Council for Geoscience

A FEASIBILITY LEVEL DOLOMITE STABILITY INVESTIGATION REPORT FOR CHURCHILL, IN THE JURISDICTION OF JOE MOROLONG LOCAL MUNICIPALITY, NORTHERN CAPE

OCTOBER 2017

REPORT NO: 2017 – 0174

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Department:
Co-operative
Governance, Human
Settlement & Traditional
Affairs
Northern Cape

Engineering Geosciences & Geohazards		
CGS REPORT NUMBER: 2017- 0174	Council for Geoscience	LEVEL OF CLASSIFICATION Restricted
REVISION: 0		COPY NO.

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AUTOHORISE DATE:	PROJECT NUMBER:
October 2017	CO-2017-5810 Phase 20

DOCUMENT APPROVAL		
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Executive Summary

The Council for Geoscience (CGS) was appointed by the Northern Cape Department of Co-operative Governance, Human Settlements & Traditional Affairs (CoGHSTA) to conduct feasibility level dolomite stability investigation for five (5) sites which are located within the jurisdictions of Kgatelopele, Joe Morolong and Ga-Segonyana Local Municipalities. This report presents findings of a dolomite stability investigation which was carried out in Churchill which is located within the jurisdiction of Joe Morolong Local municipality to facilitate development planning for low cost housing.

This dolomite stability investigation was carried out in accordance with the latest standard practice (SANS 1936-2:2012); and broadly included desk study, site-walk over, gravity survey, percussion drilling, analysis of results and report writing. A gravity map was produced and used to determine borehole positions from gravity highs, lows and gradients. A total 62 percussion boreholes for this 151 Ha site were proposed and drilled.

According to the 1:250 000 scale, geological map, 2722 KURUMAN, the site is predominantly underlain by aeolian sands, calcrete and calcified pan dunes of Gordonia Formation. The area also hosts surface limestone of tertiary age.

Recorded water rest levels ranged between 2.5 m and 58.7 m with a general average of 10 m.

The profile of the site generally consists of aeolian deposits, calcrete or calcified (pedogenic) deposits, weathered dolomite and hard rock dolomite. Other rocks types and most noticeably dolerite was intersected in some boreholes.

The stability evaluation was conducted in accordance with the widely accepted scenario supposition method which considers the factors which include blanketing layer, receptacles, mobilisation or mobilizing agents and maximum potential development space.

The assessment favoured the site to be zoned into one (1) Inherent Hazard Zone: Zone A, as dictated by geological conditions revealed by percussion drilling results and geohydrological data.

Zone A

- *Inherent Hazard Class: 3/4 (1) // 3(1)*

This zone is largely characterised by a medium inherent hazard of a medium (2-5 m diameter) sinkhole and subsidence (with sub areas of medium inherent hazard of large [5-15 m diameter] sinkhole and subsidence) in a non-dewatering scenario. The inherent hazard for any size sinkhole and subsidence is low with respect to a dewatering scenario.
The overburden which is non-dolomitic consists of aeolian deposits and pedogenic calcrete which is in a form of hardpan and calcified nodules in places. This zone occupies all gravity zones i.e. highs, lows and gradients. Neither wad nor low density material was recorded in the boreholes drilled. The groundwater level rests within the solid dolomite bedrock.

- *Dolomitic Area Designation*

This zone is assessed as D3 and implies that extra precautionary measures in addition to those pertaining to the prevention of concentrated ingress of water into the ground, in accordance with the relevant requirements of SANS 1936-3, are required and must be adhered to.

- *Development Potential*

Restrictions are placed on the types of residential development that may be considered on IHC: 3/4 land. Full title residential development (RN2-3) on stands of 300 m^2 or greater is recommended or 10 – 25 dwelling houses per hectare and a population of ≤ 60 people per hectare is recommended. Any form of commercial, retail and/or light industrial development is permissible (C1 to C10) with appropriate stringent precautionary measures. Footprint investigations are required for each commercial development.

A Competent Person must be appointed to compile a site specific ***Dolomite Risk Management Strategy (DMRS)****. Such a plan, which is considered beyond the scope of this investigation, should define ongoing processes to manage water ingress and assign responsibilities to particular persons. General principles are provided. Groundwater Monitoring should also form part of the DRMS.*

The drop in water rest level from 3 m in 2012 to about 10 m in 2017, shows that the compartment may have been impacted by excessive extraction. Accordingly, as an immediate precautionary measure two (2) monitoring boreholes were drilled and equipped for continuous groundwater level monitoring.

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1. INTRODUCTION

1.1 Terms of Reference

The Council for Geoscience (CGS) was appointed by the Northern Cape Department of Co-operative Governance, Human Settlements & Traditional Affairs (CoGHSTA) to conduct feasibility level dolomite stability investigation for five (5) sites which are located within the jurisdictions of Kgatelopele, Joe Morolong and Ga-Segonyana Local Municipalities. The appointment was made through a letter by then CoGHSTA head of department Mr. D Heerden, dated 16 November 2017. A service level agreement was signed on the 17 January 2017.

1.2 Background

This report presents findings of a dolomite stability investigation which was carried out in Churchill which is located within the jurisdiction of Joe Morolong Local municipality.
A site hand-over meeting took place on 13 January 2017 and was attended by the Joe Morolong Local Municipality official, CoGHSTA project management unit (PMU) personnel and Council for Geoscience personnel.
The overall purpose of the investigation was to determine the Inherent Hazard Class (IHC) and the Dolomite Area Designations for the area, in order to facilitate development planning for low cost housing.

The primary objectives of the investigation are to provide the following:

- The overview of the geology and groundwater conditions of the site,
- The description and discussion of subsurface profiles from ground surface to dolomite bedrock,
- The assessment of the dolomite bedrock morphology,
- The assessment of Inherent Hazard Class(es) (IHC) for sinkhole and subsidence formation,
- The determination of appropriate dolomite area designation(s),
- The establishment of allowable development type, in terms of the National Standard (SANS 1936) with due cognisance of the Inherent Hazard Class,

- The determination of precautionary measures; and
- The determination of the risk management required to achieve and sustain a tolerable hazard rating.

2. INFORMATION USED IN THE STUDY

Information supplied to CGS before the start of the project was a site boundary and other geological reports in the vicinity of the study area.

At the time of the investigation the following sources of information were available and consulted:

- 1:250 000 geological map: 2722 KURUMAN – Council for Geoscience
- 1:50 000 topographical map: 2723AD KURUMAN – Surveyor General
- 1:500 000 Hydrogeological Map: 2722 KIMBERLERY – Department of Water Affairs
- Google Earth® Satellite Imagery

Only one (1) dolomite stability report in the vicinity of the study area for the establishment of library was available and can be cited as follows:

- Breytenbach, I.J. (2012). A report on dolomite stability conditions at the Moshaweng Municipality near Kuruman: A report for the proposed establishment of Churchill library. SoilKraft Cc Report No: 2012/J054/UCE.

The reports met the minimum requirements of SANS 1936-1&2 (2012) and was revised once.

3. SITE LOCATION AND DESCRIPTION

3.1 Site Location and Physiography

The site is located approximately 20 km north-east of Kuruman (Figure 1); and is accessible via Seoding Road from Kuruman CBD. The village is named ***Letlhokane*** in most of available

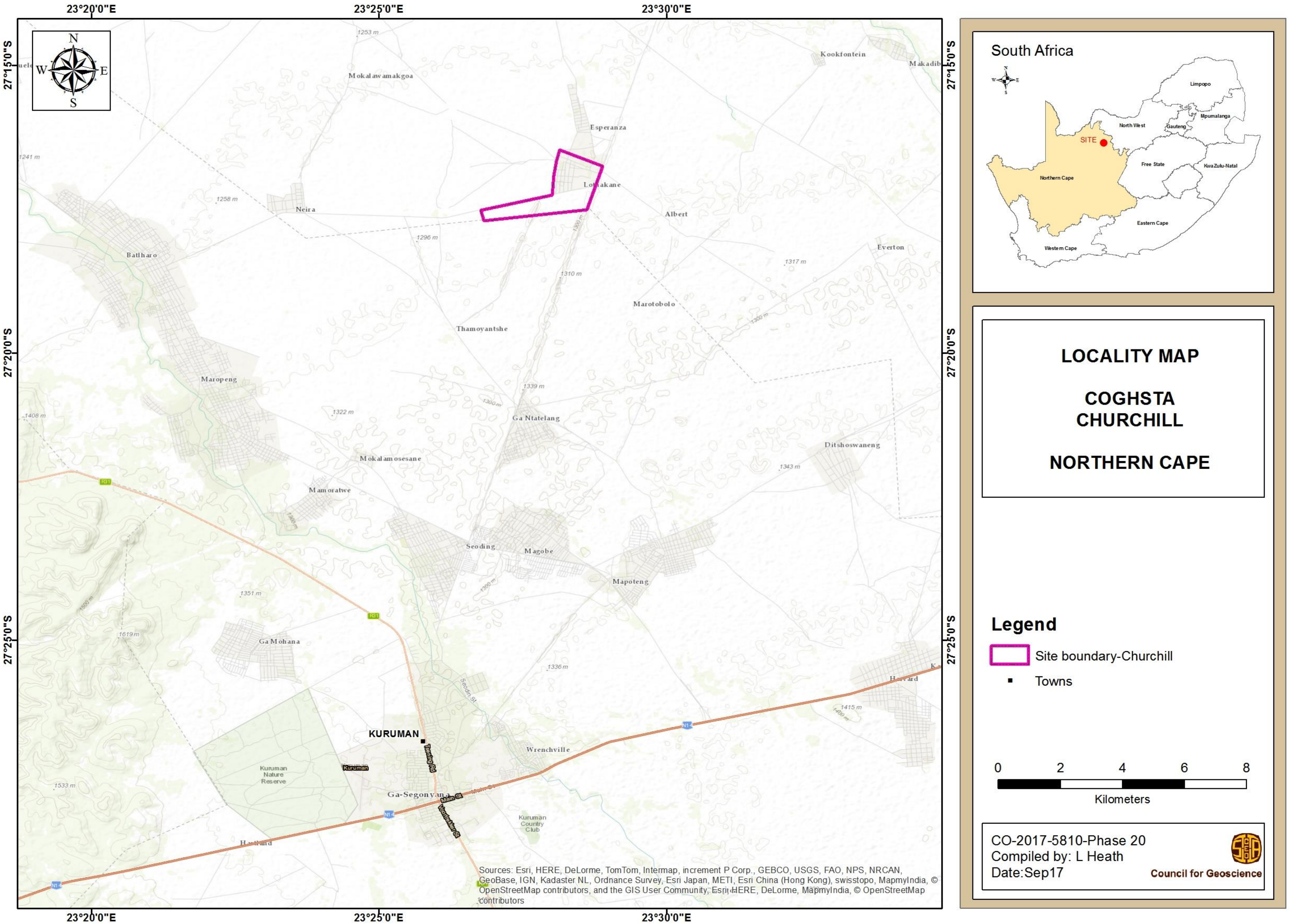


Figure 1: Locality Map.

maps e.g. GPS maps, topographical map and on Google Earth. The site boundary is characterised as a north facing L shape village land which is approximately 337 Ha in size.

The north eastern portion of the site is built up with schools, playing fields, small business premises and residential houses. The southern part of the site is a greenfield and is generally used for sheep and goats grazing. In places there are small borrow pits for natural gravel material (calcrete) particularly towards the main road in the eastern boundary. The layout of the stand is semi-formal with average stand sizes of about 900 m^2 and is equipped with a network of gravel roads.

3.2 Topography and Drainage

The site topography is essential flat but slightly undulating in places. The highest and lowest elevations within the site boundary are 1 287 m and 1 271 m above minimum sea level in the eastern and western boundaries respectively. The site generally slope towards south east with average slope of less than 2% (<1°). What appears to be a non-perennial and dry drainage course occurs in the eastern boundary and traverses the site from north to south. Site drainage is largely by sheet wash.

3.3 Climate

Frost is frequent in winter. Mean monthly maximum and minimum temperatures ranging from 35.9°C and -3.3°C for January and June, respectively (Mucina and Rutherford, 2006).

Churchill receives about 300 – 450 mm of rain per year with most of its rainfall occurring during summer and autumn with very dry winters (Mucina and Rutherford, 2006). The climatic N-value for the area is greater than 5 indicating that the environment is more arid and the predominant mode of weathering is physical weathering. According to Brink (1979), under semi-arid zones, there is a possibility of founding on rock at shallow depth.

3.4 Vegetation

The indigenous vegetation of the area is mainly classified as the Kuruman thornvelds which consists of closed shrub layer and well-developed open tree stratum mainly made of Acacia erioloba (Mucina and Rutherford, 2006). The site is extensively covered by tall grass, shrubs and trees in places.

Vegetation cover comprises grass, formal gardens, shrubs and trees in places.

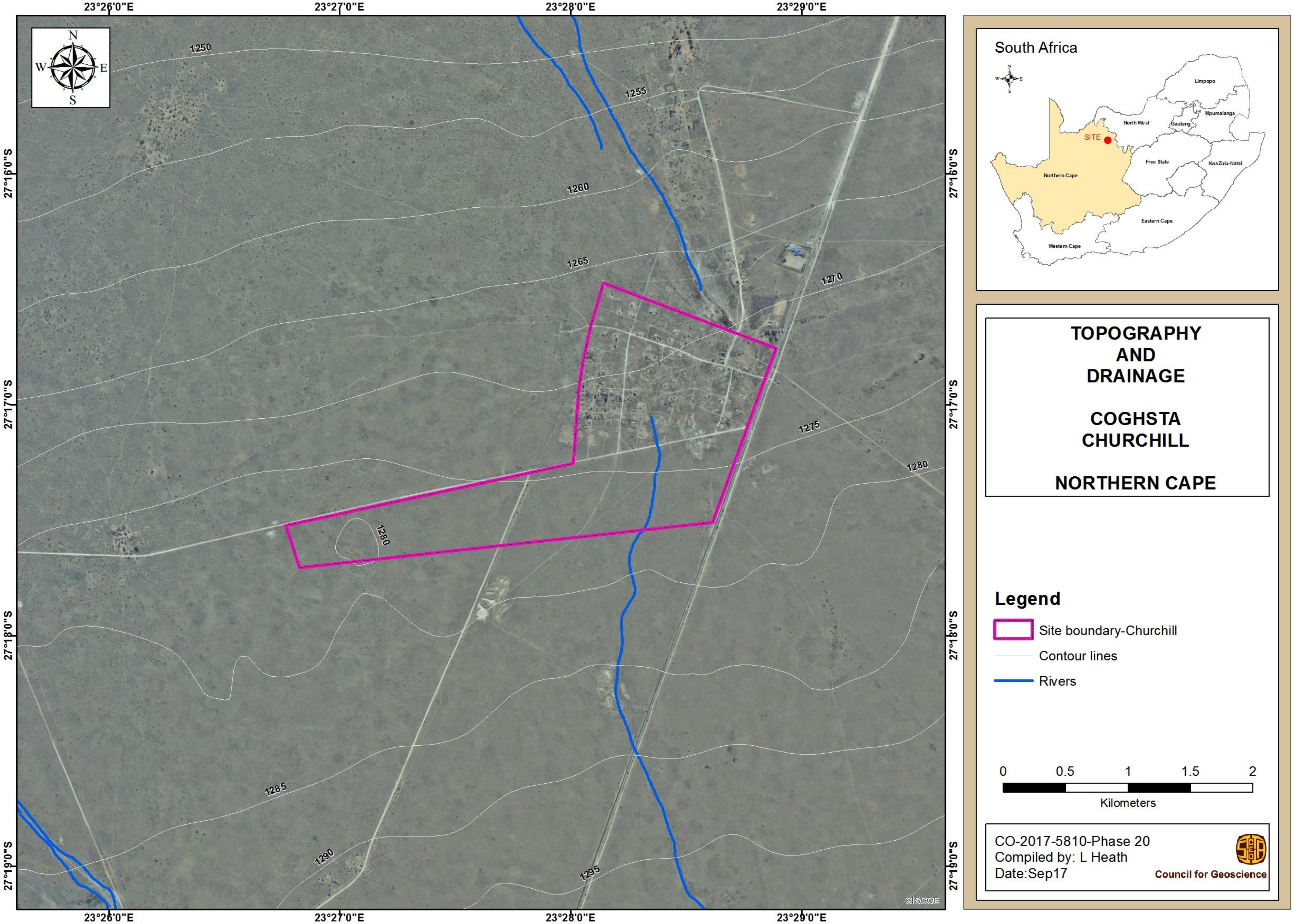


Figure 2: Site drainage.

4. INVESTIGATION PROCEDURES

This dolomite stability investigation was carried out in accordance with the latest standard practice (SANS 1936-2:2012); and broadly included desk study, site-walk over, gravity survey, percussion drilling, analysis of results and report writing.

4.1 Desk study

The initial step of the investigation took form the of a desk study, where all available and relevant information was collected and reviewed. Google Earth® satellite imagery was also reviewed to assess the terrain and elevation profile of the site.

4.2 Site Walk-Over Survey

A site walk-over survey was conducted on 13 January 2017. The site walk-over mainly revealed that access to the site was good and that no accessibility problems were anticipated for gravity surveys and percussion drilling.

4.3 Gravity survey

The gravity survey was conducted by the Geophysics and Remote Sensing Unit of the Council for Geoscience in accordance with SANS 1936-2: 2012 requirements for geophysical surveys in dolomitic land. The survey was conducted between 17 May and 31 June 2017 with a total of 3 974 points completed. Gravity survey involves measuring variations of the gravitational field, which aids to locate areas of greater or lesser density than the surrounding formations. The points were surveyed by means of Trimble real time GPS at 30 m spacing. A Scintrex CG-5 Autograv gravity meter no. G078 was calibrated and used to correspond with the known difference in absolute gravity between the Pretoria and Mowbray (Cape Town) stations. This is in accordance with the International Gravity Standardisation Net (IGSN′71) as described by Morelli *et al.* (1974) and the gravity formula, based on the 1967 Geodetic Reference System (Moritz, 1968). The gravity data was reduced to Bouguer anomaly and gridded to create the Bouguer Anomaly map. The Bouguer anomaly was upward continued to 500 m, The Bouguer anomaly was subtracted from the upward continued in order to separate the regional trend from the local trend. A gravity map was produced and used to determine borehole positions from gravity highs, lows and gradients. A gravity report titled "Detailed Gravity Survey at Churchill, Northern Cape Province" is presented in Appendix **1.**

4.2 Rotary percussion drilling

Drilling commenced on 4 August and was completed on 25 August 2017. A total 62 percussion boreholes for this 151 Ha site were proposed and drilled as per SANS 1936-2 minimum frequency of percussion boreholes in dolomitic areas. Twenty boreholes were drilled by Leruo Resources (Pty) Ltd and the rest by the Council for Geoscience drilling unit, using Super Rock 1000 and Prakla-Thor 5000 percussion rigs respectively. Rotary percussion boreholes were drilled to a minimum of at least 6 m into hard rock dolomite. Alternatively boreholes were drilled at least 60 m in gravity highs, lows anomalies as well as gradients. The two machines could hardly achieve a 3 minutes plus penetration per meter even for boreholes which were drilled in gravity highs and up to 60 m. This could be attributed to both compressor capacity of 2.4 kbar which is higher than the prescribed minimum 1.8 kbar as well as drill bit and hammer efficiency. During percussion drilling soil and rock-chip samples were recovered for every meter of advance and retained in a small labeled sample bag. The penetration rate per meter advance was recorded together with air loss, sample recovery and any other information regarding groundwater strike by the driller.

The logging of percussion borehole chips was done by a registered engineering geologist in accordance with accepted standard methodologies as per the national standard SANS 633: 2012 "*Soil profiling and rotary percussion borehole logging on dolomite land* in *Southern Africa* for *engineering purposes*". Borehole logs were prepared using Dotplot® software. Logs of the percussion borehole are presented in Appendix 2. The setting of percussion borehole positions was determined solely on the basis of the gravity survey results, where gravity highs, lows and gradient anomalies were targeted. Borehole positions setting and their distribution are indicated in the subsequent sections of this report.

5. SITE GEOLOGY AND GEOHYDROLOGY

5.1 Regional geology

According to the 1:250 000 scale, geological map, 2722 KURUMAN, the site is predominantly underlain by aeolian sands, calcrete and calcified pan dunes of Gordonia Formation. The area also hosts surface limestone of tertiary age.

The Ghaap Group outcrops are found within 10 kilometres from the study area. According to the Ghaap Group is subdivided into four subgroups of different depositional composition, namely; Schmidstdrift (siliclastic carbonates), Campbell Rand (dolomite and siliclastic mudstone), Asbestos Hill (banded and granular Banded Iron Formation) and Koegas (submarine fans) Subgroups (Kendal *et al*, 2012). The beds tend to dip 5° in a south westerly direction.

Dolomitic rock is composed mainly of the mineral dolomite, which is a carbonate of calcium and magnesium. Groundwater that is weakly acidic through enrichment with carbon dioxide, dissolves and removes the calcium and magnesium in the form of bicarbonates as it percolates through the network of joints, fractures and faults in the rock mass. This dissolution gives rise to karst features in the form of cave systems and voids. In many parts of South Africa, the karst landscape is buried beneath younger deposits and/or weathering products of the dolomitic formation, and these materials can either collapse or be transported into voids or cave systems, resulting in catastrophic ground movement at surface.

Because of risks of sinkhole and subsidence development associated with the presence of these soluble dolomitic rocks, it is required that a dolomite stability assessment be conducted, in accordance with SANS 1936-2:2012. It is further stated that developments on such dolomitic land shall be in accordance with the Inherent Hazard Classes and the Dolomite Area Designations as determined by the geotechnical site investigations.

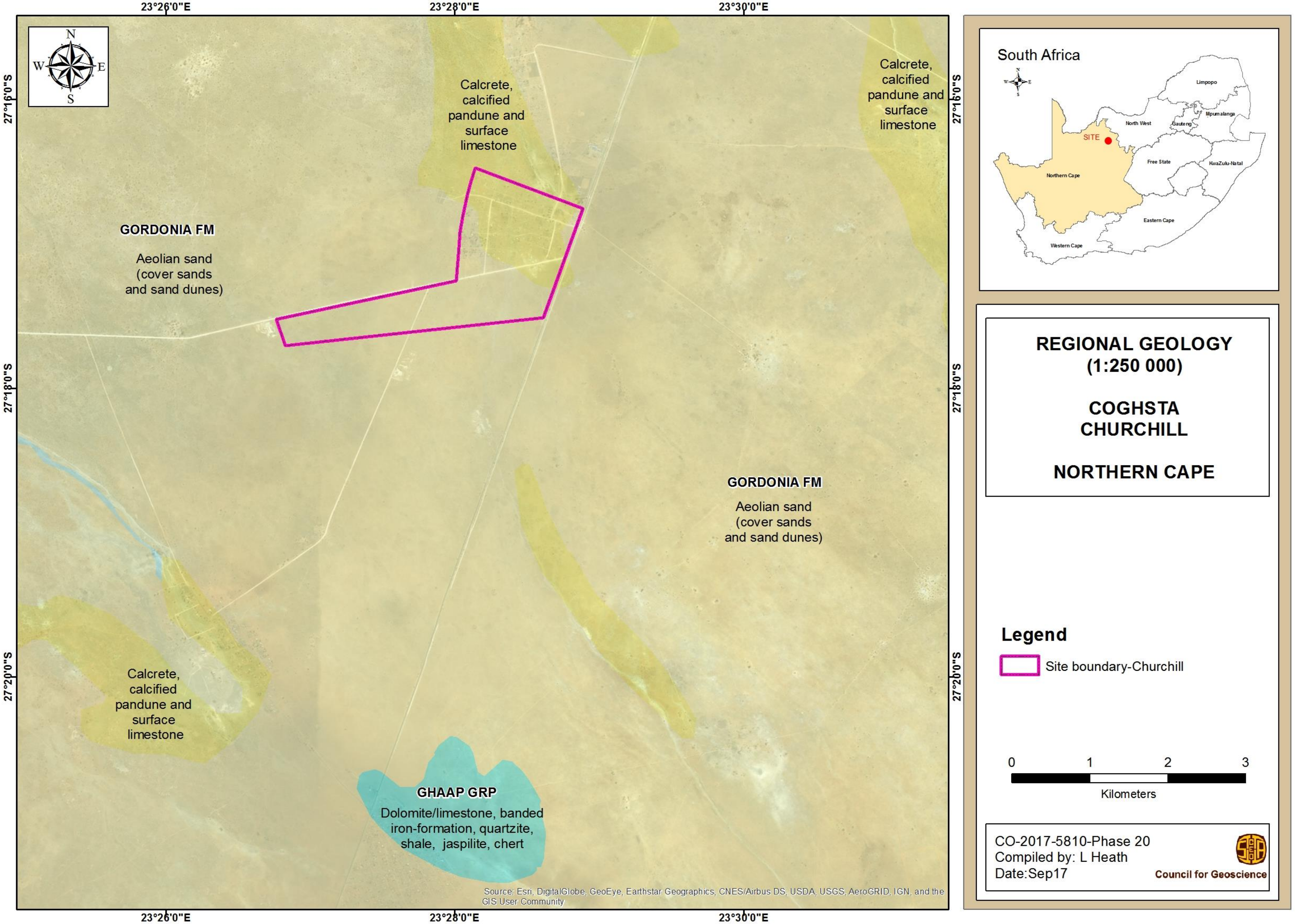


Figure 3: Site Geology Map.

5.2 Geohydrology

The groundwater scenario is a key risk assessment factor in the engineering-geological characterisation of dolomitic environments. According to a 1:500 000 hydrogeological Map 2722 KIMBERLERY, the principal groundwater occurrence system is a fractured, karstic and fissured dolomite aquifer type. The borehole yield (i.e. groundwater potential) class is >2.0 (median l/sec). The probability of such borehole for this yield class is between 50% and 60%. The municipality exclusively relies on groundwater resources for domestic, agricultural and business water supply. According the Department of Water Affairs' (DWA) National Groundwater Archive (NGA), there are 4 groundwater monitoring boreholes in close proximity of the site. They fall under Lower Vaal Water Management Areas and D41L drainage region. According to DWA records the water rest level ranges from 1.3 m to 2.51 m.

During percussion drilling of this investigation water strikes were encountered and water rest levels readings were taken using a dip meter after 24 hours as per SANS1936-1(2012). Water rest level measurements indicated that water rest levels were around 10 m in most of drilled boreholes. Recorded water rest levels varied between 2.5 m and 58.7 m in boreholes CH57 and CH55 respectively as shown in Figure 4. This shows a drawdown fluctuation of at least 8 m when comparing the current average of 10 m to that of 3 m measured by Breytenbach (2012) study, where water rest levels in all three (3) boreholes drilled were around 3 m. Breytenbach (2012) stated that, there was very little additional information of significance for this area and he deduced that the area has historically not been dewatered extensively. He added that, the last observation (monitoring) in this area was made in 2003, with observation supposed to have continued to 2007.

The drop in water rest level from 3 m in 2012 to more than 10 m in 2017, shows that the compartment may have been impacted by excessive extraction. In terms of dolomite stability for a dewatering scenario, the risk of sinkhole and subsidence to form is medium as the groundwater generally rests within the overburden which is calcrete in this case. Accordingly, as an additional precautionary measure 2 monitoring boreholes were drilled and equipped for continuous groundwater level monitoring.

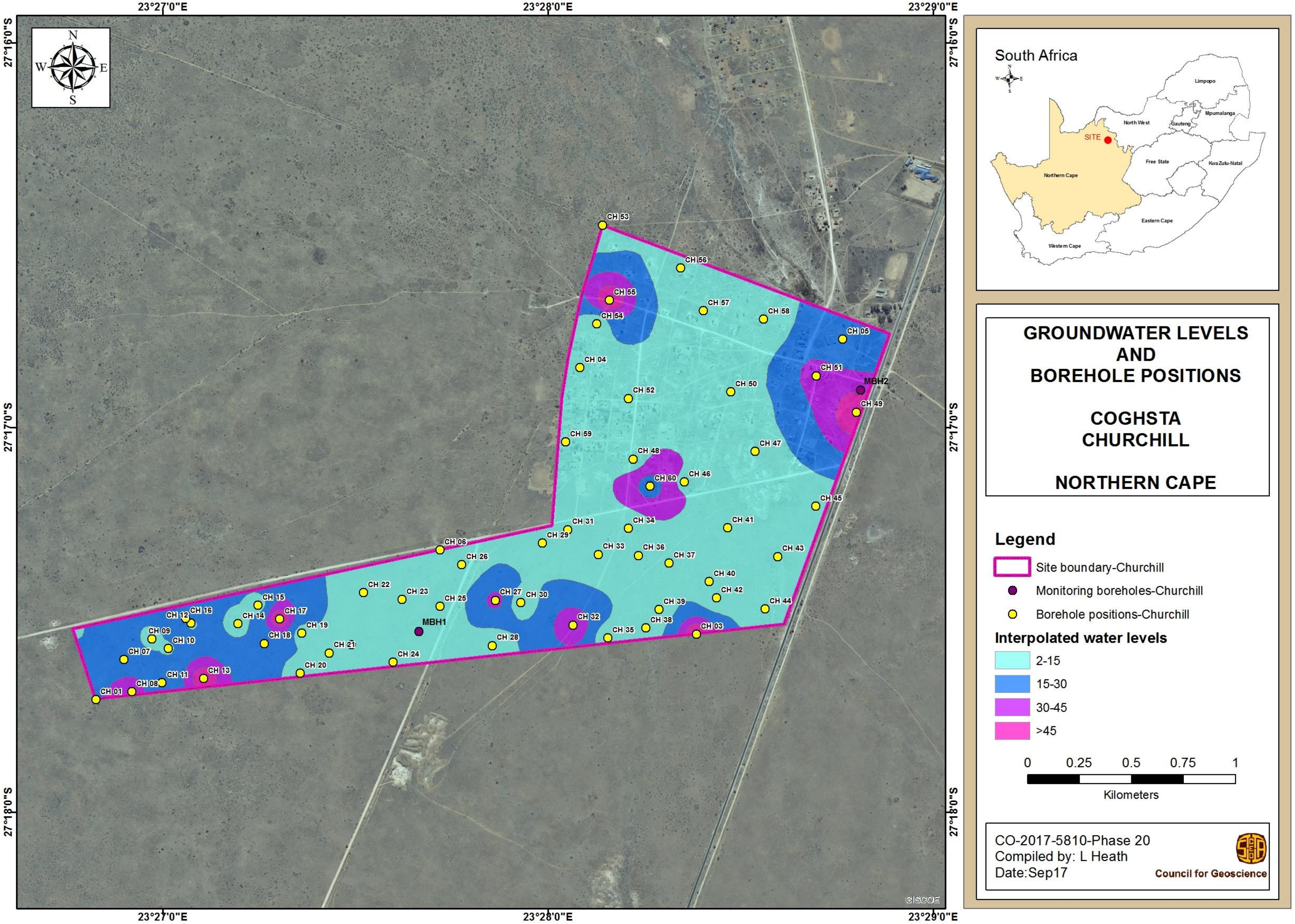


Figure 4: Ground water level Map

6. GEOPHYSICAL SURVEY RESULTS

6.1 Gravity

In a dolomitic environment gravity highs are usually associated with shallow dolomite bedrock or more dense material and gravity lows often represent deeply weathered intrusives, thick overburden or low density material. The residual gravity presented here is based on theoretical data as it was not re-calibrated after drilling was concluded.

A gravity report is attached as Appendix 1, but may be summarized as follows: (see also in Figure 5).

In general, alternating lows and highs are present in the study area, indicating possible features (bedrock) that are shallower at 0.163 mGals and those that are deeper than the surrounding area at 0.404 mGal. Gravity low patches are found in the south eastern and south western of the site, while gravity gradients and highs area are predominant and occur in different places across the site. Percussion drilling results confirmed the anticipated variation in the depth to bedrock and weathering profiles with relatively deep bedrock and thicker overburden profile being prevalent in gravity lows and much shallower or surface outcrops in gravity highs.

The correlation between the residual gravity pattern and drilling results was assessed as moderate to good.

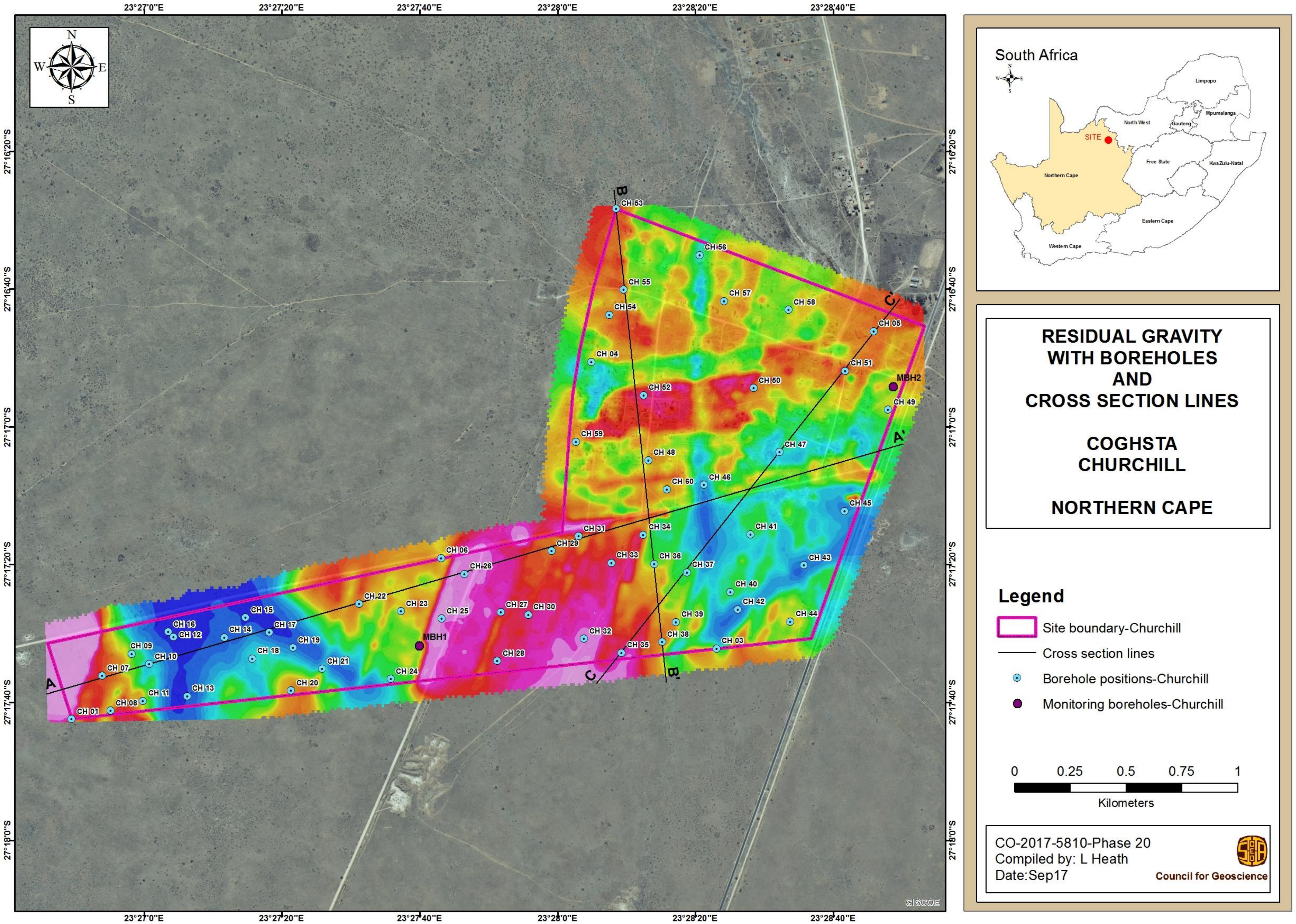


Figure 5: Map showing residual gravity, borehole positions and cross-section lines.

7. GEOLOGICAL PROFILES (SITE GEOLOGY)

Relevant information from the percussion boreholes is summarised in Table 1, and a general description of the respective geological horizons is presented in the paragraphs that follow. The profile of the site generally consists of aeolian deposits, calcrete or calcified (pedogenic) deposits, weathered dolomite and hard rock dolomite. Other rocks types and most noticeably dolerite was intersected in some boreholes as shown in Appendix 2.

It must be noted that while the process of percussion drilling is well suited for identification of the broader components of the dolomite profile and therefore assessment of the dolomite stability, detailed delineation of the subtleties within the soil profile is not possible. The geological cross sections in Figure 6, shows a subsurface model of the profile on site. They are based on the actual drilling results.

7.1 Aeolian Deposits

Percussion drilling results showed that this well-developed layer of transported material consists of brown, sandy silt with traces of calcified gravels in places. The horizon contains some plant roots in places. The thickness of this layer varies between 1 m and 2 m.

7.2 Hardpan Calcrete and Calcified (Pedogenic) Deposits

The pedogenic hardpan calcrete which is in the form of calcified gravel in certain places is well developed across the site; and occurs below the aeolian deposits.

Pedogenic hardpan calcrete generally occurs as very pale orange speckled black, moderately weathered slightly weathered, sub-rounded to sub angular, 15 mm diameter chips, calcrete. This calcrete layer was encountered in all boreholes drilled. The layer varies in thickness from 4 m up to 18 m in boreholes CH 05 and CH 55 respectively.

7.3 Weathered Dolomite

Moderately to highly weathered dolomite as per definition for surface characteristics (i.e. partial to complete discolouration and friable in places) was encountered only in CH 12 and CH 17. This horizon was described as light to dark grey, moderately to highly weathered, 10 mm diameter of chips, dolomite. The layer occurs between 13 m and deeper than 60 m in CH 12 and CH 17 respectively with an average thickness of 21m in gravity low areas.

7.4 Unweathered dolomite bedrock

As pointed out earlier, consistent penetration rates of greater than 3 minutes per meter (m/m) were not recorded. Unweathered dolomite bedrock refers to dolomite chips which showed surfaces with unchanged colour and very partial discolouration in certain places with an average penetration rate of 1.5 m/m.

In some boreholes, drilling was continued to 60 m after a continuous intersection of unweathered dolomite bedrock in order to prove that consistent penetration rates of greater than 3 minutes per meter (m/m) were not achievable given the efficiency of the compressors, hammer and drill bits for both machines. Unweathered dolomite bedrock is represented in the chip samples by light to dark grey, unweathered to slightly weathered, angular to sub-angular, 10 mm diameter of chips, dolomite.

7.6 Non-dolomitic bedrock

Another rock type which was revealed by drilling results was identified as dolerite. In boreholes CH: 18, 19, 41, 42, 43 and 58 It also occurred as minor component or interbedded with dolomite and chert in places. In boreholes CH: 34, 55, 56, and 57; was described as olive green weathering to brown, unweathered to slightly weathered, sub-angular to angular, 15 mm diameter of chips, dolerite. It is highly weathered in places. Its thickness varies from 14 m in CH 34 to 37 m in CH 56.

Table 1: Summary of borehole logs.

BH No.	Collar elevation (m)	Y- Coordinate (latitude)	X – Coordinate (longitude)	Overburden material (i.e. “unconsolidated” loose soil overlying the hard rock geology and includes residual soils)		Non dolomite bedrock	Dolomitic profile			Groundwater: water strike/ rest level (m)
				Colluvium (m)	Pedogenic material		Dolomite residuum	Weathered dolomite bedrock (m)	Hard dolomite bedrock (m)	
CH01	1279.327	-27.2951	23.447095	0 – 1 (1)	1– 13 (12)			13 – 28 (15)	28 – 48 (20)	37/30
CH02	1277.693	-27.2927	23.458156	0 - 1 (1)	1 – 11 (10)				11 – 60 (49)	Dry/5.0
CH03	1277.528	-27.2923	23.473095	0 – 1 (1)	1 – 14 (13)			14 – 21 (7)	21 - 60	15/58.7
CH04	1268.426	-27.2807	23.468045	0 – 1 (1)	1 – 9 (8)			19 – 21 (2)	9 – 37 (26)	15/4.60
CH05	1270.811	-27.2795	23.479426	0 – 1 (1)	1 – 5 (4)				5 – 25 (20)	Dry/24.6
CH06	1273.924	-27.2886	23.461986	0 – 1 (1)	1 – 17 (16)				17 – 30 (13)	Dry/7
CH07	1278.653	-27.2934	23.448318	0 – 1 (1)	1 – 14 (13)				14 – 28 (14)	Dry/24
CH08	1278.958	-27.2948	23.448654	-	0 – 12 (12)			12 – 24 (12)	24 – 60 (36)	Dry/43
CH09	1278.53	-27.2925	23.449516	0 – 1 (1)	1 – 12 (11)				12 – 25 (13)	22/10.4
CH10	1279.472	-27.2929	23.450226	0 – 1 (1)	1 – 13 (12)				10 – 37 (27)	Dry/13.47
CH11	1279.359	-27.2944	23.449959	0 – 1 (1)	1 – 13 (12)				13 – 60 (47)	Dry/12
CH12	1279.552	-27.2918	23.451207	0 – 1 (1)	1 – 13 (12)			13 – 60 (47)		22/9
CH13	1279.941	-27.2942	23.45176	0 – 1 (1)	1 – 14 (13)			35 – 45 (10)	14 – 35 (21), 45 – 55 (10)	37/
CH14	1278.438	-27.2918	23.453239	0 – 1 (1)	1 – 12 (11)				12 – 60 (48)	
CH15	1277.52	-27.291	23.454106	0 – 1 (1)	1 – 12 (11)			12 – 26 (14)	26 – 40 (14)	Dry/9

CH16	1279.312	-27.2916	23.450991	0 – 1 (1)	1 – 11 (10)	16 – 20 (2)			11 – 24 (13)	Dry/
CH17	1277.449	-27.2916	23.455061	0 – 2 (2)	2 – 16 (14)			16 – 60 (44)		39/
CH18	1278.163	-27.2927	23.45438	0 – 1 (1)	1 – 13 (12)				13 – 31 (18)	14.28
CH19	1277.552	-27.2923	23.456014	0 – 1 (1)	1 – 12 (11)				12 – 60 (48)	9.49
CH20	1278.371	-27.294	23.455941	0 – 1 (1)	1 – 13 (12)				13 – 30 (17)	10
CH21	1277.907	-27.2931	23.457191	0 – 2 (2)	2 – 15 (13)				15 – 40 (25)	11.5
CH22	1275.961	-27.2905	23.458684	0 – 1 (1)	1 – 11 (10)				11 -37 (16)	7.8
CH23	1276.205	-27.2908	23.460359	0 – 1 (1)	1 – 11 (10)			11 – 35 (24)	35 - 60 (25)	8.09
CH24	1277.958	-27.2935	23.459959	0 – 3 (3)	3 – 11 (8)				11 – 55 (44)	Dry/10.4
CH25	1276	-27.2911	23.462004	0 – 1 (1)	1 – 14 (13)				14 – 25 (11)	Dry/8.75
CH26	1275.006	-27.2893	23.462935	0 – 1 (1)	1 – 12 (11)				12 – 24 (12)	8
CH27	1276.049	-27.2908	23.464388	0 – 2 (2)	2 – 11 (9)				11 – 31 (20)	-
CH28	1277.129	-27.2928	23.464258	0 – 2 (2)	2 – 12 (10)				12 -31 (9)	9
CH29	1274.394	-27.2884	23.466434	0 – 2 (2)	2 – 10 (8)				10 – 22 (12)	8
CH30	1276.675	-27.2909	23.465499	0 – 1 (1)	1 – 13 (12)				13 – 60 (47)	Dry/8.81
CH31	1273.81	-27.2878	23.467525	0 – 1 (1)	1 – 10 (9)				10 – 21 (11)	Dry/7.9
CH32	1277.617	-27.2919	23.467754	0 – 3 (3)	3 – 11 (8)				11 – 43 (32)	24/
CH33	1274.986	-27.2888	23.468854	0 – 1 (1)	1 – 10 (9)				10 – 19 (9)	Dry/8.5
CH34	1274.073	-27.2877	23.470138	0 – 1 (1)	1 – 9 (8)	20 – 34 (14)			9 -60 (37)	14/8.54
CH35	1277.624	-27.2925	23.469265	0 – 1 (1)	1 – 9 (8)				9 – 32 (23)	18/9
CH36	1275.17	-27.2889	23.470578	0 – 1 (1)	1– 13 (12)				9 – 30 (21)	Dry/11.8
CH37	1275.679	-27.2892	23.471902	0 - 3 (1)	3 – 10 (7)				10 – 60 (50)	8.9
CH38	1277.44	-27.292	23.470897	0 – 1 (1)	1 – 8 (7)				8 – 35 (27)	8
CH39	1277.085	-27.2912	23.471464	0 – 1 (1)	1 – 11(10)				11 – 26 (15)	7.8
CH40	1276.015	-27.29	23.473639	0 – 3 (3)	3 – 9 (6)				9 – 40 (31)	6.7
CH41	1274.15	-27.2877	23.474451	0 – 1 (1)	1 – 8 (7)				8 – 43 (35)	7.4
CH42	1276.543	-27.2907	23.473952	0 – 1 (1)	1 – 13 (12)	13 – 42 (29)			13 – 42 (29)	26/7.6
CH43	1275.002	-27.2889	23.476616	-	0 – 12 (12)	12 – 43 (31)		12 – 43 (31)		7.2
CH44	1276.419	-27.2912	23.476064	0 – 1 (1)	1 – 12 (11)				12 – 25 (13)	5.8

CH45	1273.222	-27.2867	23.478248	0 – 1 (1)	1 – 13 (12)				10 – 37 (27)	7.6
CH46	1272.669	-27.2857	23.472574	0 – 1 (1)	1 – 13 (12)				13 – 60 (47)	13.6
CH47	1272.232	-27.2844	23.475635	0 – 1 (1)	1 – 8 (7)				8 – 40 (32)	4.6
CH48	1271.996	-27.2847	23.470344	0 – 1 (1)	1 – 12 (11)				12 – 31 (19)	8.8
CH49	1272.294	-27.2827	23.480011	0 – 1 (1)	1 – 10 (9)				10 – 60 (50)	44/
CH50	1270.707	-27.2818	23.474581	0 – 2 (2)	2 – 9 (7)				9 – 43 (34)	4.9
CH51	1271.36	-27.2811	23.478285	0 – 1 (1)	1 – 10 (9)				10 – 31 (21)	-
CH52	1270.545	-27.2821	23.470152	0 – 1 (1)	1 – 12 (11)				12 – 37 (25)	Dry/5.4
CH53	1263.584	-27.2746	23.469039	0 – 1 (1)	1 – 13 (12)				13 – 31 (18)	5
CH54	1267.014	-27.2788	23.468771	0 – 1 (1)	1 – 10 (9)				10 – 25 (15)	Dry/4.8
CH55	1266.366	-27.2778	23.469333	0 – 1 (1)	1 – 19 (18)	19 – 60 (41)				58.7
CH56	1265.671	-27.2764	23.472403	0 – 1 (1)	1 – 13 (12)	23 – 60 (37)	13 – 23 (10)			Dry/5.2
CH57	1268.02	-27.2783	23.473391	0 – 1 (1)	1 – 11 (10)	32 – 39 (7)			11 – 46 (35)	38/2.4
CH58	1268.661	-27.2786	23.475991	0 – 1 (1)	1 – 8 (7)	22 – 42 (20)			8 – 42 (34)	21/2.8
CH59	1270.823	-27.284	23.467428	0 – 2 (2)	2 – 13 (11)				13 – 60 (47)	6
CH60	1272.895	-27.2859	23.471086	0 – 1 (1)	1 – 14 (13)				14 – 25 (11)	-
MBH1	1276.000	-27.29217	23.46109		0 – 9 (9)			9 – 11 (2)	11 – 30 (19)	17/17
MBH2	1216.00	-27.28173	23.48019		0 – 6 (6)				6 – 60 (54)	17/9

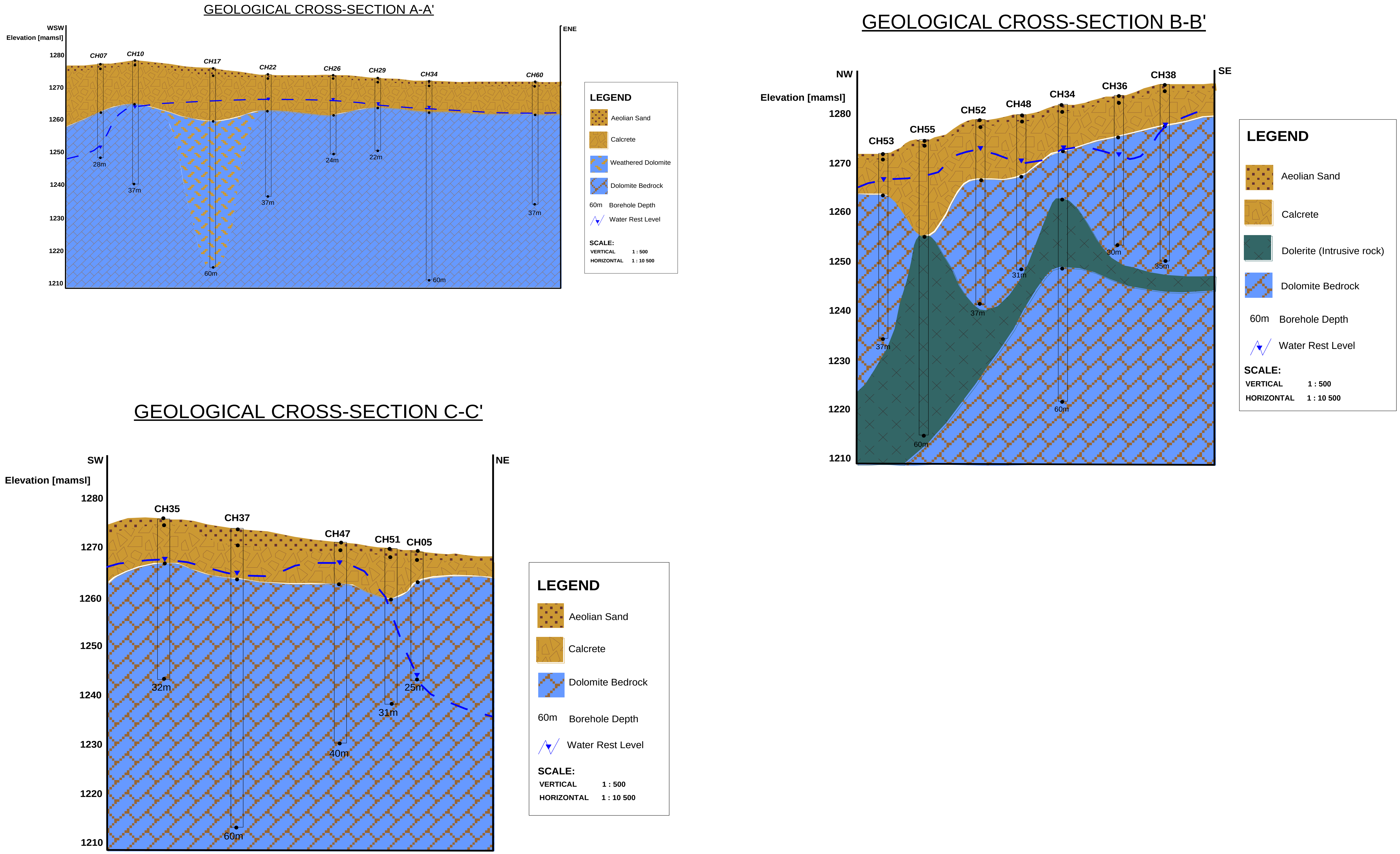


Figure 6: Geological cross sections A - A', B - B' and C - C' showing a geological model of the study area.

8. DOLOMITE STABILITY EVALUATION

8.1 Hazard (stability) characterisation procedure

The Inherent Hazard for sinkhole formation is a reflection of the geotechnical characteristics of the materials in the blanketing layer and depends mainly on the susceptibility (also termed mobilising potential) of materials to exploitation and mobilisation under the influence of a mobilising agency (Buttrick *et al*, 2001). The Inherent Hazard Class is defined in terms of ingress (non-dewatering scenario) and groundwater level drawdown (dewatering) reflected by two Inherent Hazard Class designations separated by a double forward slash, i.e. Inherent Hazard Class (ingress scenario) // Inherent Hazard Class (groundwater level drawdown).

The Method of Scenario of Supposition for evaluating the risk of sinkhole and subsidence formation (Buttrick and Van Schalkwyk, 1995) requires hypothesising the impact of man's future activities on the potential for sinkhole and subsidence formation, in a dolomitic karst environment in the context of either a dewatering or non-dewatering scenario. For stability evaluation purposes in a de-watering scenario, were borehole had collapsed or where they had to be backfilled immediately after drilling due to safety concerns, the groundwater rest level was assumed to be above dolomite bedrock. This would be a worst case scenario and was applied in the IHC characterization of boreholes 13, 16, 17, 27, 32, 49, 51 and 60.

Factors considered in assessing the hazard potential of the site are blanketing layer characteristics, the presence of receptacles, mobilisation potential of materials, mobilizing agents in operation and the maximum potential development space.

8.1.1 Nature of overburden

Dolomitic overburden comprises all the materials occurring between the ground surface and the dolomitic bedrock surface. It typically consists of residual dolomitic soils (wad and chert rubble), unweathered and weathered intrusive sills, and layers of Karoo sedimentary rock and quaternary deposits. The term blanketing layer is defined as that component of the dolomitic overburden that overlies the potential receptacles (Buttrick *et al,* 2001). It determines the susceptibility of the subsurface material to erosion by water ingress. The presence of material such as shales or intrusive, act as aquitards, to reduce the mobilisation potential and enhance the stability.

8.1.2 Receptacles

Receptacles may occur either as small disseminated and interconnected openings in the overburden (especially where chert rubble is present), or as substantial openings (cavities) in the bedrock. Both types of openings may be able to receive mobilised (transported) materials from overlying horizons (Buttrick *et al*, 2001). Information gathered from boreholes such as penetration rate, air loss combined with geophysical and geological information is used to formulate an impression of the degree of voids.

8.1.3 Mobilization and mobilizing agent

Mobilisation is defined as the movement of dolomitic overburden by subsurface erosion which is controlled by dramatic groundwater level fluctuations. Mobilising agents may include ingress water, ground vibrations, water level drawdown or any activity or process that can induce mobilisation of the material within the blanketing layer under the force of gravity. In a non-dewatering scenario the static ground water level is not an agent but a positive, mitigating factor (Buttrick *et al*, 2001).

8.1.4 Maximum potential development space

This is a simplified estimation of the maximum size sinkhole that can be expected to develop in a particular profile, provided that the available space is fully exploited by the mobilising agency. The available space depends on the depth below ground surface to the throat of a receptacle or disseminated receptacle and the ‘angle-of-draw’ in the various blanketing materials (Buttrick *et al,* 2001). The gravity survey results combined with borehole information influences the appraisal of this factor.

The hazard of sinkhole and subsidence formation is expressed in three broad categories, namely low, medium and high (Table 2).

Table 2: Hazard levels in terms of likelihood of events occurring.

Hazard Characterization	Anticipated events per hectare over time
Low	0 up to and including 0.1 events per hectare anticipated, but occurrence of events cannot be excluded. Return period is greater than 200 years.
Medium	Greater than 0.1 and less and equal to 1.0 events per hectare. Return period is between 200 and 20 years.
High	Greater than 1.0 event anticipated per hectare. Return period is less than 20 years.

The study area is characterised in terms of potentially eight standard Inherent Hazard Classes. These classes denote the chance of a sinkhole or subsidence occurring as well as its likely size (diameter) (Table 3). The terminology used in terms of likely size of an event (sinkhole or subsidence) is defined as follows:

Table 3: Classification of sinkhole size (after Buttrick et al, 2001).

Maximum potential development space	Maximum diameter of surface manifestation (dimension: meters)	Suggested terminology
Small potential development space	<2	Small sinkhole
Medium potential development space	2-5	Medium-size sinkhole
Large potential development space	5-15	Large sinkhole
Very large potential development space	>15	Very large sinkhole

The larger the Inherent Hazard Class number, the greater the likelihood of a sinkhole or subsidence occurring and the larger its potential size should it occur (Table 4).

The meaning/definition of each Inherent Hazard Class is as follows:

Table 4: Definition of the eight standard Inherent Hazard Classes.

Hazard Class	Characterization of Area
Class 1	Areas characterized as reflecting a low Inherent Hazard of sinkhole and subsidence formation (all sizes) with respect to ingress of water.
Class 2	Areas characterised as reflecting up to a medium Inherent Hazard of small sinkhole and subsidence formation with respect to ingress of water.
Class 3	Areas characterised as reflecting up to a medium Inherent Hazard of medium sinkhole and subsidence formation with respect to ingress of water.
Class 4	Areas characterised as reflecting up to a medium Inherent Hazard of large size sinkhole and subsidence formation with respect to ingress of water.
Class 5	Areas characterised as reflecting up to a high Inherent Hazard of small sinkhole and subsidence (all sizes) formation with respect to ingress of water.
Class 6	Areas characterised as reflecting up to a high Inherent Hazard of medium size sinkhole and subsidence formation with respect to ingress of water.
Class 7	Areas characterised as reflecting up to a high Inherent Hazard of large sinkhole and subsidence formation with respect to ingress of water.
Class 8	Areas characterised as reflecting up to a high Inherent Hazard of very large size sinkhole and subsidence formation with respect to ingress of water.

Based on the outcomes of the investigation and the Inherent Hazard Class assigned, an appropriate dolomite area designation (Table 5) is determined so that appropriate precautionary measures can be communicated. On land categorised as D2 and D3, appropriate precautionary measures in accordance with SANS 1936-3: 2012 must be implemented. In proposing suitable foundations types in D3 areas, consideration should be given to the potential loss of support which could be anticipated for the designated Inherent Hazard class based on expected sinkhole size.

Table 5: Dolomite Area Designations.

Dolomite area designation	Description
D1	No precautionary measures are required
D2	General precautionary measures, in accordance with the requirements of SANS 1936-3, that are intended to prevent the concentrated ingress of water into the ground, are required.
D3	Precautionary measures in addition to those pertaining to the prevention of concentrated ingress of water into the ground, in accordance with the relevant requirements of SANS 1936-3, are required.
D4	The precautionary measures required in terms of SANS 1936-3 are unlikely to result in a tolerable hazard. Site-specific precautionary measures are required.

8.2 Monitoring designations

Monitoring designations which indicate monitoring activities to are also allocated in terms of SANS 1936-4:2012 (Table 6). The higher the hazard, the more frequent the monitoring activities.

Table 6: Monitoring Area Designation.

Monitoring Area Designation	Risk Reduction Measures
A	Visual inspections of ground, structures and above-ground infrastructure (e.g. roads, storm water canals, ditches), surface runoff, obstructions to free flow, etc. Any evidence of cracking or ground settlement shall immediately be reported and investigated.
B	Visual inspection of storm water system for blockages, leaks, misalignment and ponding. Any evidence of blockages, leaks, misalignment and ponding shall be reported and cleared immediately.
C	Testing of wet services for leaks. Any leaks shall be reported and repaired immediately.
D	Visual inspection of dry services sleeves, ducts, manholes and facility chambers for water ingress. Any water ingress shall be reported and point of entry repaired/blocked immediately.
E	Monitoring of structures and ground levels. Any evidence of sustained movement shall be reported and investigated.
F	Monitoring of the groundwater level. Evidence of lowering shall be reported to the relevant national authority. On de-watered compartments, such as on the Far West Rand, monitoring of levels need only commence once de-watering has ceased and water level rise takes place.

Table 7: Frequency designation.

Frequency Designation	**Frequency of Activates**
0	Not required
Daily	Daily
Weekly	Weekly
1	Once a month
3	Quarterly
6	Bi-annually
12	Annually
24	Every two years
TBD	To Be determined

The monitoring area designation is described in terms of the risk reduction measures and the frequency of activities, as follows: (Monitoring area designation from Table 6) Frequency designation from table 7 e.g. (A) DAILY or; (E) 24

- Zones with a D1 dolomite area designation in accordance with SANS 1936-1 require no monitoring from a dolomite risk management perspective.
- Zones with a D2 dolomite area designation are assigned a low priority and require basic monitoring and maintenance activities at long intervals.
- Zones with a D3 or D4 dolomite area designation are assigned high priority in terms of monitoring and maintenance should receive attention more frequently.

TBD should be assigned, indicating that these are yet to be determined as no data or insufficient data exist and the inherent hazard classification is undetermined.

8.3 Stability characterisation of the site

In order to characterise the stability of the site (scenario supposition), the available information, geophysical gravity data, borehole logs and geohydrological information gathered during the investigation were reviewed and evaluated to determine the Inherent Hazard Class(es) (IHC) for individual boreholes. The following characteristics were gathered and analysed during the assessment process. The condition, nature and occurrence of material and geological horizons are generally uniform and persistent across the site.

- *Nature of blanketing layer*

As per the definition dolomitic overburden comprises all the material occurring between the ground surface and the dolomite bedrock surface, while the blanketing layer refers to a component of a dolomitic overburden that overlies receptacles. At the site, the overburden which is non-dolomitic consists of aeolian deposits and pedogenic calcrete which is in a form of hardpan and calcified nodules in places. The overburden thickness ranges from 5 m in CH 05 to 60 meters and CH17 if considering weathered dolomite as part of the overburden. Aeolian deposit material lacks cohesion and therefore is highly susceptible to mobilisation. However, this horizon attains a maximum thickness of only 2 m across the site. The pedogenic calcrete which underlies aeolian sand is considered to have a low mobilisation potential and competent to prevent the aeolian from being eroded or mobilised.

Although weathered dolomite in CH 22 may be considered as part of the overburden, it was deemed to have a low potential to mobilise.

- *Receptacles*

Receptacles occur as interconnected openings in the dolomitic overburden (especially where chert rubble is present) or as large solution cavities in the bedrock. During drilling, air loss was minimal and no cavities were intersected across the sites hence receptacle development is unlikely.

- *Mobilization and mobilizing agent*

The mobilization potential by head ward erosion due to water ingress from leaking services of surface ponding is low. In a dewatering or lowering of the groundwater level scenario, the mobilisation potential is medium for a sinkhole or subsidence to form because the groundwater rests within the blanketing layer.

- *Maximum potential development space*

The potential development space at the site is very limited as the bedrock is generally present at shallow depths (<15 m) and is also overlain by relatively strong and competed pedogenic calcrete.

All IHC results for individual boreholes are given in Table 3. They were assigned on the basis of overburden material properties, receptacle development, mobilising potential and potential development space as outlined in Hazard (stability) characterisation procedure section 8.

Table 8: Characterisation of sinkhole hazard formation.

BH No.	Thickness of overburden (m)	Receptacles	Overburden Mobilization potential	Potential maximum sinkhole size	Water rest level recorded after 24 hrs. (m)	Depth to bedrock (m)	Hazard characterization (sinkhole or/ doline formation)	IHC
CH 01	0 – 28 Aeolian sands, calcrete weathered dolomite	No air loss and medium to good sample recovery (75-100%)	Low to Medium	Large sinkhole	30.0	28 -48 Unweathered dolomite	Medium	3//3
CH 02	0 – 11 Aeolian sands, calcrete	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	5.00	11 - 60 Unweathered dolomite.	Medium	3//3
CH 03	0 – 21 Aeolian sands, calcrete weathered dolomite	No air loss and good sample recovery (100%)	Low to medium	Large sinkhole	58.7	21 -60 Unweathered dolomite.	Medium	4//1
CH 04	0 – 21 Aeolian sands, calcrete	No air loss and good sample recovery (90%)	Low to Medium	Medium sinkhole	4.60	21- 37 Unweathered dolomite.	Medium	3//3

CH 05	0 – 5 Aeolian sands, calcrete	No air loss and good sample recovery (90%)	Low to Medium	Medium sinkhole	24.6	5 – 25 Unweathered dolomite.	Medium	3//1
CH 06	0 –17 Aeolian sands, calcrete.	No air loss and good sample recovery (100%).	Low to medium	Large sinkhole	7.00	17 - 30 Unweathered dolomite.	Medium	4//3
CH 07	0 – 14 Aeolian sands, calcrete.	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	24.0	14 - 28 m Unweathered dolomite.	Medium	3//1
CH 08	0 – 24 Aeolian sands Calcrete Weathered dolomite.	No air loss and good sample recovery (80%).	Low to Medium	Large sinkhole	43.0	24 - 60 Unweathered dolomite	Medium	4//1
CH 09	0 – 12 Aeolian sands, calcrete.	No air loss and good sample recovery (100%)	Low to medium	Medium sinkhole	10.4	12 - 25 Unweathered dolomite.	Medium	3//3
CH 10	0 – 13 Aeolian sands, calcrete.	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	13.47	13 - 37 Unweathered dolomite.	Medium	3//1
CH 11	0 – 13 Aeolian sands, calcrete.	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	12.0	13 - 60 Unweathered dolomite.	Medium	3//3
CH 12	0 – 60 Aeolian sands, calcrete. weathered dolomite	No air loss and good sample recovery (100%)	Low to medium	Large sinkhole	9.00	>60 Unweathered dolomite.	Medium	4//3

CH 13	0 – 45 Aeolian sands, calcrete, weathered dolomite	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	-	45 - 55 Unweathered dolomite.	Medium	4//3
CH 14	0 – 12 Aeolian sands, calcrete.	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	9.1	12 - 60 Unweathered dolomite.	Medium	4//3
CH 15	0 – 26 Aeolian sands, calcrete. weathered dolomite	No air loss and good sample recovery (95%)	Low to medium	Large sinkhole	9.00	26 – 40 Unweathered dolomite.	Medium	4//3
CH 16	0 – 11 Aeolian sands, calcrete	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	-	11 - 31 Unweathered dolomite.	Medium	3//3
CH 17	0 – 60 Aeolian sands, calcrete weathered dolomite	No air loss and good sample recovery (100%)	Low to Medium	Large sinkhole	-	>60 Unweathered dolomite.	Medium	4//3
CH 18	1 – 13 Aeolian sands, calcrete	No air loss and good sample recovery (100%)	Low to medium	Medium sinkhole	14.28	13 - 31 Unweathered dolomite	Medium	3//1
CH 19	0 – 12 Aeolian sands, calcrete.	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	9.49	12 - 60 Unweathered dolomite.	Medium	3//3

CH 20	0 – 13 Aeolian sands, calcrete.	No air loss and medium to good sample recovery (75 - 100%).	Low to Medium	Medium sinkhole	10.0	13 - 30 Unweathered dolomite.	Medium	3//3
CH 21	0 – 15 Aeolian sands, calcrete	No air loss and good sample recovery (100%)	Low to medium	Medium sinkhole	11.5	15 - 40 Unweathered dolomite.	Medium	3//3
CH 22	0 – 11 Aeolian sands, calcrete	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	7.80	11 - 37 Unweathered dolomite.	Medium	3//3
CH 23	0 – 35 Aeolian sands, calcrete weathered dolomite	No air loss and good sample recovery (100%).	Low to Medium	Large sinkhole	8.09	35 - 60 Unweathered dolomite.	Medium	4//3
CH 24	0 – 11 Aeolian sands, calcrete	No air loss and good sample recovery (90%).	Low to medium	Medium sinkhole	10.4	11 - 55 Unweathered dolomite.	Medium	3//3
CH 25	0 – 14 Aeolian sands, calcrete	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	8.75	14 - 25 Unweathered dolomite.	Medium	3//3
CH 26	0 – 12 Aeolian sands, calcrete	No air loss and medium to good sample recovery (75- 100%).	Low to Medium	Medium sinkhole	8.00	12 - 24 Unweathered dolomite.	Medium	3//3
CH 27	0 – 11 Aeolian sands, calcrete	No air loss and good sample recovery (100%).	Low to medium	Medium sinkhole	-	11 – 31 Unweathered dolomite.	Medium	3//3

CH 28	0 – 12 Aeolian sands, calcrete	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	9.00	12 - 31 Unweathered dolomite	Medium	3//3
CH 29	0 – 10 Aeolian sands, calcrete	No air loss and good sample recovery (100%).	Low to Medium	Medium sinkhole	8.00	10 - 22 Unweathered dolomite.	Medium	3//3
CH 30	0 – 13 Aeolian sands, calcrete	No air loss and good sample recovery (100%).	Low to medium	Medium sinkhole	8.81	13 - 60 Unweathered dolomite.	Medium	3//3
CH 31	0 – 10 Aeolian Sands Calcrete	No air loss and medium sample recovery (50%)	Low to Medium	Medium sinkhole	7.9	10 – 21 Unweathered dolomite	Medium	3//3
CH 32	0– 11 Aeolian Sands Calcrete	No air loss and good sample recovery (90%)	Low to Medium	Medium sinkhole	-	11 – 43 Unweathered dolomite	Medium	3//3
CH 33	0 – 10 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low to medium	Medium sinkhole	8.5	10 – 19 Unweathered dolomite	Medium	3//3
CH 34	0 – 9 Aeolian Sands Calcrete	Slight to no air loss and good sample recovery (90%)	Medium	Medium sinkhole	8.54	9 – 60 Unweathered dolomite	Medium	3//3
CH 35	0 – 9 Aeolian Sands Calcrete	No air loss and good sample recovery (80%)	Low to medium	Medium sinkhole	9	9 - 32 Unweathered dolomite	Medium	3//1

CH 36	0– 9 Aeolian Sands Calcrete	Slight to no air loss and medium to good sample recovery (70%)	Low to medium	Medium sinkhole	11.8	9 – 30 Unweathered dolomite	Medium	3//1
CH 37	0 – 10 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low Medium	Medium sinkhole	8.9	10 - 60 Unweathered dolomite	Medium	3//3
CH 38	0– 8 Aeolian Sands Calcrete	Slight to no air loss and good sample recovery (80%)	Low to medium	Medium sinkhole	8	8 – 35 Unweathered dolomite	Low to Medium	3//1
CH 39	0 – 11 Aeolian Sands Calcrete	No air loss and good sample recovery (90%)	Low to Medium	Medium sinkhole	7.8	11 - 26 Unweathered dolomite	Medium	3//3
CH 40	0 – 9 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	6.7	9 - 40 Unweathered dolomite	Medium	3//3
CH 41	0 – 8 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low to Medium	Large sinkhole	7.4	8 - 43 Unweathered dolomite	Medium	3//3
CH 42	0 – 13 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Medium (to high?)	Medium sinkhole	7.6	13 – 42 Unweathered dolomite interlayered with dolerite	Medium	4//3

CH 43	0 – 30 Aeolian Sands Calcrete Dolomite residuum?	No air loss and good sample recovery (100%)	Medium (to high?)	Large sinkhole	7.2	30 – 43 Unweathered dolomite interlayered with dolerite	Medium	4//3
CH 44	0 – 12 Aeolian Sands Calcrete	Slight air loss and good sample recovery (80%)	Low to Medium	Medium sinkhole	5.8	12 - 31 Unweathered dolomite	Medium	3//3
CH 45	0 – 10 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	7.6	10 – 60 Unweathered dolomite	Medium	3//3
CH 46	0 – 31 Aeolian Sands Calcrete weathered dolomite	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	13.6	31 - 60 Unweathered dolomite	Medium	3//1
CH 47	0 – 8 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	4.6	8 – 40 Unweathered dolomite	Medium	3//3
CH 48	0 – 12 Aeolian Sands Calcrete	No air loss and good sample recovery (90%)	Low to medium	Medium sinkhole	8.8	12 - 31 Unweathered dolomite	Medium	3//3
CH 49	0 – 10 Aeolian Sands Calcrete	Slight air loss and good sample recovery (80%)	Low to Medium	Medium sinkhole	-	10 - 60 Unweathered dolomite	Medium	3//3

CH 50	0 – 9 Aeolian Sands Calcrete	No air loss and good sample recovery (90%)	Low to Medium	Medium sinkhole	4.9	9 - 43 Unweathered dolomite	Medium	3//3
CH 51	0 – 10 Aeolian Sands Calcrete	Slight to no air loss and good sample recovery (80%)	Low to medium	Medium sinkhole	-	10 – 31 Unweathered dolomite	Medium	3
CH 52	0 – 12 Aeolian Sands Calcrete	Slight to no air loss and good sample recovery (90%)	Low to Medium	Medium sinkhole	5.4	12 - 37 Unweathered dolomite	Medium	3//3
CH 53	0 – 8 Aeolian Sands Calcrete	No air loss and good sample recovery (95%)	Low to Medium	Medium sinkhole	5	8 – 37 Unweathered dolomite	Medium	3//3
CH 54	0 – 10 Aeolian Sands Calcrete	Slight to no air loss and good sample recovery (90%)	Low to medium	Medium sinkhole	4.8	10 – 25 Unweathered dolomite	Medium	3//3
CH 55	0 – 23 Aeolian Sands Calcrete weathered dolerite	No air loss and good sample recovery (100%)	No Hazard	None	58.7	23 - 60 Unweathered Dolerite	None	1//1
CH 56	0 – 23 Aeolian Sands Calcrete	No air loss and good sample recovery (90%)	Low to medium?	Small to medium?	5.2	23 - 60 Unweathered Dolerite with minor dolomite	Low to medium	4//1

CH 57	0 – 11 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low to medium	Medium sinkhole	2.4	11 - 46 Unweathered dolomite interlayered with dolerite	Medium	3//3
CH 58	0 – 8 Aeolian Sands Calcrete	No air loss and good sample recovery (100%)	Low to Medium	Medium sinkhole	2.8	8 - 42 Unweathered dolomite interlayered with dolerite	Medium	3//3
CH 59	0 – 13 Aeolian Sands Calcrete	Slight air loss and good sample recovery (90%)	Low to Medium	Medium sinkhole	6	13 - 60 Unweathered dolomite	Medium	3//3
CH 60	0 – 10 Aeolian Sands Calcrete	Slight air loss and good sample recovery (80%)	Low to medium	Medium sinkhole	-	10 - 37 Unweathered dolomite	Medium	3//3
MBH 01	0 – 11 Calcrete Weathered dolomite	Slight air loss and good sample recovery (80%)	Low to medium	Medium sinkhole	17	11 – 30 Unweathered dolomite	Medium	3//1
MBH 02	0 – 6 Calcrete	Slight air loss and good sample recovery (80%)	Low to medium	Medium sinkhole	9	6 – 60 Unweathered dolomite	Medium	3//1

9. CONCLUSIONS, PRECAUTIONARY MEASURES AND RECOMMENDATIONS

9.1 Summary of Dolomite Hazard

The hazard zonation is based on geophysical surveys and drilling results from 62 boreholes. An assessment of all these based on the method of scenario supposition, Buttrick *et. al.* (2001) favours the site being zoned into one (1) Inherent Hazard Zone as dictated by geological conditions revealed by the drilling results.

Based on the percussion drilling results, geohydrological data and geological information, the dolomite stability of the site is described in terms of the following zones as:

Zone A

- *Inherent Hazard Class: 3/4 (1) // 3(1)*

This zone is largely characterised by a medium inherent hazard of a medium (2-5 m diameter) sinkhole and subsidence (with sub areas of medium inherent hazard of large [5-15 m diameter] sinkhole and subsidence) in a non-dewatering scenario. The inherent hazard for any size sinkhole and subsidence is medium with respect to a dewatering scenario.

The non-dolomitic overburden consists of aeolian deposits and pedogenic calcrete which is in a form of hardpan and calcified nodules in places. This zone occupies all gravity zones (i.e. highs, lows and gradients). Neither wad nor low density material was recorded in the boreholes drilled. The groundwater level rests within the blanketing layer.

- *Dolomitic Area Designation*

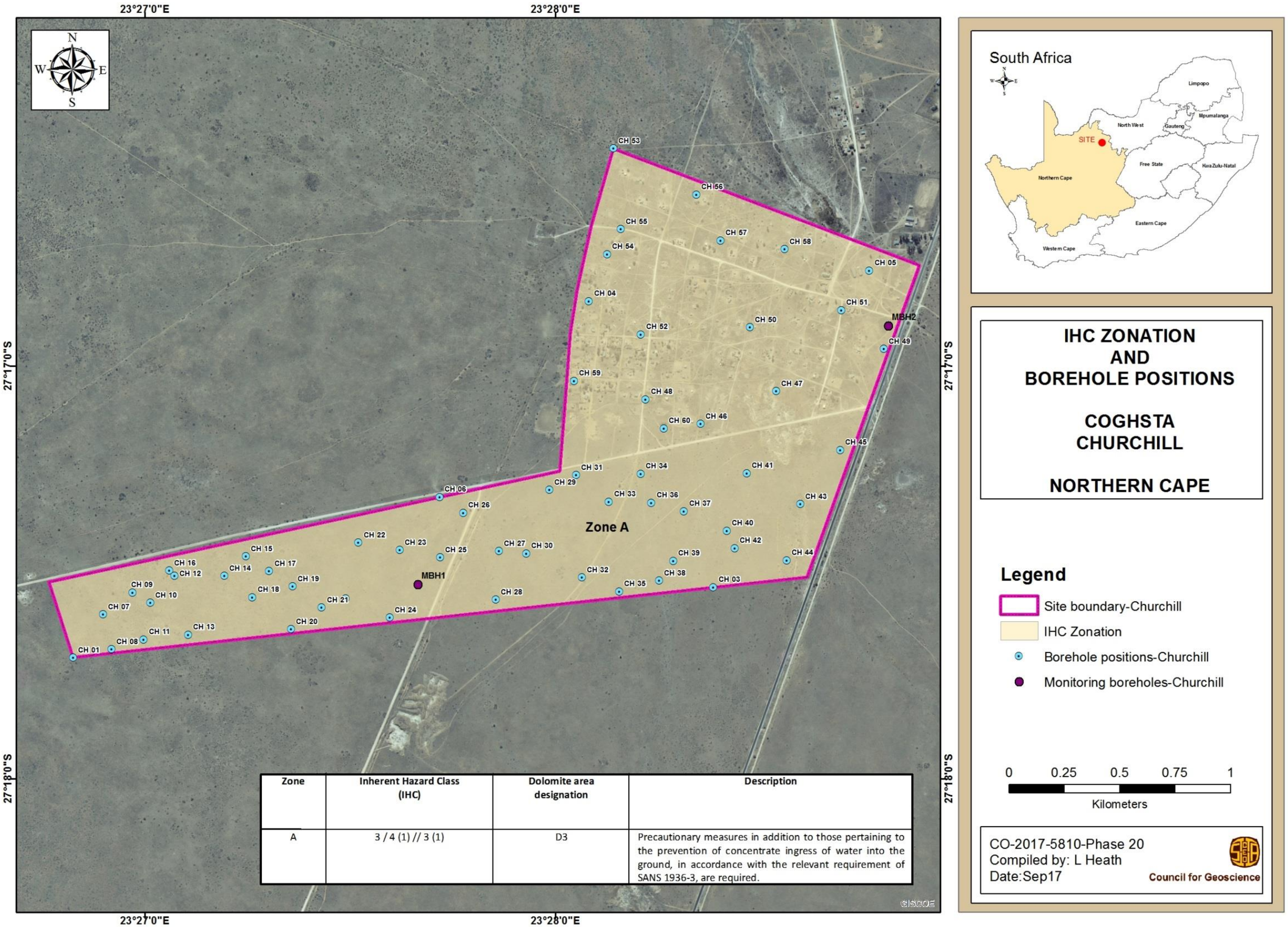
This zone is assessed as D3 and implies that extra precautionary measures in addition to those pertaining to the prevention of concentrated ingress of water into the ground, in accordance with the relevant requirements of SANS 1936-3, are required and must be adhered to.

- *Location*

The zone covers the entire site boundary area.

- *Development Potential*

Restrictions are placed on the types of residential development that may be considered on Class 3 land. Full title residential development (RN2-3) on stands of 300 m^2 or greater is recommended or 10 – 25 dwelling houses per hectare and a population if ≤ 60 people per hectare is recommended. Any form of commercial, retail and/or light industrial development is permissible (C1 to C10) as in SANS 1936-1(2012) Table 1 with appropriate stringent precautionary measures. Footprint investigations are required for each commercial development.



Zone	Inherent Hazard Class (IHC)	Dolomite area designation	Description
A	3 / 4 (1) // 3 (1)	D3	Precautionary measures in addition to those pertaining to the prevention of concentrate ingress of water into the ground, in accordance with the relevant requirement of SANS 1936-3, are required.

Figure 7: Interpreted Inherent Hazard Classes (IHC) zones

9.2 Drainage, Monitoring and General Precautionary Measures

9.2.1 Drainage

The ingress of surface water can have dire implications for dolomite stability and strict drainage measures must be implemented. It is important that prospective developers of the township are made aware of the importance of the recommended precautionary measures as stipulated in SANS 1936-3 (2012) and these include:

- All pipes and channels must be watertight, with all wet services being tested for leakage on installation,
- Piping material should be appropriate to local subsurface conditions,
- No accumulation or ponding of surface water should occur adjacent to foundations both during and after construction.
- Storm water should be effectively captured and led away from all structures preferably by means of lined, surface canals.

9.2.2 Monitoring

Frequent monitoring and maintenance is recommended for the whole site for the purposes of identifying the effects of concentrated ingress of water or groundwater level drawdown. The generic activities considered appropriate are as follows:

- Visual inspection of ground, structures and above ground infrastructure (e.g. roads, storm water canals, ditches).
- Visual inspection of storm water systems crossing the site for blockages.
- Testing of wet-services for leaks
- Monitoring of structures and ground levels.
- Monitoring of the groundwater level.

9.2.3 Precautionary measures

The prevention of sinkhole and subsidence formation is largely related to the control and or removal of the triggering mechanism i.e. the prevention of ingress water/dewatering. NHBRC and SANS 1936-3 (2012) water precautionary measures must be implemented for the site (Appendix 4). All water borne services must meet SANS 1936-3 (2012) requirements for water ingress prevention measures.

SANS 1936-1 requires the owners of the infrastructure on parcels of land categorized as dolomite area designation D2, D3 and D4 sites to implement appropriate dolomite risk management strategies in accordance with the principles and requirements of SANS 1936-4 in order to mitigate the risks associated with the development of such land. SANS 1936-1 also provides requirements for local authorities to establish implement and maintain a dolomite risk management strategy.

A Competent Person must be appointed to compile a site specific ***Dolomite Risk Management Strategy (DMRS)***. Such a plan, which is considered beyond the scope of this investigation, should define ongoing processes to manage water ingress and assign responsibilities to particular persons. General principles are attached in Appendix 5. Groundwater Monitoring should also form part of the DRMS.

9.3 Recommendations

- It is recommended that the municipality sets up at least two groundwater monitoring boreholes distributed across the current study area to establish trends.Any future developments must be investigated in accordance with SANS 1936-2 (2012).
- A high density development, i.e. 150 m^2 stands or developed as group housing such as a block of flats, has a greater probability of inducing a sinkhole than a commercial development on the same property because of the higher density of wet services and greater chance of an undetected leak. Therefore, new development should take into cognizance the allowable land use densities shown in Appendix 3 as per SANS 1936-1 (2012) permissible land use Tables.
- Based on this feasibility study, the entire site is suitable for most planned low cost housing development.
- Any signs of ground instabilities or subsidence should be reported immediately to the municipality, and remediated in accordance with SANS 1936-4 (2012).

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