°	80°	90°
Dolomite	70°	85°	90°
Chert rich dolomite residuum	70°	-	-
Chert poor dolomite residuum	65°	-	-
Wad	60°	-	-

Source: AGES, 2012

The comparative legend for each of the zones is identified at the end of the description of each zone. This legend is a working legend and is therefore subject to change with the availability of more recent information. The legend is sorted in order of priority.

3.10.2 Dolomite Hazard Zone A

This area is characterised as reflecting a **low** inherent susceptibility for the formation of **all size** (with sub areas of medium susceptibility of small size) sinkholes and subsidences with respect to **ingress of water** and a **low to a medium** susceptibility for the formation of **small size** sinkholes and subsidences with respect to **water level drawdown**. In the event of groundwater level drawdown, the susceptibility of the subsurface profile increases to a **low to a medium** susceptibility from an **ingress of water** perspective. **Composite characterisation: Inherent Hazard Class 1(2)//1/2**

- Gravity

The area is characterised by a gravity low in the western and central section, grading into a high in the east. The area is bordered by a gravity gradient in the west, flowing through to the south.

- Blanketing Layer

The blanketing layer in this zone is characterised by the following:

The area is underlain by an average of 35 meters of moderately weathered shale or an average of 45 meters of a combination of moderately weathered shale and diabase;

No boreholes in this zone reflected any air or sample loss;

Some moderately weathered chert and dolomite, without any residuum (wad), has been recorded at depth below the shale and above the solid dolomite bedrock:

- Bedrock morphology

All boreholes were drilled at least 6 meter into competent dolomite bedrock, or to a depth of 60 meter. The depth to competent dolomite bedrock increases to the south west of the zone, with the 60 meter below ground level as the western, south-western and southern border of the zone.

The faults identified in this zone may be regarded as fractured and shattered fault zones, comprised of a multitude of smaller faults. It is therefore impossible to delineate all the individual faults within the zone in detail.

- Geohydrology

The water levels measured in this zone indicates that the groundwater level below surface level increases to the north, from 8 mbgl in FA4 30, to 28 mbgl in FA4 45. There is no indication of what the original water level (OWL) of the area is.

No monitoring boreholes have been drilled in this zone.

- Final Characterisation

The blanketing layer consists of sedimentary (shale) and igneous (diabase) material with an average thickness of 40 meters. The material is moderately weathered, with a resulting low mobilisation potential with respect to ingress of water. The dolomite bedrock is generally located at a depth of 40 meter, but due to the nature of the material, the potential development space results in a medium size feature forming. The nature of the blanketing layer and the subsurface conditions result in a low inherent susceptibility for the formation of all size sinkhole and subsidence formation with respect to water ingress. The area is also characterised by various fault systems, which increases the inherent susceptibility from a low to a medium. Due to the nature of the faulting, it is characterised with possible development of small size sinkholes. The resulting classification is therefore given as Inherent Hazard Class 1 (with pockets of 2) with respect to ingress of water.

Even though the groundwater level is located within the blanketing layer in all the boreholes, the inherent susceptibility for mobilisation is low from a groundwater level drawdown perspective. The fault zones may be characterised as having a low to a medium susceptibility for the formation of small size sinkholes, resulting in a classification of Inherent Hazard Class 1/2 with respect to groundwater level drawdown.

In the event of groundwater level drawdown, the susceptibility of the subsurface material remains unchanged from a water ingress perspective. The blanketing layer is of such a nature that it will buffer ingress water and no additional material will consequently be subject to mobilisation.

The composite risk designation is Inherent Hazard Class 1(2)//1/2 based on the following legend application: $A < E < F < C$

3.10.3 Dolomite Hazard Zone B

This area is characterised as reflecting a **medium** inherent susceptibility for the formation of **large size** sinkholes and subsidences with respect to **ingress of water** and a **medium** susceptibility for the formation of **large** size sinkholes and subsidences with respect to **water level drawdown**. In the event of groundwater level drawdown, the susceptibility of the subsurface profile does not change from an **ingress of water** perspective. **Composite characterisation: Inherent Hazard Class 4//4**

- Gravity

The area is characterised by a gravity high plateau.

- Blanketing Layer

The blanketing layer in this zone is characterised by the following:

The area is underlain by 10 to 20 meters of moderately weathered shale;

Some of the boreholes in this zone reflected slight air loss, but none reflected any sample loss;

The dolomite bedrock is overlain by 10 to 20 meters of highly weathered chert rich dolomite residuum with traces of wad, grading into wad with traces of chert.

- Bedrock morphology

All boreholes were drilled at least 6 meters into competent dolomite bedrock. The dolomite outcrops in the north of the area, and increases to the south to about 30 mbgl.

- Geohydrology

The water levels measured in this zone indicates that the groundwater level below surface level increases to the north, from 7 mbgl in FA4 27, to 20 mbgl in TDRC 01. There is no indication of what the OWL of the area is.

No monitoring boreholes have been drilled in this zone.

- Final Characterisation

The upper section of the blanketing layer consists of sedimentary material (shale) ranging from 10 to 20 meters in thickness. The material is moderately weathered, with a resulting low mobilisation potential. A highly weathered section, ranging from 10 to 20 meters, overlies the dolomite bedrock. The material within this highly weathered section ranges from chert rich dolomite residuum with traces of wad to wad with traces of chert, both characterised as having a high mobilisation potential. The resulting nature of the blanketing layer and the subsurface conditions result in a medium inherent susceptibility for the formation of large size sinkhole and subsidence formation with respect to water ingress. The resulting classification is given as Inherent Hazard Class 4 with respect to ingress of water.

The groundwater level is located above the dolomite bedrock, within either the dolomite residuum or the shale. The inherent susceptibility for mobilisation is medium from a groundwater level drawdown perspective. The resulting classification is an Inherent Hazard Class 4 with respect to groundwater level drawdown.

In the event of groundwater level drawdown, the susceptibility of the subsurface material may increase from a water ingress perspective. But the upper section of the blanketing layer is of such a nature that it will buffer ingress water and no additional material will consequently be subject to mobilisation.

The composite risk designation is Inherent Hazard Class 4//4 based on the following legend application: $G < F < D \ll E$

3.10.4 Dolomite Hazard Zone C

This area is characterised as reflecting a **medium** inherent susceptibility for the formation of **large size** sinkholes and subsidences with respect to **ingress of water** and a **medium** susceptibility for the formation of **large** size sinkholes and a **high** susceptibility for the formation of **large** size subsidences with respect to **water level drawdown**. In the event of groundwater level drawdown, the susceptibility of the subsurface profile does not change from an **ingress of water** perspective. **Composite characterisation: Inherent Hazard Class 4//4/7**

- Gravity

The area is characterised by a gravity low plateau, bordered by a transition to a gravity high on the western side.

- Blanketing Layer

The blanketing layer in this zone is characterised by the following:

The area is underlain by about 30 meters of a combination of moderately weathered shale and diabase;

Some of the boreholes in this zone reflected slight to medium air loss, but none reflected any sample loss;

The dolomite bedrock is overlain by about 30 meters of highly weathered chert rich dolomite residuum with traces of wad.

- Bedrock morphology

Only one of the boreholes intersected competent dolomite bedrock, the other was drilled to a depth of 60 meter.

The faults identified in this zone may be regarded as fractured and shattered fault zones, comprised of a multitude of smaller faults. It is therefore impossible to delineate all the

individual faults within the zone in detail.

- Geohydrology

The water levels measured in this zone indicate that the groundwater level is at about 20 mbgl, within the sedimentary overburden. There is no indication of what the OWL of the area is.

No monitoring boreholes have been drilled in this zone.

- Final Characterisation

The upper section of the blanketing layer consists of about 30 meters of sedimentary material (shale). The material is moderately weathered, with a resulting low mobilisation potential. A highly weathered section of about 30 meters overlies the dolomite bedrock. The material within this highly weathered section ranges from highly weathered chert, dolomite residuum with wad and chert rich dolomite residuum with wad. This material is characterised as having a high mobilisation potential. The resulting nature of the blanketing layer and the subsurface conditions result in a medium inherent susceptibility for the formation of large size sinkhole and subsidence formation with respect to water ingress. The resulting classification is given as Inherent Hazard Class 4 with respect to ingress of water.

The groundwater level is located above the dolomite bedrock, within the shale. The inherent susceptibility for mobilisation is medium from a groundwater level drawdown perspective for the formation of sinkholes. Due to the compressibility of the highly weathered material underlying the shale, the material has a medium to a high susceptibility for the formation of subsidences with regard to water level drawdown. The resulting classification is an Inherent Hazard Class 4/7 with respect to groundwater level drawdown.

In the event of groundwater level drawdown, the susceptibility of the highly weathered subsurface material may increase from a water ingress perspective, but due to the nature of the upper section of the blanketing layer, it will buffer ingress water and no additional material will consequently be subject to mobilisation.

The composite risk designation is Inherent Hazard Class 4//4/7 based on the following legend application: D < C < E << A

3.10.5 Dolomite Hazard Zone D

This area is characterised as reflecting a **medium** inherent susceptibility for the formation of **large size** (with sub areas of low susceptibility for all size) sinkholes and subsidences with respect to **ingress of water** and a **medium** susceptibility for the formation of **large size** (with sub areas of low susceptibility for all size) sinkholes and subsidences with respect to **water level drawdown**. In the event of groundwater level drawdown, the susceptibility of the subsurface profile does not change from an **ingress of water** perspective. **Composite characterisation: Inherent Hazard Class 4(1)//4(1)**

- Gravity

The area is characterised by a gravity low in the north, grading into a gravity high in the south.

- Blanketing Layer

The blanketing layer in this zone is characterised by the following:

The area is underlain by a combination of moderately weathered shale and diabase ranging from 30 to 35 meter, according to the current drilling data;

None of the boreholes in this zone reflected air or sample loss;

The dolomite bedrock is overlain by about 5 meters of weathered material, ranging from wad with traces of chert to moderately weathered dolomite.

- Bedrock morphology

The bedrock material ranges from moderately weathered chert and dolomite to competent dolomite bedrock. All boreholes were drilled 6 meter into competent bedrock, or to a depth of 60 meters.

The structure of the dolomite bedrock, as seen in the surrounding bedrock, has been drastically altered in this zone. The faults identified in this zone may be regarded as fractured and shattered fault zones, comprised of a multitude of smaller faults. It is therefore impossible to delineate all the individual faults within the zone in detail.

- Geohydrology

The water levels measured in this zone indicate that the groundwater level is between 10 and 15 mbgl, within the sedimentary overburden. There is no indication of what the OWL of the area is.

No monitoring boreholes have been drilled in this zone.

- Final Characterisation

The upper section of the blanketing layer consists of between 30 and 35 meters of sedimentary material (shale). The material is moderately weathered, with a resulting low mobilisation potential. A highly weathered section of about 5 meters overlies the dolomite bedrock. The material within this highly weathered section ranges from moderately weathered dolomite to wad with traces of chert. This material is characterised as having a high mobilisation potential. The zone has been subjected to faulting and the bedrock character has been altered. The resulting nature of the blanketing layer and the subsurface conditions result in a medium inherent susceptibility for the formation of large size (with sub areas of low susceptibility for any size) sinkhole and subsidence formation with respect to water ingress. The resulting classification is given as Inherent Hazard Class 4(1) with respect to ingress of water.

The groundwater level is located above the dolomite bedrock, within the shale. The inherent susceptibility for mobilisation is low to medium from a groundwater level drawdown perspective for the formation of sinkholes and subsidences. The resulting classification is an Inherent Hazard Class 1/4 with respect to groundwater level drawdown.

In the event of groundwater level drawdown, the susceptibility of the highly weathered subsurface material may increase from a water ingress perspective, but due to the nature of the upper section of the blanketing layer, it will buffer ingress water and no additional material will consequently be subject to mobilisation.

The composite risk designation is Inherent Hazard Class 4(1)//1/4 based on the following legend application: $F < D < C \ll A < E$

3.10.6 Dolomite Hazard Zone E

This area is characterised as reflecting a **medium** inherent susceptibility for the formation of **large size** sinkholes and subsidences with respect to **ingress of water** and a **medium to a high** susceptibility for the formation of **large to very large size** sinkholes and subsidences with respect to **water level drawdown**. In the event of **groundwater level drawdown**, the susceptibility of the subsurface profile increases to a **medium to a high** susceptibility from an **ingress of water** perspective. **Composite characterisation: Inherent Hazard Class 4//4/8**

- Gravity

The area is characterised by a gravity low in the northern section, grading into a high in the south. The area is bordered by a gravity high in the south.

- Blanketing Layer

The blanketing layer in this zone is characterised by the following:

The blanketing layer increases in thickness from the outcropping dolomite in the north, with no blanketing, to a thickness of about 30 m in the south. The material is comprised of moderately weathered shale in the north, grading into a combination of moderately weathered shale and diabase in the south.

Some of the borehole in this zone reflected air and sample loss;

Some highly weathered chert and dolomite, grading into wad with traces of chert, has been recorded at depth below the shale and above the solid dolomite bedrock;

- Bedrock morphology

All boreholes were drilled at least 6 meter into competent dolomite bedrock. The depth to competent dolomite bedrock increases to the south west of the zone.

- Geohydrology

The groundwater levels measured in this zone indicate that the groundwater level is at about 20 mbgl in the northern part. This water level is within the weathered section. There is no indication of what the OWL of the area is.

No monitoring boreholes have been drilled in this zone.

- Final Characterisation

The blanketing layer consists of sedimentary (shale) and igneous (diabase) material, increasing in thickness to the south. The material is moderately weathered, with a resulting low mobilisation potential with respect to ingress of water. The dolomite bedrock is exposed in the south, increasing to a depth of about 30 m in the south. The material overlying the dolomite is moderately to highly weathered chert and dolomite residuum, with in some places wad and traces of chert. The nature of the blanketing layer and the subsurface conditions result in a medium inherent susceptibility for large to very large size sinkhole and subsidence formation with respect to ingress of water. The resultant classification is Inherent Class 4.

The groundwater level is located within the highly weathered overlying material, so groundwater level drawdown will result in a medium to a high the inherent susceptibility for mobilisation from a groundwater level drawdown perspective. The resulting classification is Inherent Hazard Class 4/8 with respect to groundwater level drawdown.

In the event of groundwater level drawdown, the susceptibility of the subsurface material will increase from a medium to a high from a water ingress perspective, resulting in a high susceptibility for the formation of very large sinkholes or subsidences.

The composite risk designation is Inherent Hazard Class 4//4/8 based on the following legend application: $F < D \ll E \ll A$

3.10.7 Dewatered scenario

In the event of groundwater level drawdown, the following will take place:

- The susceptibility of the surface material in Zones B, C and D will not increase from an ingress of water perspective, and the zonation will stay as indicated;
- The susceptibility of the subsurface material in Zone A will increase from a low to a low to a medium from an ingress of water perspective, resulting in a classification of Inherent Hazard Class 2//1/2;
- The susceptibility of the subsurface material in Zone E will increase from a medium to a high from an ingress of water perspective, resulting in a classification of Inherent Hazard Class 4/8//8;

- Zone A will be extended to the zone indicating the area where the dolomite bedrock is 100 mbgl. This entire Dolomite 100 mbgl Zone will then be classified as Inherent Hazard Class 1(2)/1/2.



**Tlokwe Focus Area 4,
North West Province**

Legend

- Focus Area 4
- No Risk Zone
- Dolomite 100 mbgl
- Zone A
- Zone B
- Zone C
- Zone D
- Zone E

Source: AGES, 2012

NORTH WEST OFFICE
76 Steve Biko Avenue
Pretoria/Steinburg 2531
Tel: +27 18 297 6588
Fax: +27 18 297 4813

0 62.5 125 250 375 500
m

Coordinate system: WGS 1984

Figure 12: Final Zonation Map