# 5 Hazard identification

In the concept of risk management, a ranking process is followed whereby the risks with the greatest loss (or impact) and the greatest probability of occurring are handled first, and risks with lower probability of occurrence and lower loss are handled in descending order. In practice the process of assessing overall risk can be difficult, and balancing resources used to mitigate between risks with a high probability of occurrence but lower loss versus a risk with high loss but lower probability of occurrence can often be misjudged.

## *5.1 Physical factors*

### 5.1.1 Geological assessment

The geology (specifically the occurrence of dolomite and character thereof) within the study area is the most important factor in determining the risk related to land use and spatial development in the area. This section deals with the geology of the study area as a basis for the risk zone determination related to land use and spatial development. After the description of the regional and site specific geology in the study area, the methodology is described to develop a conceptual geological zone model and a risk zoning for the area.

The geology of the study area, with the focus on karst dolomitic land, must be seen within the regional context of the Transvaal Supergroup, specifically the Malmani subgroup, and as influenced by regional structures related to regional geological impacts as the greater Vredefort Dome meteoric impact and the Bushveld Intrusion:

The occurrence of the Malmani Subgroup defines the area that may be underlain by dolomite, resulting in risk for land use and spatial development. In Figure 5-1 the position of the study area is shown in context of the occurrence of the Malmani Subgroup for the Gauteng and Northwest Province (2626 Wes-Rand (Wilkinson, 1986)).

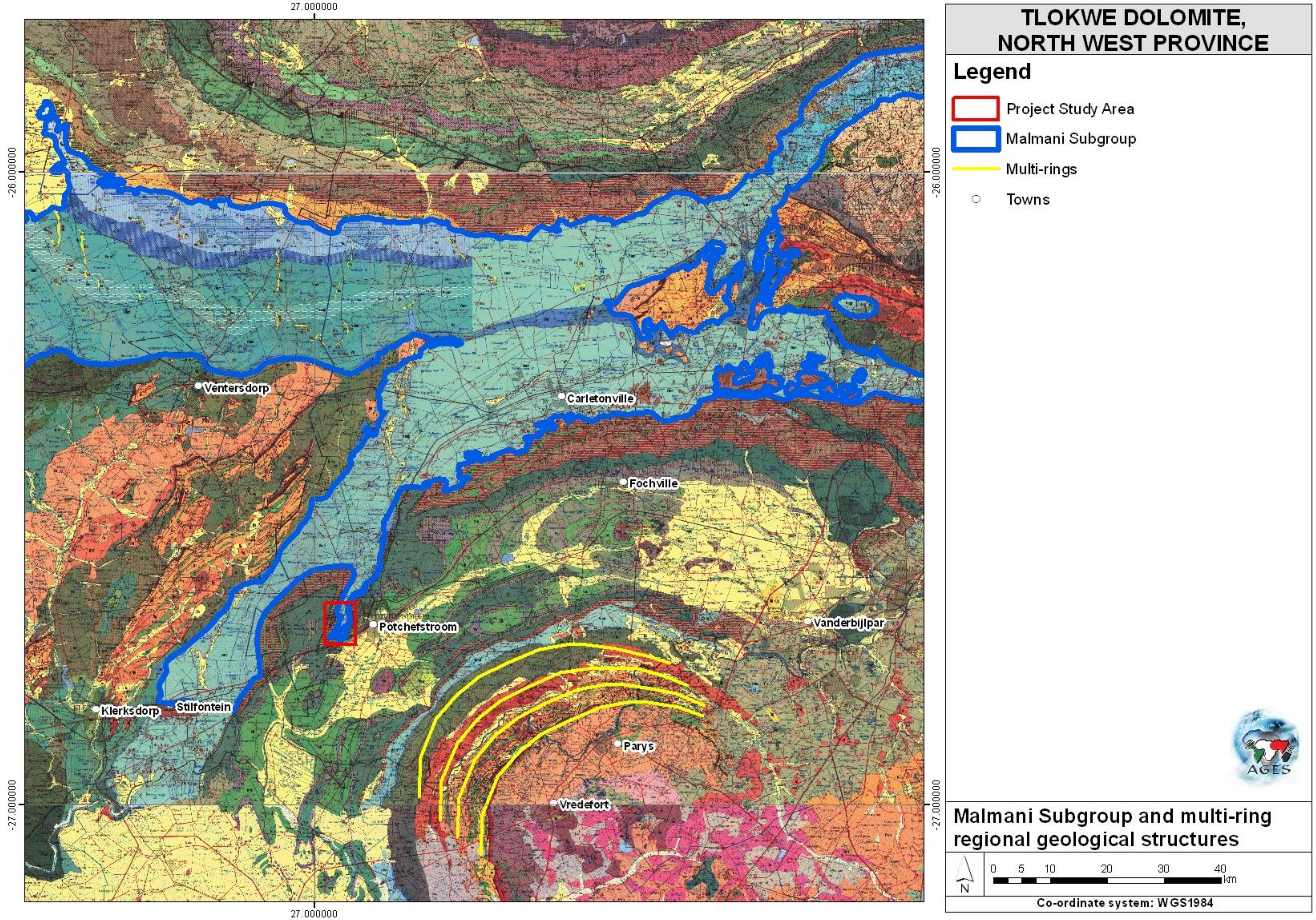



**Figure 5-1: Multi-ring regional geological structure and Malmani Subgroup in the Gauteng and Northwest Province in relation to the project study area.**

The study area is underlain by various rock types and formations from the Transvaal Supergroup Sequence, as described above, with related groups and subgroups as summarised in Table 5-1. Dolomite occurs in the central portion and represents the upper section of the Chuniespoort Group (Malmani Subgroup, Eccles Formation), which has been thrust on top of the Hekpoort Formation andesites. Small outcrops of Black Reef quartzite occurs within the dolomite due to thrusting. The dolomite is flanked by a variety of sedimentary and volcanic rocks from the Pretoria Group including rocks from the Timeball Hill, Boshoek, Hekpoort, Strubenkop, Daspoort and Silverton Formations. Localised intrusion of younger igneous rocks occurs in the study area (Wilkinson, 1986).

**Table 5-1: Stratigraphic units in the study area (Wagener, 1984).**

| STRATIGRAPHIC UNITS | | | | | |
|---|---|---|---|---|---|
| SUPERGROUP | GROUP | SUBGROUP | FORMATION | Member | Lithology |
| TRANSVAAL SUPERGROUP | PRETORIA | Rooihoogte | Strubenkop | TBC | TBC |
| | | | Hekpoort | TBC | TBC |
| | | | Timeball Hill | TBC | TBC |
| | | | | Pologround | Sandstones and interbedded siltstones |
| | | | | | Shales and interbedded siltstones |
| | | | | Bevets | Chert conglomerate in ferruginous matrix |
| | | | | | Shales and siltstones |
| | CHUNIESPOORT | Malmani | Frisco | | Chert-free dark-brown dolomite |
| | | | Eccles | Leeuwenkloof | Silicified chert breccia |
| | | | | | Chert-rich light-grey dolomite |
| | | | Lyttelton | | Chert-free dark-brown dolomite |
| | | | Monte Christo | Crocodile River | Chert-rich grey-brown dolomite |
| | | | | Rietspruit | Chert-rich and colour-banded dolomite |
| | | | | Mooiplaats | Chert-rich light-grey dolomite |
| | | | | Rietfontein | Chert-rich light-grey dolomite |
| | | | Oaktree | | Chert-free dark-brown dolomite |
| | | | Black Reef | | Interbedded quartzite and shale |

The occurrence of the Pretoria Group and the Chuniespoort Group described above is shown in a simplified geological map for the study area (Figure 5-1). The occurrence of these two groups is shown on a background geological map (Bisschoff, 1992).

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

Many faults and fractures were identified in the dolomite around the Potchefstroom–Fochville areas. 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. It was also noted by Obbes (2000) that the presence of regional deformation, faulting and fracturing is evident in the heterogeneous structural deformation of the black Reef-Malmani-Rooihoogte succession that is non-pervasive and more pronounced in the lower half of the carbonate succession. The deformation was recorded as: strike-slip faults, low angle normal faults, bedding-parallel faults, low-angle thrust faults and shear zones. Movement vectors were derived from the orientations of thrust and low-angle normal faults, folds, deformed stromatolites, pebbles, oolites and quartz-fibre lineations (Obbes, 2000). The deformation as evident in the Transvaal Supergroup is associated with major region geological events including the 2060 Bushveld Intrusion (Truswell, 1970) and the 2023 Ma Vredefort meteoric impact (Brink *et al*., 2000).

In order to evaluate all geological results and do a final spatial assessment of risk, the structural geology from all existing maps were re-evaluated and a map compiled to reflect an updated integrated interpretation thereof in context with a baseline aerial photo interpretation.

In addition all linear structures within the study area were identified by means of a structural aerial photo interpretation according to methodology described by Lattman and Ray (1965). The structures as presented in Figure 5-2 are important as it indicates a dis-homogeneity in geology and also act as preferential pathways for groundwater flow and contaminant transport with the potential for leaching of the dolomite along these zones (Geocon, 2003).

All structural geological observations from previous maps (dip and strike), as well as new field observation, were added and included in the final structural geological map (Figure 5-3).

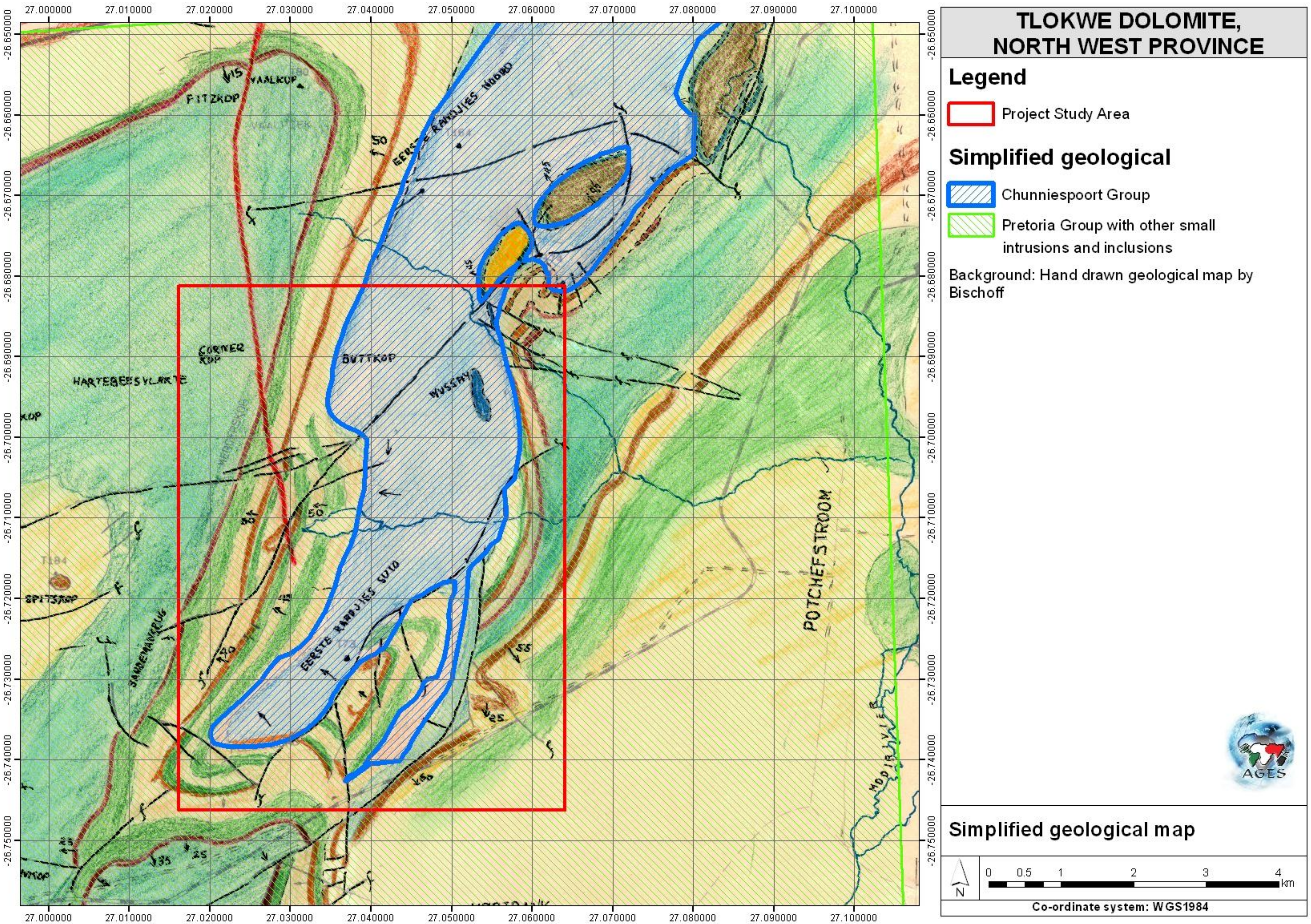



**Figure 5-2: Simplified geological map according to Bisschoff (1992) indicating the study area for illustrative purposes**

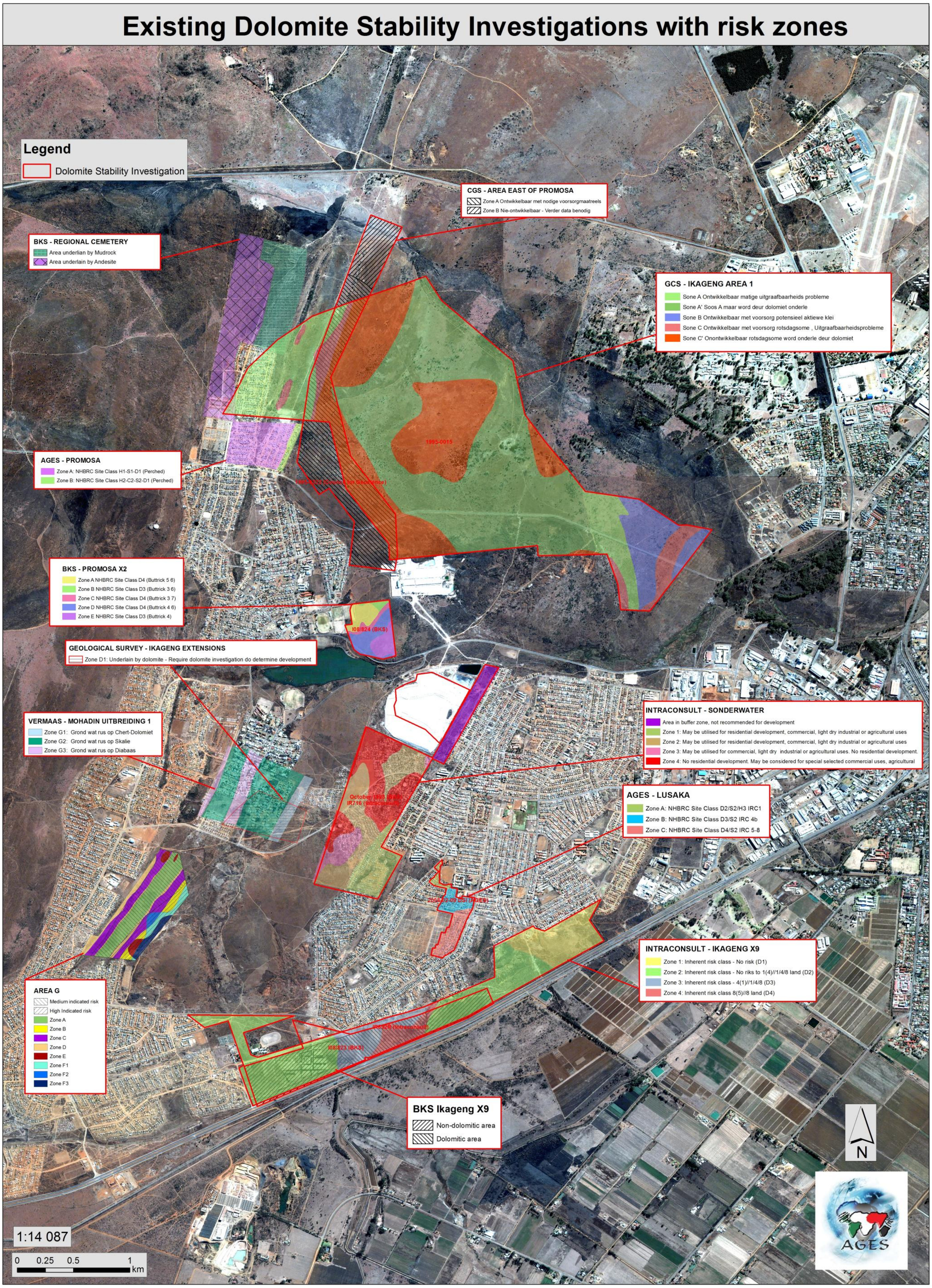



**Figure 5-3: All available geotechnical reports within the study area**

**Geological based zone map compilation**

In order to develop a zone map with indication of risk for spatial development and land use from the basic geological information, all mapping compilations available within the study area were identified and re-interpreted in the light of geology as reflected in the drilling results of 127 boreholes as part of 29 identified geotechnical investigations in the study area.

This re-interpretation was used to identify areas lacking in information where 32 new boreholes were drilled and the geology described. Mapping and outcrop identification were done in specific areas identified in order to complete the data set needed for final interpretation.

All results were evaluated and spatially coordinated with a structural aerial photo interpretation verified according to methodology described by Lattman and Ray (1965) and finally incorporated in a risk zone map.

**Incorporation of geological information from existing maps**

The following existing baseline geological maps were identified in and around the study area and were studied and used to develop a baseline outcrop map prior to all incorporation of all drilling results and new information.

- Geological map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland, 1:1 000 000 (Keyser, 1997).
- The 1:250 000 geological map 2626 Wes-Rand (Wilkinson, 1986).
- Hand drawn map including the study area, Council of Geoscience no KF 587 (Truter, 1936).
- Map of Potchefstroom showing fifteen mile radius, Council of Geoscience no KF 589 (Mellow, 1934).
- Hand drawn regional map including the study area enlarged to a 1:35 000 scale for interpretation, Council of Geoscience no KF 588 (Lombaard, 1935).
- The Potchefstroom Dorp en Dorpsgronde Geologiese Kaart. 1:50 000

(Bisschoff, 1992). This information was regarded as very important and reliable geological background to the study as the map were completed in much detail on a 1:50 000 scale, reflecting a vast personal knowledge of the area by Prof. Bisschoff. This information was verified on field visits with him, assessing the availability of new drilling results.

**Incorporation of drilling results**

The existing geological maps were re-interpreted in light of existing and new drilling results. Figure 5-3 indicates the position of the key reports from 29 available geotechnical reports within the study area, with related geotechnical zoning as reflected in the reports. All documented geological borehole profiles (190 in total) were revised and compiled in one format.

**Field observation and mapping**

The existing geological information was used to launch a reconnaissance mapping and outcrop identification process. During this process the following deliverables were achieved:

- Outcrops of different lithological units were identified and coordinated/photos documented. In this process 164 outcrops were cited, rock types identified, of which 101 were photographed.
- Dip and strike were measured and added to the structural map in Figure 5-4 contributing to the understanding of the geological model of the area.

The local public showed interest in the mapping exercise. Continuous interaction and discussion with interested parties ensured that they had a good understanding of the tasks at hand (Figure 5-5).

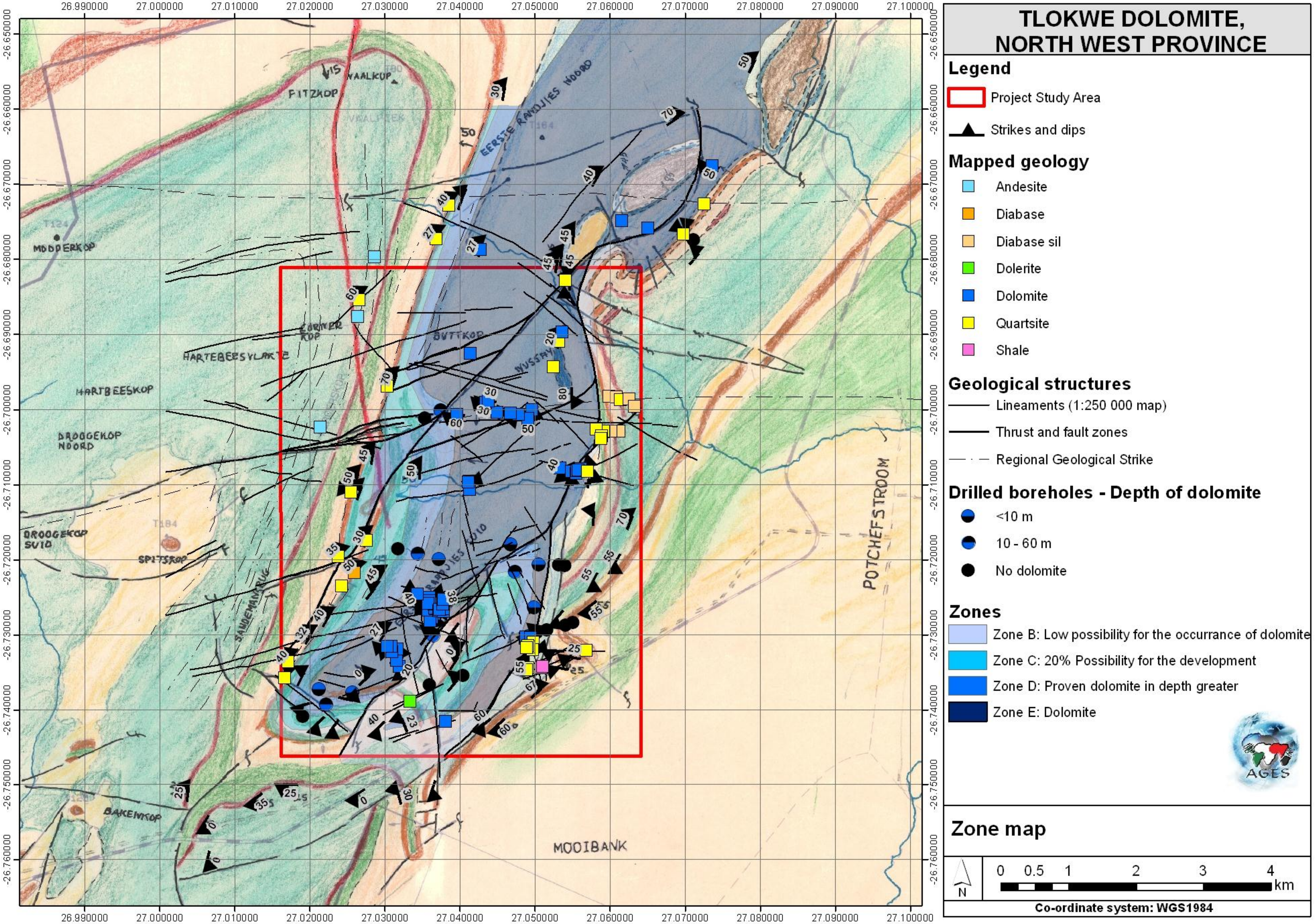



**Figure 5-4: Classification of drilling results according to this study**

**Figure 5-5: Geological mapping and public interaction**

### 5.1.2 Geohydrological assessment

The risk of instability in dolomitic terrains is directly affected by the geohydrological conditions of the area. Changes in the groundwater quantity and quality within the karst terrains can lead to ground instability and sinkhole formation, with catastrophic results. Due to the chemical nature of dolomitic rock, it is readily dissolved by acid. Over time this action leads to the development of large underground cavities (karsts) that are interlinked to create significant underground storage compartments for groundwater.

When these cavities are located close to the surface, the weight of the overbearing rock can cause the roof of the cavity to collapse and form a sinkhole. Often the weathered zone on surface prevents sinkholes from forming by providing additional support. On dolomitic terrains the weathered material is referred to as WAD (weathered after-dolomite) and consists of an iron and manganese rich clay.

The ability of this weathered material to provide support to the overburden is closely related to the moisture conditions within the weathered zone. When the water table is lowered (due to pumping) it reduces the hydrostatic support to the material, lowers the cohesion and density of the weathered material, and the overburden collapses to form a sinkhole or doline (Brink, 1996).

Both the natural character of the groundwater regime and human interference is important in this regard and needs to be defined.

There are three apparent (interconnected) processes that cause sinkhole formation in association with the dewatering of the underlying dolomite compartments:

1. Since the large scale sinkhole development in the Wonderfonteinspruit area occurred as soon as dewatering activities commenced, there seems to be a connection between dolomite stability and the hydrostatic pressure provided by a saturated subsurface. As soon as the supporting hydrostatic pressure was removed by the dewatering activities, the weight of the overburden on top of near surface cavities

exceeded a critical point, and sinkholes and dolines formed.

2. Many sinkholes form during the rainy season, and especially after periods of heavy rainfall (Moen & Martini, 1996, De Bruyn *et al.*, 2000). As the unsaturated soil zone becomes saturated, the critical weight is also exceeded whereby the supporting rock in the roof of a cavity fails to support the heavier overburden.

3. Rainfall also causes erosion of unconsolidated surface material through pre-existing channels into underground cavities, leading to the upward migration of cavities.

The rate and extent of water level drawdown is one of the critical contributing factors to sinkhole formation. The risk of sinkhole formation in dolomitic areas are higher where the static groundwater level occurs close to surface (<30m) and where water level fluctuations of more than six metres occur in response to pumping, or where the aquifer is dewatered (Barnard, 2000; Department of Water Affairs, 2009).

From a dolomite stability perspective, it is therefore not only important to determine the scope and extent of subsurface cavities in Ikageng, but also to monitor the groundwater level. Sinkholes are more likely to form in areas with relatively shallow dolomite when the water table fluctuates with more than 5-6 m in response to pumping. While little can be done to curb seasonal fluctuations in the groundwater level, excessive groundwater abstraction in the area can be controlled.

The following methodology was defined in order to characterise the geohydrological setting in Potchefstroom:

1. A desk study and information research were done in order to:

    - delineate the study area with a local focus and regional setting – applied to the Tlokwe DRMS;

    - define the physiographical, geological and geohydrological character and setting of the study area;

- compile principles from the literature study on the effect of geohydrological conditions on dolomite stability including the interaction between surface and groundwater;

- reflect results from previous and existing reports on the geohydrology of the area;

- give legal and institutional context to the use of groundwater in the area.

2. Field surveys and verifications were done in order to:

    - do a confirmation of the geohydrological setting as derived from the desk study through mapping, inspection and reconnaissance surveys;

    - identify boreholes, water use and monitoring points through hydrocensus surveys;

    - compile a database of geohydrological census and monitoring results;

    - define and describe flag situations.

3. Alignment with strategic aspects of the DRMs was achieved by:

    - integration of all geohydrological findings on a continuous basis with the on-going development of strategic reporting.

4. Incorporation of best practices, known procedures and standards available was achieved by working according to the following guidelines:

    - The Dolomite Guideline (Department of Water Affairs, 2009) was developed as a tool to effectively enable the assessment, planning and management of groundwater resources in dolomitic terrain. (Although the intention of the document is directed towards groundwater resources, it is applicable in this case since the management of groundwater in dolomitic terrain is vital from a ground stability point of view).

The main findings of the geohydrological investigation are summarised below: The dolomite finger underlying areas of Ikageng forms part of a larger regional outcrop of dolomite that has seen thousands of sinkholes form as a result of dewatering of the dolomite aquifers to allow safe mining of the gold resources underlying the dolomite on the Far West Rand. The direct link between groundwater fluctuations and sinkhole formation was then realised.

The geohydrological character of the focus area is not independent of the regional geohydrology of the areas surrounding it. Therefore the Welgegund Groundwater Management Area (GMA) (

Figure 5-6) was chosen as the widest regional area with an independent geohydrological character in which context the focus area can be defined, and in which activities related to groundwater might have an impact on the focus area and need to be investigated and managed.

Within this predefined area two main aquifer types are identified: a karst type aquifer associated with the occurrence of dolomite, and intergranular and fractured type aquifers associated with the clastic sedimentary and igneous rock types flanking the dolomite finger. The two aquifer types differ on the following aspects (Table 5-2):

**Table 5-2: Aquifer types (Parsons, 1995; DWA, 1998a)**

| **Karst type (dolomite) aquifer** | **Intergranular/fractured type aquifer** |
|---|---|
| High groundwater potential | Low to medium potential |
| High transmissivity | Low transmissivity |
| High yielding boreholes | Low to medium yielding boreholes |
| Shallow (flat) hydraulic gradient | Steeper, more defined hydraulic gradient |
| Major aquifer | Minor aquifer |

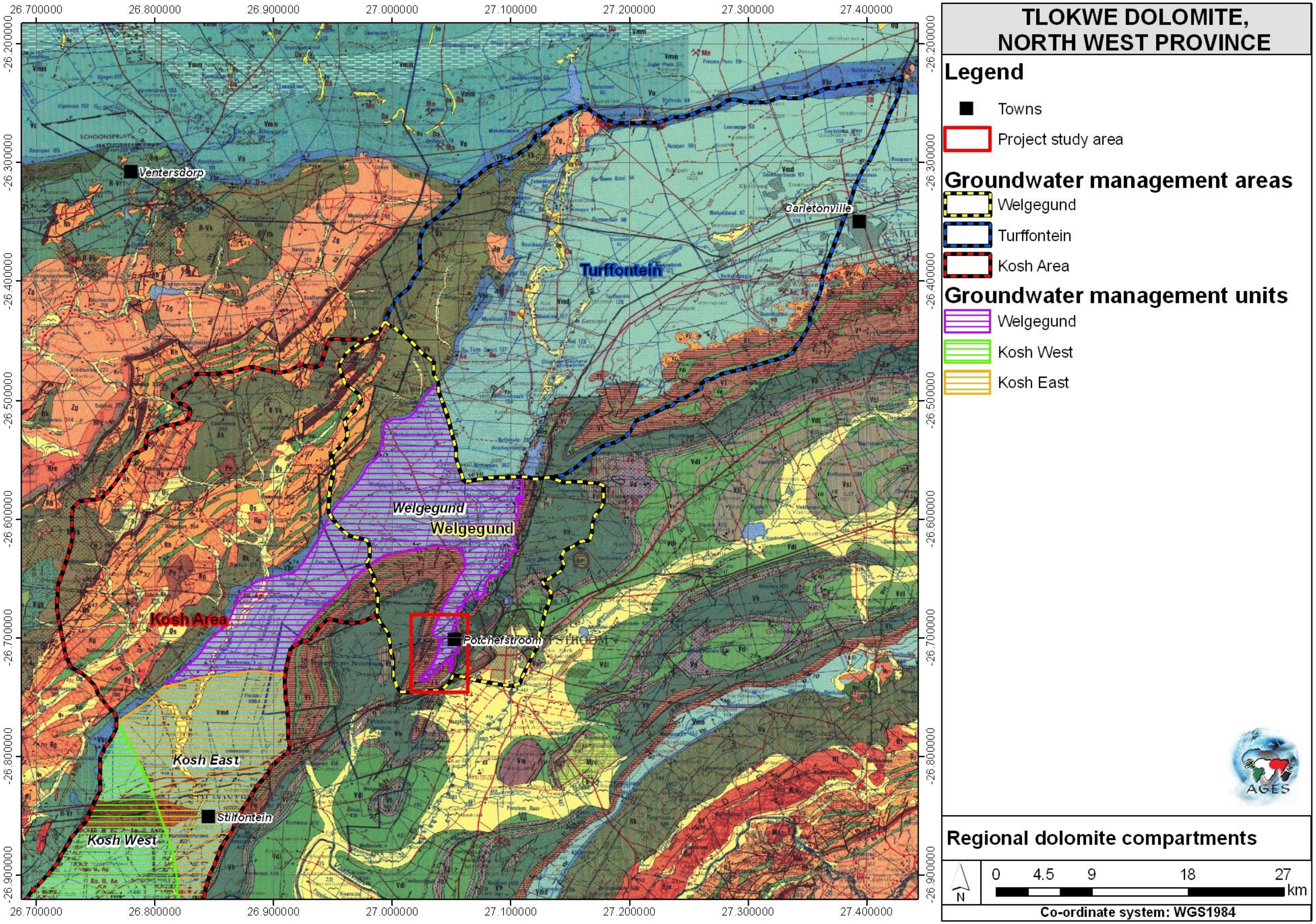



**Figure 5-6: The following groundwater management areas and groundwater management units are indicated on the West rand geological map 2626 (Wilkenson, 1996)**

Groundwater use in the area consists of agricultural, industrial, mining related and domestic use. The only two groundwater uses identified as possibly having a local effect on the groundwater table in the focus area is Boitshoko High School and Oranje Mynbou en Vervoer (OMV). No mining related dewatering occurs in the regional area, although prospecting plans inside the neighbouring Turffontein GMA is currently being undertaken by Wits Gold.

Groundwater levels occur between 30 mbgl and surface throughout the focus area. Springs have been reported, and one monitoring borehole was observed to be artesian on occasion (meaning that the water level pushes up to above ground level). Water level fluctuations exceeding six metres have been observed in monitoring boreholes in the dolomite. This raises the risk for sinkhole formation and continuous monitoring of water levels is required.

The initial or historical groundwater level is an important concept when it comes to groundwater related dolomite instability. In order to ascertain historical groundwater levels in the area, the NGA database was consulted to find monitoring boreholes with historical data. Some boreholes were identified, but the data were inconclusive to determine whether the historical data were any different from the current. Seasonal fluctuations were however identified as can be seen in Figure 5-7. Groundwater level fluctuations in excess of 6 m are regarded as excessive and may contribute significantly to the formation of instability features. However, in some cases, groundwater level fluctuations of far less than 6 m may also be very dangerous (Barnard, 2000; DWA, 2006).

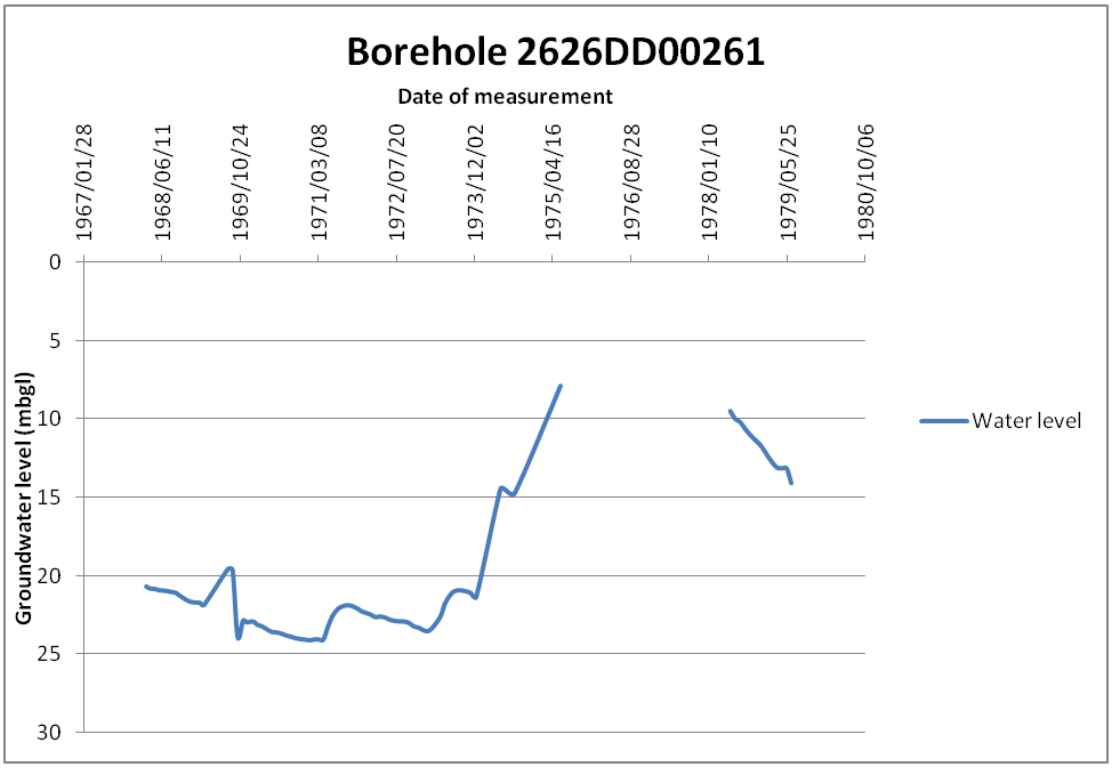



**Figure 5-7: Groundwater level fluctuations in borehole 2626DD00261 show fluctuations exceeding 15 m. Borehole location 5 km SW of focus area.**

The main contributing factors to artificial groundwater fluctuations are groundwater abstraction from boreholes, and ingress of water from old water supply infrastructure. The influences of both the above on the water level fluctuations have not been quantified.

Although signs were found of severe surface water pollution of the Spitskopspruit from the Kynoch gypsum tailings dam, the extent of this pollution further downstream was not assessed.

Apart from the minimal impact on the water from the borehole located at Boitshoko High School southeast of the tailings dam, it is unclear at this stage what the impact on the groundwater quality in the immediate environment north and east of the tailings dam is since the annual water quality monitoring reports were not made available by Oranje Mynbou en Vervoer (OMV). This should be assessed in detail as a matter of urgency, since the acidic seepage water from the tailings dam was found to dissolve dolomite over time.

Since dolomite instability can be linked to both groundwater quantity and quality, flag situations to be highlighted in the study area are divided into these two categories.

**Quantity**

Two groundwater abstraction flags exist on the dolomite inside the critical zone:

The borehole at Boitshoko High School is located within 200 m of the Kynoch tailings dam. Not only can the groundwater abstraction from the Boitshoko borehole create groundwater level fluctuations within the dolomite surrounding the school, but it can also draw in pollutants from the tailings dam over time. This has fortunately not yet been observed by sample analyses. It is recommended to inform the school's management board of the risk, and to supply the school with municipal water in order to decommission this borehole. This borehole can then be incorporated into the monitoring network

Large scale industrial use groundwater abstraction is taking place from boreholes at OMV's processing plant. It is unclear whether any geohydrological investigation was done to support the water use license application (WULA) for abstraction. Although no real impact can be observed in the monitoring boreholes surrounding OMV and the Kynoch tailings dam, the immediate impact on OMV's premises is unknown and a specialist impact investigation is recommended.

It is recommended that Tlokwe City Council (TCC) engage with the Department of Water Affairs (DWA) on the licensing of this use, and ensure that proper steps are followed and the necessary studies are done.

Potch Industria has been included in the critical zone due to the large scale water use associated with inductrial activities. Several boreholes have been identified in this area prior to 2003, but the use has not been verified since it is located off the dolomite. The current use must be verified, as well as the possible impact on the dolomite.

Likewise it is possible that other groundwater users have not been identified in

Ikageng due to the difficulty of access to private property. A public participation process is recommended to try and obtain all groundwater use information by explaining the relevance thereof. Cooperation of the TCC with DWA in this regard is also recommended.

Any new groundwater use in the critical zone must be approved by TCC and DWA based on area of location, volume and intended use. If located on one of the high risk zones, studies will have to prove that the intended use will not have an adverse effect on the water tables locally and regionally. This can be implemented by passing a bylaw containing a borehole moratorium in the critical zone. Any drilling of boreholes will have to be applied for at the TCC.

**Quality**

The Kynoch gypsum tailings dam was identified as the main quality flag in the area. This dam still hosts highly polluted water that seeps out into the surface water bodies north of the dam, and has an unidentified impact on the groundwater resources surrounding the dam. OMV is monitoring the quality of the groundwater in certain monitoring boreholes surrounding the dam, but the results of the annual monitoring reports were not made available to AGES. It is recommended to initialise an in-depth investigation into the groundwater quality surrounding the dam, and its impact on the dolomite. These actions would include:

- Obtain and interpret monitoring reports from OMV.
- Electrical conductivity (EC) logging of the monitoring boreholes and compare with logs.
- Sampling of monitoring boreholes at water strike.
- Sampling of water from OMV's abstraction borehole.
- Sampling of artesian borehole BH19.
- Model the current location of the pollution plume and compare with 2002 numerical model predictions.

- Do X-ray diffraction (XRD) analyses on the salt precipitates where seepage water decants next to the tailings dam to determine chemical nature of the precipitate.
- Do chemical balance modelling and investigate impact of seepage on dolomite.
- Interpretation and risk quantification.

On a regional scale, the uncertainty surrounding the potential quality of the groundwater flowing from the Gerhard Minnebron as soon as gold mining on the Far West Rand ends and dolomite dewatering ceases in future, was raised as a flag. This might force the TCC to find alternative water sources, of which the dolomite in the area is an obvious alternative. Any bulk groundwater abstraction from within the Welgegund GMA must be accompanied by detailed geohydrological investigations and numerical flow modelling to determine the long term impact of such abstractions.

Likewise any future mining in the Welgegund GMA must be accompanied by environmental impact assessments (EIAs) containing specialist geohydrological investigations that consider the impact on the focus area and the critical zone dolomites.

### 5.1.3 Geotechnical assessment

Karst terrains are landforms with distinctive hydrology and topography. This is mainly due to the high solubility rate of rocks associated with karstic terrains as well as well-developed secondary porosity (Williams, 1993). There are many different karst structures such as paleo-, ekso-, endo-, crypto- and pseudokarst, to name just a few. Dolomite is the only karst formation that occurs in the study area.

In order to understand the implication of land use and spatial development on karst dolomite land within the study area, it is important to conclude the geological description with reference to the character of dolomite and the occurrence of related karst structures: sinkholes and dolines.

**Mechanism of sinkhole and doline formation**

Rain water ($H_2O$) takes up carbon dioxide ($CO_2$) from the atmosphere and soil to form a weak carbonic acid ($H_2CO_3$) which circulates along fractures, faults and joints in the dolomite succession causing leaching of the carbonate minerals. The removal of carbonates, giving rise to instability as hard competent dolomitic bedrock, is succeeded vertically by leached incompetent residual material consisting of manganese oxides, chert and iron oxides, in some instances up to several tens of meters thick. Instability may occur naturally, but is increased by human activity giving rise to change in groundwater activity (ingress of water from leaking water-bearing services or groundwater level drawdown) (Department of Water Affairs, 2009)

According to Brink (1996) the following conditions must exist in order for sinkholes or dolines to form:

- There must be rigid material to support the roof of the cavity. The span of the cavity must be appropriate to the strength of the material, because if the span is to great or the material to weak, a cavity will not be able to form.

- A condition of arching must form, whereby all the vertical weight must be carried.

- A void must develop below the arch.

- A reservoir must exist below the arch to accept the material which is removed from below the arch, as to enlarge the void. Some means of transportation of the material is also needed, such as flowing water.

- When a void of appropriate size has been formed, some sort of disturbing agency must arise to cause the roof to collapse.

Conditions that advance karst development were listed by Obbes (2000):

- The region should experience a moderate rainfall, and have a fluctuating water table within 30m of the surface.

- The topography should consist of steeply incised valleys underlain by well-jointed, shallow, soluble bedrock.

- Solid dolomite, chert or diabase arches, which will support material above the cavity.

- The soluble rock should be dense, highly jointed and thinly bedded to facilitate chemical weathering. Weathering occurs in the phreatic and vadose zones (above and below the water table), and is accelerated by closely spaced fractures. A strong relationship exists between zones of fracture concentration and sinkholes, subsidences and springs.

When a sufficiently large cavity has developed, a trigger mechanism is needed to initiates the collapse, which grows upwards towards the roof of the cavity, until it breaks through the surface and a sinkhole forms. The trigger mechanisms include excessive wetting of the arch material, which decreases the soil strength and promotes collapse, piping and the occurrence of earth quakes, which disturbs the equilibrium in the underlying material. The unconsolidated, eluvial overburden is characterized by an increased porosity in depth as openings and conduits coalesce. Because the degree of compaction is greatest at the surface, it easily forms an arch, which is not representative of the actual strength of the arch (Brink, 1996).

The potential instability may also be increased due to the existence of Palaeo karst structures. These ancient karst structures include sinkholes that have formed through the passage of geological time and refilled by debris of a different origin, such as wind transported sand or mud that has flowed into the sinkhole. Palaeo karst structures contribute to the dis-homogeneity in geology in existing karst dolomite land and are indicative of further potential instability. In the study area, there are indications that some karst structures that have been detected during drilling could be palaeo karst features that were later partially filled with transported (gravel) or collapsed material (GeoCon, 2003).

### Interaction of infrastructure and dolomite

The specific quality of infrastructure on dolomite is of great importance to the stability of the dolomite sites. This is due to the weathering effect of fluids on dolomite. Water infiltration from leaking sewage or water pipes has the potential to dissolve and erode the fragile Ca-rich dolomite at a far greater rate than its natural dissolving rate (Blinkova & Eliseev, 2005). This increased dissolution rate may cause underground cavities to form at greater speeds in the built up areas than in the surrounding areas. These cavities then inevitably lead to sinkhole formation around the faulty and insufficient infrastructure. This process of subsurface erosion and dissolution can clearly be seen in Figure 5-8 by the Department of Public Works (2003):

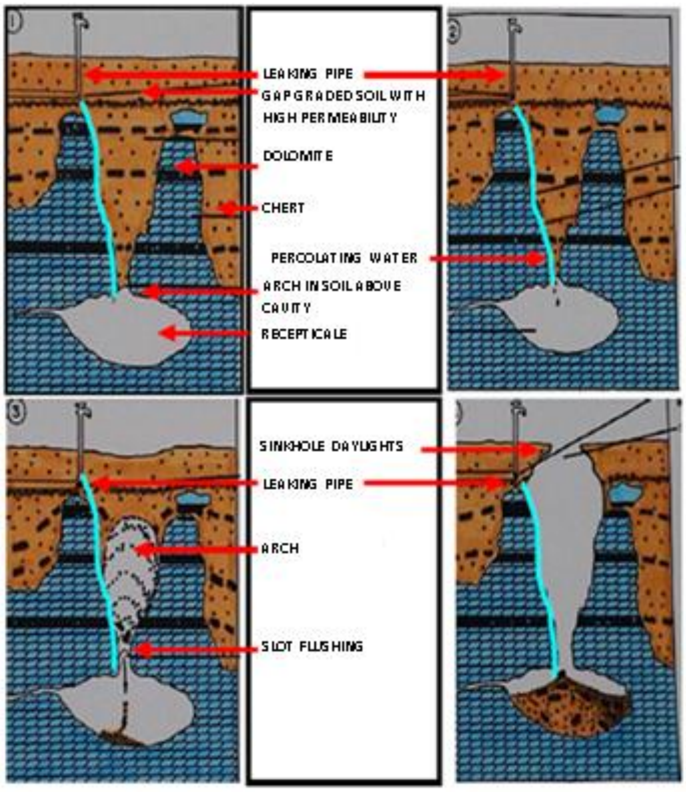



**Figure 5-8: Subsoil erosion of dolomite grounds**

### Evidence of dis-homogeneity in the study area

There is some evidence of dis-homogeneity within the study area. This could be seen as sinkholes and cavities as well as variation in the character of the dolomite. Here are a few examples from the study area:

- Drilling logs
    - Evidence of dis-homogeneity within the study area can clearly be seen from the drilling logs. The recurrences of these zones are not that high, but the detected zones can easily form dangerous cavities. The zones have wad-rich chert and dolomite sections, which can easily form sinkholes. Figure 5-9 is a good example of one of these borehole logs
    - The high penetration rate and high air loss are typical of layers that have very low resistance and are highly fractured. The wad-rich dolomite and chert samples are evidence of highly compressible wad being present underneath the top layers of soil.

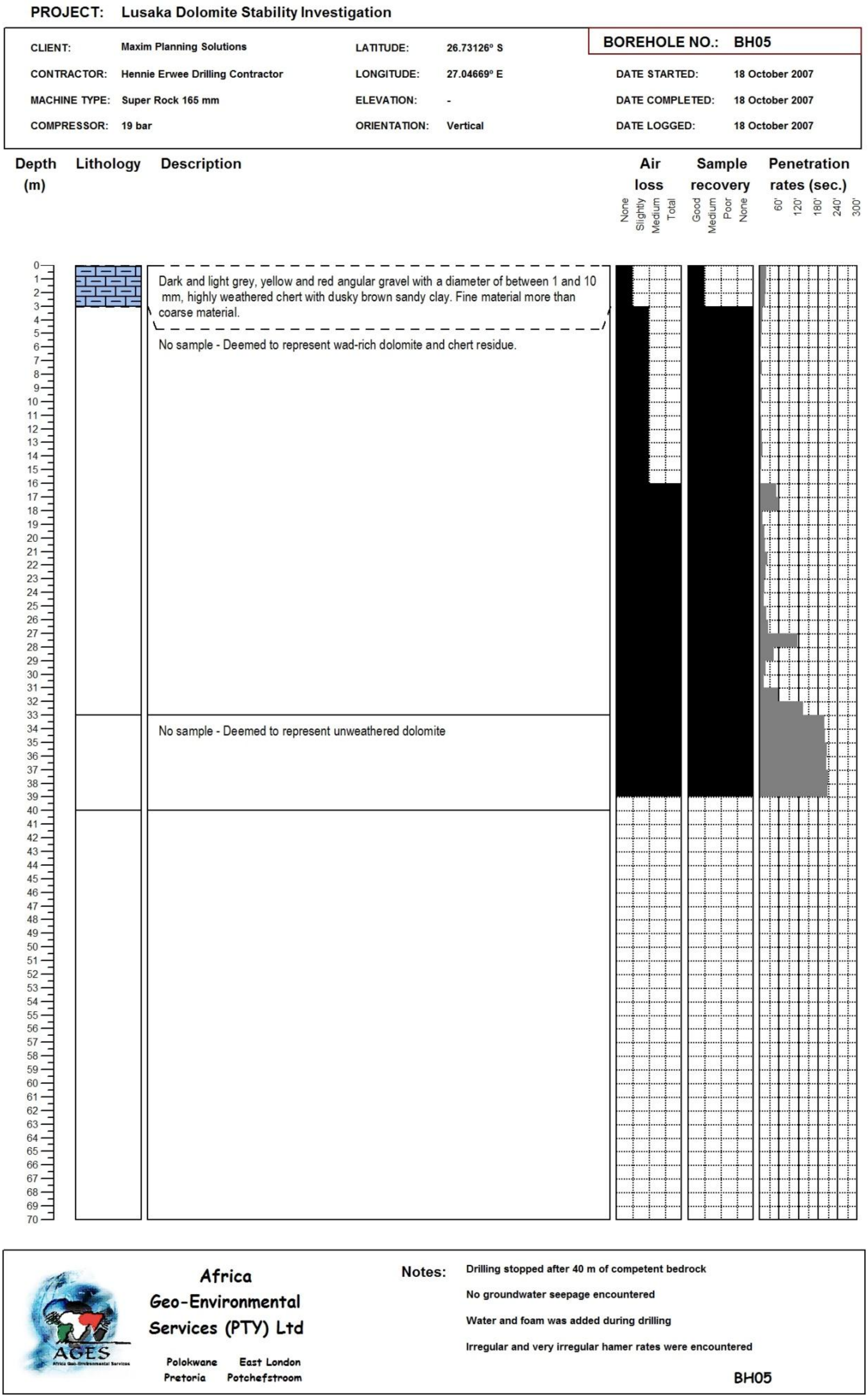



**Figure 5-9: Borehole log**

- Sinkholes in the study area

Two sinkholes within the study area where visited. The first is between Sonderwater and Mohadin, with the following coordinates:

  - 26.71798 S
  - 27.03851 E

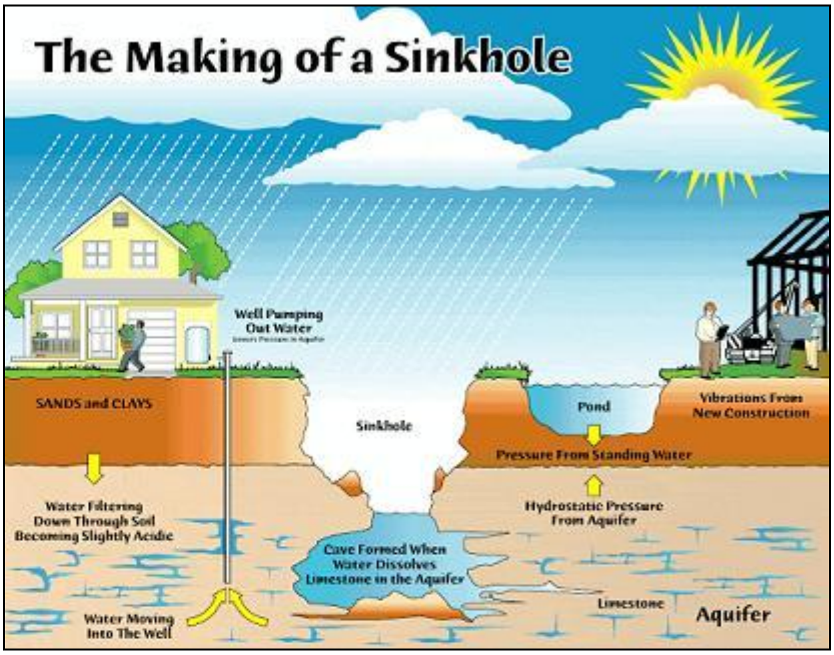
This sinkhole would more likely represent a doline. The entire sinkhole is about 7 m in diameter, and 1 m deep at its deepest end. It has been refilled with boulders excavated from building sites nearby, but has not been remediated and could still pose a possible threat in the future.

The second sinkhole within the study area is classified by Buttrick & Van Schalkwyk (1995) as a large sinkhole. Its location is:

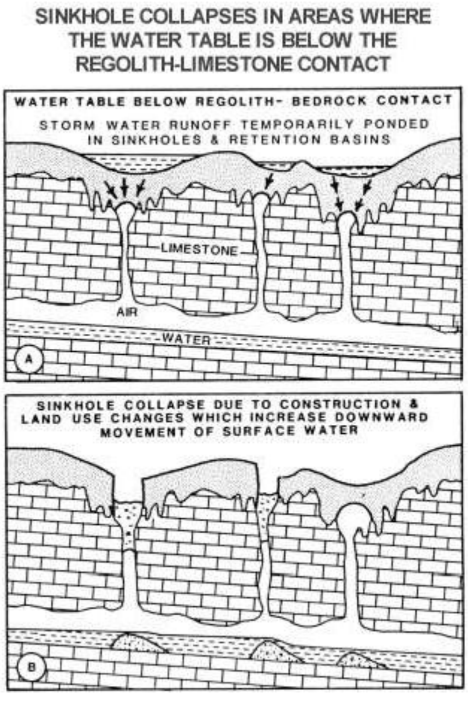
- 26.71798 S
- 27.03851 E

This sinkhole is 4 – 5 m deep and has a floor area of 4 X 5 m. It has two holes in the roof where the overburden has fallen into the cavity below. This is a very important sinkhole because it leads to more cavities. The entrance to the other cavity is 1 m high and has a 3 m long corridor which is connected to both cavities. The second cavity has a bigger floor area than the first, but is not as high. This second cavity has no other openings than its corridor to the first cavity, and can therefore not be seen from above. This second cavity can therefore be seen as a very good example for the formation of a sinkhole.

The development of sinkholes within dolomite rocks is schematically shown in Figure 5-10:




(Lake Country Florida Government, 2007)




(Crawford & Whallon, 1985)

**Figure 5-10: Various schematic presentations of the development of instability on dolomite**

The following are the most important geotechnical reports used in the characterisation process:

- BKS RAADGEWENDE INGENIEURS, 1993, Verslag oor die dolomietstabiliteits- en ingenieursgeologiese ondersoeke vir die voorgestelde dorpsontwikkeling Ikageng Uitbreidings, Potchefstroom.

- GEO SPECIALISTS INCORPORATED, 1993, Ikageng Extensions, Potchefstroom. Phase 2: Engineering geological investigation for township establishment purposes. Report 55015/G1/1993

- INTRACONSULT, 1992, A Report to the Chief Director, Geological Survey, on a phase 1 engineering geological investigation of proposed township extension areas; Ikageng; Potchefstroom District.

- INTRACONSULT ASSOCIATES, 2005, A GFSH-2, Phase 1 Geotechnical Report on portions of Sonderwater, Potchefstroom. IR716.

- Lourens & Sonnekus, 2003, Summary Report on Geotechnical investigations done in the Ikageng Area.

Based on the location of this existing investigation and available information, as well as from regional geological interpretations from the existing geological maps, areas were identified in need for drilling results in order to support a geological assessment of the study area. The positions of 34 new boreholes are shown in Figure 5-11.

Based on this profiling, the borehole positions were classified to reflect a geological setting as indication of probable risk. The following classification was decided on within the constraint of the available data, investigation funding and appointment period:

**Classification A: Dolomite and related geological rock types and weathered products identified in the top 10 meter of the borehole profile.** This geological setting was identified as a specific unit due to the following:

- Dolomite and related rock types as well as the weathered products within the top 10 meter are highly exposed to interaction with the atmosphere and the groundwater in the phreatic zone above the water table. This results in the highest risk to leaching, destabilization and potential collapsing.

- This section of geology is mostly exposed to human activity contributing to destabilization through ingress of water from leaking water bearing services and also groundwater level chances. (Department of Water Affairs, 2009).

- Paleo karst topography feature is mostly develop in the zone and giving rise to complex changes in dolomite character and high risk to development.

- Occurrence of dolomite and related rocks and weathered product in the top 10 meter of the geological succession is therefore regarded as of high risk to land use and spatial development and need to be identified for the implementation of specific management and monitoring arrangements.

**Classification B: Dolomite and related geological rock types and weathered products identified with highest level in the section 10 to 60 meter depth of the borehole profile.** This geological setting was identified as a specific unit due to the following:

- Dolomite deeper than 10 meter is less exposed to atmospheric processes.

- The effect of water ingress is more focused in this zone as preferential groundwater flow will develop along structural controlled pathways.

- The status of character of dolomite will be influenced by secondary effects determining risk. Factors that may contribute to change in dolomite character on a spatial basis may include topography, lithological changes and structural geological setting. Different risk zones may therefore be identified within this broad classification based on the availability of more information.

- Groundwater abstraction from the aquifers related to dolomite may have an effect on groundwater level changes within this section as the natural groundwater level will fall within this section. Groundwater stability will contribute to lowering of risk within this classification area.

**Classification C: No dolomite and related geological rock types and weathered products identified in the top 60 meter of the borehole profile.** This geological setting was identified as a specific unit due to the following:

- Budget and logistical constrain in ratio to risk were playing a role in determining the depth of investigation drilling. (Drilling was focused more at identifying the occurrence of dolomite in the top 60 meter as this reflects higher risk than deeper dolomite).

- Structural geological interpretation on a regional scale was used to determine the possibility of the occurrence of dolomites deeper than the drilling depth. This include the regional geological succession of formations, dip and strike as well as the occurrence of faults and deformation.

- Where no dolomite was found in the top 60 meter, and reasonable assurance could be argued for the absence of dolomite in depth, the area was regarded of no risk regarding to dolomite related surface destabilization.

This classification of the drilling results is presented in Figure 5-4 as final input to the development of a risk zone map described in the next section.

**Risk zone map compilation**

The geological maps and information, drilling results, field observations and, structural data were used to develop an integrated zoning map in order to understand the relationship between dolomite and other formations within the study area. This zoning map was used to assess the geology expected deeper than the available drilling results, in order to compile the risk zoning of the area. This zoning map indicates the following two zones:

1. Indicated risk based on the probable occurrence of dolomite

2. Measured risk based on the proven occurrence of dolomite (Figure 5-12).

It is evident that there are very large gaps in basic geotechnical information within the study area.

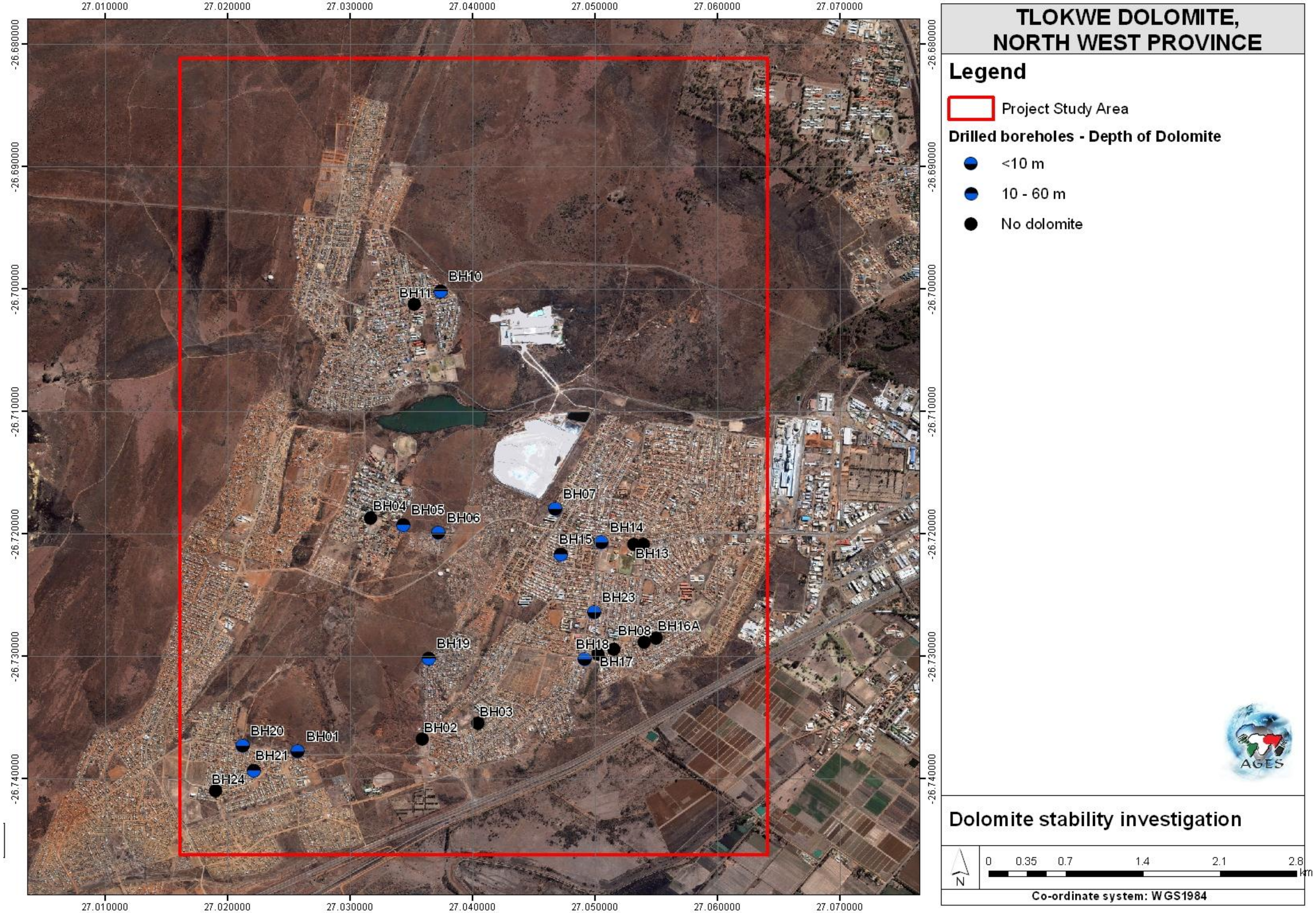



**Figure 5-11: Position of new boreholes used in this study and the depth of dolomite encountered**

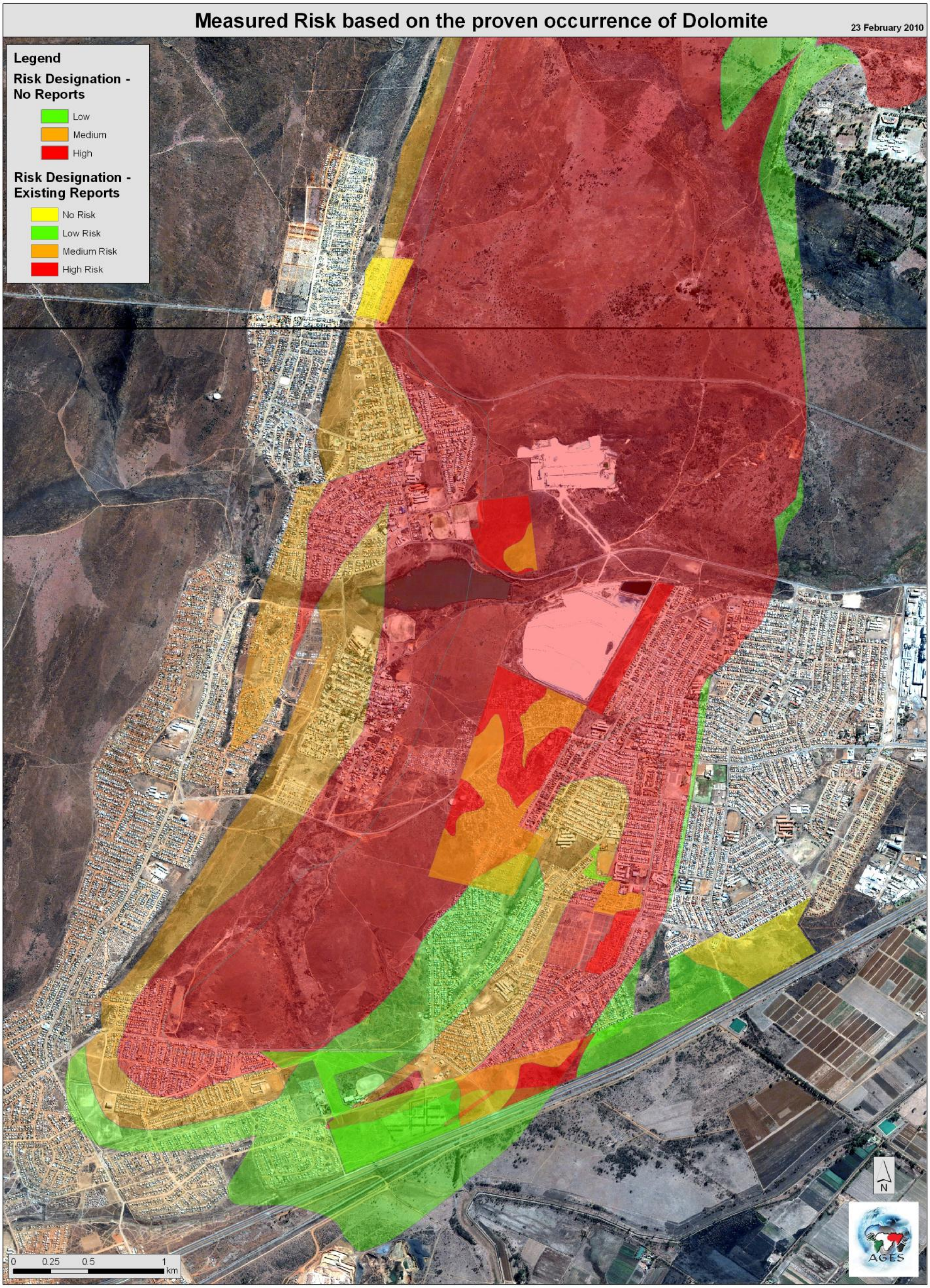



**Figure 5-12: Measured risk based on proven occurrence of dolomite**

### 5.1.4 Physical assessment

The main findings of the three contributing factors within the physical environment can be summarized as follows:

1. The effect of the Vredefort meteorite impact on the dolomite enhances the risk due to complex structural geological deformation. This resulted in a map indicating the indicated risk based on the probable occurrence of dolomite, ranked from low to high.

2. Although there is no large scale dewatering taking place, the absence of the local authority's involvement in groundwater management cannot guarantee it from not happening and therefore increases the risk.

3. The absence of adequate detail inherent geotechnical information enhances the risk. The measured risk based on the proven occurrence of dolomite was ranked from low to high based on the inherent hazard classes for the applicable areas. A map was compiled showing the measured risk based on the proven occurrence of dolomite, ranked from low to high (Figure 5-12).

The combination of the three major contributing factors within the physical environment results largely in an estimated average overall high risk. Further basic research is deemed essential.

## *5.2 Anthropogenic factors*

### 5.2.1 Existing infrastructure and development

The specific quality of infrastructure on dolomite is of great importance to the ground stability of urban areas underlain by dolomite. This is due to the weathering effect of fluids on weathered material overlying cavities. Water infiltration from leaking sewage or water pipes has the potential to dissolve and erode the fragile Ca-rich dolomite at a far greater rate than its natural dissolving rate (Blinkova & Eliseev, 2005).

The following is of importance in general:

- After heavy rains, the ponding of water can cause sinkholes to form suddenly. Water in urban areas has its flow impeded by vertical structures like brick and concrete walls. This can add sudden weight to the surface, and soak the subsurface to the point where ingress of water into subsurface voids start, leading to sinkholes.
- Any water infiltration from water-bearing infrastructure may enhance instability.
- Poor workmanship, the use of inferior materials and deterioration of the materials used in infrastructure leads to a greater likelihood of sinkholes occurring.
- Areas with older or faulty infrastructure are more likely to be higher risk areas. These areas must therefore be seen as more critical to do investigations on, seeing as the dolomite deterioration in those areas have come a long way, and the cavities could be more developed comparing to areas with no infrastructure or no infrastructural deficiencies.

The Department of Public Works (2010) have created an extensive report on the specifics of appropriate development of infrastructure on dolomite. This includes a broad list of requirements, restrictions and recommendations such as:

- Avoiding high concentrations of subsurface services near buildings
- Avoiding the use of rigid, short length piping (promote long, un-jointed, flexible piping)
- Incorporating the appropriate water precautionary measures for the different risk level areas: low, medium and high

On the other hand, the civil structures and related infrastructure of the areas underlain by dolomite can also be used to determine the current situation in regard to sinkhole or doline development. This can be determined by gathering data concerning the houses and other buildings and walls in the area. The areas that have cracks in the building structures may be seen as areas that have more unstable ground conditions. But this type of data is also subsequent to the structural integrity of building material and the age of the building.

**The infrastructure in Ikageng**

A preliminary survey of the existing infrastructure in Ikageng was conducted on 03 March 2010 (Personal communication with Carson, 2010). Priority was given to the areas underlain by dolomite. Sixteen main infrastructural features have been identified and their current situations have been quantified (Table 5-3, Figure 5-13).

Based on similar characteristics (i.e. age, type, etc.), the 16 infrastructure focus points were grouped into 6 broad manageable categories in order to quantify the risk associated with the dolomitic land, as indicated in Figure 5-14:

A. Most of the infrastructure is older than 35 years.

B. Mostly old infrastructure, with scattered new infrastructure. This area is in average older than 20 years.

C. Mostly new infrastructure, with scattered older areas. This area is in average younger than 15 years.

D. New infrastructure (younger than 5 years).

E. Temporary infrastructure. Inhabitants are in the process of being relocated and permanent infrastructure has not been installed in this area.

F. Assumed to be in process of installing dolomite compliant infrastructure.

**Table 5-3: Infrastructure zones (1-16) in the study area.**

| | Name | | Water provision | | Sewage | Storm Water | | | General Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | Age | Type | Leakages | Type | Type | Type of pipe | Leakages | |
| 1 | Ikageng Proper | >35 | Center block - Asbestos | Into sewage | Center block -Clay | Roads and pipes | Concrete | Not maintained due to unpaved roads | ± R 15 mil approved for upgrading; Water pipes to be replaced (On sidewalk) |
| 2 | Ikageng Proper | >20 | UPVC 12 | | Clay | Roads and pipes | Concrete | | Unpaved roads present |
| 3 | Boitshoko School | >20 | Municipal/ groundwater | | | | | | Borehole not to be pumped, or determine a safe abstraction |
| 4 | Reservoir | >40 | | | | | | | Leakages |
| 5 | Sonderwater Informal | <5 | Standpipes | | Chemical toilets | N/A | | | Will be formalised elsewhere |
| 6 | Greenfields | <5 | | | | N/A | | | To be finalised |
| 7 | Mohadin - Promosa | >35 | Center block - Asbestos | Into sewage | Center block- Clay | Roads and pipes | Concrete | Not maintained due to unpaved roads | Water pipes to be replaced (On sidewalk) |
| 8 | Ext -7 and Promosa | <15 | PVC | | PVC | Roads and pipes | Concrete | | Unpaved roads present |
| 9 | Pipeline | N/A | Asbestos | | | N/A | | | Asbestos - No leakages |
| 10 | Sarafina | <15 | PVC/ Asbestos | | Clay | Roads and pipes | Concrete | | Unpaved roads present |
| 11 | Sarafina | <15 | PVC | | PVC | Roads and pipes | Concrete | | Unpaved roads present |
| 12a | Lusaka | >20 | Asbestos | | Clay | Roads and pipes | Concrete | | Unpaved roads present |
| 12b | Lusaka | >20 | PVC/ Asbestos | | Clay | Roads and pipes | Concrete | | Unpaved roads present |
| 12c | Lusaka | >20 | PVC | | Clay | Roads and pipes | Concrete | | Unpaved roads present |
| 12d | Top City | <15 | PVC | | Clay | Roads and pipes | Concrete | | Unpaved roads present |
| 13 | Pipeline | N/A | | | Fiber-Glass | N/A | N/A | | Fibrer-glass pipe |
| 14 | Pipeline | N/A | Steel | | | N/A | N/A | | Chemical reaction between tailings dam and pipe causes rusting - Needs to be patched yearly |
| 15 | Pipeline | N/A | | | Asbestos | N/A | N/A | | |
| 16 | | N/A | PVC | | PVC | N/A | None | | Unpaved roads present |

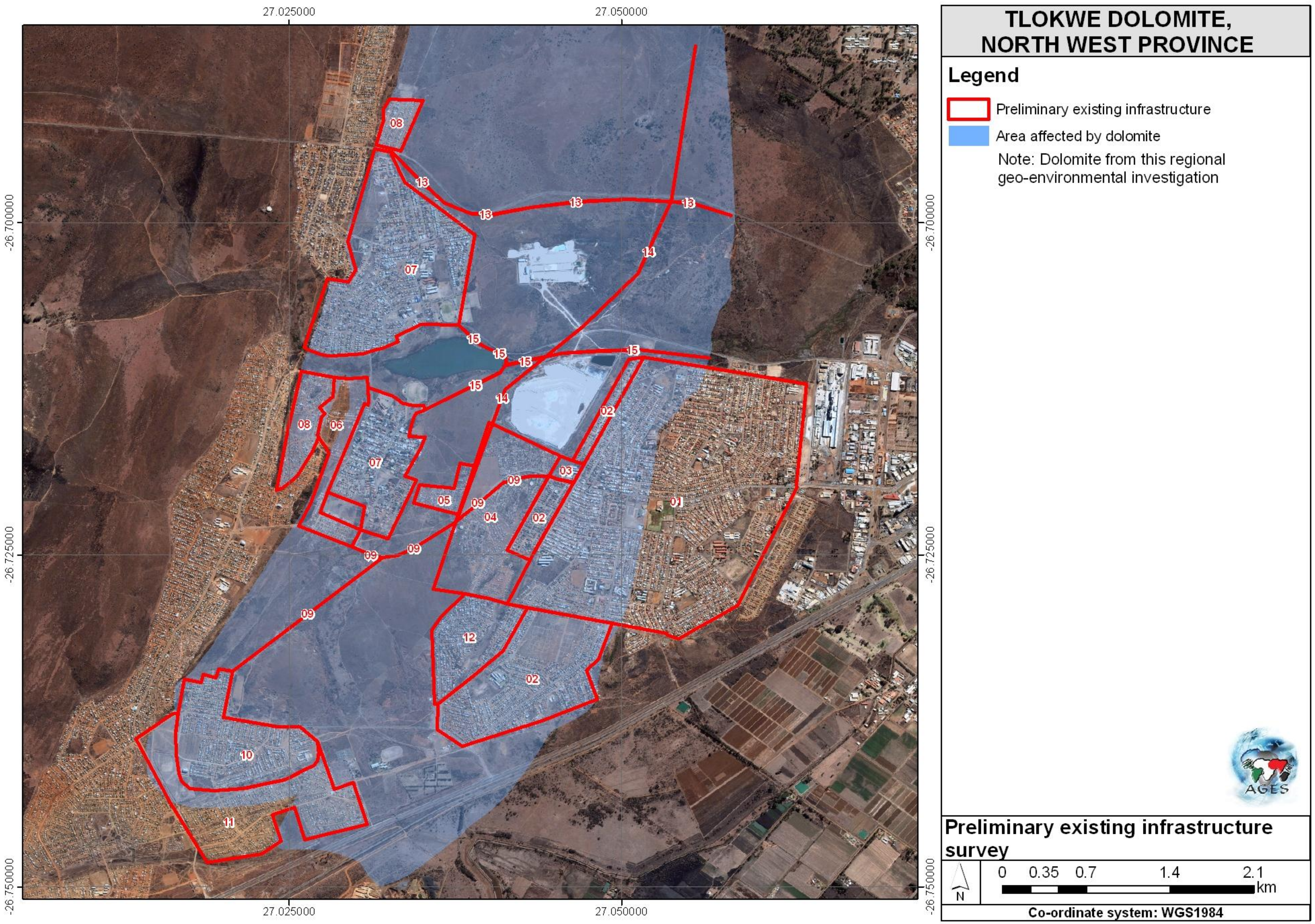



**Figure 5-13: Infrastucture zones in the study area as described in Table 5-3.**

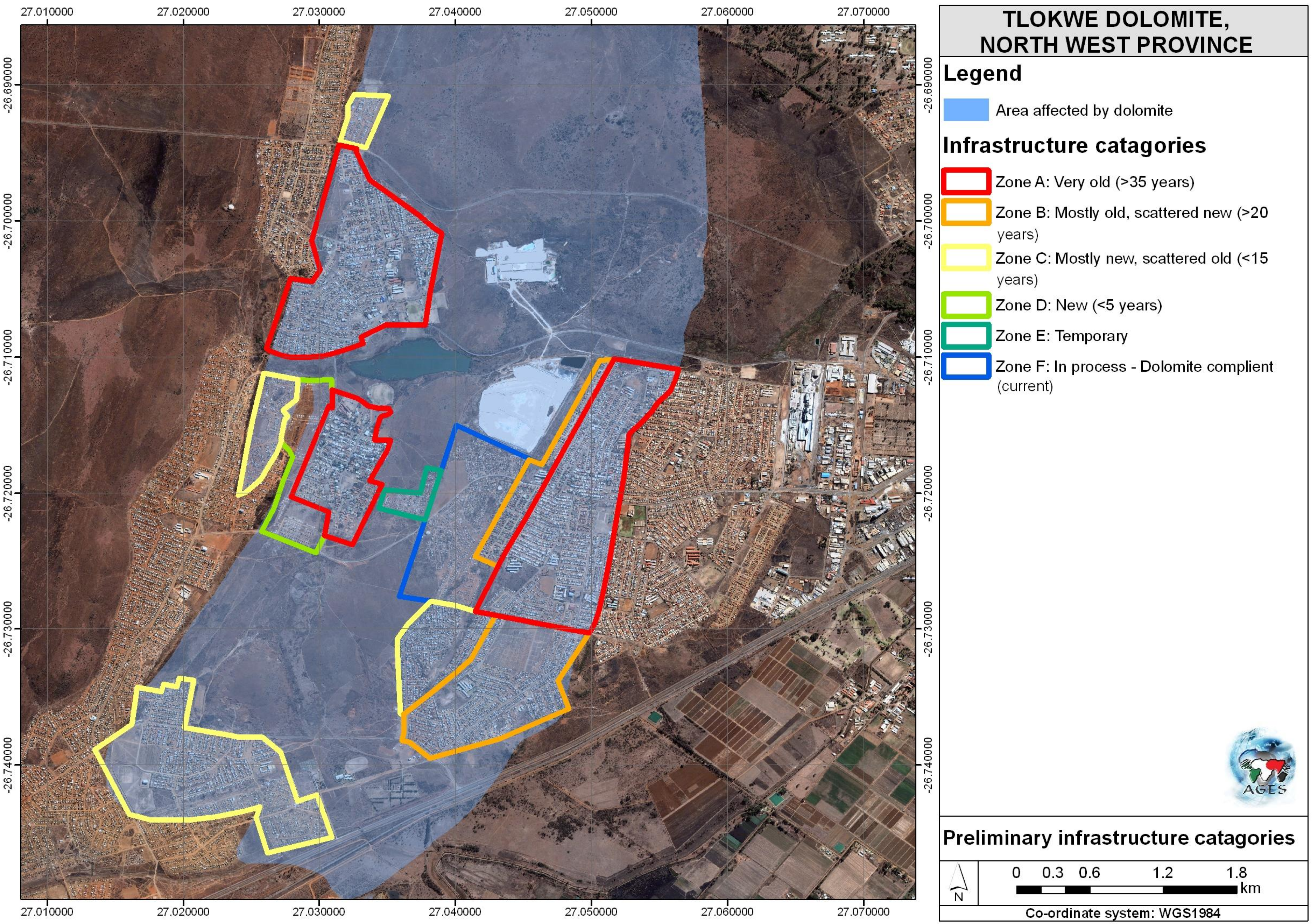



**Figure 5-14: Preliminary infrastructure categories, based on age and type, indicating the risk associated with dolomitic land**

### 5.2.2 Land use planning

**Sustainable development**

It will be important to measure all development on dolomite and the related risks management against a framework of sustainability. A well developed strategic planning process is therefore essential including both financial and social capital to ensure sustainable development and related socio-economic empowerment. In order to contribute to this process the following basic concepts were defined and included as background.

**Basic sustainable development**

The World Commission on Environment and Development (WCED), also known as the Brundtland Commission, offers the most published definition of sustainable development: 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). In this definition, the ability of the environment to meet both present and future needs is very important. Thus the built environment needs to be in a safe and lasting area, which offers a long term housing solution, without the possibility of damage to the infrastructure.

The International Council for Local Environmental Initiatives (1995) have developed a definition for sustainable development that is more useable for the local governments and has a focus on their developmental role: 'Development that delivers basic environmental, economic and social services to all without threatening the viability of the natural, built and social systems upon which these services depend.'

Venter (2010) states that the essence of sustainable development is the need to develop a strategic management and planning approach by which sustainable development can be promoted without destroying the natural resource base on which it depends or negatively affecting the human communities that it is intended to serve. The *vice versa* is then also true, that a natural resource base needs to be sustainable in order for the strategic management to be done successfully. It is evident that sustainable development on dolomite land poses a challenge in this regard.

Poister and Streib (1999) compiled a review of what strategic management and planning in action is:

- It is concerned with identifying and responding to the most fundamental issues facing an organization;
- Has to address subjective questions of the purpose of the development, as well as addressing the competing values that influence the mission and strategies;
- Attempts to be politically realistic;
- Requires confrontation of critical issues by key participants in order to build commitment for completion of plans;
- Is action orientated, and not just a theoretical exercise;
- Stresses the importance of developing plans for implementation of strategies; and
- Focuses on implementing decisions now in order to position the affected bodies favourably for the future.

Strategic management is therefore essential when it comes to dolomite. Strategic management is defined as the process by which the guiding members (in this case the Tlokwe City Council) of an organisation envision its future and develop the necessary procedures and operations to achieve that future (Goodstein *et al.*, 1993)

**Practical sustainability measures**

Sustainable development and socio-economic empowerment are two central aspects within the government structures and legislation at present. These factors should therefore be considered and included during the whole process as a focus point for the people. Whether infrastructure of the community will be improved or a community needs to be relocated, the end result should be sustainable development and improvement, along with socio-economic empowerment of the affected community.

In order for development to be truly sustainable, more than just financial support is needed. Social capital, something that does not have a monetary value in the traditional sense, can add to the wealth of a community. Social capital can be defined as a public good comprised of trust among a diverse group of citizens within the same community that facilitates cooperative networks among those citizens (Young, 1934). Barrow (2002) adds to this by stating that social capital comprises the abilities, traditions and attitudes that help ensure that a group of people will support each other, respond to challenges in a constructive manner, and innovate. A community that possesses social capital will thus participate more in community matters and work together for collective benefits. Research in the field indicates that enhanced community integration can promote local economic development (Midgley, 1999).

Eade (1997) states that:

*"development is about women and men becoming empowered to bring about positive changes in their lives; about personal growth together with public action; about both the process and the outcome of challenging poverty, oppression, and discrimination; and about the realisation of human potential through social and economic justice. Above all it is about transforming lives and transforming societies"*

Land-use planning is defined by the White Paper on Spatial Planning And Land Use Management (South Africa, 2001) as the planning of human activity to ensure that land is put to the optimal use, taking into account the different effects that land-uses can have in relation to social, political, economic and environmental concerns.

Land use planning encourages further population growth and economic development, and is supposed to take the interrelation with the environmental and social consequences into account. Typically, this leads to uncontrolled urban growth and sprawl, so when a land use plan is developed, governments can control the uses of variable parcels of land by legal and economic methods. This is done through zoning where various parcels of land are designed for certain uses. This is then used to help reduce uncontrolled sprawl and slow the resulting degradation of air, water, land, biodiversity and other natural resources (Miller & Spoolman, 2009).

The environment and land use planning have a two way effect on each other. The one needs the input of the other. It is therefore essential to take the geology of an area into account. Just as mineral-bearing areas are optimized and mined, so also caution should be taken in the planning of areas underlain by dolomite.

**Tlokwe land uses**

Tlokwe Local Municipality forms part of the Dr Kenneth Kaunda District Municipality along with four other local municipalities

- City of Matlosana (Klerksdorp, Stilfontein, Hartbeesfontein, Orkney)
- Merafong City (Carletonville, Fochville, Khutsong, Wedela)
- Maquassi Hills (Wolmaransstad, Leeudoringstad, Makwassi, Witpoort)
- Ventersdorp (DTI, 2008)

The Tlokwe Local Municipality developed a land use framework of its area of jurisdiction. The Urban Land Use Map for this area, as developed by Maxim Planners for the Tlokwe Spatial Development Framework, was acquired from the Tlokwe Local Municipality for preliminary usage in this document.

Although the Land Use Framework of an area is created in such a way that it protects the environment (Dale, *et al.*, 1998), the Urban Land Use Framework does not take the existence of dolomite into account.

The existence of a dolomite risk as defined in Chapter 3 was used as background to the spatial planning taken from the Urban Land Use Framework.

As can be seen from Figure 5-15, the main land use in the dolomite risk zone is residential. Public Open Spaces and Educational facilities are the second most and Business the least. This means that the danger of possible sinkholes poses a threat to people of all age groups.

The Land Use Map gives no indication of dolomite sensitive area, which means that future housing, as the main land use in the area, could have been allocated on areas where sinkholes could possibly form.

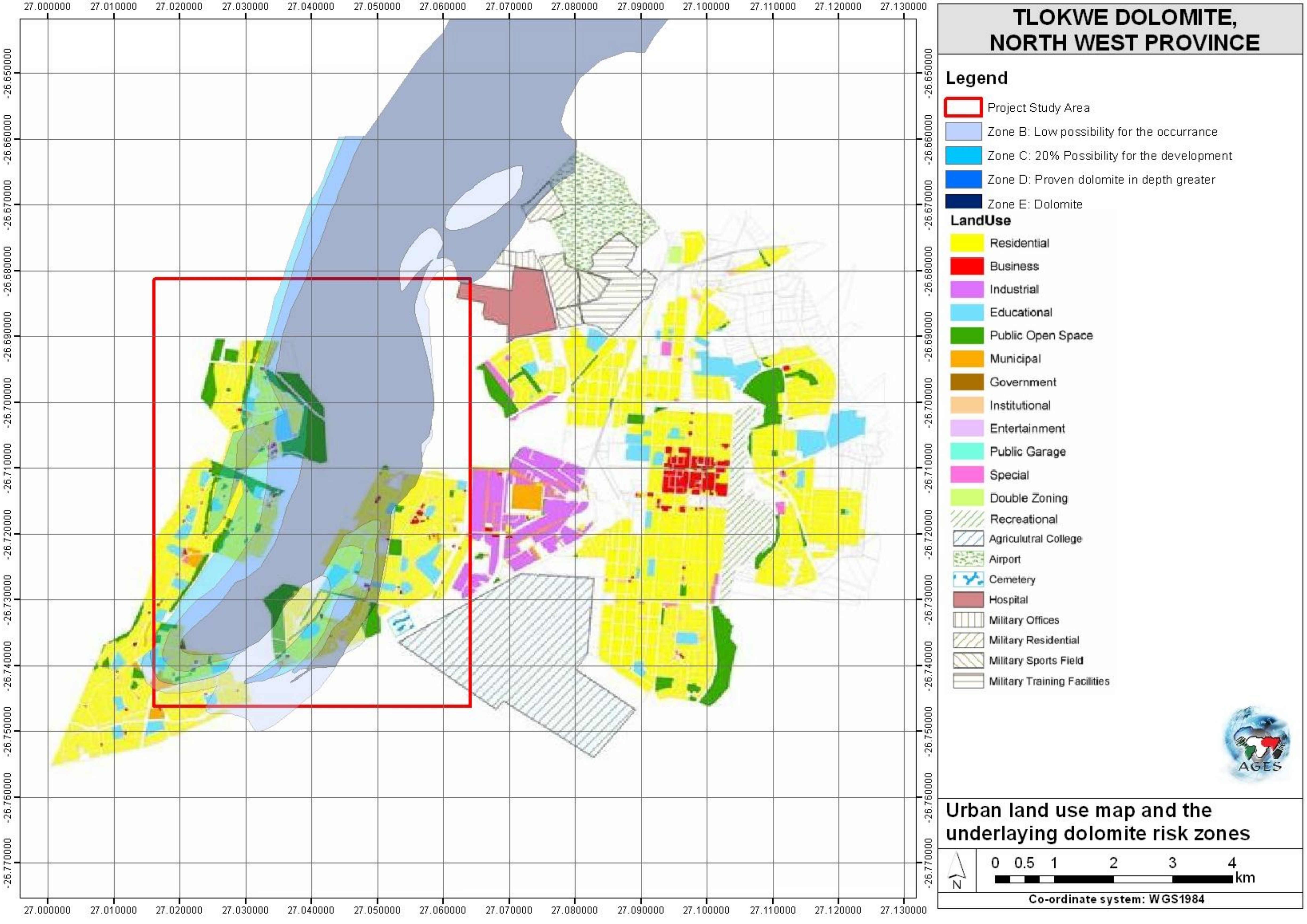



**Figure 5-15: Tlokwe urban land use map and the underlying dolomite risk zones**

5.2.3 Social structure and awareness

**A broader perspective on social awareness**

Social Awareness needs to be the precursor, facilitating and sustainability agent to any project impacting the community directly or indirectly.

This must take place hand in hand as part of the project life-cycle within a Social Impact Assessment (SIA) and a Public Participation process, as part of the social strategy.

A clear distinction must be made between Social Awareness, Social Impact Assessment and Public Participation. Though the three processes impact each other and develop concurrently, they should be defined separately in the Social Strategy for the project.

A SIA must be done to set a baseline while the Public Participation feedback and legal frameworks define the social awareness programs needed. While engaging in the social awareness programme, SIA must be done to monitor the impact of the Social awareness interventions on the baseline.

Measuring these impacts, will guide the social awareness practitioner to adjust interventions to be more effective and appropriate. Through the Public participation process valuable data may be collected towards an intermediate SIA and/or adjustment of the Social Awareness programme.

The SIA has to identify the social equity or distribution of impacts across different populations. Attention must be given to the impact on vulnerable segments of the human population. Examples include the poor, the elderly, adolescents, the unemployed, women, members of the minority and/or other groups that are racially, ethnically, or culturally distinctive; or occupational, cultural, political, or value-based groups for whom a given community, region, or use of the biophysical environment is particularly important.

As humans are affected by external factors according to their distinctly human environment (known as the social construction of reality), this must be considered in determining the significance of impacts. During controversies, participants are often tempted to dismiss the concerns of others as being merely imagined or perceived.

Two important reasons to accommodate all concerns are: Firstly, positions taken by all sides in a given situation are likely to be shaped by differing perceptions of the issue. The decision to accept one set of perceptions while excluding the other may not be scientifically defensible. Secondly, if the one party asserts that the other is "emotional" or "misinformed", for example, it is guaranteed to raise the level of hostility between itself and community members and it will stand in the way of a successful resolution of the problem.

In summary, some of the most important aspects of social impacts involve not the physical relocation of human populations, but the meanings, perceptions, or social significance of these changes.

**Social awareness during research**

During the first phase of the Dolomite Awareness programme we made the decision to depart from the awareness as a separate program and to rather run it concurrently with the Geotechnical process. This strategy proved to be so successful that it will be implemented on all projects in future.

As precursor to the community awareness programme, workshops were held to create awareness with technical and research stakeholders and officials from the municipality. Out of this it was also clear that a social map needed to be drawn to facilitate social boundaries (Figure 5-16). This tool has proven to be of immense value in all liaison and awareness processes.

By doing a comprehensive stakeholder analysis we knew who had to be involved in the awareness programme. It is however necessary to update and review this process regularly, as the stakeholder profile might change and create complications for the smooth flow of the Tlokwe Dolomite Strategy.

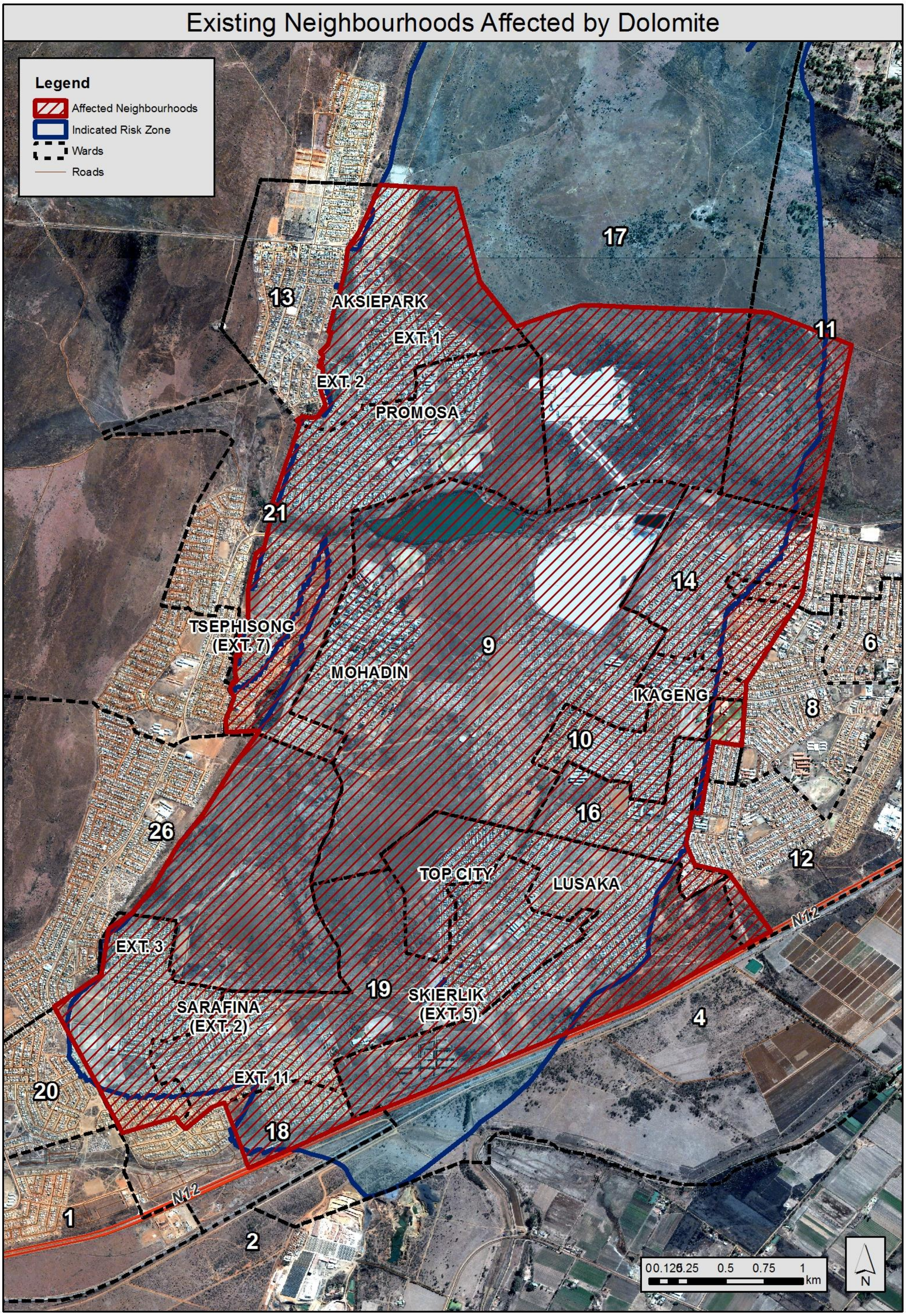



**Figure 5-16: Social awareness boundary**

We knew that involving the ward councillors was of great importance. Individual sessions proved to be valuable and also involving them on site in their own wards. This process is ongoing and many ward councillors will be involved as soon as the Geotechnical process starts in their wards. It is essential to keep them updated and informed as they have great influence on perceptions and attitudes towards the process, but also because their leadership needs to be respected.

The most effective tool used in this first phase was the liaison officers on site. While the drilling took place they were available to address all concerns and kept a register of incidents and queries. Through this the technical team could follow up incidents and report to Housing and Planning. They also involved schools and gatherings at community centres. The onsite liaison will be a valuable tool in the awareness process as it creates opportunity for reporting of incidents and pro-active intervention.

Housing and planning also collaborates closely with our technical and social team to facilitate the follow up and feedback to applicants who want to build or do extensions. This process is essential and will continue throughout the management of Dolomite in Tlokwe.

The media was involved through a radio interview and press release as well as press articles. Although a big impact was made by this first stage, the awareness process will have to be intensified to reach all affected households and to establish a sustainable awareness in the community, starting at school level and moving on to community structures.

The Social Awareness will also evolve as the research unfolds to include more public participation actions as well as processes to hedge Tlokwe municipality against indemnity and actions resulting from research outcomes.

**Dolomite awareness programme**

The Dolomite Awareness Program (DAP) aims to achieve the following in order to ensure a long-term program to avoid future disaster and risk to the Council:

- Optimise the existing Dolomite Assessment Program by identifying and running of a social component parallel to the scientific process. This will optimise all actions, and the effect and outcome of the Dolomite Assessment Program.

- Knowledge transfer and awareness creation regarding to dolomites and the associated risks in order to address wrong perceptions and create an understanding of the dolomite spatial reality versus development and the running of the Dolomite Assessment Program.

- To train stakeholders form all categories to be cooperative regarding to the management of dolomite risks and the related monitoring and mitigation processes regarding to human interference and surface practices on dolomites. Focus areas will be:

    - Understand the reality of dolomites within the City Council.

    - Understanding the risks, roles and responsibilities on various governmental levels.

    - Property owners within the effected neighbourhoods.

- To establish a defined communication and social liaison plan aligned with the scientific and social components of the Dolomite Assessment Program.

**Legal and institutional framework**

There are several legal and institutional requirements that should be conformed with during public participation:

- South African Constitution. Chapter 2 of the Constitution contains the Bill of Rights *Section 151(1) (e), Section 152, Section 195 (e).*

- White Paper on Local Government 1998

- Municipal Structures Act (117 of 1998)

- Municipal Systems Act (32 of 2000)

- The National Policy Framework for Public Participation (2007)
- Tlokwe Public Participation Policy

**Towards a social awareness strategy**

The Social Awareness campaign concerns at its core, the relationship between social scientists and biophysical scientists. As the level of sophistication of the various disciplines drawn into the assessment process increases, along with the increasing complexity of developments and activism of the public, so neither group of scientists can afford to ignore the other. In fact each has something unique to contribute to the evaluation process making a compelling case for an inter-disciplinary as opposed to a multi-disciplinary approach to a combined Dolomite Risk assessment. A distinction is made between multi- and inter-disciplinary approaches in the sense that the former requires of specialists to work alongside each other while the latter refers to a more intense relationship where specialists function together as a team.

For decision makers and stakeholders it is of great importance to appreciate this complex and sensitive relationship and the impact it has on the unfolding of the Social Awareness campaign and the facilitation of perceptions, emotions and attitude towards Dolomite Risk.

The interventions up to now have been approached in this way, creating synergy between Geotechnical specialists and Social impact- and awareness specialist

**Phased multi-level approach**

A phased multi level approach is recommended.

**Phase 1**

Phase 1 represents the short term, initial awareness. This phase was extremely important as it set the tone for the whole awareness program. If during this phase mistakes were made, it would complicate the rest of the process for all stakeholders. The opposite has just as powerful an effect: successes in this phase can pay dividends for years to come.

For this phase, a comprehensive stakeholder analysis was done and actions were identified, using the National and Local Frameworks for public participation as guideline. This entails identifying the level of involvement required for each stakeholder as well as their contribution to the program.

Press liaison, workshops and drilling liaison and other actions as described in 4.3 of this document formed part of this phase.

**Phase 2**

This phase concerns the second phase of drilling, research, and dissemination of results. The social facilitation and awareness corresponding with these actions as well as actions taken in response to the results of the research are included in this phase.

During this phase awareness will peak, while decisions are made in response to results. The following actions will be taken or continued:

- Dolomite desk
- Educational Programme
- Dolomite Facilitation Training
- Community Liaison
- Stakeholder Liaison
- Municipality and government Liaison
- Meetings and Workshops
- Media Liaison
- Public Participation Processes

**Phase 3**

This phase reaches beyond a 10 year period and keeps dolomite awareness alive:

1. Yearly Workshop for council to create general awareness for future town planning, consideration of mining applications and assessment of water infrastructure upgrades and maintenance.
2. Dolomite desk
3. Hosting and update of dolomite website.

### 5.2.4 Anthropogenic assessment

When assessing the three main factors of the anthropogenic environment together, the following can be concluded:

1. Infiltration from ponding or leaking infrastructure is a major contributing factor to instability features. Most of the sub-surface water-bearing infrastructure in the study area was found to be old and not on the current standards for such development on dolomite. Some of the infrastructure is very old and leaking is almost a given. Stormwater management is also not adequate, resulting in ponding of water. This enhances the risk significantly. The infrastructure within the study area was ranked in order of risk.

2. Existing land use as well as future planning includes high-density residential development on dolomite, which increases the overall risk.

3. Probably the most significant factor to consider in the management of development on dolomite is the people living on the dolomite. It was found that neither the local authority nor the residents was aware of the presence of dolomite and the associated risk. It was also confirmed that many of the affected residents are very vulnerable to such risk as they are mostly from a low-income bracket. This also contributes to the final disaster risk score.

The three main anthropogenic factors also culminate to an estimated overall average high risk.