Technical Report
2011/04/08 GWSA

Tlokwe City Council:
Geohydrological Assessment of the Tlokwe Dolomite, Potchefstroom area

Prepared for: **Tlokwe City Council**

August 2012

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Compiled by: JJ Smit and SJ Pretorius

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Tlokwe City Council

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Geohydrological Notations and terms

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater.

Anisotropic is an indication of some physical property varying with direction.

Cone of depression is a depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a borehole from which water is being withdrawn. It defines the area of influence of a borehole.

A *confined aquifer* is a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

The *darcy flux*, is the flow rate per unit area (m/d) in the aquifer and is controlled by the hydraulic conductivity and the piezometric gradient.

Dispersion is the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown is the distance between the static water level and the surface of the cone of depression.

Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Groundwater table is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

A *fault* is a fracture or a zone of fractures along which there has been displacement.

Hydrodynamic dispersion comprises of processes namely mechanical dispersion and molecular diffusion.

Hydraulic conductivity (**K**) is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the area [L/T]. Hydraulic conductivity is a function of the permeability and the fluid's density and viscosity.

Hydraulic gradient is the rate of change in the total head per unit distance of flow in a given direction.

Heterogeneous indicates non-uniformity in a structure.

Karstic topography is a type of topography that is formed on limestone, gypsum, and other rocks by dissolution, and is characterised by sinkholes, caves and underground drainage.

Mechanical dispersion is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

Molecular diffusion is the dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Observation borehole is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

Permeability is related to hydraulic conductivity, but is independent of the fluid density and viscosity and has the dimensions L^2. Hydraulic conductivity is therefore used in all the calculations.

Piezometric head (ϕ) is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a *piezometric surface*, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.

Porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Pumping tests are conducted to determine aquifer or borehole characteristics.

Recharge is the addition of water to the zone of saturation; also, the amount of water added.

Sandstone is a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale is a fine-grained sedimentary rock formed by the consolidation of clay, silt or mud. It is characterised by finely laminated structure and is sufficiently indurate so that it will not fall apart on wetting.

Specific storage (S_0), of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. In the case of an unconfined (phreatic, watertable) aquifer, *specific yield* is the water that is released or drained from storage per unit decline in the watertable.

Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity is the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total dissolved solids (TDS) is a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity (T) is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

An *unconfined, watertable or phreatic aquifer* are different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the watertable, which is in contact with the atmosphere so that the system is open.

Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

LIST OF ABBREVIATIONS

Abbreviation	Description
DWA	Department of Water Affairs
FWR	Far West Rand
GMA	Groundwater Management Area
GMU	Groundwater Management Unit
Ha	Hectare
KGTD	Kynoch Gypsum Tailings Dam
L/s	Litres per second
m^3/a	Cubic metres per annum
Mm^3/a	Million cubic metres per annum
MAP	Mean annual precipitation
MBGL	Metres Below Ground Level
NGA	National Groundwater Archive
NWA	National Water Act (Act 36 of 1998)
SRTM	Spatial Radar Topography Mission (NASA)
TCC	Tlokwe City Council
ToR	Terms of Reference
WMA	Water Management Area
WULA	Water Use Licence Application

Executive Summary

Sinkholes develop on dolomitic land when surface material collapses into subsurface cavities. These cavities are the result of dissolution of the dolomite by acidic groundwater, and are strongly correlated with the current water table. The extent of cavity formation in the otherwise impermeable dolomite gives it its water bearing properties. Dolomite can store and transmit large volumes of groundwater. This type of aquifer is described as a Karst Type aquifer according to the hydrogeological map, and because of the high groundwater potential (>20 L/s boreholes) is classified as a Major Aquifer according to the South African Aquifer Classification System. In the focus area the dolomite is surrounded by clastic rock types creating a Minor Aquifer. The hydraulic gradient in dolomite is flat which is indicative of high permeability and transmissivity while in the surrounding clastic rock aquifers it is more inclined.

There is a usual direct link between (artificial) groundwater fluctuations and sinkhole development on dolomitic land. Since sinkholes in residential areas like Ikageng pose a threat to human lives, proper management of the inherent risk associated with dolomite is important, and groundwater management plays an important role. Time dependent fluctuations of more than six metres have been observed in monitoring boreholes around the Kynoch Gypsum Tailings Dam, increasing the risk of sinkhole development, and necessitating continuous monitoring.

Since dolomite instability can be linked both to groundwater quantity (level fluctuations) and quality (dolomite dissolution), several flag situations were identified that needs addressing or further investigation:

Quantity flags include:

- The uncontrolled daily groundwater abstraction by Boitshoko High School. The impact on groundwater levels is unknown. This borehole must be replaced by municipal water supply, and monitored for water quality on a monthly basis until then.
- Uncontrolled and unlicensed groundwater abstraction by OMV from two boreholes on their premises does not seem to have a major impact on the surrounding monitoring boreholes, although a detailed geohydrological investigation supporting the Water Use Licence Application to DWA is a requirement.
- Verify other groundwater use in Potchindustria and in Ikageng
- New groundwater use must be approved before being developed

Ingress of water from surface can also accelerate sinkhole development by eroding weathered surface material into subsurface voids. Ingress of water can occur from:

- The tailings dam (acidic water) which is regarded as a perched aquifer
- Old infrastructure (reservoirs and pipelines)
- Ponding of water in borrow pits and built-up areas.

Quality flag:

- The major quality flag situation identified is the impact of the Kynoch gypsum tailings dam seepage on the surface and groundwater. The acidic nature of the seepage water from the dam was found to dissolve dolomite, and therefore the potential exists that the underlying dolomite is slowly being dissolved by the percolating seepage water. OMV currently monitors the surface and groundwater quality around the tailings dam, but a detailed assessment of the current situation is recommended.
- The old Kynoch factory was decommissioned in 2006 and no new pollutants are generated here. The extent of the cleanup of pollutants is unknown and this flag can be investigated further in terms of impact on the environment.
- OMV's operations might relocate the pollutants to north of the Spitskopspruit. The polluting potential of OMV must be investigated.
- Other potential pollution sources on the dolomite need to be surveyed.

To control groundwater abstraction from within the study area (Ikageng), it is proposed to place a borehole moratorium on the drilling of new abstraction boreholes in Ikageng as a municipal bylaw. A critical zone was delineated for this reason around the entire Ikageng residential area including Potch-Industria in which groundwater management is considered critical. All new borehole applications inside the critical zone must be approved by the Tlokwe City Council based on position relative to dolomite, and volume to be abstracted.

A monitoring protocol is recommended to monitor groundwater levels over time in the dolomite, and water quality of surface and groundwater near the tailings dam which should include chemical and radiological parameters.

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1 INTRODUCTION

During the regional geo-environmental investigation of dolomitic land in Potchefstroom (AGES, 2010b), it was recorded that 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, often with catastrophic results.

This is due to the chemical nature of dolomitic rock ($CaMg(CaCO_3)_2$) which is readily dissolved by acid. Over time this subsurface dissolution process can lead 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 often consists of an iron and magnesium rich clay that is referred to as WAD (weathered after-dolomite). The ability of this weathered material to provide support to the overburden is closely related to the moisture conditions in the weathered zone.

When the water table is lowered by artificial causes like the over-abstraction of groundwater from an area, it reduces the hydrostatic support to the material, which lowers the cohesion and density of the weathered material and the overburden collapses to form a sinkhole or doline.

Furthermore artificially induced ingress of water (from leaking water supply and sewage infrastructure) into subsurface cavities can lead to the steady erosion of weathered surface material into the cavity, which can also lead to sinkhole formation.

In both instances sinkholes are likely to form after heavy rainfall events, where the weathered material overlying cavities becomes saturated and exceeds a critical weight threshold.

1.1 Project background setting

AGES (Pty) was appointed by the Tlokwe City Council to develop a framework for the implementation of a regional Dolomite Risk Management Plan (DRMP) (AGES 2010a). This led to a preliminary Geo-Environmental Assessment of the dolomitic land in Potchefstroom (AGES 2010b). The recommendations from this assessment were acknowledged in Council Resolution C120/2010-06-09 and included in a memorandum of agreement (Tlokwe City Council, 2011) between the Tlokwe City Council and a team of consultants defining the actions related to the facilitation of the implementation of a DRMP for the Tlokwe City Council.

From the assessment it became evident that a geohydrological assessment and geohydrological monitoring of the Tlokwe dolomite area in Potchefstroom will be of importance to the effective implementation of a DRMP. A geohydrological assessment and the development of a monitoring program were therefore defined as part of the implementation of the DRMP (see paragraph 1.3).

Results from this Geohydrological Assessment were included in the 2011 Strategic Planner of the Dolomite Risk Management Strategy (AGES, 2011), with 2012 status of results concluded in this report.

1.2 Information sources

The following information sources were used in this report:

- Hydrogeological map Johannesburg 2625 Scale 1:500 000 (Barnard, 1999)
- Explanation of the Hydrogeological map (Barnard, 2000)
- Geological map West Rand 2626 Scale 1:250 000 (Wilkinson, 1996)
- Existing reports, publications and databases
- Remote sensing data: SRTM data, aerial photos and satellite images
- Field investigations (mapping, drilling, hydro-census surveys, water samples)

1.3 Terms of reference

According to table 2.1 contained in the Memorandum of Agreement (Tlokwe City Council, 2011) a specialist supporting project to the DRMP implementation was defined as:

"Geohydrological assessment and groundwater monitoring implementation on dolomites"

A budget allocation was made for the 2011 financial year – resulting in this report, and a budget allocation was made for future work to be defined from this assessment which is addressed in this report.

From the framework for the implementation of a regional DRMP the following detail were defined as aspects to be addressed during the Geohydrological Assessment (AGES 2010a, table 3) from the first budget allocation:

- Regional geohydrological investigation and conceptual groundwater model.
- Effect from regional groundwater abstraction (for example Stilfontein and Carletonville mining areas, nearby farming activities)
- Identification and establishment of monitoring boreholes

- Implementation of a monitoring program, related database, reporting and interactions with regulatory authorities
- Establish a grip on groundwater abstraction and ensure lowering of groundwater use in an identified area of influence
- Identification and addressing of flags (for example – schools, surface water interference points)

1.3.1 Objectives

From these terms of reference and in context with the project background as described above it follows that the objective of this project is to do a Geohydrogical Assessment of the Tlokwe Dolomites; Potchefstroom area in order to:

- define the geohydrological conditions of the area
- evaluate and quantify human interference in the geohydrological conditions of the area
- quantify the effect of the geohydrological conditions on the stability of dolomite and the application of the DRMP within the set legal and institutional framework.
- develop a groundwater monitoring system and program as part of an early warning system for the area
- define any situations that must be flagged to the city council and align related actions with the DRMP
- define future required detail geological research and application projects supportive to the DRMP.

1.3.2 Scope of work and methodology

The following scope of work and methodology were defined in order to meet the terms of reference and objectives:

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 DRMP.
    - 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 DRMP 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 (DWA, 2006) 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).
    - Baseline as was reported in Volume 1 Geo-environmental Assessment of Dolomite Land in Potchefstroom (AGES 2010b).

2 STUDY AREA

2.1 Delineation

Two areas of investigation were defined for this study: a local **focus** area that forms the basis of the main dolomite stability investigation, and a **regional** area in which the focus area is located. The reason for this is that the geohydrological character of the focus area is not independent of the surroundings, and a broader area needs to be defined in which the geohydrological character fits, and in which any groundwater activity might have an impact on the focus area specifically.

2.1.1 Defining the focus area

The focus area of the investigation is taken from the delineation of the study area as was defined during the first geo-environmental assessment done as part of the DRMP development (AGES 2010b) and includes Ikageng and areas adjacent as part of the Tlokwe urban area. The focus area is indicated in the maps as the Project Area (Figure 2-1). The boundaries were arbitrarily chosen and do not correspond to geological or hydrogeological boundaries, therefore the need for a broader delineation of an area in which the focus area can be described.

2.1.2 Defining the regional area of interest

The focus area includes the dolomite 'finger' that branches towards Potchefstroom from the main strike of an arc-shaped dolomite band that occurs between Carletonville in the northeast to Stilfontein in the southwest. This regional arc-shaped dolomite zone follows the main circular outline of the Vredefort Dome impact rim located to the southeast (Figure 2-1).

Since the geohydrological character of the dolomite within the focus area is not independent of that outside this focus area, a broader area was delineated in which the focus area geohydrology fits. It is possible that groundwater abstraction outside the focus area might have an effect on the geohydrology inside the focus area and therefore a larger area needs to be defined in which this interaction can be investigated.

For this reason the Welgegund Groundwater Management Area (GMA), as defined by Holland and Wiegmans (2009) is used as the regional area of interest (Figure 2-1). It was specifically delineated for groundwater management purposes, making it applicable to this investigation since groundwater actions that might have an effect on the focus area need to be managed. The delineation of this area within the broader scope of dolomite geohydrology in South Africa and especially in the Far West Rand (FWR) will be discussed in detail in chapter 4.

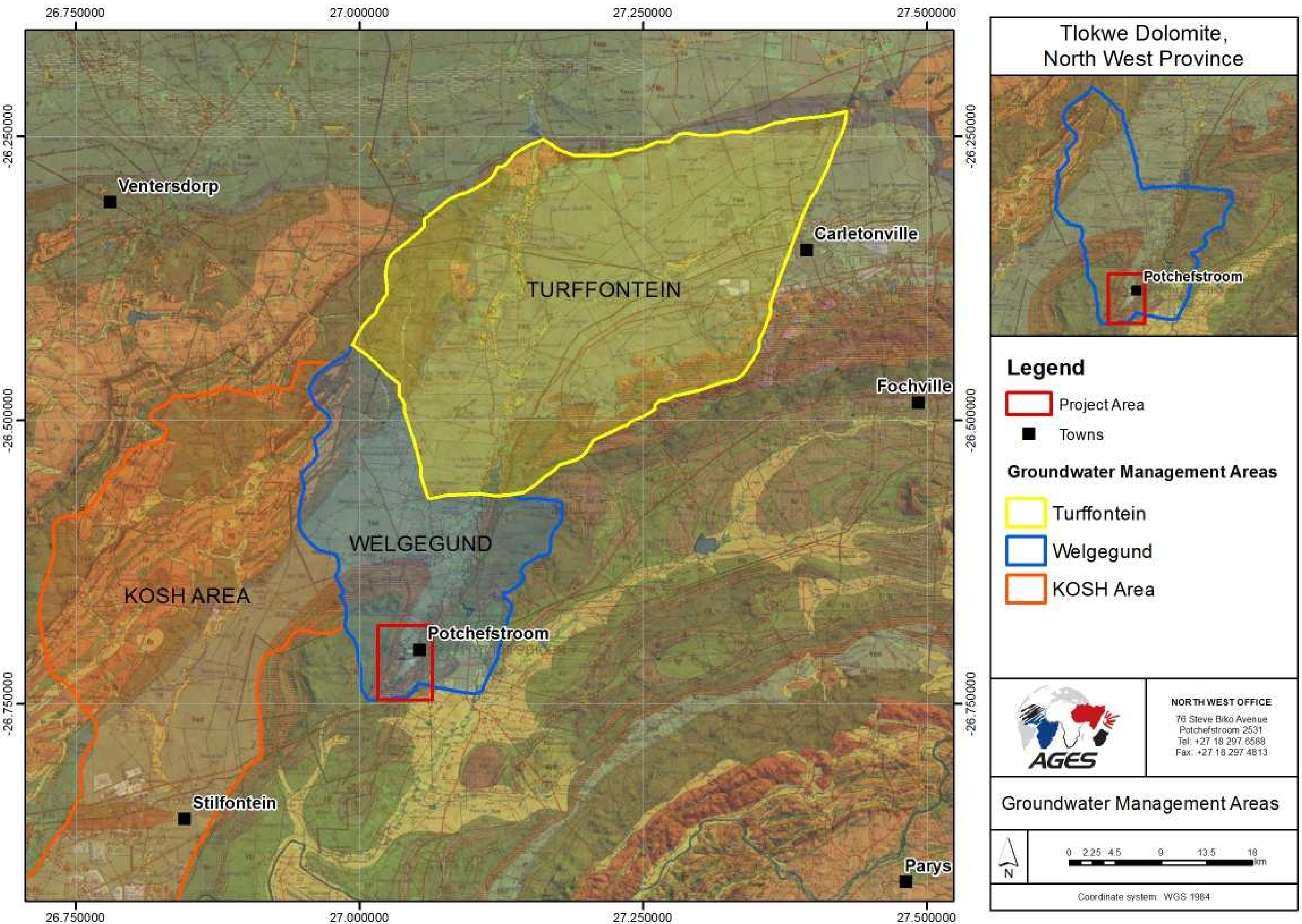

Figure 2-1: The locality of the Tlokwe focus area relative to the Welgegund GMA as regional study area

2.2 Physiographic setting

2.2.1 Topography and drainage

2.2.1.1 Regional area

In order to illustrate the topography and geomorphology of the study area, digital elevation data from SRTM have been obtained online and depicted with a colour shader in Global Mapper (v 12) to highlight the topography around the regional area (Figure 2-4). The regional area is situated at a mean elevation of 1 400 mamsl. Regionally the topography is sloping down from the north at a very flat gradient.

The topography is mainly characterised by flat areas interrupted by isolated hills and ridges. The most prominent being hills located to the west and northwest of Potchefstroom (Ikageng) and to the northeast of Potchefstroom. These hills define the water divides that form the western and eastern boundaries of the regional study area.

Regional surface water drainage is from the north through the Mooi River system. There is a non-perennial stream entering the Mooi River from the northwest just south of the Boskop Dam. Outside and to the east of the regional study area (Welgegund GMA) the Loopspruit joins the Mooi River just southeast of Potchefstroom.

2.2.1.2 Local area

Contours have been generated in Global Mapper at 20 m intervals and displayed in the same program with a different colour shader to highlight the topography in and around the focus area. In the centre of Ikageng the topography is characterised by a very prominent ridge with a peak elevation of roughly 1 465 mamsl. Towards the far south the topography flattens out, as well as eastwards towards the town of Potchefstroom where the gradient becomes slightly undulating to flat.

The main topographical feature in the western portion of the focus area is Dassierant, a very linear ridge flanking the western side of Ikageng, striking north-northeast, and dipping 50 degrees to the west.

Locally water enters the focus area from the koppies to the west and northwest. There is a prominent drainage from west to east through the centre of the focus area namely the Spitskopspruit. This river is dammed up artificially in the Poortjie Dam where it cuts through a ridge east of Promosa from where it flows eastwards between the old Kynoch gypsum tailings dam and OMV's premises (who are now responsible for the reworking of the tailings dam). The Spitskopspruit eventually joins the Mooi

River via a storm water canal through a portion of the residential area of Potchefstroom.

2.2.2 Climatic setting

2.2.2.1 Rainfall

Historical weather data were obtained from Agrimet for a mechanical weather station (Nr. 19827) at Potchefstroom Agricultural Centre for the period 1914 to 2004 when the station closed. Data from a new station (Nr. 30649) were obtained from the same source for the period 2004 to present (March 2012). The data for 98 years of continuous monitoring are presented in Figure 2-2.

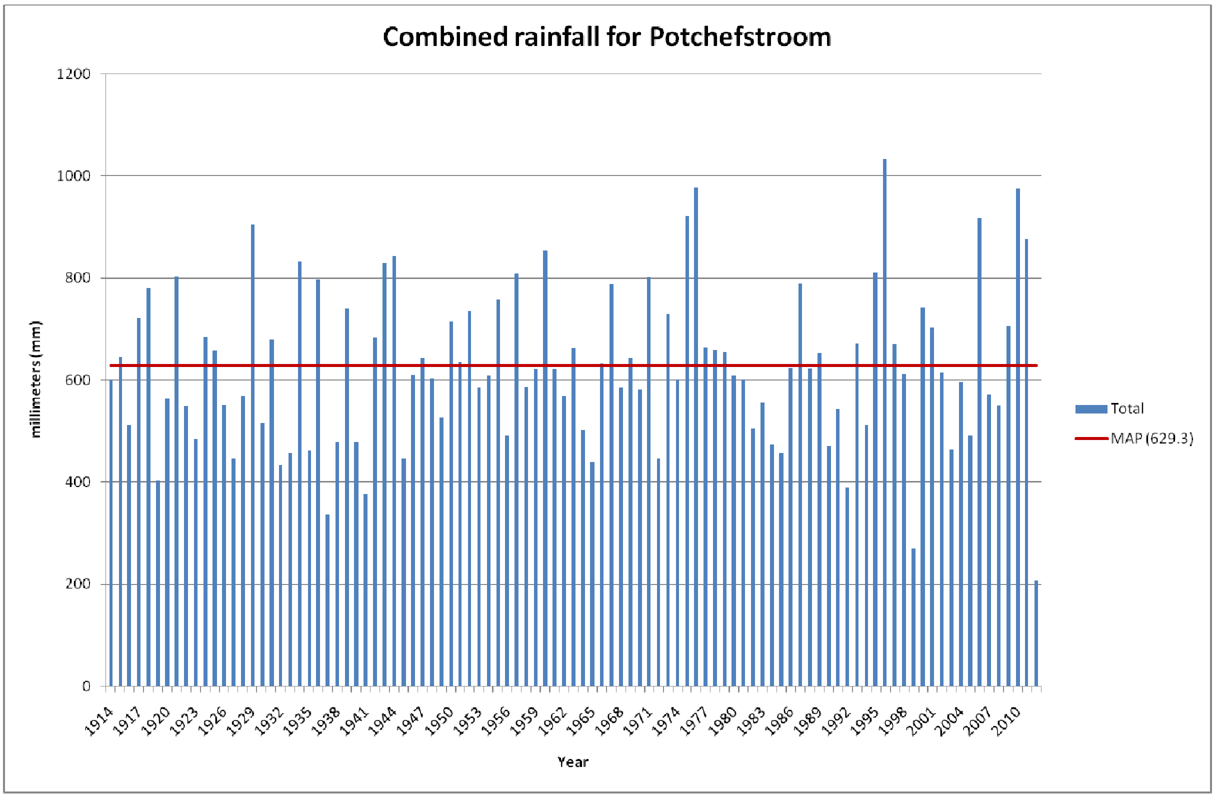

Figure 2-2: Combined rainfall data for Potchefstroom

The mean annual precipitation (MAP) for Potchefstroom is 629 mm/a. The rainfall occurs mainly during the summer months (October to March) as short, intense thundershowers. The rainfall is also highly variable, varying from a maximum annual rainfall of 1 033 mm in 1996 to a minimum of 270 mm three years later.

2.2.2.2 Temperatures

The temperature data over the same 98 year period have also been obtained. The average monthly minimum and maximum temperatures have been calculated over the entire period and graphically displayed in Figure 2-3. From this figure it can be seen that the winter months (roughly April to September) have significantly lower minimum temperatures, frequently dropping below 0 C. The maximum temperatures are cool to mild during this time period, compared to the warm to hot maximum temperatures of the summer months. Although the average maximum temperatures during summer are below 30 C, it frequently exceeds this threshold on individual days. Minimum temperatures during the summer months average around 13-15 C.

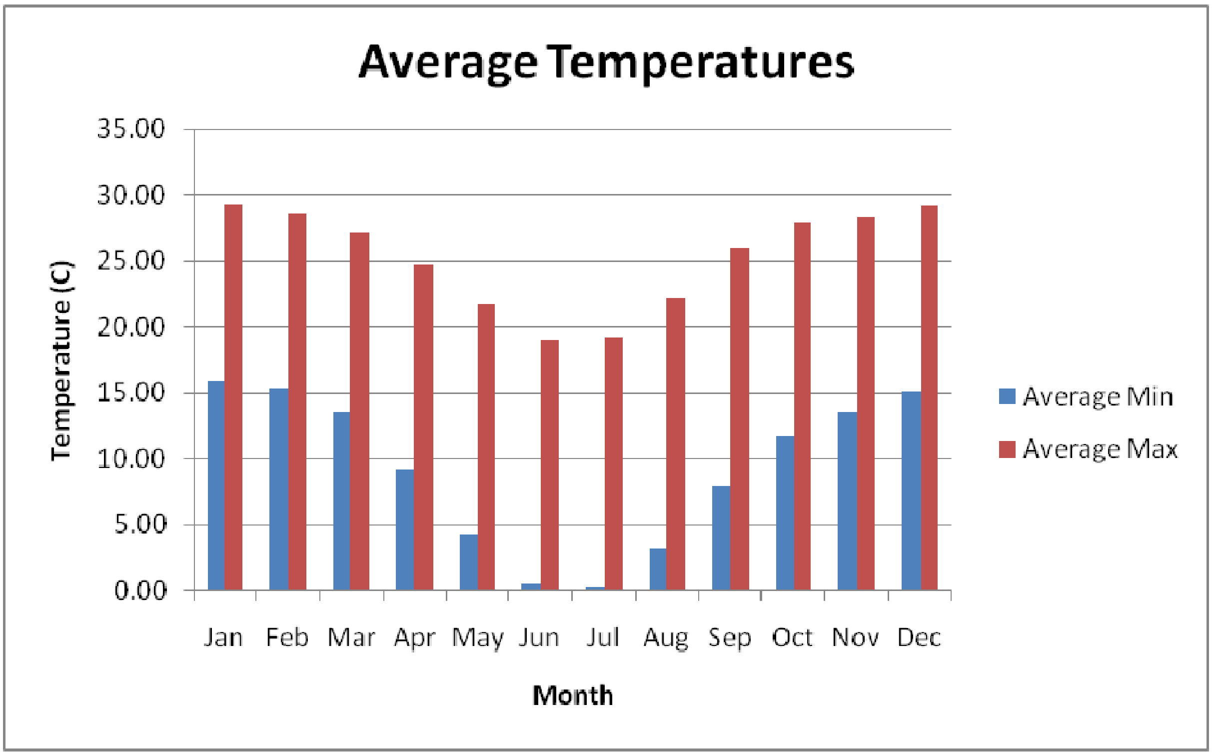

Figure 2-3: Average temperatures over Potchefstroom

2.2.3 Demographic setting

According to 2011 demographic data obtained from DWA, greater Ikageng (including Lusaka and Sarafina areas) currently has around 74 000 residents. The townships of Mohadin and Promosa have 1,300 and 11 600 respectively. The city of Potchef-stroom itself is home to some 34 800 people (see Figure 2-7).

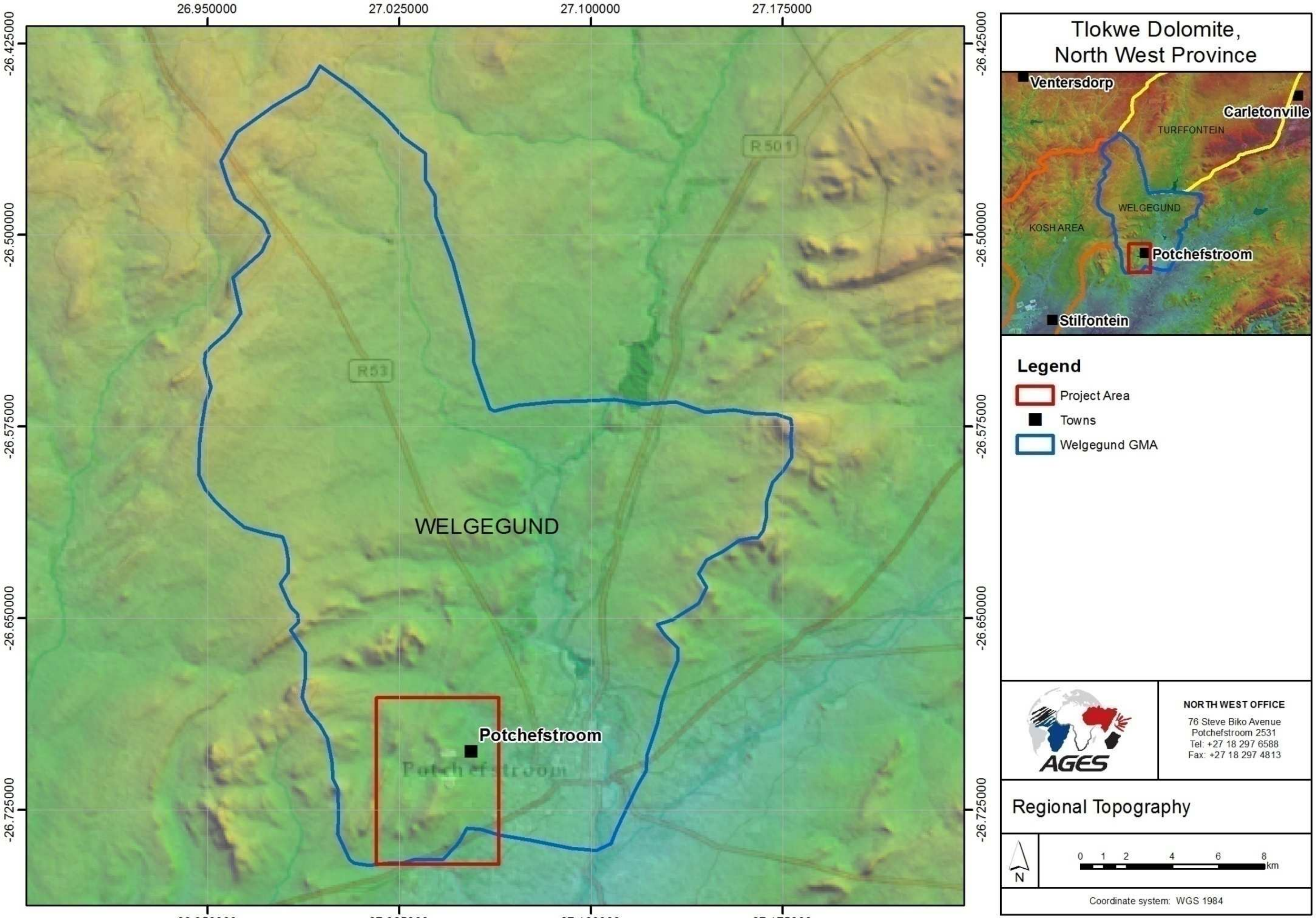

Figure 2-4: Topography and drainage of the regional study area

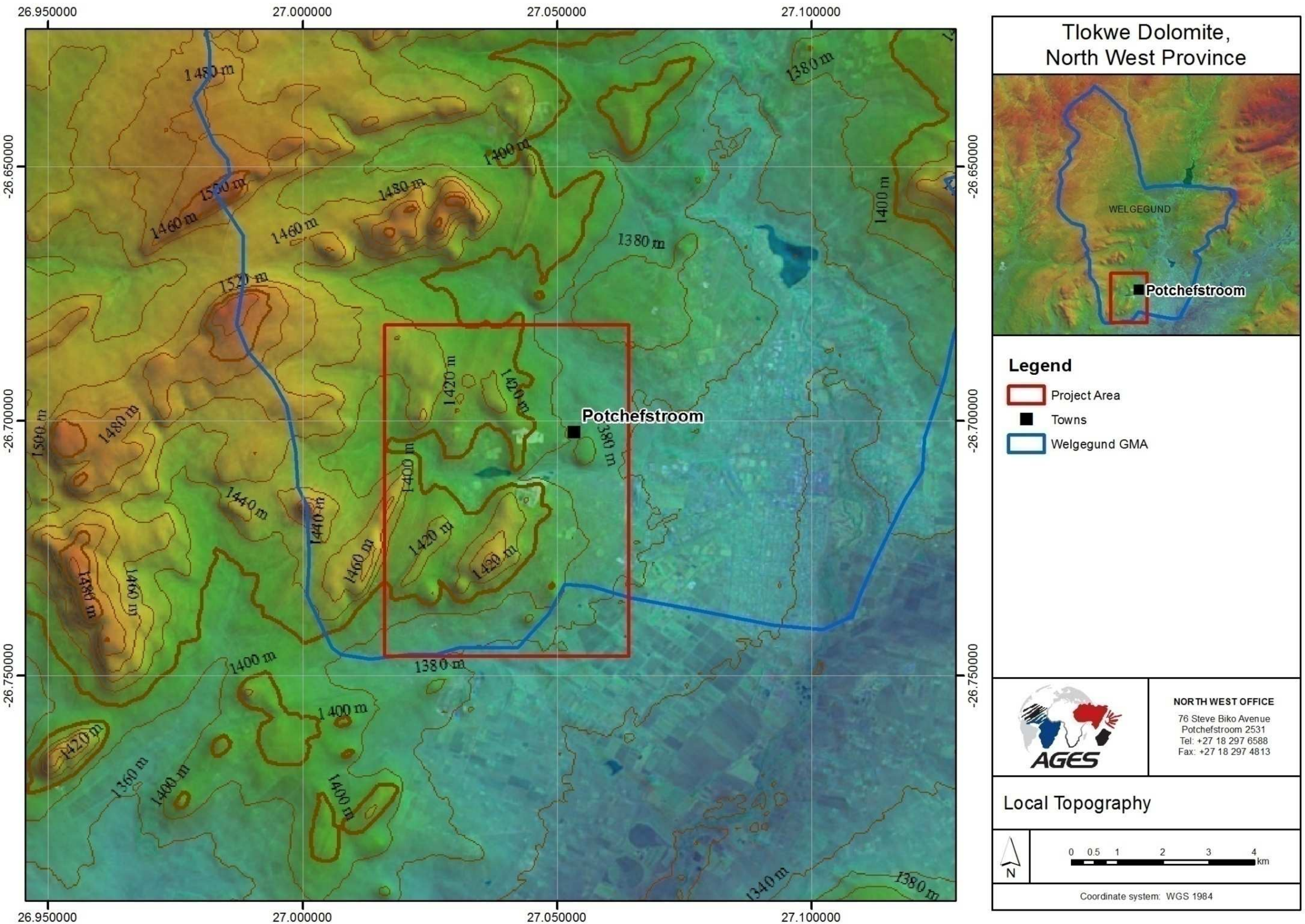

Figure 2-5: Topography of the study area. 20m contour intervals generated from SRTM data.

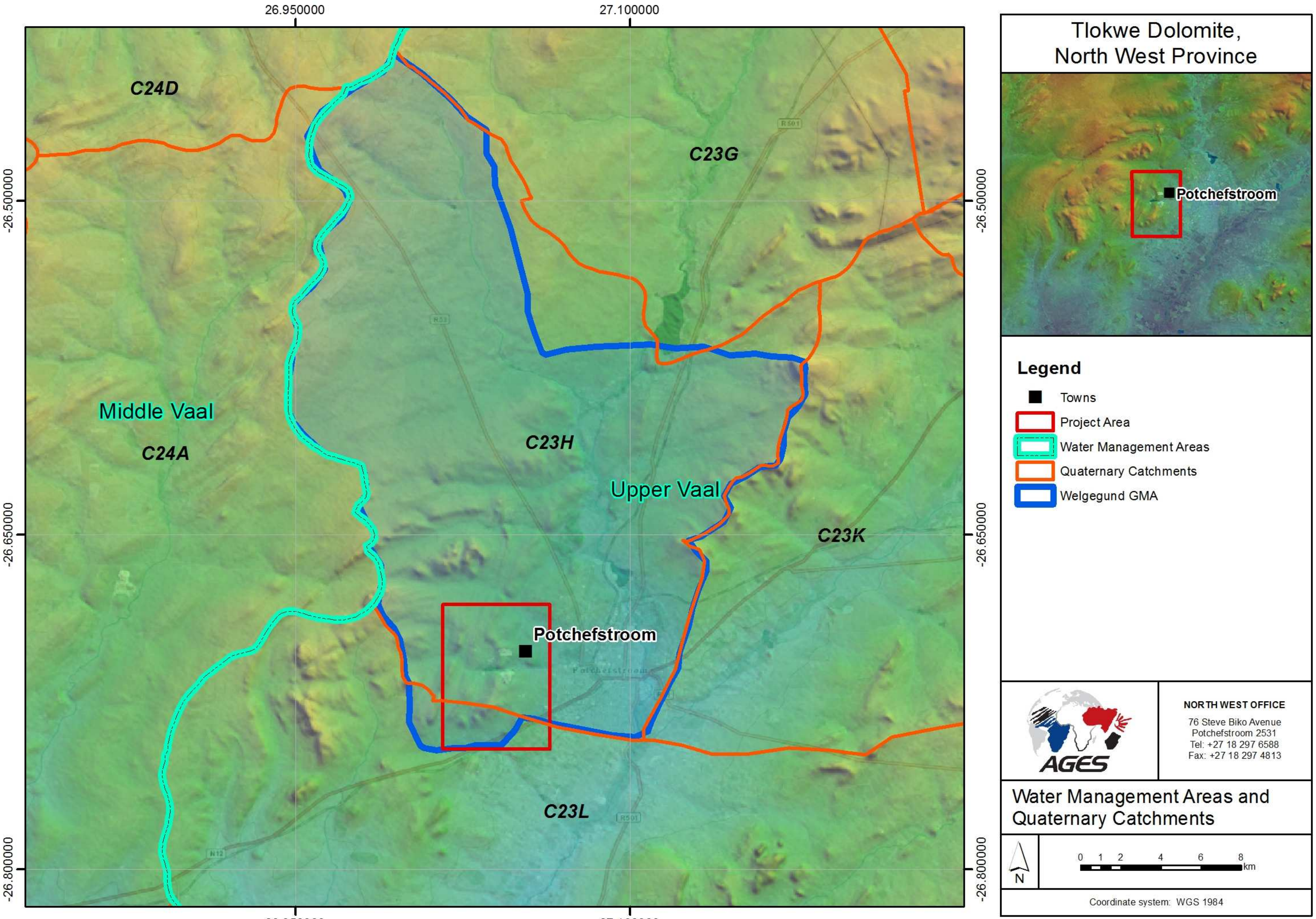

Figure 2-6: Quaternary catchments intersecting the focus area.

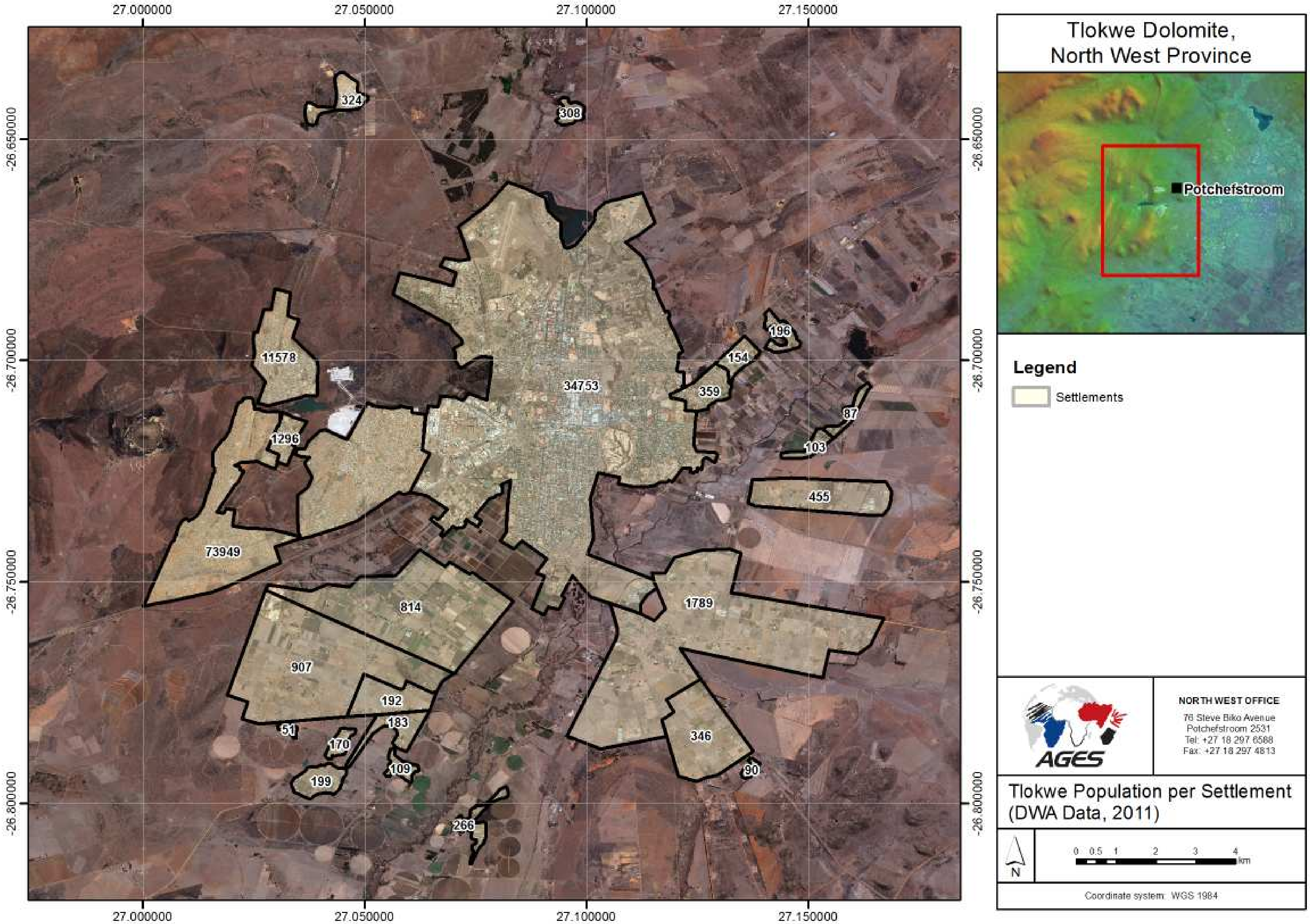

Figure 2-7: Population figures in and around the study area

3 GEOLOGY

3.1 Introduction

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 chapter 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 for risk zoning in the area.

The geology of the study area, with the focus on dolomite land, must be seen within the regional context of the stratigraphy, and as influenced by regional structures related to geological events such as the greater Vredefort Dome impact event. This will briefly be discussed for both the regional and the focus areas. The geology of the area is discussed in detail in AGES (2010b).

3.2 Stratigraphy

The arc-shaped dolomite outcrop referred to earlier forms part of the Potchefstroom Syncline which is centred on the Vredefort Dome impact structure (Figure 2-1). It consists of sedimentary rocks from the Transvaal Supergroup which directly overlies the Ventersdorp Supergroup (mainly lavas). The Witwatersrand Supergroup sedimentary rocks, containing the gold-bearing conglomerate (or reefs), occur below the Ventersdorp Supergroup. The famous Ventersdorp Contact Reef (VCR) is a thin but highly profitable gold bearing conglomerate layer directly below the Ventersdorp lavas.

The base of the Transvaal Supergroup consists of the Black Reef Formation comprising relatively mature quartz arenites, lesser conglomerates and subordinate mudrocks. This is overlain by the Chuniespoort Group which is subdivided into the Malmani Subgroup, followed by the Penge Formation and the Deutschland Formation.

The extensive succession of dolomite belongs to the Malmani Subgroup, and is often informally referred to as the Malmani Dolomites (Figure 3-1). The dolomite can be further divided into the **Oaktree Formation** (overlying the Black Reef Formation), a unit transitional from siliciclastic sediments to platform carbonates. It consists of between 10 and 200 m of carbonaceous shales, stromatolitic dolomites and locally developed quartzites.

	Formation	Lithologies
Malmani Subgroup	Frisco Fm	Stromatolitic dolomites, more shale upwards
	Eccles Fm	Erosion breccias and cherty dolomite
	Lyttelton Fm	Shale, quartzite and stromatolitic dolomite
	Monte Cristo Fm	Stromatolitic and oolitic platform carbonates
		Erosive breccias
	Oaktree Fm	Siliciclastic to platform carbonate rocks
Black Reef Fm		Mainly clastic sedimentary rocks

Figure 3-1: Schematic representation of the Malmani Subgroup lithologies

Overlying this formation is the **Monte Christo Formation**, between 300 and 500 m thick and beginning with erosive breccias followed by stromatolitic and oolitic platform dolomites. This is overlain by the **Lyttelton Formation**, between 100 and 200 m thick and comprising shale, quartzite and stromatolitic dolomite. The overlying **Eccles Formation** can be up to 600 m thick and includes a series of erosion breccias between cherty dolomites. The **Frisco Formation** (>400 m) overlies one of the breccia units and mainly comprises stromatolitic dolomites, containing more shale towards the top. On the geological map the different dolomite formations are well defined in the area to the north of the anticline defined by the Black Reef outcrop between Krugersdorp and Ventersdorp. South of the anticline, in the Potchefstroom syncline the dolomite is grouped into the Malmani Group (Eriksson et.al, 2006).

Regionally the Malmani dolomite from the Chuniespoort Group is overlain by 6-7 km of Pretoria Group rocks. The Pretoria Group consists of mudrocks, quartzitic sandstones, and significant interbedded basaltic-andesitic lava, conglomerate, diamictite and carbonate rocks. In the southern section of the Transvaal basin the stratigraphy of the Pretoria group is as follows:

The basal Rooihoogte Formation consists mainly of breccia. It is overlain by the Bushy Bend Lava Member of the Timeball Hill Formation that otherwise consists of mudrocks and subordinate quartzite layers interbedded. The overlying Boshoek Formation is between 30 and 60m thick and comprises sandstone, conglomerate and localised diamictite. The Hekpoort Formation overlying the Boshoek consists of basaltic andesite containing significant tuff. The Dwaalheuwel Formation overlies the Hekpoort in the rest of the Transvaal basin, but is absent in the southern area. The Hekpoort is therefore overlain by the Strubenkop Formation in this area, consisting of mudrock and subordinate sandstone (Eriksson et.al, 2006). For a detailed geological map of the area see Figure 3-2

The regional dolomite outcrop towards Carletonville and Westonaria was host to thousands of sinkholes that formed once the dolomite aquifers were dewatered to allow mining of the gold bearing conglomerates underlying the dolomite. The strong link between groundwater and sinkhole formation was then realised. (This link between groundwater in carbonate (karst) geology and sinkhole formation is described in detail in Appendix A: Karst geology).

3.2.1 Regional Area

The bulk of the central portion of the Welgegund GMA is underlain by dolomite. To the northwest, the dolomite is bounded by an outcrop of the underlying Black Reef Formation, striking southwest-wards. Further west of the Black Reef, rocks from the underlying Ventersdorp Supergroup are exposed.

The dolomite finger branching off towards Potchefstroom is separated from the main dolomite arch by outcrops of overlying Timeball Hill Formation (inter-layered quartzite and shale), Boshoek and Hekpoort Formations. It is unknown to what extent the dolomite from the finger is still connected to the main arc-shaped outcrop at depth.

The eastern edge of the dolomite outcrop is defined by the same overlying sequence of Timeball Hill, Boshoek and Hekpoort Formations. The contact is indicated on the regional geological map as being an overthrust fault from the southeast (Vredefort Dome).

Towards the far southeast, the flatlying area is indicated to be overlain by quaternary sediments associated with the Mooi and Loopspruit Rivers.

3.2.2 Focus Area

Structurally the focus area is relatively complex, making it difficult to conceptualise the geohydrological model of the various aquifers and their extent. The dolomite finger extends through the central part of the focus area from the north, and splits into two smaller fingers in the far south of the focus area. This smaller split mimics the larger split-off of the dolomite finger from the main arc-shaped dolomite outcrop north of Potchefstroom.

There is a strong northeast-wards strike in the strata in the western portion of the focus area, with Dassierand forming the most prominent linear ridge. This is composed of Timeball Hill Formation quartzite. Towards the central portion of the focus area, this strong linear trend is gradually exchanged for more localised hills formed by dolomite and chert, although the strike of the outcrops still resemble this general trend. Towards the far east of the focus area, the area is underlain by shale (Timeball Hill) and diabase forming flat topography.

In general the topography can be correlated to structural displacements, although this is not always clear. For instance the eastern contact between the dolomite and shale occurs underneath flat topography.

The focus area has also been covered by various geotechnical drilling projects and geological mapping by various institutions, including AGES, over the past two decades. The data have been collated to provide more detail in the focus area.

The mentioned data points are depicted on the local geology as interpreted by Bisschoff (1992) in Figure 3-4.

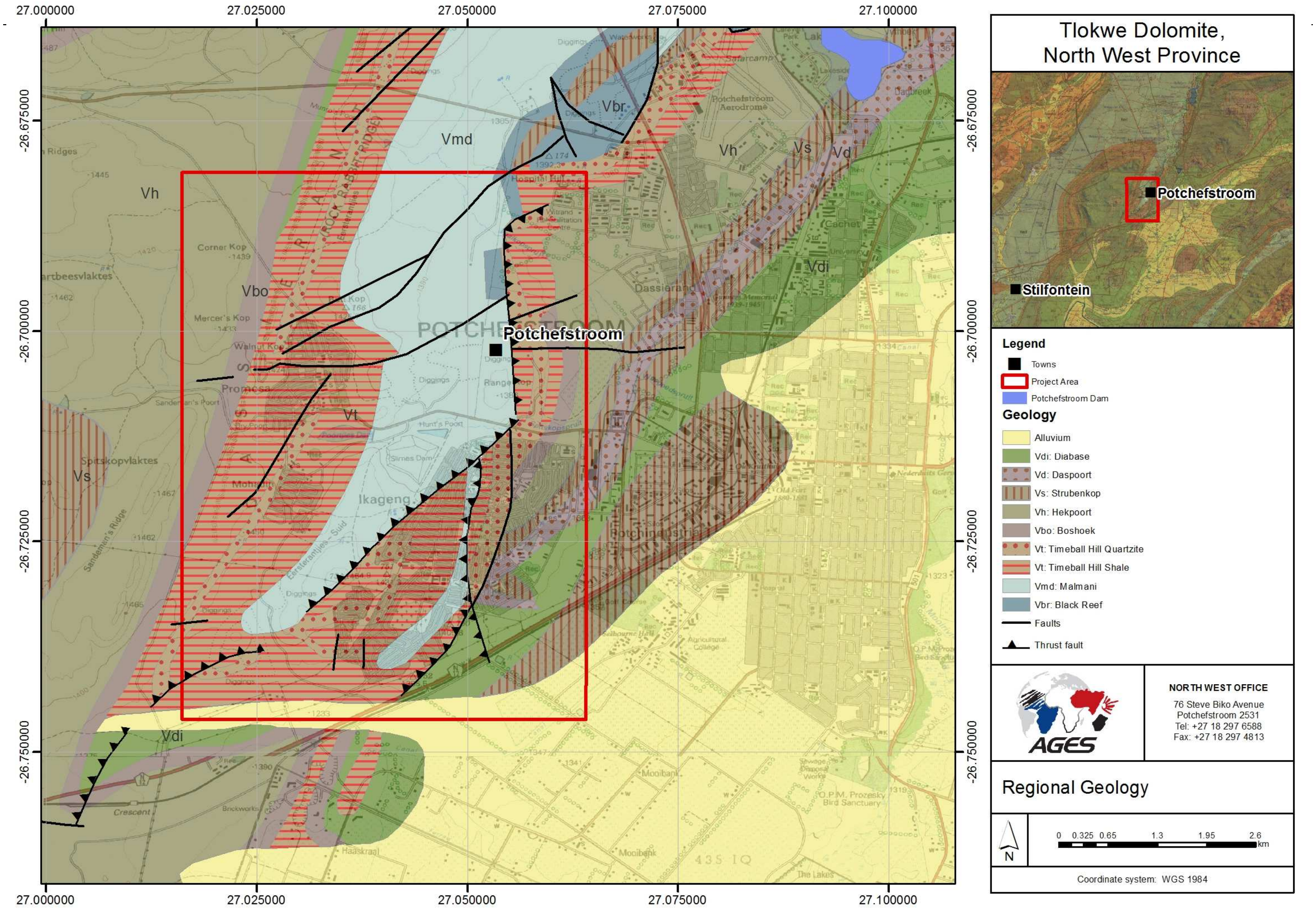

Figure 3-2: Geology of the area according to the 2626 Johannesburg geological map

3.3 Structural geology

On a more regional scale, 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, oölites and quartz-fibre lineations (Obbes, 2000). The deformation as evident in the Transvaal Supergroup is associated with major regional geological events including the Bushveld Intrusion (Trustwell, 1970) and the Vredefort Impact event (Brink *et al*., 2005).

In order to evaluate the geological results and to do a final spatial assessment of risk, the structural geology from the existing maps was re-evaluated and a map compiled to reflect an updated integrated interpretation thereof in context with a baseline aerial photo interpretation. In addition the linear structures within the study area were identified by means of a structural aerial photo interpretation according to the methodology described by Lattman and Ray (1965). The structures as presented in Figure 3-3 are important as they indicate heterogeneity 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).

It is evident from Figure 3-3 that there are two sets of fault zones in the area. They strike east-west and north-south. Some of the fault zones are intruded by diabase dykes. The fault zones form permeable fractures that act as conduits for groundwater flow. The dykes are expected to be impermeable and compartmentalise the dolomite while the dyke-contact zones are permeable and fractured.

The Spitskopspruit is expected to follow an east-west fault zone that cuts through the Malmani Dolomite and the Pretroria Group fractured rocks and displaced the contact towards the east.

A north-south trending lineament, which is interpreted as a dyke, forms springs in the area north of the Spitskopspruit (GeoCon, 2003).

Aerial photographs used in this interpretation:

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

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 3-3).

3.4 Final Geology and Risk Zone Map

All of the geological and geotechnical data and information were re-interpreted to compile a final geological map for the purpose of defining zones of higher and lower risk in terms of ground subsidence and sinkhole formation associated with spatial development and land use in Ikageng. The process followed and description of the Risk Zones is detailed in AGES (2010b).

This information included geological maps, mapping and the drilling results of 127 boreholes as part of 29 identified geotechnical investigations. A gap analysis led to the drilling of 32 additional boreholes.

The zones are divided between Indicated Risk Zones (high, medium or low) based on the preliminary indication of geology at depth, or Measured Risk Zones (high, medium or low) based on the actual confirmation of the geology at depth (dolomitic vs non-dolomitic). The zones are in the process of being refined from Indicated to Measured as more confidence is achieved by field confirmation through drilling.

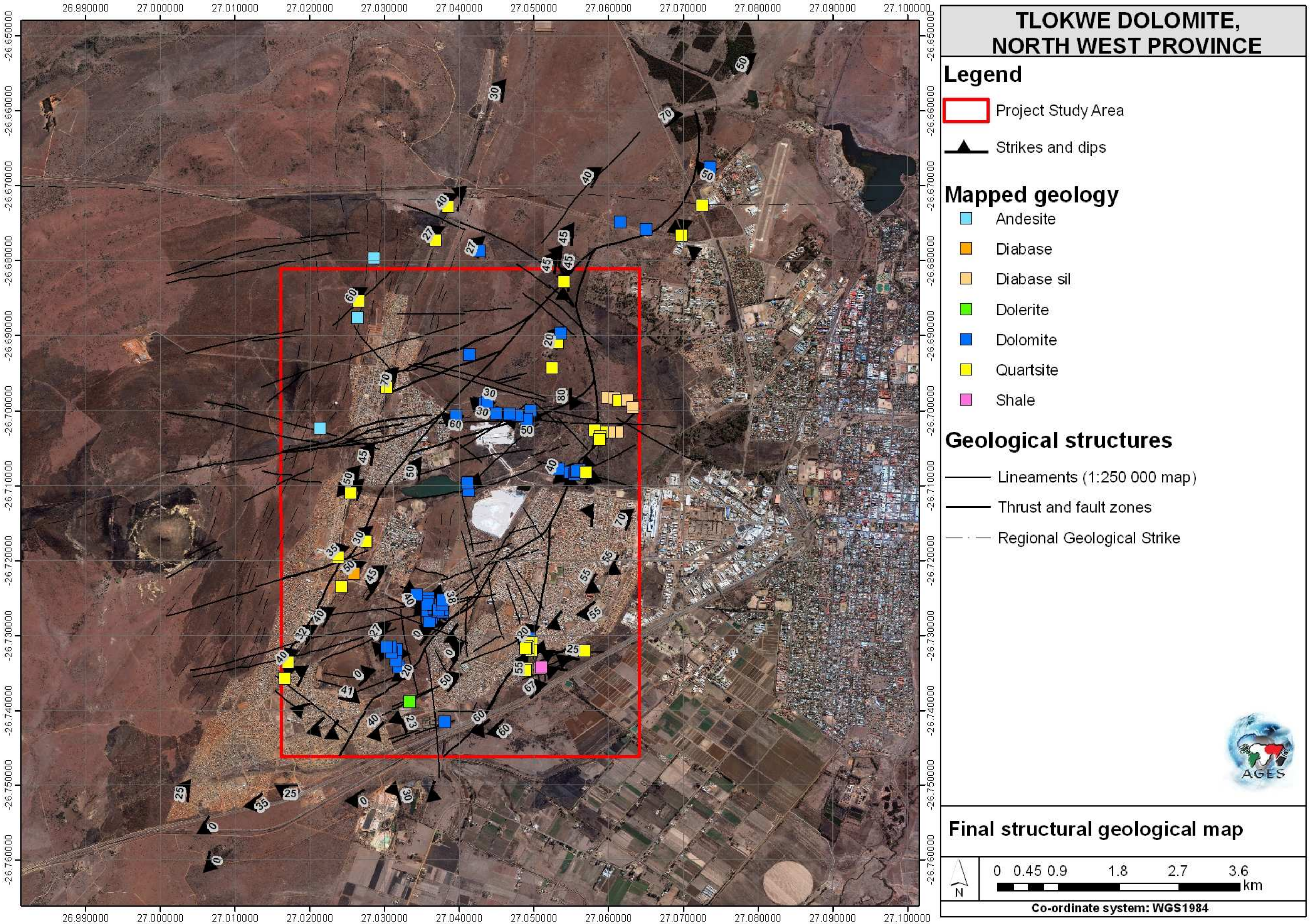

Figure 3-3: Structural map of the study area

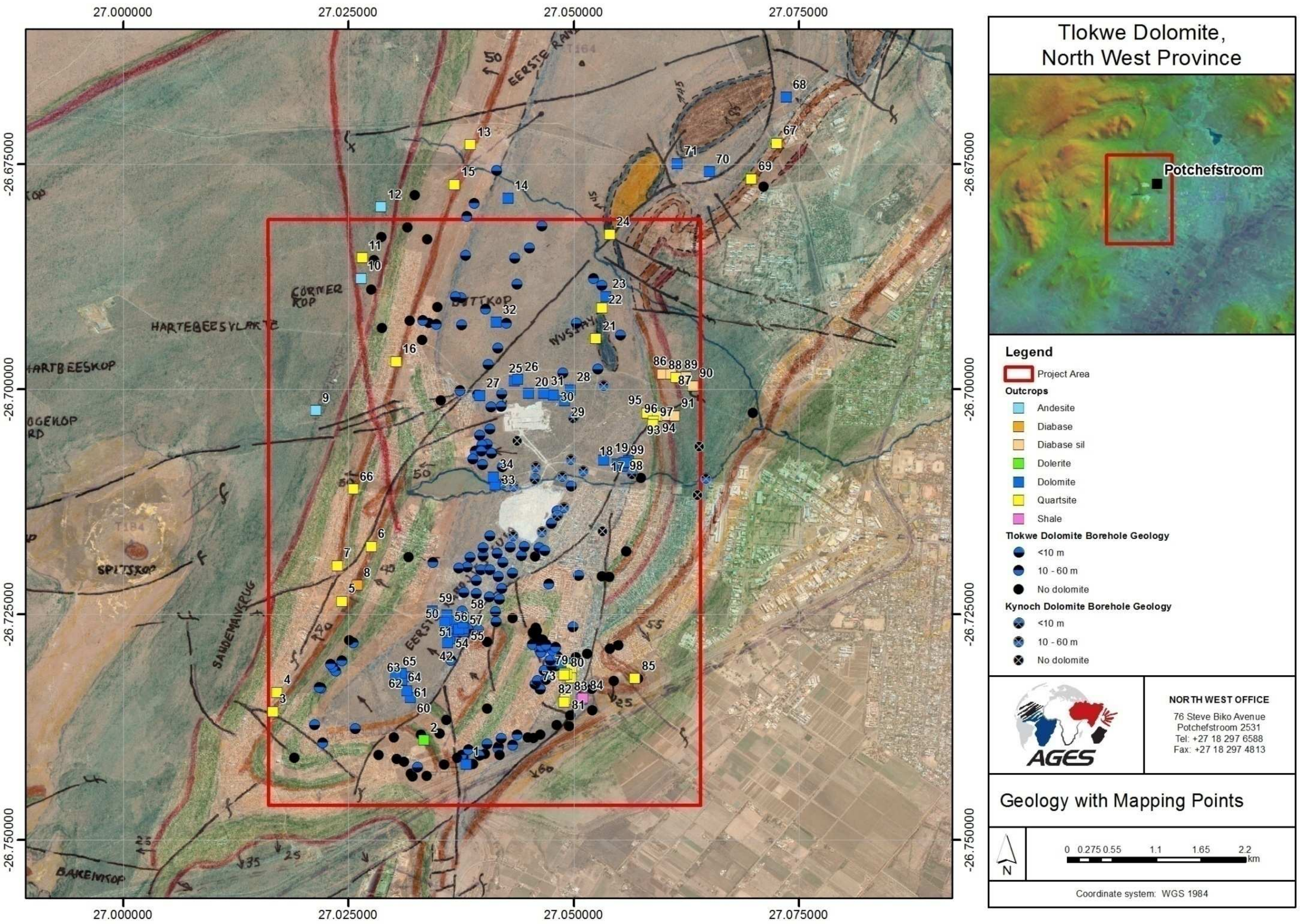

Figure 3-4: Initial local geology map (Bisschoff, 1992) with new data points

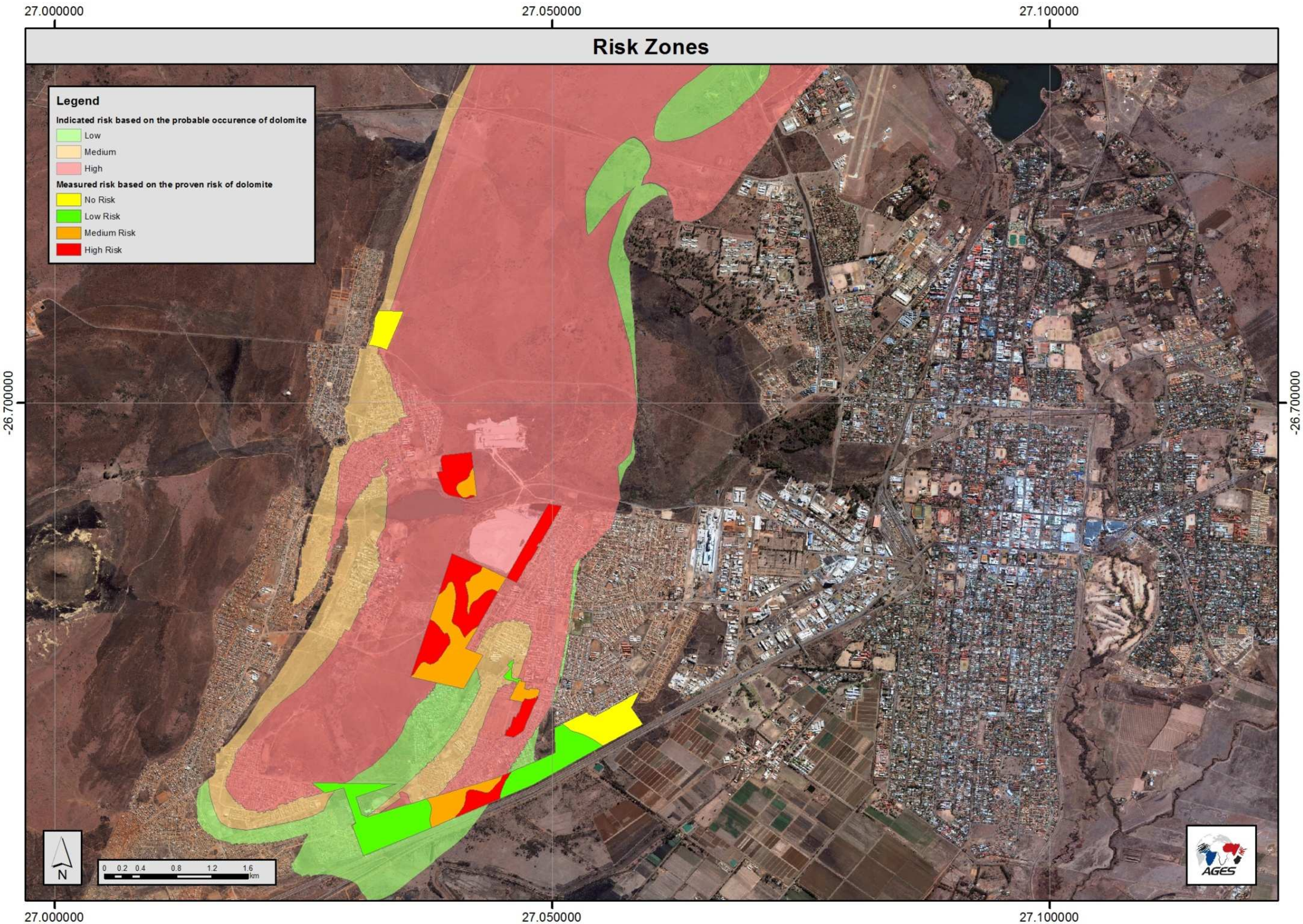

Figure 3-5: Geological Risk Zone Map (AGES, 2010b)

4 GEOHYDROLOGY

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 ($CaMg(CaCO_3)_2$), 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.

4.1 Hydrogeological boundaries

Since the focus area boundaries were chosen arbitrarily and do not correspond with any hydrogeological boundaries, the hydrogeology of the focus area is not independent of the regional hydrogeological character.

As mentioned, the regional area of investigation is defined by the Welgegund GMA. The reasoning behind the decision to use this delineation as the regional study area will be discussed in detail:

4.1.1 Dolomite compartments

Underground dolomite cavities are interlinked via tunnels, cracks and fissures of various sizes. This creates the high groundwater potential associated with dolomitic aquifers. The nature of the interlinked underground voids in dolomite has the effect that the countless smaller voids are now connected to form one bigger reservoir of groundwater. Currently it is estimated that the dolomite in the FWR gold mining region has a water storage capacity exceeding the full storage capacity of the Vaal Dam several times (Winde, 2010a).

After the regional dolomite succession was deposited, several impermeable syenite and dolerite dykes intruded vertically into the sedimentary sequence of rocks, compartmentalising the voids into several individual ‘compartments’ that are now hydraulically separated from each other. The only hydraulic interaction between two adjacent compartments would be through small cracks in the otherwise impermeable dyke (i.e. faults, joints) or on surface where surface water flows from one compartment to the next via streams and rivers.

New work published by DWA in 2009 defined new regional dolomite compartments and groundwater units based on geohydrological characteristics (Holland and Wiegmans, 2009). The dolomite compartments have been categorised as smaller Groundwater Resource Units (GRU) that form part of bigger Groundwater Management Units (GMU) which are areas of a catchment that require consistent management actions to maintain a desired level of use or protection of groundwater.

These GMU’s ultimately form part of bigger Groundwater Management Areas (GMA) that generally coincide with surface drainage boundaries (e.g. quaternary catchments) and are not limited to the extent of the dolomite outcrops. The difference between the three divisions is described below (Holland and Wiegmans, 2009):

- Groundwater Resource Unit (GRU): A groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit.
- Groundwater Management Unit (GMU): The GMU’s are based on surface water drainage and hydrogeological considerations, each of which represents a hydrogeologically homogeneous zone wherein boreholes tapping the shallow groundwater system will be in hydraulic connection to some degree. In dolomite this can be seen as true ‘compartments’.
- Groundwater Management Area (GMA): Does not necessarily represent a dolomite compartment or unit but consists of larger areas comprising a number of GMU’s and GRU’s and is delineated solely for managerial purposes.

The dolomite compartment south of the Boskop dam was previously interpreted as forming part of the Boskop-Turffontein Compartment (or BTC) (see Barnard, 2000). This compartment has been subdivided by Holland and Wiegmans (2009) into the Turffontein Compartment north of the Boskop Dam, and an unnamed compartment south of the Boskop Dam that are being separated by two intersecting dykes south and west of Boskop Dam. The western boundary of the Welgegund GMA is located on a water divide between quaternary catchments C23H to the east and C24A to the west. This water divide coincidentally also forms the boundary between the Upper and Lower Vaal Water Management Areas (WMA's).

The dolomite forming the basis of the classification exercise, is indicated to cross this divide into the adjacent GMA, called the KOSH Area GMA (named after the Klerksdorp – Orkney – Stilfontein – Hartbeesfontein area) (Holland and Wiegmans, 2009). It is assumed that the dolomitic groundwater unit crossing this divide still forms part of the same homogeneous system of dolomites, and technically is not compartmentalised at this boundary.

However according to the definition of the GMU the dolomitic groundwater unit inside the Welgegund GMA can be regarded as a separate entity. It is not indicated on the map by Holland and Wiegmans (2009) as a GMU, but for the purpose of this study it will be named the Welgegund GMU since it is located within the larger Welgegund GMA (Figure 4-1).

It is therefore clear from the map that the focus area lies within the Welgegund GMU inside the Welgegund GMA (within the Upper Vaal WMA) and is separate from the Turffontein Compartment north of Boskop Dam.

It is also possible that the dolomite finger might be compartmentalised by intrusive dykes that are not yet identified, and form smaller GRU's inside the Welgegund GMU.

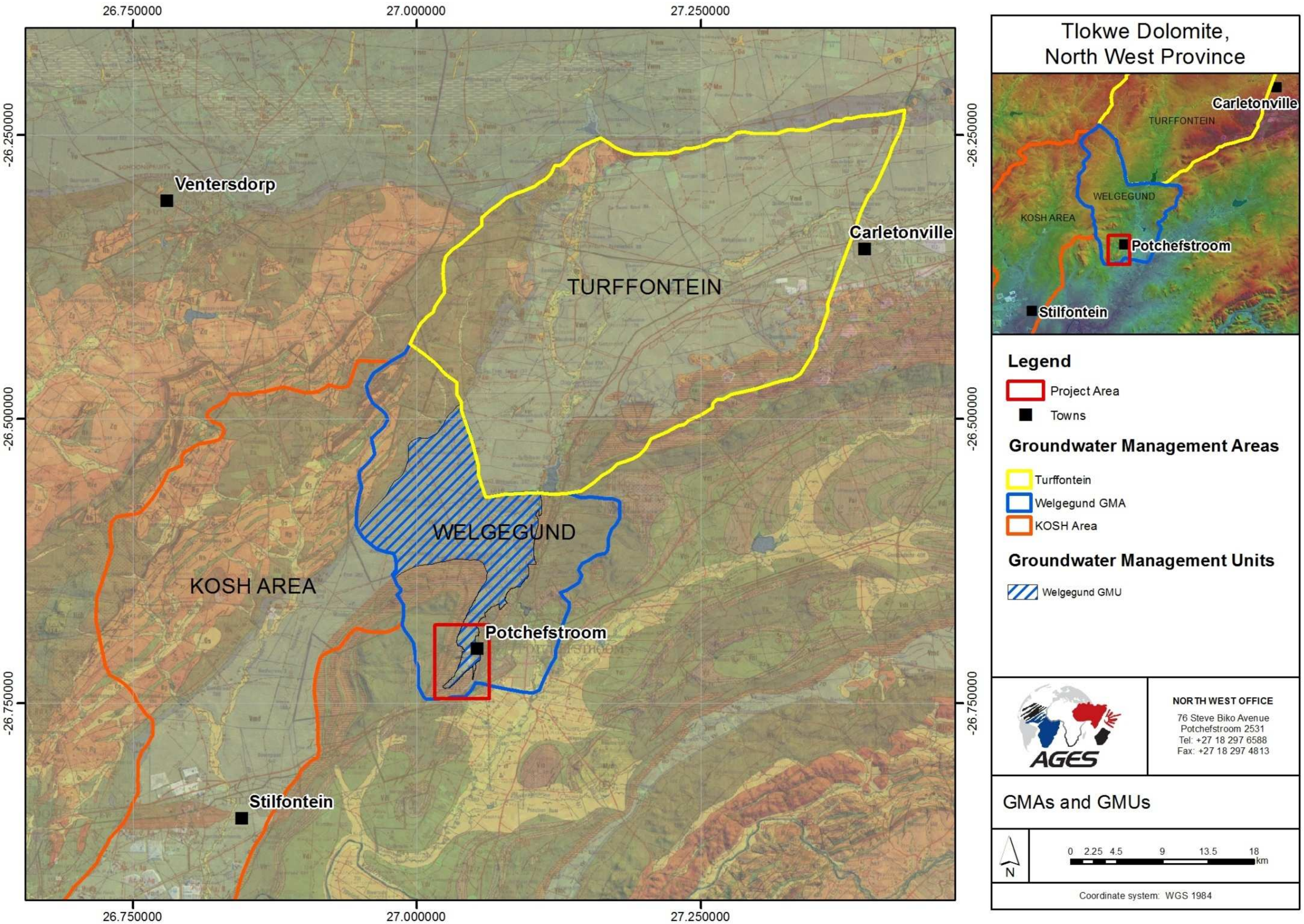

Figure 4-1: Relationship between the focus area and the Welgegund GMA and GMU (from Holland and Wiegmans, 2009)

The Welgegund GMA was therefore chosen as the regional area of investigation based on the following:

- It is assumed to form an independent groundwater unit, bounded by either impermeable dykes or water divides that act as hydrological boundaries, even though different (but interdependent) aquifers with different local characteristics are identified within this area (see next section).
- It is defined as a groundwater management area, in which the responsible authorities can exercise management rights pertaining to any groundwater activities that might have a negative impact on the dolomitic aquifer underlying the focus area.

4.2 Aquifer description

According to the hydrogeological map series of South Africa, three aquifer types can be distinguished in the study area. These three aquifer types are related to the degrees of porosity as will be discussed here:

Porosity	Origin (from Ford and Williams, 2007)	Aquifer Type
Primary	The spaces left between grains during and after deposition of sediments	Intergranular Type
Secondary	After sediments solidified to form rock, primary porosity reduces to a degree, but fractures in the hard rock creates new secondary porosity	Fractured Type
Tertiary	Especially in carbonate sedimentary rocks like dolomite, the rock is dissolved as acidic water infiltrates along fractures. This dissolution process causes tertiary porosity	Karst Type

Although no primary Intergranular Type aquifers are indicated in the study area, this type of aquifer exists in combination with Fractured Type aquifers where unconsolidated weathered rock material overlie solid (but fractured) bedrock, or in limited extent along the banks of the Mooi River where unconsolidated fluvial sediments occur. For this reason, the majority of non-dolomitic bedrock is indicated to host Intergranular and Fractured Type aquifers.

Where dolomite is mapped, the groundwater is indicated to occur in tertiary porosity forming Karst Type aquifers. The term ‘karst’ is used to describe landscapes characterised by caves and extensive underground water systems that developed especially in (soluble) carbonate rock types such as limestone and dolomite (Ford and Williams, 2007).

The hydraulic properties vary greatly for these two aquifer types due to the nature of the rock matrix. Since water occurs within dissolution cavities or 'karsts' within the otherwise impermeable dolomite, it can have significant groundwater potential (depending on the size and extent of the karsts) with increased transmissivity and storativity values.

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

4.3 Aquifer classification

4.3.1 Karst Type Aquifer

According to the Internal Strategic Perspective (ISP) of the Upper Vaal Water Management Area (WMA), the large dolomitic aquifers in the north-western section of the WMA play a very significant role with regard to total groundwater resources in the WMA. Much of the water in the Mooi River originates as spring flow from dolomite compartments (DWAF, 2004). On a local scale this is also true as can be seen by the springs identified in the area.

The boreholes on the dolomite can have yields in excess of 20 L/s and according to Geocon (2001) the dolomitic aquifers can have significant economical value and needs to be protected from overexploitation and pollution. The quality of the dolomitic groundwater is generally of a very high standard (DWAF, 2004), apart from local areas where groundwater pollution occurs (AGES, 2005a), and therefore the Karst Type aquifer can be classified as a **Major Aquifer** according to the aquifer classification system proposed by Parsons (1995).

4.3.2 Intergranular and Fractured Type Aquifer

Boreholes on the fractured clastic rock have average yields of between 1 and 2 L/s (AGES, 2005a). Higher yields of up to 5.0 L/s can be achieved on fractured rock aquifers depending on the nature of fracturing intersected, but these are exceptions rather than the norm.

Groundwater quality in the area is variable. The Inter-granular and Fractured Type aquifer can be classified as a **Minor Aquifer** (Table 4-1).

4.3.3 Other

Technically a third aquifer can be defined in the area. Due to the water retention properties of gypsum, the KGTD of roughly 25 ha in the centre of the focus area can be regarded as a **perched aquifer** overlying the major dolomite aquifer. The KGTD was a product of the Kynoch Fertiliser Factory in the Industrial area of Potchefstroom, but has been decommissioned from 2006, after which the dam was acquired by Oranje Mynbou Vervoer (OMV) for further processing of the gypsum. This aquifer can be classified as a **Non Aquifer**.

Due to the good municipal water supply infrastructure in the greater Potchefstroom residential area, no aquifers are classified as **Sole Source Aquifers**.

Table 4-1: Aquifer Classification Scheme after Parsons (1995) and DWAF (1998b)

Aquifer System	Defined by Parsons (1995)	Defined by DWAF Min Requirements (1998b)
Sole Source Aquifer	An aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.	An aquifer, which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major Aquifer	High permeable formations usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (<150 mS/m).	High yielding aquifer (5-20 L/s) of acceptable water quality.
Minor Aquifer	These can be fractured or potentially fractured rocks, which do not have a high primary permeability or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying baseflow for rivers.	Moderately yielding aquifer (1-5 L/s) of acceptable quality or high yielding aquifer (5-20 L/s) of poor quality water.
Non-Aquifer	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and need to be considered when assessing the risk associated with persistent pollutants.	Insignificantly yielding aquifer (< 1 L/s) of good quality water or moderately yielding aquifer (1-5 L/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special Aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	An aquifer designated as such by the Minister of Water Affairs, after due process.

4.4 Water use

4.4.1 Regional area

No mine dewatering occurs in the Welgegund GMA. The neighbouring Turffontein compartment is also not dewatered, but the effect of the mine dewatering of the compartments neighbouring the Turffontein compartment further to the east (Venterspost, Bank and Oberholzer compartments) can be seen in the flow of the Gerhard Minnebron Spring eye. The flow decreased drastically from ~25 Mm^3/a to an average of ~5 Mm^3/a since the early 1960's when mine dewatering commenced (Holland and Wiegmans, 2009). The Bank and Oberholzer eyes ceased flowing in 1959 when dewatering started (Winde and Stoch, 2010).

There are no current mining plans for gold mining within the Welgegund Compartment in the area underlying and north of Potchefstroom, although current localised prospecting projects are underway within the greater Potchefstroom Goldfield. Wits Gold has secured prospecting rights for precious minerals in the Potchefstroom Goldfield that stretches south-westwards from current mining operations west of Carletonville towards Potchefstroom.

The Potchefstroom Goldfields are divided into smaller prospecting projects, with the largest gold resources believed to be located in the Potch Deeps Project area, which is a 160 km^2 area located directly to the north of Potchefstroom. The gold resources are located at depths ranging from 3 000 to 5 000 mbgl but no immediate prospecting is planned for this project area. The only current and immediate prospecting projects occur in the Kleinfontein Project area immediately west of the current mine workings near Carletonville, with drilling that was planned in 2011 in the Boskop Project area roughly halfway between Potchefstroom and Carletonville (Wits Gold, 2010). This would fall outside of the regional study area defined by the Welgegund GMA, in the neighbouring Turffontein GMA.

The most significant water use on a regional scale is the abstraction of surface water from Boskop and Potchefstroom Dams for municipal use in the Tlokwe Local Municipal (LM) area.

Groundwater is mainly used for agricultural use. Boreholes are spread throughout the regional area. Most pivot points in the Welgegund GMA are located in the alluvium of the Mooi River.

4.4.2 Registered Groundwater Use

No groundwater abstraction is registered at DWA within the focus area. This was confirmed by obtaining the WARMS (Water Resource Management System) database for the affected catchments from DWA. The closest registered groundwater abstraction is by Bert's Bricks' clay quarry and brick making operations located just south of the N12. This quarry is mining shale from the Timeball Hill Formation.

Several groundwater abstraction points (boreholes and springs) are registered within the Welgegund GMA, north of the focus area. Most of these points are located near the Mooi and Wonderfonteinspruit Rivers and are used for agricultural purposes (Figure 4-2).

4.4.3 2003 Hydrocensus

According to a 2003 census that focussed on the area surrounding the old Kynoch Factory, the groundwater use downstream (east) of the Kynoch Factory specifically was qualified from 33 abstraction boreholes to be 400 m^3/d (4.6 L/s). Water is mainly used for gardening and cleaning purposes in Potch-Industria and in the beer production process at Premier Malt (AGES, 2005a).

The borehole yields identified range between 10-170 m^3/d (0.1-2 L/s) for the fractured aquifers. None of the abstraction boreholes in Potch-Industria are located on dolomite.

4.4.4 Recent Hydrocensus Surveys

Hydrocensus surveys by AGES's North West Office (Potchefstroom) in 2009 and 2011 identified a number of abstraction boreholes throughout the focus area – some from within the dolomite (data tabled in Table 4-2 and Table 4-3 and depicted in Figure 4-3). The most notable is the Boitshoko High School located next to the Kynoch dump that solely relies on groundwater from a single borehole on the school property. The borehole is located within 200 m of the Kynoch Gypsum Tailings Dam on the dolomite.

Another major abstraction borehole located on dolomite is located on the premises of OMV Crushers just north of the dump. The main supply borehole is pumped on a 24 h cycle to deliver 45 m^3/h. There is a back-up borehole close-by with similar yield. The water is being used in the processing of the gypsum mined from the old tailings dam, and some domestic use. Neither of these boreholes was identified on the WARMS database of groundwater users. According to OMV, a licence application for abstraction has been submitted (Muller, 2011).

Smaller scale abstraction occurs from boreholes drilled in other lithologies (shale/quartzite).

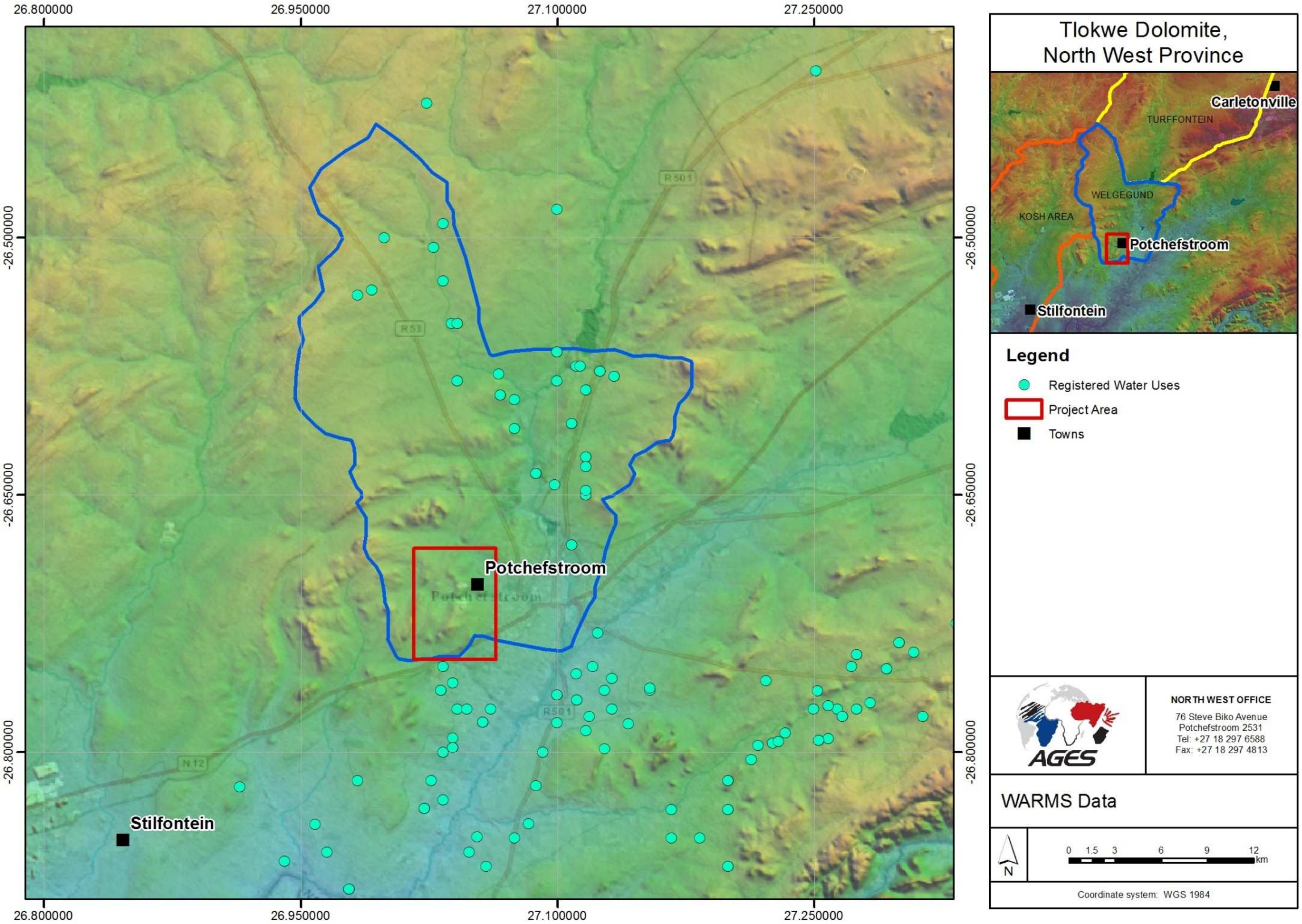

Figure 4-2: WARMS groundwater abstraction data as registered at DWA

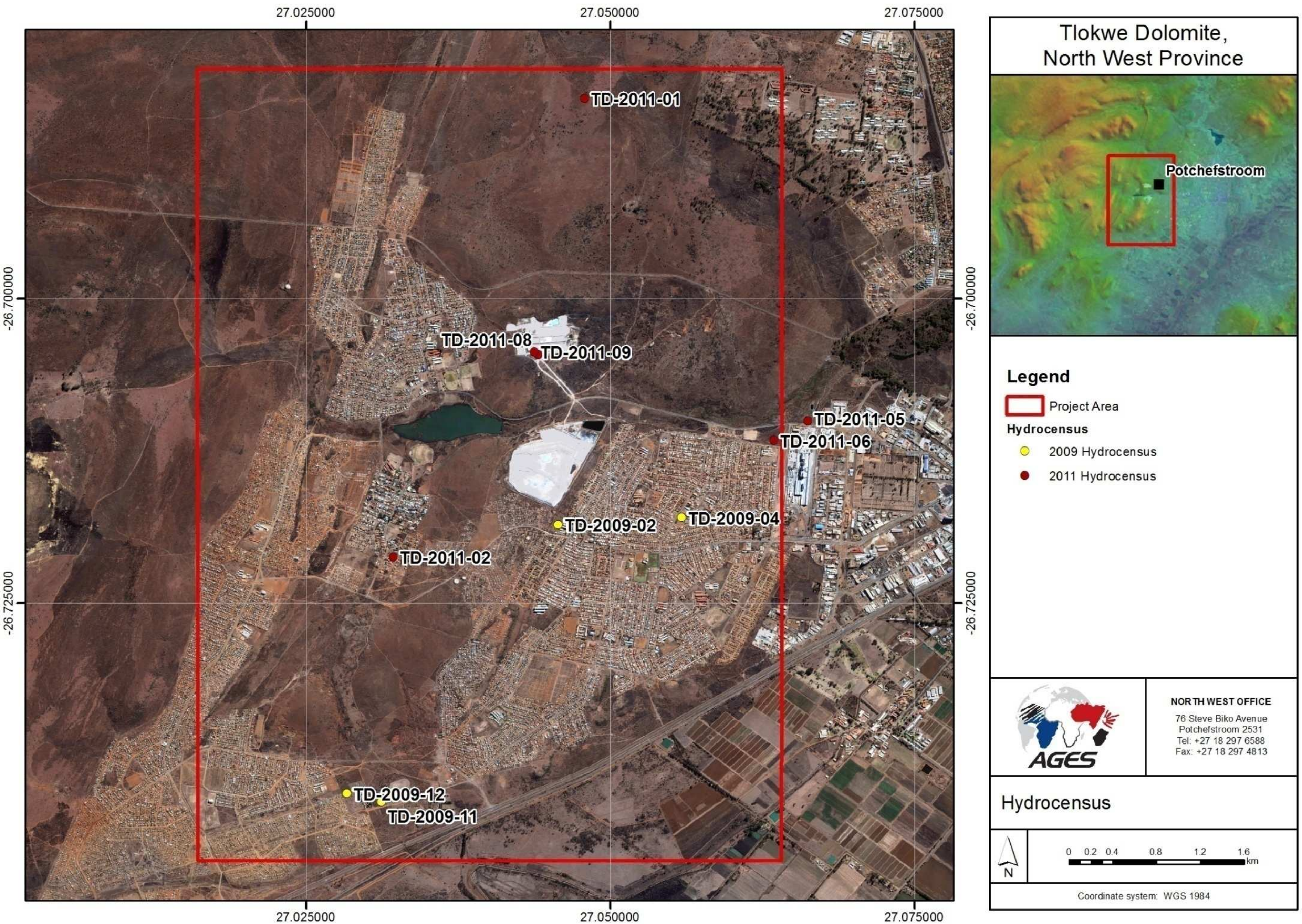

Figure 4-3: AGES NW surveyed boreholes

Table 4-2: AGES NW 2009 Hydrocensus results

BOREHOLE SITE	Site Description	Site No	TD-2009-02	TD-2009-04	TD-2009-11	TD-2009-12
		Date Visited	01-Sep-09	01-Sep-09	02-Sep-09	02-Sep-09
		Type	Borehole	Borehole	Borehole	Borehole
		Status	In use	In use	In use	Not in use
		Condition	Good	Good	Good	
		Purpose	School Supply	Supply	Garden - back-up	
		Use	School use - only source of wa	Toilets, garden	Garden & beack-up supply for school	
		Abstraction (m3/year)		3-5 m3/a		
		Site Comments	Big elevated steel tank (48m3). Close to Kynoch dump site.		Strong Borehole	Pump stolen long ago - used tc
		Site Owner	Boitshoko High School	Katlego Pub	Ikalafeng School (Special) - Kos	Eskom site
		Owner Detail	018 295 2413	4557 Moleme Street, Ikageng.	018 295 5003	018 464 6853
		Farm	Boitshoko High School	Katlego Bottle Store & Pub	Ikalafeng School (Special) - Kos	Eskom site
	Location	Lat / Long System				
		Ref Point				
		Accuracy	3.9m	3	5.6m	4.2m
		Latitude	-26.71856	-26.71804	-26.74134	-26.74064
		Longitude	27.04575	27.0562	27.0312	27.02838
		Altitude (GPS)			1374	1377
BOREHOLE EQUIPMENT	Pump	Type	Mono (unsure?)	Submersible	Submersible	
		Condition	Good	Good	Good	
		Protection Comment				
		Pump House / Fence	Fence with locked gate	behind property fence/gate		No
	Motor	Type	Electric	Electric	Electric	
		Condition	Good			
WATER	Water Levels	Can WL be measured	No	Yes	yes	
		Date measured	2009/09/01	2011/07/01	2009/09/02	
		WL Status	Pumping	Static	Recovering rapidly	
		WL Method		Dipmeter		
		WL Depth		5.1	27m	
		Datum (coller) height				
	Samples	Sampled	Yes	Yes		Yes
		Analysed	Yes	Yes		Yes
	Field Measure ments	pH				
		EC mS/m				
		TDS ppt				
		Temp				
Additional Comments			1600 people depend on BH. Water pumped slowly - often			

Table 4-3: AGES NW 2011 Hydrocensus results

BOREHOLE SITE	Site Description	Site No	TD-2011-01	TD-2011-02	TD-2011-05	TD-2011-06	TD-2011-08	TD-2011-09
		Date Visited	29-Jun-11	29-Jun-11	01-Jul-11	01-Jul-11	15-Nov-11	15-Nov-11
		Type	Borehole	Borehole	Borehole	Borehole	Borehole	Borehole
		Status	Not in use	In use	In use	Destroyed	In use	Back up
		Condition		Good	Good	Sealed	Good	Good
		Purpose	Monitoring	Supply	Monitoring	Monitoring?	Supply	Supply
		Use		Domestic			Industrial, domestic	Industrial, domestic
		Abstraction (m3/year)		15-30Mm3/a estimated			~380,000	Back up
		Site Comments		borehole beneath pavmnt	Locked cap	sealed borehole	Well equipped,	Well equipped
		Site Owner			Kynoch/OMV monitoring?		OMV	OMV
		Owner Detail					Hendrik Muller	Hendrik Muller
		Farm		Mohadin residential				
	Location	Lat / Long System						
		Ref Point						
		Accuracy	3	3	3	3		
		Latitude	-26.68355	-26.72121	-26.71006	-26.71166	-26.7046	-26.70436
		Longitude	27.04791	27.03221	27.06625	27.06347	27.04412	27.04378
		Altitude (GPS)						
BOREHOLE EQUIPMENT	Pump	Type	None	Submersible	None	None	Mono	Mono
		Condition		Good			Good	Good
		Protection Comment		under pavement			Cement fence	Cement fence
		Pump House / Fence	No	No, behind yard fence	None		Cement	Cement
	Motor	Type		electric			Electric	Electric
		Condition		running 24h/d			Good	Good
WATER	Water Levels	Can WL be measured	Yes	No	No	No	No	No
		Date measured	2011/06/29					
		WL Status	Static					
		WL Method	Dipmeter					
		WL Depth	9					
		Datum (coller) height						
	Samples	Sampled						
		Analysed						
	Field Measure ments	pH						
		EC mS/m						
		TDS ppt						
		Temp						
Additional Comments					Locked cap on suspected monitoring BH		Borehole pumped continuously for process	

4.5 Hydraulic properties

As part of the 2001 modelling report done for Kynoch Fertiliser by Geocon, the aquifer parameters were determined for the dolomite underlying the Kynoch site from the aquifer tests conducted on 11 boreholes. All of the boreholes are located on dolomite and the aquifer parameters for the dolomite aquifer have been determined through the aquifer tests and various relevant interpretations. The results show that although the water levels do not fluctuate much in the dolomite due to the high secondary permeability, there is a high degree of heterogeneity within the dolomite as well.

According to Geocon (2001), the dolomite varies from fairly impermeable (T<1 m^2/d) in solid dolomite to highly permeable (320 to >3 000 m^2/d) with open dissolution cavities (karsts). The results are presented in Table 4-4. Note that the borehole numbers correspond to the numbers in the report referenced, and not to final monitoring borehole numbers suggested in this report. These boreholes were not logged geotechnically (i.e. penetration rates, air and sample loss to indicate cavities).

A new groundwater monitoring borehole was drilled in Lusaka Cemetery specifically for the monitoring of groundwater levels in Ikageng in November 2011. This borehole (TMBH08) intersected a cavity at water strike depth and was tested with a submersible pump for six hours (constant rate of 3.0 L/s). Minimal drawdown was achieved during the six hours, and a minimum transmissivity of 1240 m^2/d was calculated for this highly fractured stretch of dolomite (Table 4-5).

Table 4-4: Boreholes tested as part of 2001 modelling report (Geocon, 2001)

Borehole	Type of test	Duration (min)	Abstraction rate (m^3/d)	Drawdown at end of test (m)	T (calculated) (m^2/d)
BH1	Step-drawdown	75	8,64	15,0	0,58
BH2	Constant rate	1 440	96,0	11,9	33,0
BH3	Constant rate	1 440	168,0	9,6	25,9
BH4	Step-drawdown	128	29,81	19,0	2,8
BH8	Constant rate	1 440	345,6	0,2	>3 000*
BH9	Constant rate	1 440	1 728,0	6,3	320,0
BH10	Constant rate	1 440	1 382,4	4,2	1 190,0
BH11	Constant rate	1 440	950,4	5,3	1 020,0
BH12	Constant rate	1 440	345,6	8,6	66,4
BH14	Constant rate	1 440	114,91	17,8	10,0
BH19	Constant rate	1 440	1 296,0	3,2	2 810,0

* BH8 intersected a large cavity and the original transmissivity was calculated as >70 000 m^2/d.

Table 4-5: Monitoring borehole TMBH08 tested in 2012

Borehole	Type of test	Duration (min)	Abstraction rate (m^3/d)	Drawdown at end of test (m)	T (calculated) (m^2/d)
TMBH08	Constant rate	360	259.2 (3 L/s)	0.15	> 1240

4.6 Groundwater levels and hydraulic gradient

Several clusters of boreholes were drilled for various projects throughout the focus area over the past several years (all boreholes on record are reflected in Figure 4-6). Because the water level data were measured over periods of years, during different seasons, it is technically not possible to construct a single groundwater contour map of water levels at a specific time. This is due to seasonal fluctuations that would give a wrong interpretation. Instead, the data were used to interpret the changes in water level due to geology (aquifer type), and over time (seasonal) where possible.

4.6.1 Water levels in different aquifers

Those boreholes that intersected water were added to a database containing coordinates and static water levels. The collar elevations of each of the coordinate points were either surveyed or obtained from the SRTM elevation data. The static water levels were then subtracted from this elevation to give a hydraulic head elevation in metres above mean sea level (mamsl).

The borehole logs were then used to compare the water levels in dolomitic boreholes to those drilled in clastic rocks relative to the collar elevation. This was done by plotting a graph of collar elevation vs. water level elevation.

4.6.1.1 Water level variations in clastic rock

As a general rule, the hydraulic gradient follows or mimics the topography. Therefore a positive correlation should exist between collar elevations and water level elevations. This was confirmed to be the case in the clastic rock in the focus area.

Figure 4-4 indicates this correlation for several clusters of boreholes located off the dolomite. There is a general increase in hydraulic head with the increase in collar elevation. Each cluster was drilled during a particular time span after which water levels were taken in boreholes with water strikes. The water level data in each cluster can be assumed to be a true representation of the water level at a specific time, but since the clusters were not all drilled at the same time, there is a time variation (of years) in data between clusters, and no correlation exists between the clusters.

Furthermore it can be noted that steeper hydraulic gradients exist even within individual clusters. As an example the collars of the boreholes in the AGES Promosa cluster vary by about 10 m in topographic elevation, while the hydraulic head in the boreholes vary by almost 30 m. This indicates heterogeneous geological and hydrogeological conditions within the Intergranular and Fractured Type (clastic rock) aquifer with lower permeability.

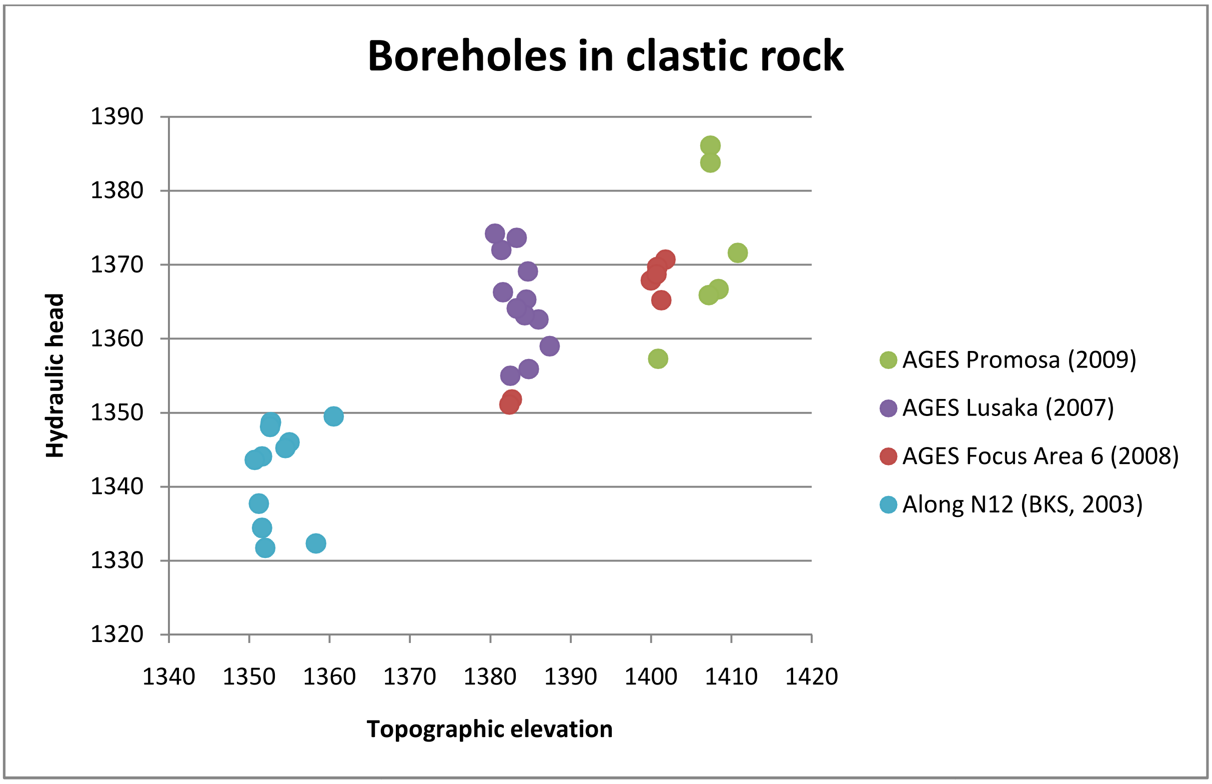

Figure 4-4: Water level variations in borehole clusters

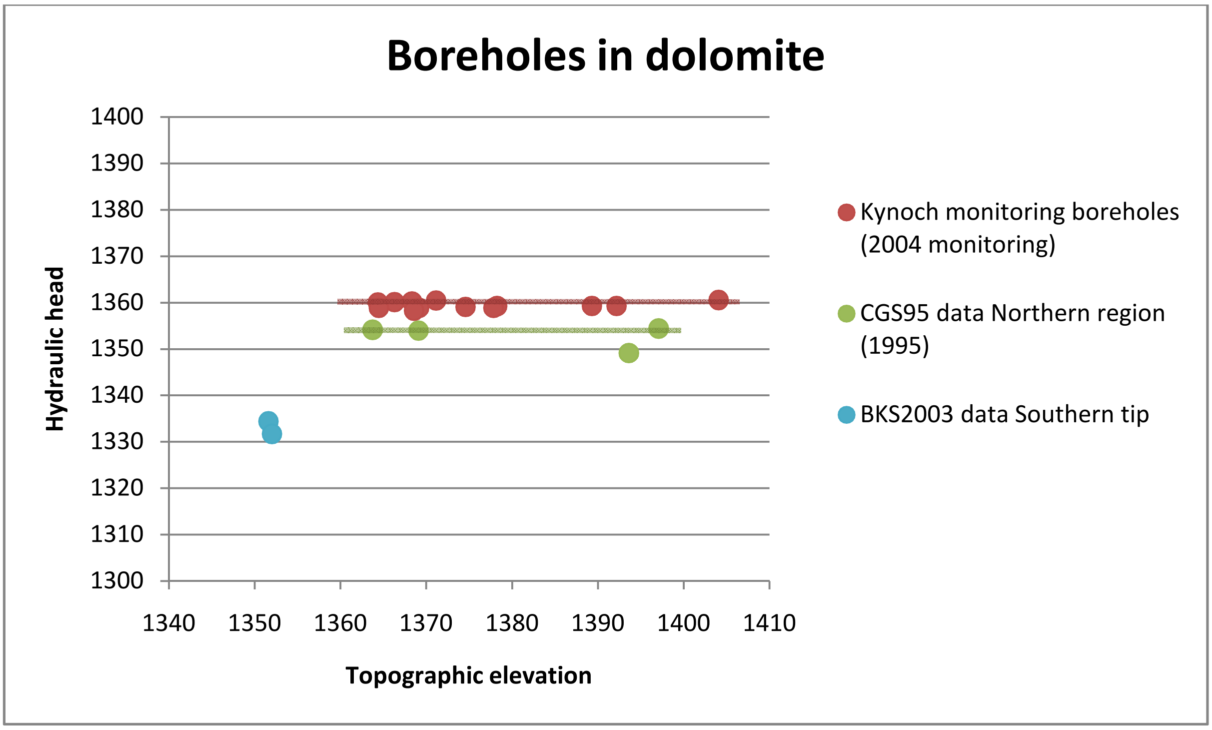

Figure 4-5: Flat hydraulic head in boreholes drilled on dolomite

4.6.1.2 Water level variations in dolomite

According to Geocon (2001), a routine assessment of a possible relationship between water levels and topography was undertaken following a hydrocensus in 2000. Indications were that no significant relationship exists for areas located on dolomite, and that the water levels are characterised by a low regional piezometric gradient which is indicative of aquifers with high permeability.

In Figure 4-5 the hydraulic head in boreholes drilled in dolomite was plotted against the collar elevation of the boreholes to indicate the flat hydraulic head encountered in each cluster. For example the collar elevations of the boreholes from the KGTD area cluster vary by as much as 40 m, while the hydraulic head stays constant at 1 360 mamsl. Council for Geoscience (CGS) data from 1995 indicate boreholes north of Promosa Road with collar elevations ranging 34 m while the head elevations vary by five metres with an average of 1 355 mamsl.

The water levels in the abovementioned clusters were measured nine years apart, and therefore a regional variation of five metres are possible, meaning that the two clusters might be hydraulically connected.

However the two data points from the southern tip of the dolomite finger according to 2003 BKS data, indicate that the hydraulic head is between 20 – 30 m lower in elevation than around the KGTDM measured just the following year. This indicates that the southern tip of the dolomite finger is hydraulically (and possibly geologically) separated from the dolomite around the KGTDM.

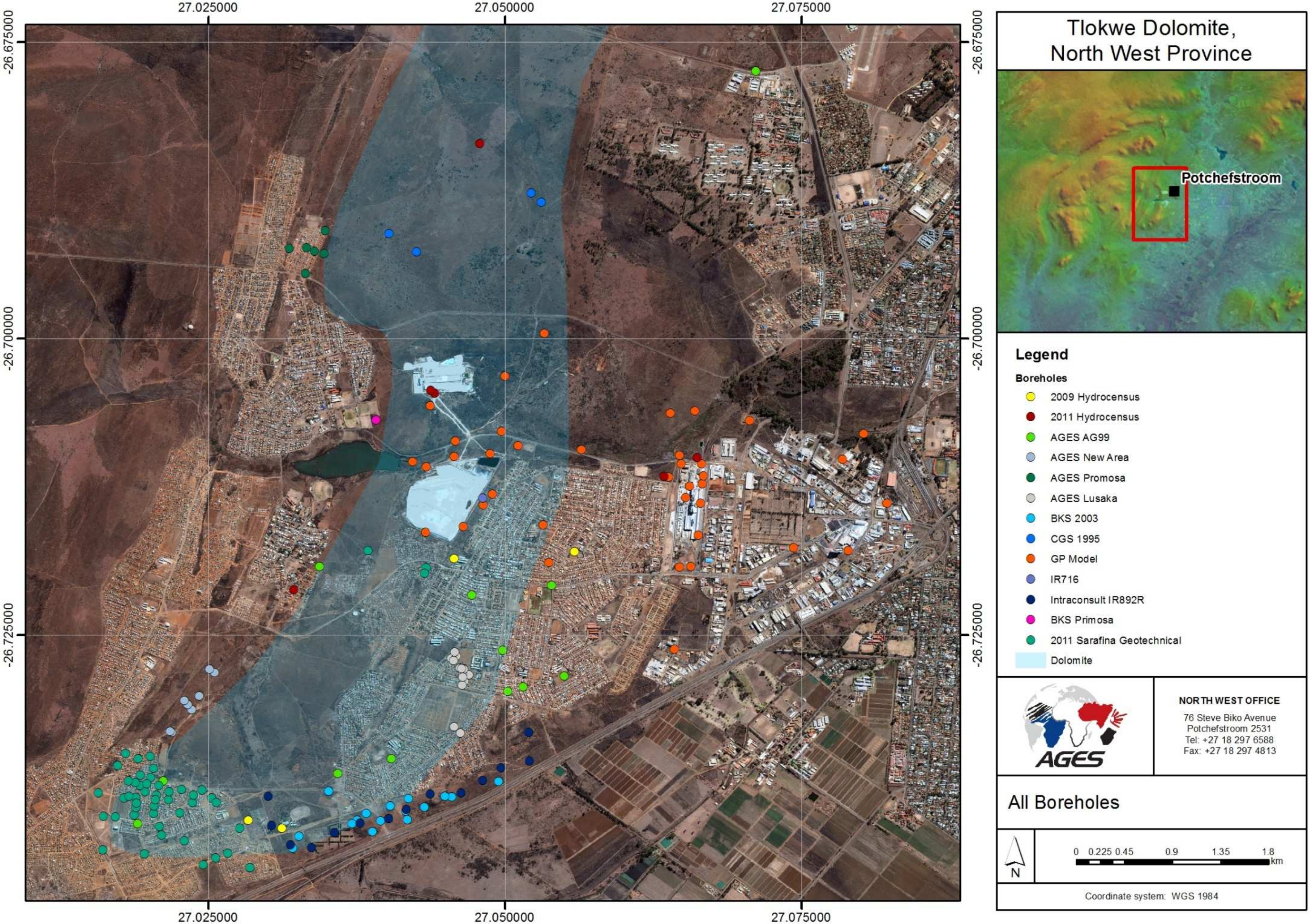

Figure 4-6: All geotechnical and water supply boreholes on AGES database

4.6.2 Historical groundwater levels

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 inside the focus area. Seasonal fluctuations were however identified as can be seen in Figure 4-7. It must be noted that this borehole is not located on dolomite. Still the fluctuations observed exceed 10-15 m.

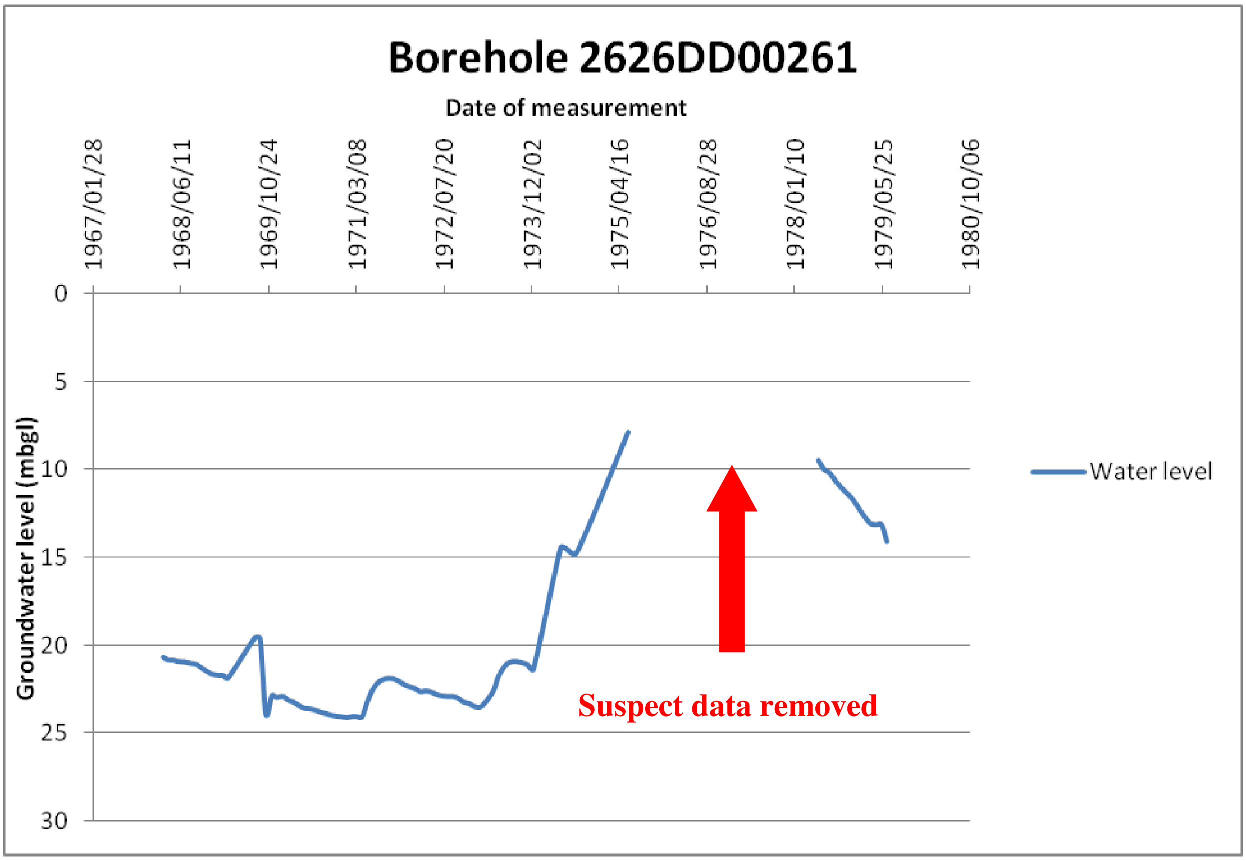

Figure 4-7: Groundwater level fluctuations in borehole 2626DD00261 show fluctuations exceeding 15 m. Borehole location 5 km SW of focus area.

4.6.3 Time dependent water level fluctuations

AGES has been monitoring water levels together with the groundwater chemistry on a continuous basis for Kynoch between 2000 and 2006. (This monitoring responsibility was taken over by OMV in 2006, but only quality monitoring took place, therefore no water level monitoring data exists between 2006 and 2011 when AGES started monitoring water levels in Ikageng as part of this project).

The relationship between rainfall and water level fluctuations has been investigated, to determine whether the water levels in boreholes located in dolomite fluctuates in response to rainfall (Figure 4-8).

While many of the boreholes showed a relatively constant water level over the six year monitoring period (2000-06), some boreholes had large inexplicable fluctuations in water level. Boreholes with water levels fluctuating less than five metres are: BH1, 3, 4, 9, 10, 14, 15, 19 and 20. Some of these boreholes show minor anomalies in the data. Of the abovementioned boreholes, only BH14 is not located on dolomite.

Boreholes BH6 and 13 however would also have counted among the abovementioned boreholes (fluctuations less than 5 m) were it not for the data anomalies during April and May 2005. While BH6 experienced a sudden rise in water level of around 10 m, BH13 experienced a sudden drop in WL of the same order. None of the other boreholes however showed any notable fluctuations and these anomalies are therefore questionable data. However, since the anomalies were recorded for two consecutive months (April and May) the data will not be deleted.

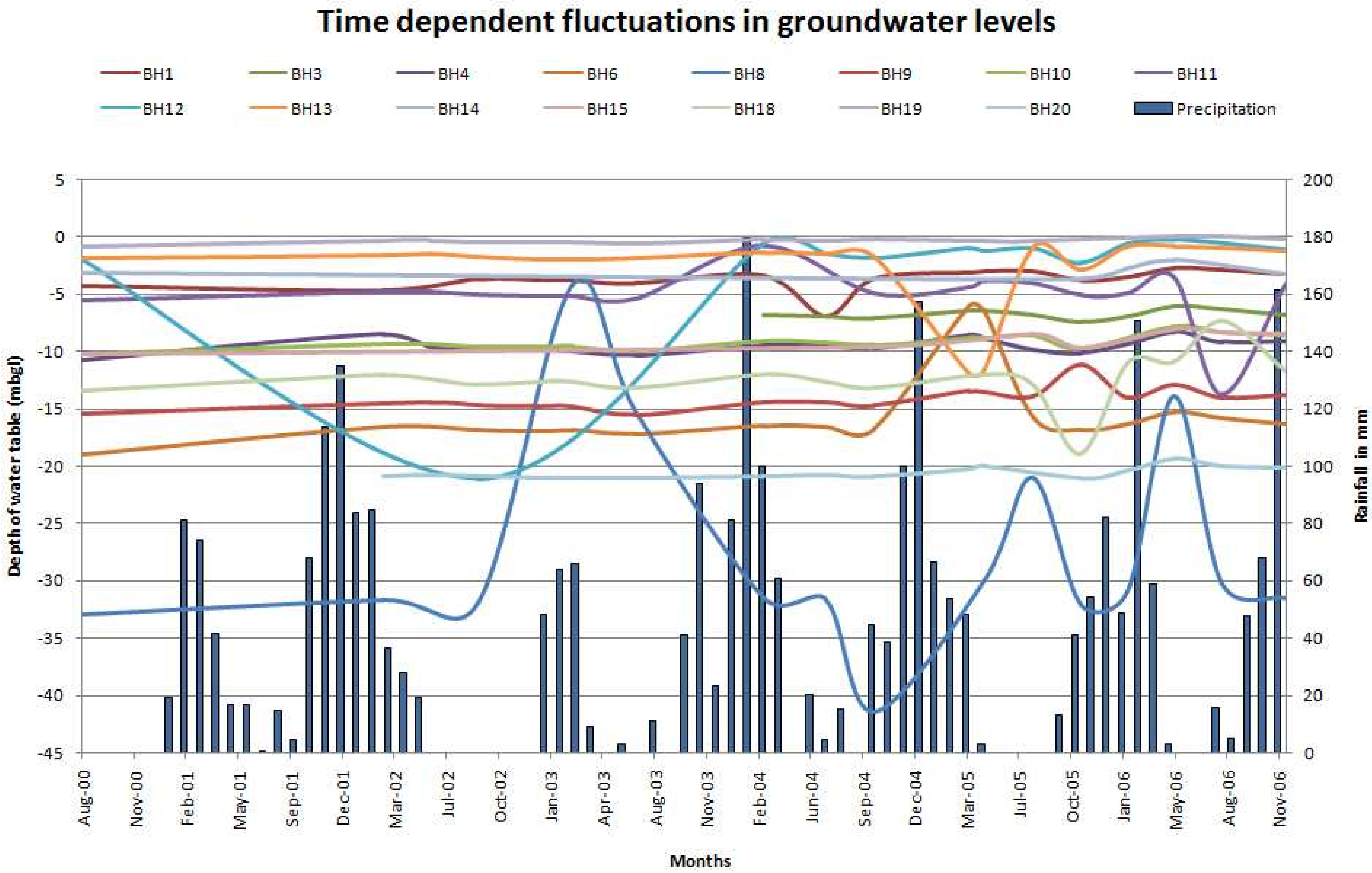

Figure 4-8: Groundwater level fluctuations over time in response to rainfall (from Vivier, 2007).

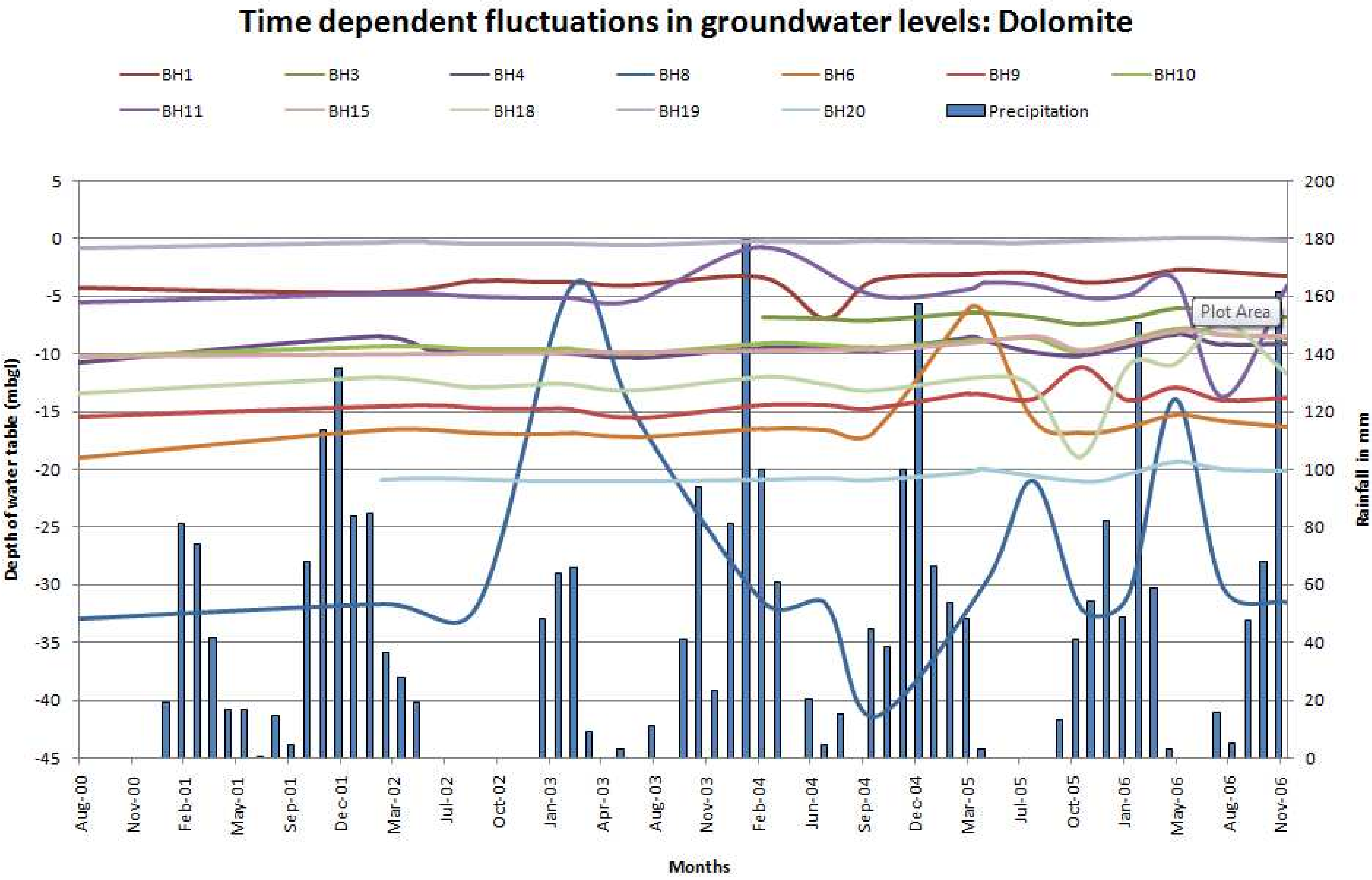

Figure 4-9: Groundwater fluctuations in dolomite only

Boreholes with large fluctuations (more than five metres) are: BH6, 8, 11, 12, 13 and 18. Of these only BH12 and 13 are located off the dolomite. BH6, located east of the tailings dam had a fairly consistent water level apart from the anomaly of April and May 2005 mentioned earlier. BH 8 is also located directly east of the tailings dam and was greatly affected by the artificial groundwater recharge on the dump. The seepage from the dam has a high EC content and this triggers conventional electrical contact dipmeters as soon as seepage is encountered, and therefore does not reflect true static water levels. The large variations in data for BH8 might be explained by this measurement anomaly. This can be rectified by using a variable resistance dipmeter, where the resistance can be adjusted to compensate for high EC seepage water.

BH11 seems to show the strongest link between rainfall and groundwater level fluctuations. After the heavy rains of February 2004 the water level in BH11 rose from an average of 5 mbgl to 0.77 mbgl, after which it returned to normal. After the 2006 winter season the water level dropped significantly, although it might have also been artificially lowered since the drop in water level was more than 10 m in three months. It recovered again after the following summer's rainfall.

4.6.4 Artificial change in water levels

The effect of groundwater level fluctuations on dolomite stability has been discussed in karst geology. Based on this the following areas can be highlighted.

The areas identified where groundwater level fluctuations may occur are around the abstraction boreholes at Boitshoko High School and at OMV. Both boreholes are located on dolomite. The extent to which the abstraction from the boreholes cause fluctuations in the water table can only be assessed by monitoring the water level in nearby monitoring boreholes. The monitoring boreholes surrounding the KGTD can be used to assess the impacts of abstraction from both boreholes. This will have to coincide with pumping tests on both boreholes which is practically not viable. Only long term fluctuations can be detected by regularly monitoring the water levels in the monitoring boreholes. Monitoring will be discussed in detail in a later section.

Leaking water from old infrastructure may be insufficient to account for the rise in water level in highly transmissive dolomitic aquifers, but can lead to the erosion of weathered surface material into existing cavities over time that may accelerate sinkhole development as discussed in 10.5.2.

Water has been observed leaking from the old Sonderwater reservoirs south of the KGTD. This water was then observed where it disappears into the ground at a geological contact in the underlying chert and dolomite formations. This proves the existence of underground cavities and pathways to surface along which further erosion of weathered material takes place. This issue will be flagged in section 5.

4.7 Springs

According to AGES (2005a) a groundwater spring that discharges groundwater at a rate of 300-400 m^3/d exists north of the Kynoch Factory site. This spring occurs at the topographic lowest point in the Spitskopspruit at the contact between the dolomite and the overlying quartzite. Geocon (2003) interpreted a north-south trending lineament in this area as a dyke which supposedly gives rise to the spring conditions. A marshy area next to the road is subsequently formed (Photo 4-1).

During the 2011 hydrocensus one of the boreholes surveyed in this area was found to be artesian, and groundwater was freely flowing from underneath the protective cap installed (Photo 4-2). This borehole is located on the eastern dolomite contact (near the spring) and was not artesian in the past according to historical monitoring records. Therefore this borehole can serve as a good first order indicator of the status of the regional groundwater table.

Photo 4-1: Marshy area north of Promosa Road caused by spring conditions (2009).

Photo 4-2: An OMV employee samples artesian water spurting from monitoring borehole BH7 during a sampling run in October 2011

4.8 Water quality

4.8.1 Surface water quality

The only surface water in the study area is found in the Spitskopspruit, which includes the Poortjie Dam northwest of the KGTD. The contamination potential of the KGTD has been known for several years and numerous studies were conducted on the topic since the mid 1990's. However, most of these studies focussed on the groundwater contamination from the Gypsum Tailings Dam, and storm water runoff from the old factory site itself. Seepage rates from the KGTM were determined in 2000 (during the operational phase) to be between 150 and 900 m^3/d, while the groundwater model was calibrated with a seepage rate of 180 m^3/d. (Geocon, 2001 and AGES, 2005a).

Due to the chemical nature of the KGTDM, the site was classified as a hazardous waste facility (AGES, 2005a). The gypsum precipitated out of slurry containing a host of dissolved metals, salts and acids. Some of the water seeping out from the sides of the tailings dam is intercepted and channelled to treatment ponds via trenches (but not treated according to Muller, 2011). Not all of the seepage is intercepted, and seepage was observed to decant just outside of the property boundary on the northern side where white and yellow salt crystals precipitated as a surface crust after evaporation (see Photo 4-3). No water is being added to the KGTM currently, apart from rainwater and intercepted seepage water from the retention dam that is being pumped back on top of the dam. It is therefore unclear what volume of seepage currently reaches the underlying dolomite aquifer.

It is believed that old BH8 on the eastern side of the tailings dam has a disintegrated casing that causes source water to directly enter the underlying aquifer, and it was recommended to seal off this borehole to stop seepage from directly entering the aquifer (AGES, 2005a).

The monitoring of several surface water monitoring points downstream of the tailings dam was initiated (with the water at the outlet of the Poortjie Dam serving as baseline data) as part of the monitoring protocol for the Kynoch Factory Site and Tailings Dam. Currently OMV Crushers is responsible for the sampling of these points, with an annual monitoring report being rendered to them by an independent consultant. These reports were not made available to AGES.

AGES took two surface water grab samples during November of 2011 as part of a groundwater level monitoring run. One was taken of seepage water north of the Tailings Dam (NW11-017 in Figure 4-10), and the other (NW11-018) was taken about 100 m downstream of the KGTD property in the Spitskopspruit at a stagnant water body, just north of the first houses in the Ikageng residential area east of the KGTD. At both locations the high salt content caused precipitation of white and yellow (salt) crystals on the edges of the water bodies.

Figure 4-10: Surface water grab samples taken by AGES in November 2011

The samples were analysed at a local laboratory (Eco-Analytica) and the results obtained are depicted in Table 4-6.

The results of the analyses below indicate that this seepage water is **highly contaminated**. The most alarming parameter is the low (acidic) pH of ~1.8. The surface water quality is further characterised by toxic levels of various major elements and compounds. The TDS of >20,000 mg/L is indicative of the high concentrations of salts in the brine. Basically all the parameters analysed were of such high concentrations that it can be considered toxic to the environment and especially human health. Notable is the fluoride concentrations of almost 24,000 mg/L sampled in water near the residential area (the drinking water standards for fluoride allows a limit of 1.0-1.5 mg/L (SANS 241, DWA, 1999)).

Table 4-6: Water quality results for two surface samples near the Tailings

		NW11-017	NW11-018
pH		1.83	1.87
EG	mS/m	4 010.00	3 710.00
TDS	mg/L	26 065.00	24 115.00
Ca	mg/L	17 670.00	16 970.00
Mg	mg/L	1 357.00	1 446.00
K	mg/L	46 860.00	43 920.00
Na	mg/L	336.10	377.70
PO4	mg/L	33 460.07	29 674.40
SO4	mg/L	2 485.12	5 927.99
NO3 (as NO3)	mg/L	741.57	643.60
NH4	mg/L	-	0.02
Cl	mg/L	786.70	712.25
HCO3	mg/L		
Fe	mg/L	250.00	199.50
Mn	mg/L	1 947.00	2 457.00
Al	mg/L	4 446.00	5 021.00
F	mg/L	17 659.12	23 795.07
Zn	mg/L	424.50	484.00
Pb	mg/L	0.12	0.14

Photo 4-3: Salt precipitating north of the tailings dam where seepage decants

4.8.2 Groundwater quality

4.8.2.1 General

During 2009, AGES sampled water from four boreholes for basic chemical analyses. The results are indicated in Table 4-7 while the positions of the sampling points are indicated in Figure 4-11. The results were compared and classed according to DWA's drinking water classification guide (DWA, 1999).

Figure 4-11: Locations of groundwater samples surveyed during 2009

Boreholes TD002 (Boitshoko High School) and 004 (Katlego Pub) are located in Ikageng east of the old Kynoch dump, while TD011 (Ikalafeng School) and 012 (Eskom Sub-station) are located in Sarafina. All except TD012 were used as abstraction boreholes.

From the results it can be seen that the water east of the Kynoch dump differs remarkably from the water in the southern part of Ikageng. The quality of samples TD002 and 004 are similar: both samples show a distinct dolomitic origin (elevated Ca and Mg concentrations and subsequent Total Hardness) and shows signs of contamination from the tailings dam (elevated EC due to increased TDS like Cl, Na, SO_4 and NO_3).

Borehole TD011 has a more distinct dolomitic fingerprint (higher Ca and Mg) than TD012. This might be due to a different aquifer (dolomite vs. shale) in TD011 or due to the fact that water from a dolomite compartment is drawn in during pumping. This borehole is pumped significantly for general use at the school, including watering of the gardens and sports fields.

The stagnant water in TD012 also shows a high manganese concentration that is usually associated with the weathering of dolomite (WAD).

Table 4-7: Groundwater quality (2009)

Water quality analyses for samples from Greater Ikageng Township, Tlokwe	DWAF Drinking water standards quality classes				
	Class 0				
	Class I				
	Class II				
	Class III and above				
	Analysed	2009/09/09	2009/09/09	2009/09/09	2009/09/09

Determinants	Units	Domestic standards: DWAF TWQG	Domestic standards: SANS Class II (max. allowable limit)	TD 002	TD 004	TD 011	TD 012
Physical and organoleptic requirements							
Electrical conductivity at 25°C	mS/m	<70	>150 - 370	70	70	35	18
Dissolved solids at 180°C	mg/l	<450	>1 000 - 2 400	455	455	228	117
pH value at 25°C	pH	5-9.5	4.0 - 10.0	8.28	8.06	6.9	6.78
Total Hardness**	mg/l CaCO3	<200	300-600	292	291	146	52
Macro chemical elements							
Calcium	mg/l Ca	<80	>150 - 300	61.32	60.52	38.88	9.22
Magnesium	mg/l Mg	<30	>70 - 100	33.78	33.91	11.91	7.05
Potassium as K	mg/l K	<25	>50 - 100	4.30	5.08	5.08	7.04
Sodium as Na	mg/l Na	<100	>200 - 400	24.14	24.14	10.35	11.04
Sulphate SO4	mg/l SO_4	<200	>400 - 600	93.18	91.26	8.73	1.70
Nitrate as N	mg/l as N	<6	>10.0 - 20.0	0.48	0.42	0.59	0.10
Ammonia	mg/l NH4	<1	>1.0 - 2.0	0.22	0.18	0.07	0.51
Chloride	mg/l Cl	<100	>200 - 600	33.68	34.21	9.57	3.90
Micro chemical elements							
Iron	mg/l Fe	<0.03	>0.2 - 2.0	0.027	0.001	0.001	0.004
Manganese	mg/l Mn	<0.1	>0.10 - 1.0	0.026	0.004	0.013	1.455
Copper	mg/l Cu	<1	>1.0 - 2.0	0.016	0.011	0.014	0.097
Zinc as Zn	mg/l Zn	<3	>5.0 - 10.0	0.039	0.046	0.050	0.805
Chemical Water quality	DWAF			Class I	Class I	Class 0	Class II
Microbial Water quality	DWAF						

4.8.2.2 Kynoch Gypsum Tailings Dam

It is well known that the KGTD has an impact on the groundwater surrounding the site. The groundwater quality monitoring performed by OMV on a quarterly basis on the monitoring boreholes surrounding the tailings dam is collated and interpreted in an annual report by an independent consultant. These reports were not made available to AGES. AGES accompanied OMV during October 2011 on a monitoring run to ascertain the positions of the boreholes used by them. It was noted that sampling is done using a PVC bailer inserted to the top of the water table to sample the top section just below the water table. No cognisance is therefore taken of possible water strikes at deeper depths that may allow for the migration of the plume, or stratification of water. These can be detected by logging the EC-profile of the water in the borehole at depth.

4.8.2.3 Oranje Mynbou & Vervoer

According to Geocon (2001), the premises of OMV where the gypsum is reworked, was also identified as a groundwater pollution source. The site was included in the contaminant transport model. No further data investigating the groundwater contamination from OMV was obtained during this study.

4.8.2.4 Boitshoko High School water quality

The groundwater from the borehole at Boitshoko (TD002) was re-sampled in 2012 to compare with the quality of the sample in 2009. This was done after the realisation that the groundwater abstraction has the potential to draw in the pollution plume from the gypsum tailings dam. The same parameters were analysed for including fluoride after realising that fluoride was one the main constituents in the seepage water from the tailings dam. The results are tabled in Table 4-8.

From Table 4-8 it can be seen that the general classification of the water deteriorated from Class I to Class II, although this is mainly based on the total hardness and the iron concentration. Total hardness is a function of the calcium and magnesium concentrations, and although the calcium concentration decreased, the increase in magnesium in 2012 caused the total hardness count to exceed the 300 mg/L threshold (Class II). Iron was already slightly elevated (Class I) in 2009, but the concentration increased drastically in 2012 (Class II aesthetic). The rest of the constituents are of comparable concentrations, apart from chloride which is slightly higher, and potassium which is lower in 2012. Fluoride is within domestic standards and does not pose a health risk to the pupils. No real health risks are associated with the iron at this concentration. Should it increase, the water will take on an objectionable taste.

Table 4-8: Quality comparison of the water from borehole TD002 (Boitshoko High School)

Water quality analyses for samples from Boitshoko High School borehole, Tlokwe

DWAF Drinking water standards quality classes		
Class 0		
Class I		
Class II		
Class III and above		
Analaysed	2009/09/09	2012/02/08

		Domestic standards			
Determinants	**Units**	**DWAF TWQG**	**SANS Class II (max. allowable limit)**	**TD 002**	**TD 002**
Physical and organoleptic requirements					
Electrical conductivity at 25°C	mS/m	<70	>150 - 370	70	65
Dissolved solids at 180°C	mg/l	<450	>1 000 - 2 400	455	423
pH value at 25°C	pH	5-9.5	4.0 - 10.0	8.28	8.1
Total Hardness**	mg/l CaCO3	<200	300-600	292	318
Macro chemical elements					
Calcium	mg/l Ca	<80	>150 - 300	61.32	47.94
Magnesium	mg/l Mg	<30	>70 - 100	33.78	48.11
Potassium as K	mg/l K	<25	>50 - 100	4.30	1.60
Sodium as Na	mg/l Na	<100	>200 - 400	24.14	25.57
Sulphate SO4	mg/l SO_4	<200	>400 - 600	93.18	91.27
Nitrate as N	mg/l as N	<6	>10.0 - 20.0	0.48	0.31
Ammonia	mg/l NH4	<1	>1.0 - 2.0	0.22	0.29
Chloride	mg/l Cl	<100	>200 - 600	33.68	41.47
Fluoride	mg/l F	<0.7	>1.0 - 1.5		0.01
Micro chemical elements					
Iron	mg/l Fe	<0.03	>0.2 - 2.0	0.027	0.400
Manganese	mg/l Mn	<0.1	>0.10 - 1.0	0.026	0.020
Copper	mg/l Cu	<1	>1.0 - 2.0	0.016	0.020
Zinc as Zn	mg/l Zn	<3	>5.0 - 10.0	0.039	0.080
Chemical Water quality	DWAF			Class I	Class II
Microbial Water quality	DWAF				

The two samples were however taken at different times of the year, and it is inconclusive whether deterioration of water quality takes place. Monitoring of the quality over a longer period is needed to determine trends. It is recommended to monitor the quality of the water on a monthly basis.

4.9 Geohydrological summary and conclusions

The geohydrological character of the focus area is not independent of the regional geohydrology of the areas surrounding it. Therefore the Welgegund GMA 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 Integranular 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:

Karst Type (dolomite) aquifer	Intergranular/Fractured Type aquifer
High groundwater potential	Low to medium potential
High Transmissivity	Low Transmissivity
High yielding boreholes (5-20 L/s)	Low to medium yielding boreholes (<5 L/s)
Shallow (flat) hydraulic gradient	Steeper, more defined hydraulic gradient
Major Aquifer	Minor Aquifer

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 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). The hydraulic gradient was found to be flat in the dolomite, signifying high permeability. 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 main contributing factors to artificial groundwater fluctuations are groundwater abstraction from boreholes, and ingress of water from old water supply infrastructure (leaking pipes, reservoirs etc.). 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 KGTD, 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 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.

5 FLAG SITUATIONS

Although the natural interaction between groundwater chemistry, water table fluctuation and dolomite stability is of long term nature, the artificial change in quality and water level may have a disastrous effect on a short term basis. To manage the human impact on the geohydrological environment, several issues were identified to be flagged to the Tlokwe City Council for further investigation or immediate action. These issues can be described as flag situations.

The identification of the flag situations were based on the following methodology:

5.1 Methodology

The methodology applied in the identification of the flag situations are based on the literature research (contained in this report) and current understanding of the effects of water quality, water table fluctuations and ingress of water on ground stability in dolomitic terrain.

Water quality

It was noted in this report that the formation of subsurface cavities in carbonate rocks such as dolomite and limestone is strongly correlated with the groundwater chemistry in the past, more so than the conventional theory of acid being derived from the dissolution of CO_2 in rainwater to form carbonic acid that percolates into the subsurface. This is evident in the fact that most cave systems are formed sub-parallel to the current water table, regardless of the dip of geological strata.

Acid in groundwater (particularly sulphuric acid) are believed to be responsible for the formation of at least 10% of the world's underground cave systems (see Appendix A).

Any issue that might have a negative impact on the groundwater quality will therefore be flagged.

Water table fluctuations

It was also stated that groundwater level fluctuations of more than six metres, where the water table is less than 30 m from surface, are conducive to sinkhole formation in dolomitic terrain.

The Geoscience Amendment Act Regulation (16/2010) (South Africa, 2010) confirm the importance of a stable groundwater table by stating that "*suitable control over dolomite groundwater resources*" is needed to ensure that no fluctuation in the groundwater table may develop. It is therefore important that the Tlokwe City Council ensures that before any permission is granted to abstract water; it must be proven that abstraction will not result in affecting the water table beyond seasonal variation.

Ingress of water

Sinkhole formation can often be traced to the ingress of surface water into subsurface cavities causing erosion of the weathered surface material (see Appendix A). Sources of water might be natural ponding of water in artificially created depressions (quarries) or leaking water supply infrastructure underground. Any issues relating to the ingress of water will be flagged.

5.2 The critical zone

An area was defined around the dolomite in Ikageng that is described as the **critical zone**. This area was not defined based on geological contacts or geohydrological zones, but rather on practical boundaries like roads. The area includes the entire Ikageng residential area and Poth-Industria, as well as the residential areas west of Louis le Grange Road (Ventersdorp Road) and south of the Eleaser Road.

The critical zone is therefore not limited to the dolomite outcrop, and technically it is not a zone where subsidence is likely (compare the risk zones in 3.4), but a zone in which groundwater activities might have an influence on the dolomite stability. For instance large scale groundwater abstraction from a borehole located right next to the dolomite outcrop, might have an impact on the stability of the dolomite.

The reason for defining the critical zone is to present an area to the TCC in which all groundwater activities must be investigated and managed. It is more practical from a groundwater management perspective than for instance the focus area that was randomly defined for the purpose of this study.

The flag situations are all located inside the critical zone. The critical zone can therefore be used for ongoing groundwater management as part of the DRMP.

5.3 Flag categories

The flag situations can be divided into quantity flags (related to water level fluctuations and ingress of water) and quality flags (related to the chemical dissolution of dolomite by groundwater with compromised quality).

5.4 Quantity Flags

5.4.1 Current groundwater abstraction flags

5.4.1.1 Boitshoko High School

The Boitshoko High School is situated next to the Kynoch gypsum dam and relies on groundwater as sole source of water supply to the school. Water is abstracted from a borehole (TD2009-02 in Figure 4-3) located in the north-western corner of the school premises, within 200 m of the tailings dam. The estimated depth of the water table is between 30 and 40 m, but the volume abstracted is unknown. It is estimated between 60 and 100 m^3/day, with abstraction taking place during daylight hours. According to the school's janitor the borehole is placed under strain in order to supply in the high water demand of the school.

The following conditions support this water use as a flag situation with a risk to the City Council:

- The water use may cause the groundwater level to fluctuate daily giving rise to ground instability in the close vicinity. The extent of groundwater level fluctuations in the immediate vicinity is not known
- The borehole is situated within ten metres from the school buildings, being double storey buildings.
- Due to the existing borehole equipment and infrastructure it is not possible to monitor the fluctuation of the water table in the direct vicinity of the borehole.

The following actions are recommended:

- The risk must be explained to the school management board, and Department of Education can be informed.
- Alternative options for water supply to the school must be investigated and implemented in order to decommission the borehole on the school property.
- The existing borehole must be equipped as monitoring borehole and incorporated in the groundwater monitoring program.

5.4.1.2 Oranje Mynbou & Vervoer (OMV)

The gypsum dam reworking industry by Oranje Mynbou & Vervoer (OMV) is located north of the old Kynoch gypsum tailings dam and makes use of water supply from groundwater for the industrial process. The main abstraction borehole (borehole TD2011-09 on Figure 4-3) is being pumped at 45 m^3/h (12.5 L/s) for 24h per day and used in the OMV gypsum reclamation process (Muller, 2011). OMV recently applied for a water use licence from the Department of Water Affairs (DWA) (Nell, 2011 and Muller, 2011). It is unknown whether a geohydrological investigation accompanied this application to DWA. Such an investigation should have identified the impact of abstraction on the local water table by means of hydraulic (pumping) tests, and take cognisance of the dolomite stability issue.

The monitoring boreholes surrounding the tailings dam does not seem to be impacted by this abstraction, apart from borehole TMBH09, directly east of the abstraction borehole (see 6.5). The impact of the abstraction in the immediate vicinity of the borehole on OMV's premises is however unknown.

The following recommendations are made in order to manage the risk related to this groundwater abstraction:

- The Tlokwe City Council must engage with the DWA in order to ensure that all requirements are followed regarding the water use license application (WULA) process. This must include the recognition of the City Council as an affected party and full insight into the geohydrological information related to the WULA.
- The geohydrological assessment supporting the WULA must ensure that water abstraction will have no effect on the water table in the critical zone. This will include long term (48-72 hours pump test analyses on the abstraction borehole while monitoring the level in the surrounding boreholes.
- If no WULA is received by the DWA or no geohydrological or water use information is available other more drastic steps must be taken to manage the risk to the City Council – even the specialist services by the "Blue Scorpions".

5.4.2 Unknown existing water abstraction in the critical zone

According to a 2003 hydrocensus the groundwater use downstream of the Kynoch Factory specifically was quantified from 33 abstraction boreholes to be 400 m^3/d (4.6 L/s). Water is mainly used for gardening and cleaning purposes in Potch-Industria and in production process at Premier Malt (AGES, 2005a). This area has specifically been included in the critical zone due to the large volumes of water used in some industrial processes. This water use was not verified during the recent hydrocensus and needs to be verified with the potential effect on the dolomite aquifer.

Several other hydrocensusses were completed in the critical zone throughout Ikageng, the difficulty of access to private ground may lead to localised water abstractions not known and included in this report. The possibility of unknown groundwater abstraction not quantified and assessed is a risk to the City Council, has to be seen as a flag situation and the following action is recommended:

- A public participation process can be initiated to explain the relevance of the information, and urge people to disclose all groundwater use.
- Interaction with the Department of water Affairs (DWA) as custodians of water use in South Africa to assist with water use verification in the critical zone by using special vehicles with authority in this regard – for example the “Blue Scorpions”.
- It must be ensured that no illegal water use occurs in the critical zone. This illegal use must be according to the water use description and licensing as defined in the National Water Act (36/1998).
- The possibility needs to be investigated on legal and institutional level to restrict groundwater use within the critical zone defined in the National Water Act as Schedule 1 use in (domestic purposes).

5.4.3 New groundwater use in the critical zone

Any new (specially uncontrolled) groundwater use in the critical zone may lead to the raising of a risk of dolomite destabilisation in the focus area. The following actions are therefore recommended:

- It must be ensured that any licensed groundwater use – or any such application – adhere to all legal requirements, accompanied by specialist geohydrological reports in order to prove that abstraction will not lead to water table changes and dolomite instabilities. Furthermore the Tlokwe City Council and the Council for Geoscience must be acknowledged as affected and involved parties during the licensing process.
- The cooperation between the Tlokwe City Council and all mentioned parties above regarding groundwater use in the critical zone must be recorded in the development of the bylaws related to the dolomite hazard risk management.
- Within the legal framework of the local authority it is recommended that the development of bylaws based on the DRMP must also address the following

aspects:

- o Permission must be obtained from the Tlokwe City Council prior to the drilling of any boreholes in the critical zone. (This must then be addressed by specialists from the ad-hoc subcommittee in place to assess new building applications in the area).
- o The regulation of groundwater use in the critical zone parallel to the application of the National Water Act. (Application also to be assessed by specialists reporting to the ad-hoc subcommittee).
- o Effective control over groundwater abstraction in the critical zone as a function of the implementation of the DRMP, including database management of applicable information.
- o Effective reporting on groundwater abstraction to be included in the monitoring report of the area.

5.4.4 Ingress of water

5.4.4.1 Seepage from the tailings dam

The volume of polluted water from the KGTD seeping into the underground dolomitic aquifer is unknown. The volume was estimated at between 150 and 900 m^3/d during the operational phase. After the factory was decommissioned, no new slurry is being added to the dam. The only addition comes from the seepage intercepted in trenches and channelled to the retention (treatment) ponds from where it is pumped back onto the stack without treatment. This volume is unknown.

Since the KGTD was designed in such a way as to limit runoff, it can be assumed that the majority of the rainfall falling on the tailings dam either infiltrates into the gypsum or is lost to evaporation (depending on the intensity and duration of rainfall events). A basic water balance will determine the volume of water entering the KGTD.

Of the volume of water added to the KGTD, a portion is known to seep out from the base horizontally which is either intercepted or decants north of the property. The seepage that exits the property either evaporates or enters the Spitskopspruit during rainfall events (or possibly as baseflow).

The balance is assumed to enter the underlying aquifer as vertical seepage. The erosive effect of this vertical seepage is unknown since it occurs below the tailings dam. It is however known from gravity surveys and geotechnical drilling that significant cavities exist underneath and surrounding the KGTD in the underlying dolomite. These cavities are obvious reservoirs for the vertical seepage. The relationship between the depth of the cavities and depth to water table needs to be investigated. This relationship can shed light on the erosive power of the vertical seepage. Should the cavities be saturated, water seeping from above would reach the water table well before the voids, whereas if the water table occurs within or below the cavities, the vertical seepage reaching the top of the voids (reservoir) can have significant erosive potential. Furthermore the vertical seepage is expected to have a low pH and will dissolve the dolomite to enlarge existing cavities.

5.4.4.2 Ponding of water

Areas where water accumulates (naturally or artificially) are conducive to sinkhole formation due to the potential ingress and associated erosion of weathered material, and added weight of the water pond.

Areas identified where water ponding is likely on the dolomite includes the quarries and borrow pits in the open area between Promosa Road and the road north of OMV between Dassierand and the Potchefstroom landfill site west of Promosa. This area is north of the residential area, but still located on the dolomite and significant excavations have been made. Illegal dumping of refuse occurs here which also has a quality impact.

Inside the residential area where solid walls are erected on slopes where runoff can accumulate need to be identified and flagged as potential hazardous areas.

5.4.4.3 Water leakages from the Sonderwater reservoirs

As mentioned in chapter 4.6.4, the reservoirs situated in Sonderwater that supply Promosa with water have a history of leakages and the sub-service conditions were confirmed to be poor. Water leaking from the side of the reservoirs was observed to disappear into the ground at a geological contact between chert/dolomite layers on surface. It is unknown whether any leakages occur right underneath the reservoirs.

The following actions are recommended:

- Loss of water from these reservoirs can be quantified by:
    - temporarily cutting off supply from one reservoir if possible, to

monitor any water level decrease inside the reservoir over time, or

- o fitting flow metres to the inlet and outlet pipes. A basic balance equation will quantify any losses not accounted for in the outlet pipes.

5.4.4.4 Water leakages from old infrastructure

Similarly water losses can occur from old water supply infrastructure throughout the rest of the residential area. It might be difficult to identify possible leaks of the underground pipeline network since leaking water is not expected to surface, especially in the presence of underground cavities into which water drains.

For this reason areas with older infrastructure were identified and delineated, and overlain with the initially identified risk zones (Figure 5-1). (AGES 2011)

Recommendations regarding this flag issue are as follows:

- After the final dolomite stability risk zone classification has been done, areas with high risk coinciding with areas with old infrastructure can be identified for further infrastructure investigation.
- Infrastructure issues that need attention include water and sewage reticulation, unpaved roads, storm water canals and pipes, built up areas with open ground conducive to ponding etc.

5.4.4.5 Storm water management in the critical zone

Along several main roads there are storm water canals and drains leading to underground storm water pipes. It is however unclear what the state of storm water management is inside the focus area in terms of general coverage and infrastructure conditions. This issue was identified as a flag to be assessed in detail.

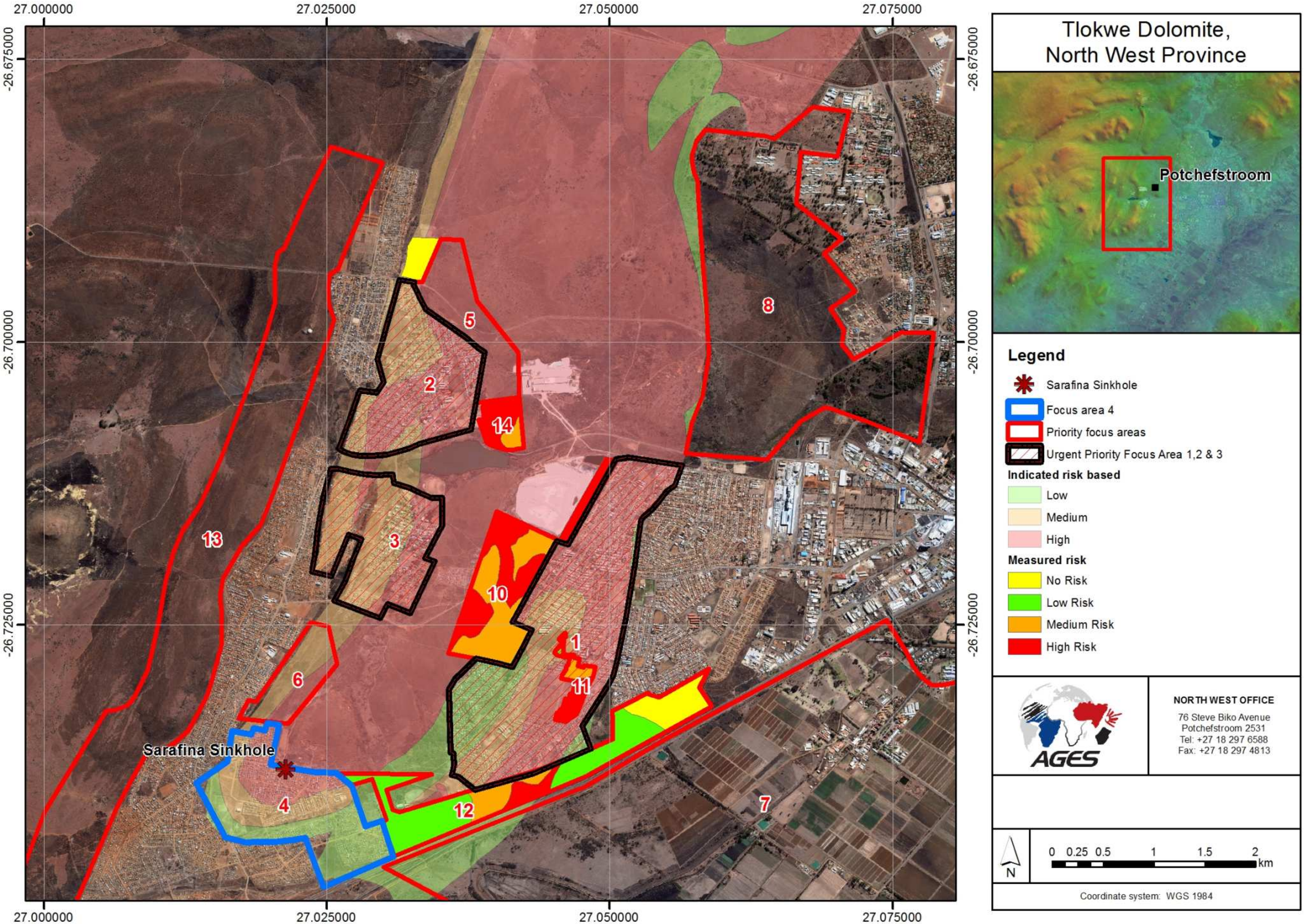

Figure 5-1: Risk zones overlain by areas with old infrastructure

5.5 Quality Flags

5.5.1 Kynoch Gypsum Tailings Dam

Many groundwater pollutants can have an acidifying effect on the water and lead to accelerated dissolution of the underground cavities. In this sense it is important to assess and monitor any possible sources of contamination that might have a negative effect on the groundwater quality in Ikageng.

The biggest source of groundwater pollution identified in the area is the Kynoch gypsum tailings dam (KGTD). The old Kynoch Fertiliser factory was commissioned in 1967 and operated for more than 35 years. The impact of the tailings dam on the surrounding water quality was identified in 1996. In 1999 the factory applied for a waste permit (which was granted) from the (then) Department of Water Affairs and Forestry since the dump was classified as a hazardous waste site (AGES, 2005a).

A series of monitoring boreholes were drilled on and off-site to monitor the groundwater quality as part of the licence conditions. Currently OMV crushers are rehabilitating the dump after acquiring the property (with liabilities). OMV continued with the monitoring of the surface and groundwater quality, but not the treatment of the seepage brine.

In the 2001 contamination modelling study undertaken by Geocon, it was noted that part of the remedial actions recommended to contain and rehabilitate the groundwater pollution around the KGTD were to place strategically positioned boreholes around the dam to abstract the polluted groundwater for treatment. Without the abstraction of the polluted groundwater it was impossible to contain the plume (Geocon, 2001). This treatment option never materialised as far as could be determined, meaning that the plume has been spreading for at least the past decade.

According to Geocon (2001), the dam is also a source of radionuclides, and the National Nuclear Regulator has issued a permit based on certain monitoring conditions. These conditions are not known. It is also not known whether OMV currently includes radionuclides as part of their monitoring framework. However, according to a 2005 water quality monitoring report for Kynoch (AGES, 2005b), the radiological public impact of the tailings dam determined that the potential dose to members of the public was below the regulatory compliance limit. There was however an increase in certain radiological parameters measured in surface water (from Poortjie Dam upstream of the KGTD) and groundwater around the

KGTD between 2004 and 2005. The current radiological impact of the KGTD on surface and groundwater must be assessed.

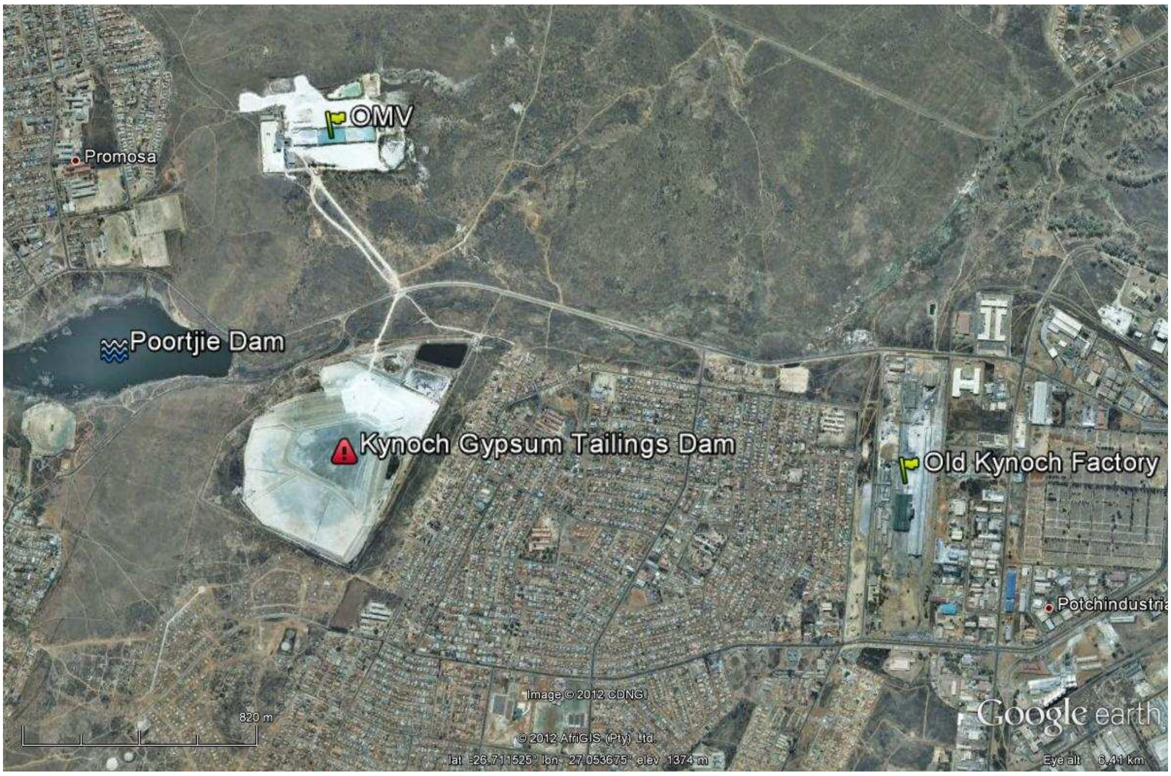

Figure 5-2: Position of the tailings dam relative to the Kynoch Factory and OMV

Photo 5-1: Photo of the reworking of the white gypsum from the tailings dam by OMV

The effluent seepage sampled by AGES in 2011 was found to be highly acidic and contaminated. Since the gypsum precipitated out of the slurry, the brine could be considered to be in chemical equilibrium and the gypsum will not neutralise the highly acidic pH. The underlying dolomite however, having a different chemical composition than gypsum, does react with this acidic effluent.

In an in-house experiment, a piece of dolomite was placed into a glass container containing a sample of the tailings effluent, and within minutes the dissolution process could be observed through bubbles forming as the $CaMg(CO_3)_2$ dissolved. This process lasted for several hours. In effect this means that the underlying dolomite which is already karstified to a great extent (AGES, 2004b) is further being dissolved by the acidic tailings seepage at an unknown rate. If left unattended, the gypsum tailings dam as a reservoir of acid seeping into the underlying dolomite will eventually cause sinkholes to form. The extent and timing can only be speculated at this stage.

5.5.1.1 Case study: Florida sinkhole

In a similar scenario a catastrophic sinkhole formed suddenly on 27 June 1994 underneath a gypsum tailings dam in Florida State in the United States (Photo 5-2).

Photo 5-2: This sinkhole formed in 1994 inside a similar gypsum tailings dam in Florida

This gypsum tailings dam is also located on carbonate rock, and the acidic nature of the brine (pH ~1.5) likely enlarged pre-existing subsurface cavities until a critical point was reached and a sinkhole formed that is considered to be one of the most catastrophic sinkholes to have ever formed. The sinkhole measured more than 120 m deep below the already 67 m high tailings dam surface, and the width reached a diameter of 32 m at a depth of 18 m below the surface of the tailings dam (Tihansky, 2012).

5.5.2 Old Kynoch factory

The old Kynoch factory is located off the dolomite, between Ikageng residential area and Potch Industria. The groundwater pollution from this site was identified and investigated further by several specialists since the middle 1990's. Several point and diffuse pollution sources from the factory site were identified, polluting a shallow and deeper aquifer around the site (Geocon, 2003). This factory has been decommissioned in 2006, and no new pollutants are believed to be added to the aquifers. It is unknown to what extent the factory has been cleared of contaminants during the decommissioning process. The extent of the current plume is also unknown and might form the basis of an investigation to determine its migration.

5.5.3 Oranje Mynbou & Vervoer

The OMV site where the gypsum is reworked was also identified as a possible source of groundwater pollution (Geocon, 2001). This was based on the water quality from one borehole (BH15) northeast of the OMV site, and it was recommended that the groundwater pollution potential from the site be investigated further. The water quality from OMV (process water and groundwater from an on-site borehole) was included in the monitoring work done by AGES (2005b). The site is located on dolomite and should be continually monitored.

5.5.4 Other potential groundwater pollution sources in the Critical Zone

Other potential sources of pollution in the critical zone might include:

- Underground storage tanks (UST's) at petrol stations,
- Leaking storm water/sewer systems
- On-site sanitation systems (pit latrines)
- Cemeteries
- Workshops (mechanical, electrical, industrial)
- Agricultural chemicals
- Abattoirs
- Metal / auto scrap yards.

- Dry cleaners disposing of chemicals in an irresponsible manner,

These pollution sources must be identified and investigated inside the critical zone, and the location of the source in relation to the dolomite must be determined.

5.6 Groundwater outside the Critical Zone

5.6.1 Groundwater abstraction from the regional area of interest

The growing concern about the quality of the water in the Boskop and Potchefstroom Dams as the primary source of water to the TCC might cause a future focus on groundwater abstraction from the dolomite. The water in the Boskop Dam shows increasingly elevated concentrations of uranium and other mining related pollutants. Due to the great groundwater potential inherent in dolomite, TCC might consider bulk groundwater abstraction to augment or replace the existing water supply that must continually be treated to remove the pollutants.

It is important to flag the fact that any potential well fields for bulk groundwater abstraction must be sufficiently far removed from Ikageng to prevent cones of depression from affecting the groundwater table below Ikageng. Detailed geohydrological investigations will be needed. Bulk groundwater abstraction must be so managed to ensure as little drawdown in the regional aquifer as possible to prevent sinkhole formation and subsidence in the immediate area of abstraction.

5.6.2 Mining and exploration rights in the regional area of interest

Recent media reports indicated a renewed interest of mining companies in commodities north of Potchefstroom. Mining and mineral processing inherently requires large volumes of water that must be sourced from somewhere.

It must be ensured that geohydrological impact studies accompanying the main EIA for the mining right application within the Welgegund GMA considered the impact of dewatering on the aquifer surrounding Potchefstroom. Close cooperation between the TCC and DMR is recommended where mining right applications within the Welgegund GMA is concerned. Since WULA's would also be a requirement, the DWA, DME and the TCC will need to be involved in the decision making process.

It is doubtful whether deep level mining operations will occur in the neighbouring Turffontein GMA due to the existence of the Gerhard Minnebron spring in this compartment. Any dewatering activities in this compartment will most certainly cause the spring to dry up. The spring feeds good quality water to the Boskop and

Potchefstroom Dams - the main source of municipal water to the TCC.

5.6.3 Activities that effect groundwater on a more regional scale

The impact of future water quality once mining and pumping ceases on the Far West Rand and the dolomitic aquifer is left to re-water remains a point of contention. Already mining related pollutants (uranium) are increasing in the groundwater emerging from the Gerhard Minnebron eye north of Boskop Dam (Winde, 2010a, b). It is further proposed by some that the mining activities have penetrated the separating dykes sufficiently to compromise their function as geohydrological boundaries. Therefore the individual compartments are now believed to form one big ‘mega-compartment’.

The Gerhard Minnebron Eye is topographically the lowest discharge point for this new mega-compartment. Once mining ceases and the mega-compartment is left to re-water, this would form the first point of discharge of groundwater. In theory then the combined flow of all springs that were affected by the dewatering of the separate dolomite compartments can discharge at the Gerhard Minnebron eye north of Potchefstroom. The quality of the future decanting groundwater from the mega-compartment might be highly compromised, and could form the topic of future studies. It is unlikely that the water from the Gerhard Minnebron would impact on the quality of the dolomitic groundwater underlying Ikageng. The main impact would however be on the municipal water supplies of TCC.

5.7 Summary

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

The borehole at Boitshoko High School is located within 200 m of the tailings dam. Not only can the groundwater abstraction from the Boitshoko borehole create daily 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. In the interim it is recommended to implement a monthly water quality programme to monitor whether the pupils are exposed to any pollutants from the KGTD.

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 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 TCC engage with 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 industrial use. 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.

Since any ingress of water into unsaturated underground cavities can lead to sinkhole formation, several sources of possible water ingress have been identified as flags: The KGTD acts as a perched aquifer containing rainwater and untreated slurry water from where vertical seepage is assumed to reach the dolomite cavities underlying the tailings dam.

Similarly old water supply and/or sewer infrastructure overlying high risk zones must be investigated for leakages. Leakages have been observed from the old Sonderwater reservoirs. It is unclear whether any leakages occur from underneath the reservoirs, and all losses must be quantified.

Lack of storm water management and ponding of water in the critical zone, especially on high risk dolomitic areas are raised as a flag to be further investigated. The Sarafina sinkhole can partly be attributed to the ponding of water. In this regard it is recommended that the areas be inspected for water ponding after heavy rains. Areas where excessive ponding occurs can be rectified by implementing proper storm water management.

It is furthermore recommended to perform routing correlations between the depths of cavities intersected during geotechnical drilling, and the depths of static water levels to determine whether (or where) dolomite cavities are unsaturated. Unsaturated cavities act as reservoirs for water ingress, enhancing the erosive power of vertical seepage.

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.
- EC logging of the monitoring boreholes and compare with logs.
- Sampling of monitoring boreholes at water strike to compare with current sampling records.
- 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 XRD analyses on the salt precipitates where seepage water decants and evaporates 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.

The old Kynoch factory between Ikageng and Potch-Industria used to be a source of groundwater pollution, but after decommissioning in 2006, it is not believed to add any more pollutants to the shallow and deeper Intergranular and Fractured Type aquifers as identified during studies. The current position of the existing pollution plume can be investigated further, but it is not believed to be a threat to dolomite stability.

OMV's gypsum reprocessing site was also identified as a potential source of pollution. The quality of process water ending up in the evaporation ponds must be assessed as well as the quality of the groundwater underneath and surrounding the site since it is located on dolomite.

Several other possible pollution sources were listed that needs to be identified and investigated inside the critical zone and in relation to the dolomite.

On a regional scale the uncertainty surrounding the potential quality of the groundwater to flow from the Gerhard Minnebron once gold mining on the FWR ends and dolomite dewatering ceases, 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 EIA's containing specialist geohydrological investigations that consider the impact on the focus area and the critical zone dolomites.

Although little impact is foreseen on the dolomite underlying Ikageng, TCC must be updated on the latest studies on the Gerhard Minnebron since its main water supply can be jeopardised.

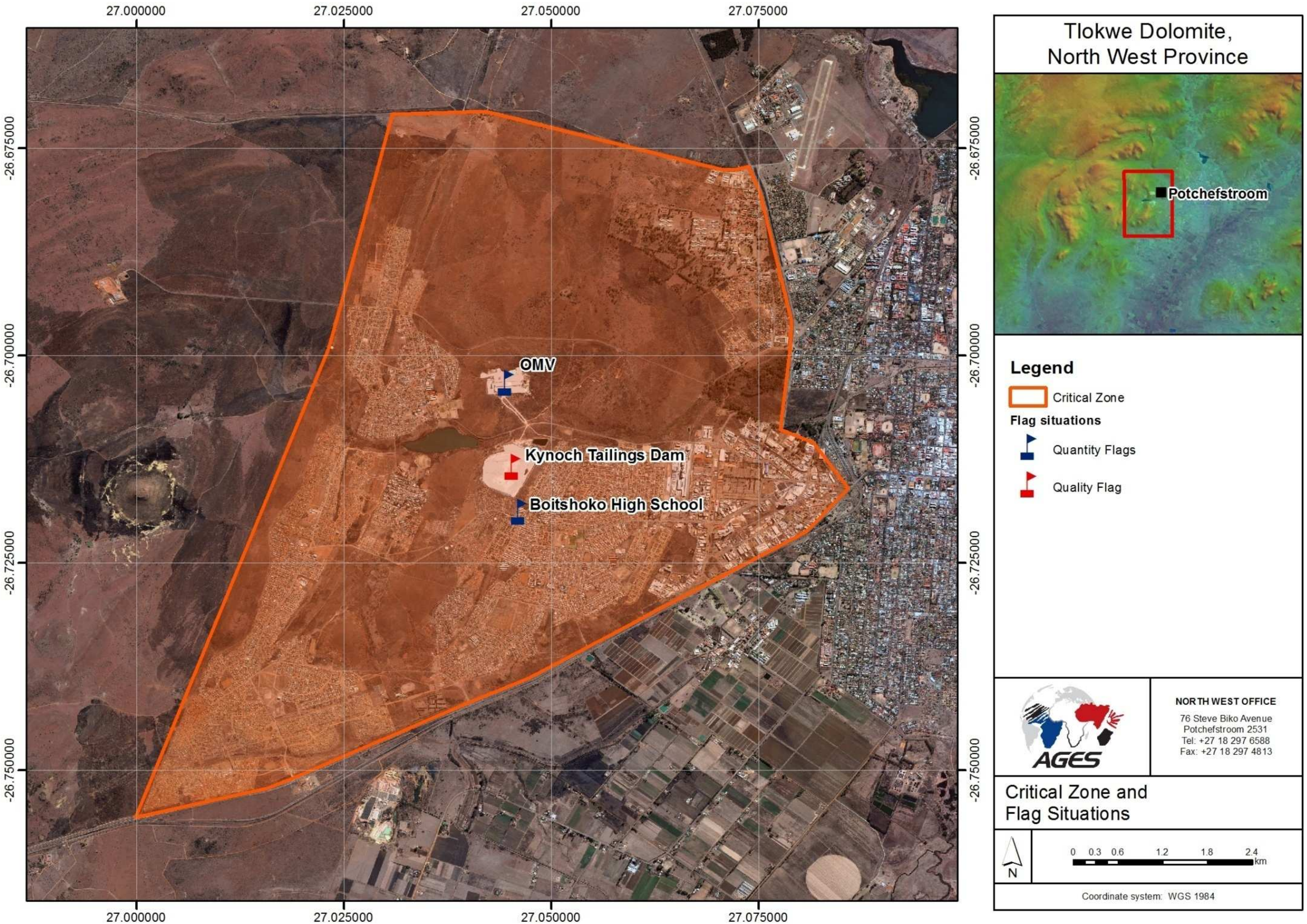

Figure 5-3: Major flag situations on dolomite and critical zone for borehole moratorium

6 MONITORING

According to the Internal Strategic Perspective of the Upper Vaal Water Management Area, the current monitoring programme for the WMA is totally inadequate. This lack is blamed on a lack of internal capacity in regional DWA offices (DWA, 2004).

The hydrology office of DWA located at Potchefstroom monitors surface water flows at monitoring stations in the Mooi River among others, as well as the water levels in several boreholes in the dolomite compartments affected by mine dewatering. These compartments however are located north of the Welgegund GMA and therefore fall outside of the regional area of investigation.

6.1 Surface water flow monitoring

Data were obtained for two monitoring stations in the Mooi River below the Boskop Dam outlet. One (C2H001) is located just north of the Potchefstroom Dam and has data stretching more than a hundred years. The other is located at the Boskop Dam outlet and has only got data since 2004. The latter data set can therefore not be compared to the former.

The data for flow monitoring station C2H001 is included in Figure 6-1. This graph indicates the mean flow in m^3/sec and flood peaks can clearly be seen. In order to draw conclusions in terms of the impact of surface water flow from the Turffontein compartment, more in-depth analyses of the flow of several stations including Gerhard Minnebron is needed.

No flow data for the Spitskopspruit exists. This might prove useful in determining the loads of certain contaminants from the KGTD entering the Mooi River to the east.

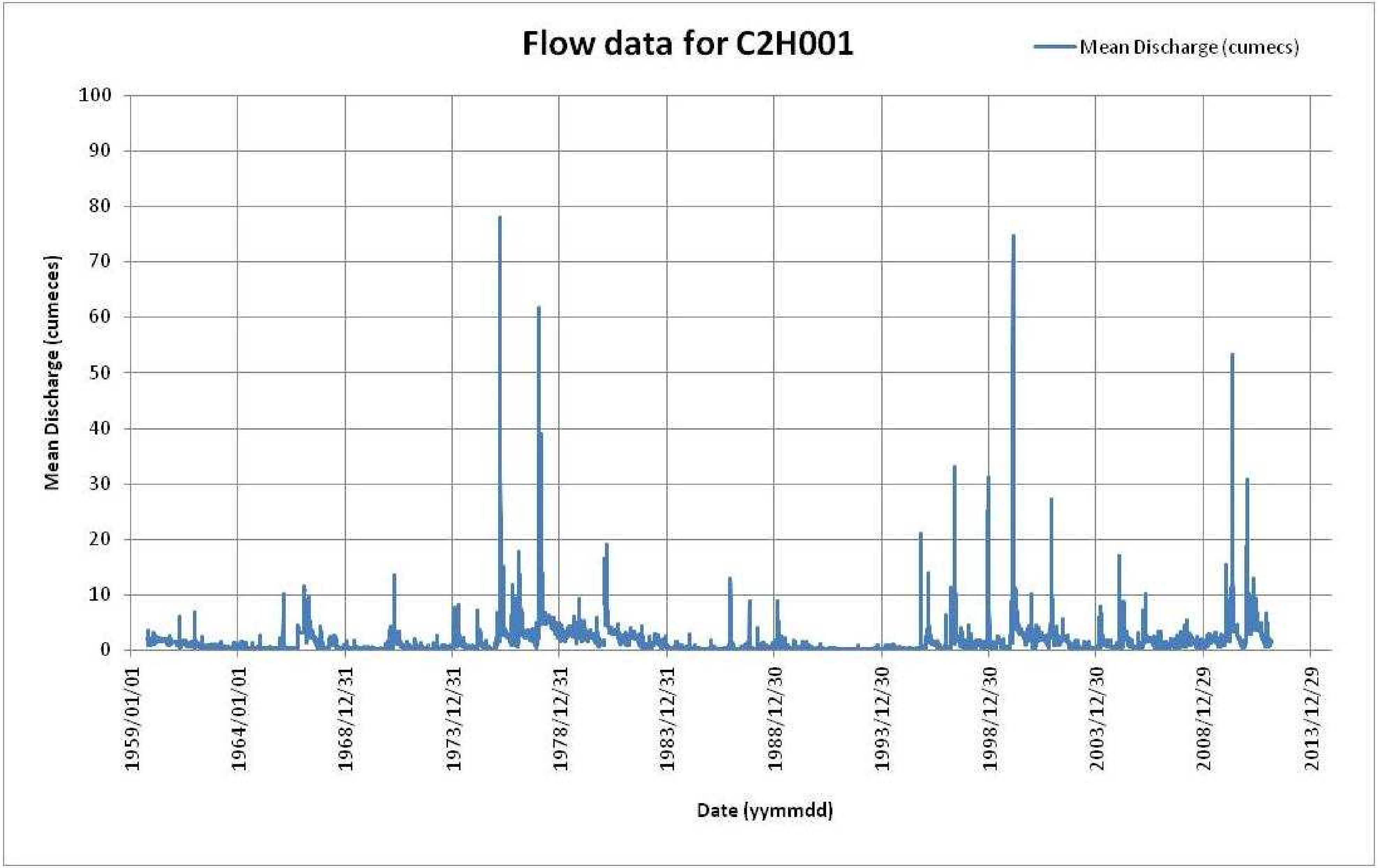

Figure 6-1: Flow data for flow monitoring station C2H001 in the Mooi River upstream of Potchefstroom Dam

6.2 Groundwater monitoring zones

Various zones were identified throughout the greater Ikageng to monitor the groundwater level for excessive fluctuations. These zones were chosen based on the following criteria:

- Underlying geology (mapping and boreholes)
- Indicated risk zones (geotechnical)
- Topography
- Residential areas

The zones are indicated in Figure 6-2 and are discussed below:

6.2.1 Northern region

The northern region stretches from south of the Eleaser Road to north of Chief Albert Luthuli Road and covers the entire dolomitic area between the roads. This area is mainly underlain by vast areas of dolomite (on which caves have been identified) with other geology on the fringes. Typical dolomite outcrops can be observed next to both roads (Photo 6-1).

This area is void of any development, but need to be monitored to establish a hydraulic connection between it and other dolomitic areas in the focus area.

Photo 6-1: Dolomite outcrop next to Eleaser Road showing solution channels.

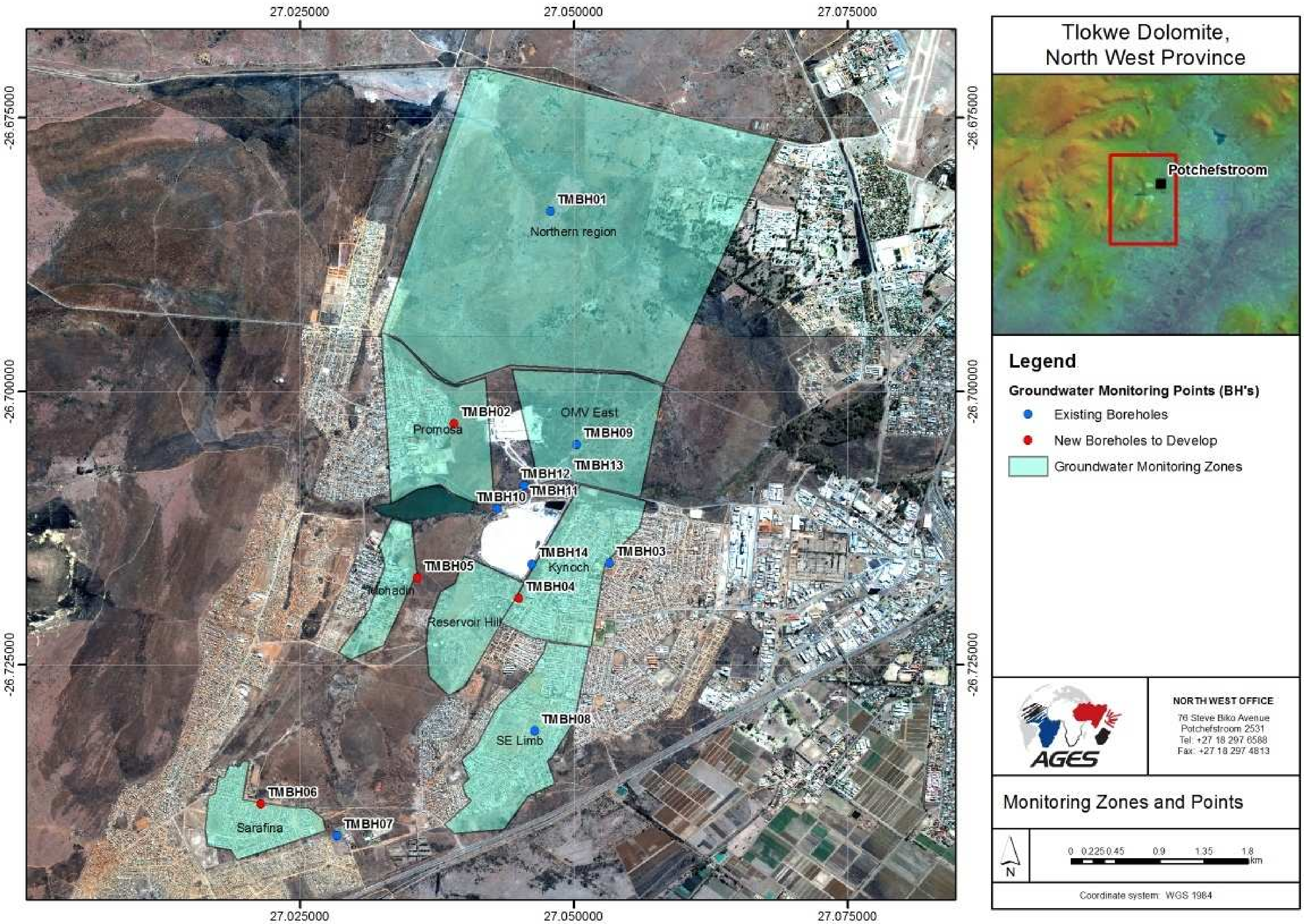

Figure 6-2: Groundwater monitoring zones and points for immediate implementation

A borehole was surveyed in this area that can be used as a monitoring point for the larger area. The borehole was equipped with a protective cap. Depth measurements of this borehole for the purposes of pump testing revealed that the borehole has an available drawdown in the order of a metre. The depth of the borehole is just more than a metre below the water table. This borehole needs to be deepened in order to give accurate monitoring results.

6.2.2 Promosa area

South of Chief Albert Luthuli Road (and north of Promosa Road) there are two groundwater monitoring zones demarcated: Promosa area to the west and OMV area to the east. The two are separated by the prominent ridge that lies between OMV and Promosa. It is possible that the two areas have separate geohydrological characters due to the ridge acting as a local water divide, although it was found that the hydraulic gradient in the underlying dolomite is independent of topography.

Promosa area includes the eastern portion of the residential area of Promosa, as well as the open space between the residential area and OMV's premises. It stretches from Chief Albert Luthuli Road southwards towards the dam. A geophysical survey was conducted in the open space east of the residential area in order to site a monitoring borehole (see 6.1).

6.2.3 OMV East

This area lies east of the OMV premises, north of Promosa Road and south of Chief Albert Luthuli Road. The whole of this area is underlain by dolomite but no residential development exists in this area. The only infrastructure belongs to OMV. Since the area is bounded to the south by the Klipspruit and the dolomitic springs are located on this zone, it is deemed important to monitor the water level fluctuations in this area in correlation to other areas. A monitoring borehole (BH10) located in this area is currently being used by OMV as part of their monitoring protocol. This borehole will be incorporated in the Tlokwe Monitoring Phase as TMBH9

6.2.4 Kynoch area

This area is so named since it is located between the old Kynoch factory and the Kynoch gypsum dump. It includes much of the residential area east of the Kynoch dump, but is limited by the extent of the (indicated) dolomite outcrop. Monitoring borehole BH18 used as part of the Kynoch groundwater monitoring project between 2002 and 2006 still exists and is capped with a locked borehole cap. It is uncertain what the condition of the borehole is at this stage (the cap could not be removed) but it is believed that this borehole can still be used for water level monitoring purposes (Photo 6-2). It is included as TMBH3.

Photo 6-2: Borehole BH18 located next to Boitirelo Primary School east of the Kynoch dump.

6.2.5 Reservoir hill

This area is so named after the reservoirs located on the hill in Ikageng. This area is characterised by the elevated topography and dolomite outcrops that can be observed to the north and west of the hill. Due to the elevated topography it is expected that the most notable water level fluctuations will occur in this area. Furthermore it is overlain by an informal residential area.

Water has been observed to disappear into the ground at dolomitic geology contacts near the reservoirs, indicating subsurface cavities. No water strikes have been recorded during geotechnical drilling, making it difficult to site groundwater monitoring boreholes.

The borehole at Boitshoko High School is proposed as a monitoring borehole in future once abstraction from this borehole has ceased. In the interim it is proposed to drill a new monitoring borehole near Boitshoko High School to serve as a monitoring point for this area. Due to the presence of magnetic interference, no geophysics were done in this area and it is proposed to drill a borehole where it is easily accessible for the drilling rig, and where it can be protected from vandalism.

6.2.6 Mohadin

Mohadin groundwater monitoring zone is located in the valley west of the Reservoir hill, and south of the dam. Mohadin residential area is only partly underlain by dolomite and therefore monitoring of groundwater levels is considered important. Due to the proximity of the area to the dam and its lower topographic elevation, the groundwater level is not expected to fluctuate much.

A geophysical survey east of Mohadin resulted in the siting of a monitoring borehole to be drilled and tested (see 6.1).

6.2.7 South eastern limb

This area refers to the eastern dolomite ‘limb’ that outcrops through central Ikageng towards the N12 highway to the south. Several geotechnical boreholes have confirmed the existence of dolomite in this area. The lower groundwater levels in the dolomite confirmed that this area is hydraulically separated from the dolomite in Ikageng proper. Monitoring in this area is considered important.

A monitoring borehole was drilled in the Lusaka Cemetery during November of 2011 into the highly weathered dolomite. The water level was measured at 23.6 mbgl after drilling and is being monitored monthly.

6.2.8 Sarafina

The southwestern portion of greater Ikageng is called Sarafina, and also partly underlain by dolomite. The occurrence of a recent sinkhole in the residential area has shifted the focus to this area. A geotechnical borehole was drilled at the house where the sinkhole occurred. This borehole intersected a five metre cavity at 19 m depth.

Several other geotechnical boreholes were drilled during 2011 throughout Sarafina as part of the project. Several had water strikes while others were dry. It is proposed to drill a groundwater monitoring borehole strategically where a known water strike has occurred.

6.3 Monitoring points

Within these abovementioned areas, certain critical points for immediate monitoring were identified. Existing boreholes that are able to be implemented as immediate monitoring boreholes were also considered (Figure 6-2). The boreholes are named as TMBH for Tlokwe Monitoring Boreholes. These are:

1. TMBH01: Existing seemingly abandoned borehole in the northern area with an open casing that was sealed with protective cap. This borehole will be tested for aquifer parameters.

- TMBH02: To be sited (geophysics) and drilled east of Promosa residential area. This borehole will also be tested.
- TMBH03: Old BH18 located next to Boitirelo School in Promosa Proper. This borehole is ready to be incorporated in the monitoring network.
- TMBH04: Borehole required near Boitshoko High School to cover the Reservoir Hill area south of the Tailings Dam. To be sited, drilled, tested and sampled during testing.
- TMBH05: East of Mohadin residential area.To be sited, drilled, tested and sampled during testing.
- TMBH06: To be sited in Sarafina, drilled and tested.
- TMBH07: Existing borehole in Eskom substation premises next to Ikalafeng Special School. This borehole was made available by Eskom for monitoring and has been capped.
- TMBH08: Newly drilled borehole in Lusaka Cemetery. This borehole was capped and tested for aquifer parameters. Transmissivity exceeds 1240 m^2/d.
- TMBH09: This borehole is part of the OMV monitoring network, but does not correspond to any of the boreholes on record. The nearest borehole on record is BH21 located some 200m to the north. This borehole is available for the Tlokwe Monitoring Network.

- TMBH10: Old BH4 northwest of the Tailings Dam. This borehole is capped and ready for use. Already being monitored by OMV. Capped and ready for use.
- TMBH11: Old BH3 north of the Tailings Dam, already part of the OMV monitoring network. This borehole must be tested while the surrounding boreholes will be used as observation boreholes. Capped and ready for use.
- TMBH12: Old BH10, this borehole is located just north of TMBH11 and part of OMV's monitoring network. Already capped and ready for use.
- TMBH13: This is the old BH11 located north of Promosa Road and is also part of the OMV network. Capped and ready for use.
- TMBH14: Old BH8 on the eastern flank of the tailings dam. This borehole is also sampled by OMV as part of the monitoring. It was found that the groundwater seepage from the tailings dam triggers the electrical contact of the dipmeter even above the water level. By increasing the resistance of the dipmeter, the water level can accurately be measured.

6.4 Monitoring protocol

6.4.1 Parameters

Parameters that need to be monitored are quantity (water level) and quality related.

6.4.1.1 Water levels

Water level fluctuations of more than six metres are conducive to ground instability in dolomitic terrains (see Appendix A). The aim is to use excessive water level fluctuations as an early warning system for possible subsidence. A fluctuation of more than five metres will be seen as an early warning sign. Monitoring the correlation between water level fluctuations in different zones can also shed light on the groundwater interaction in the area.

6.4.1.2 Water quality

Water quality needs to be monitored since water quality ultimately is responsible for the dissolution of carbonaceous rocks (dolomite). Although it is not anticipated to reflect any short term changes in water quality the influence of possible pollution sources need to be monitored over a longer term.

In this regard the KGTD and OMV need to be monitored as per the licence conditions. It is advised to compare the monitoring protocol with the suggested protocol for monitoring water quality at hazardous waste facilities (DWA, 1998a, c).

Since possible radiological contaminants were found to be associated with the KGTD, the monitoring protocol should include radiological parameters.

Furthermore the currently monitored boreholes around the KGTD must be profiled through EC-logging to determine whether any water strikes can be observed or stratification of the groundwater exists. This must be incorporated in the monitoring protocol to ensure a true reflection of the groundwater status quo.

It is important that OMV's quarterly monitoring results of surface and groundwater quality be made available to TCC as part of the DRMP.

6.4.2 Frequency

Water levels in the monitoring network should preferably be monitored on a monthly basis and data correlated with rainfall events. Continuous rainfall data from the Potchefstroom weather station must be obtained to compare with water level fluctuations.

Water quality is currently being monitored by OMV in boreholes concentrated around the Tailings Dam on a quarterly basis. The frequency must be compared to the protocol suggested as minimum requirements by DWA (1998a,c).

6.5 First water level monitoring runs

AGES's North West (Potchefstroom) office has been monitoring the existing proposed monitoring boreholes since October 2011. The data are included in Table 6-1.

Table 6-1: New Tlokwe Water Level Monitoring 2011/12

Water Level data										
Date	TMBH01	TMBH03	TMBH07	TMBH08	TMBH09	TMBH10	TMBH11	TMBH12	TMBH13	TMBH14
2011/10/20	8.60				11.95	7.80	6.40	7.30	3.05	
2011/11/11			6.75	24.70						
2012/01/31										29.70
2012/02/15				24.4						
2012/02/21		10.35	5.85	24.10	12.30	7.80	5.47	6.60	2.99	29.60
2012/03/27	8.80	10.64	5.86	24.01	11.80	7.80	5.50	7.34	3.07	29.69
2012/05/11	8.74	11.35	5.92	24.11	12.21	7.95	5.61	7.45	3.10	29.67
2012/06/08	8.66	11.74	6.06	24.29	12.22	7.97	5.69	7.52	3.10	29.67
2012/07/04	8.73	10.81	6.22	24.49	12.23	8.16	5.76	7.58	3.11	29.85
2012/08/01	8.77	11.92	6.40	24.67	12.23	6.96	5.83	7.91	3.15	29.95
2012/08/31	8.70	11.71	6.56	24.78	12.25	8.3	5.91	7.71	3.20	30.06

From the data it can be seen that the groundwater level rose during the rainy season in all of the existing monitoring boreholes except for TMBH09. The reason might be that this borehole is located directly east of the OMV abstraction borehole and might show a slight influence caused by the abstraction of groundwater from the OMV borehole. Although TMBH12 is located closer to the OMV borehole, this borehole does not seem to be affected by the abstraction.

During March the water levels in all of the monitoring boreholes started dropping after the rainy season. This trend was confirmed in the monitoring run of May 2012. The fluctuations are however small when depicted on a graph (Figure 6-3).

6.1 Geophysical profiles to site new boreholes

Two geophysical profiles were surveyed in order to site monitoring boreholes east of Promosa (TMBH2) and Mohadin (TMBH5) respectively. The profiles consisted of magnetic and resistivity survey lines. The geophysical study was done to detect possible water bearing zones which could be zones representing groundwater movement and could therefore be regarded as water level monitoring zones. The geophysical study could also give an indication of the integrity of the geology in general.

Two traverses were surveyed. Traverse 1 to cover the eastern part of Promosa in the direction in which groundwater will flow towards the surface water dam. Traverse 2 to cover the eastern part of Mohadin. The geophysical methods used for the survey are explained below.

Magnetic survey

The magnetic survey consists of a series of measurements taken by a magnetometer at closely spaced intervals. This method is used to detect any magnetic subsurface anomalies that might be caused by the existence of or geological contacts or faults in magnetic material such as dykes or sills. This method is however also susceptible to surface magnetic interference caused by metals or electromagnetic disturbances caused by electrical wiring.

Resistivity survey

This method consists of the measuring of the apparent resistivity of the subsurface by generating an electrical current via two electrodes that is put in the ground, and measuring the potential voltage difference between two potential electrodes. Readings reflect the apparent resistivity of the subsurface in the middle of the two potential electrodes, at a depth determined by the spacing of the electrodes. Anomalies give indications of subsurface geological structures.

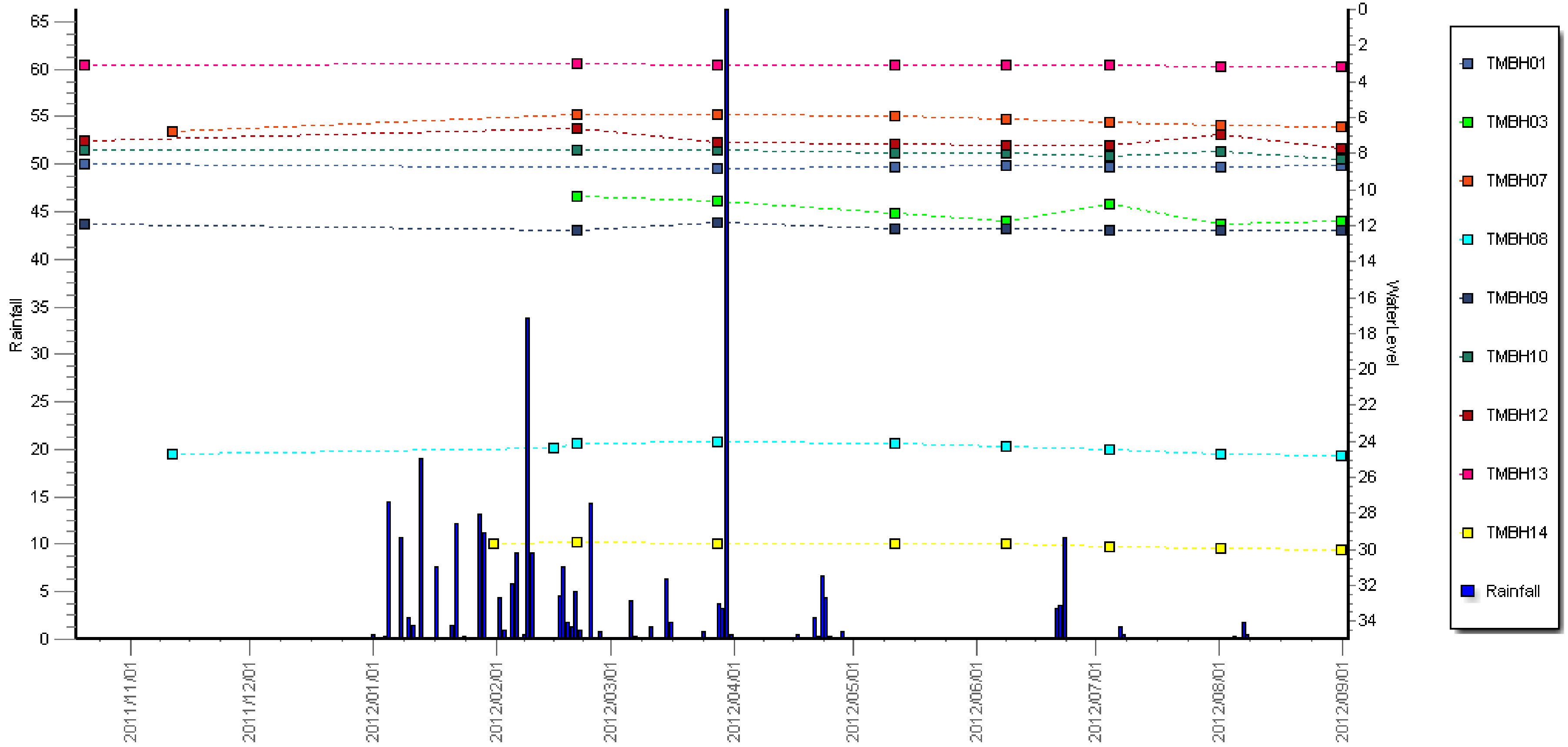

Figure 6-3: Latest water level fluctuations in Ikageng compared to rainfall

Figure 6-4: Traverse 1 east of Promosa

Figure 6-5: Traverse 2 east of Mohadin

Traverse 1 was done from the northern side of the area which is located east of Promosa. The traverse was done perpendicular to the possible geological feature. This geological features which can act as preferred groundwater ways and which can act as a transfer route for contaminants towards the river systems and would be ideal to see changes in water level prematurely. Travers 1 is 400 metres in length and covers the eastern part of Promosa. Travers 1 was stopped at the topographical low area. The area that needs to be monitored is Promosa. The borehole needs to be sited as close to the houses as possible.

Traverse 2 was done from the northern side of the area which is located east of Mohadin. It was difficult to identify a traverse position because of the power lines in the area. The traverse was done to identify the contact between the dolomite and neighbouring lithology, targeting the more weathered area. Travers 2 is 200 metres in length and covers the eastern part of Mohadin. Travers 2 was stopped at a topographical high.

Conclusions and Results

Traverse 1: The magnetic and resistivity methods show an anomaly at 65 metres that can be linked to a geological feature east of Promosa. Intrusive magnetic or conductive structures could be positively identified during the geophysical study. Preferred groundwater route could be detected by the geophysical study. The borehole was sited at 65 metres where an anomaly was encountered from 50-80 metres in the magnetic survey. The resistivity survey showed very low resistance at the same position. From 180 -200 metres the graph show no data this is due to the presence of power lines.

Traverse 2: The magnetic and resistivity methods show a possible contact between the dolomite and neighbouring lithology at 100 metres. The possible contact could be positively identified during the geophysical study. The borehole was sited at 100 metres where very low resistance was encountered in the resistivity survey. This could indicate the contact between the dolomite and shale that is highly weathered.

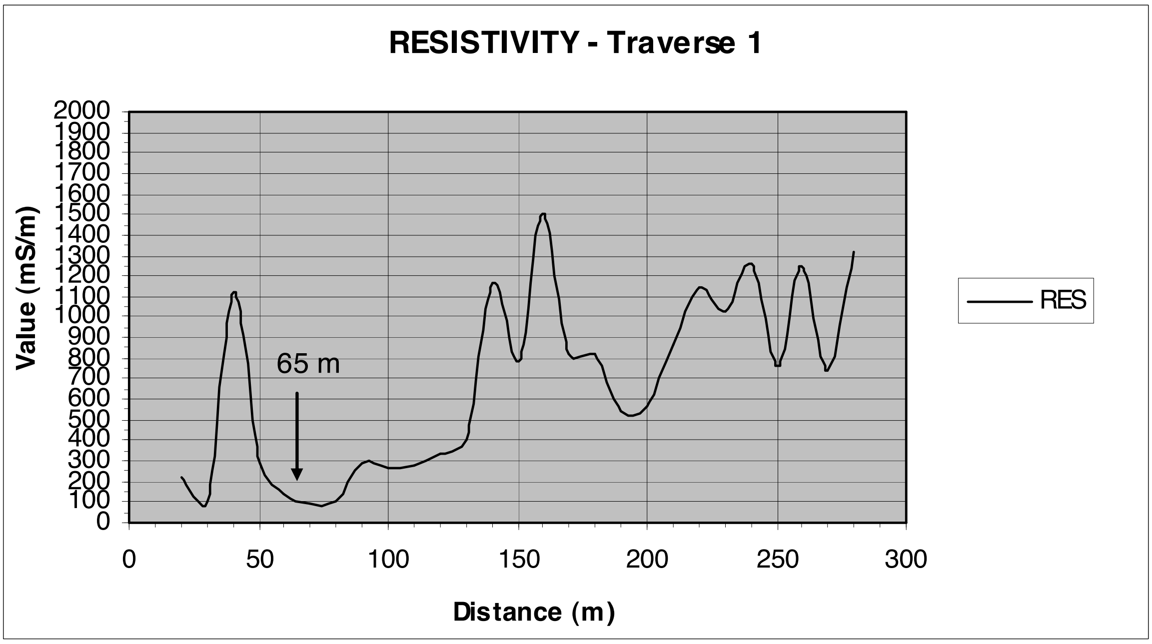

Figure 6-6: Resistivity profile of Traverse 1

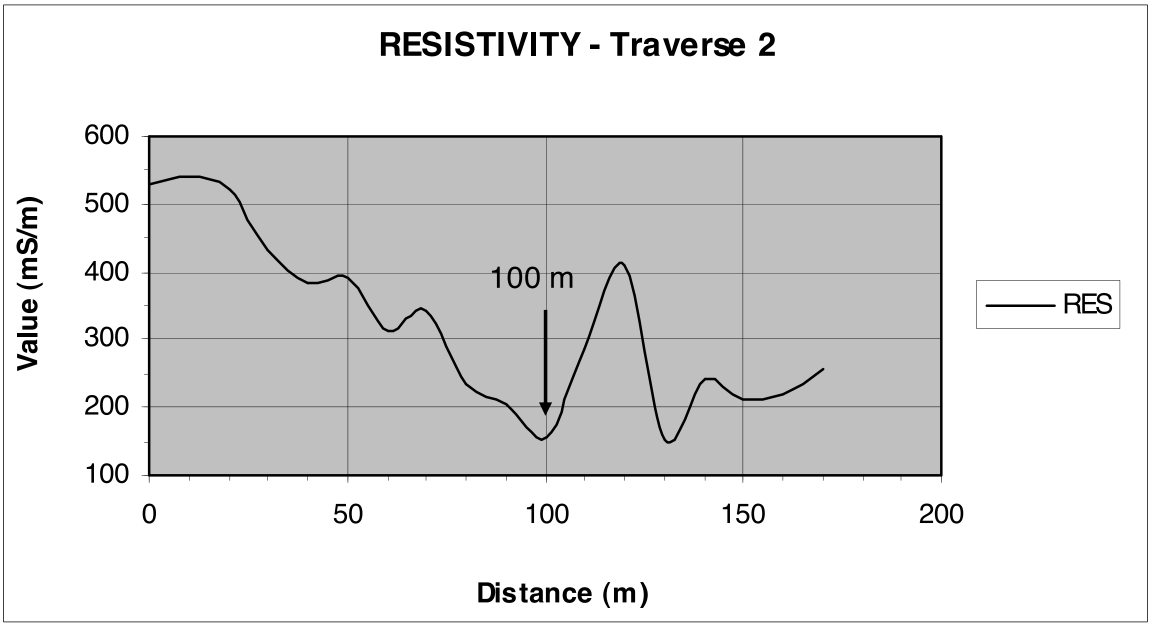

Figure 6-7: Resistivity profile of Traverse 2

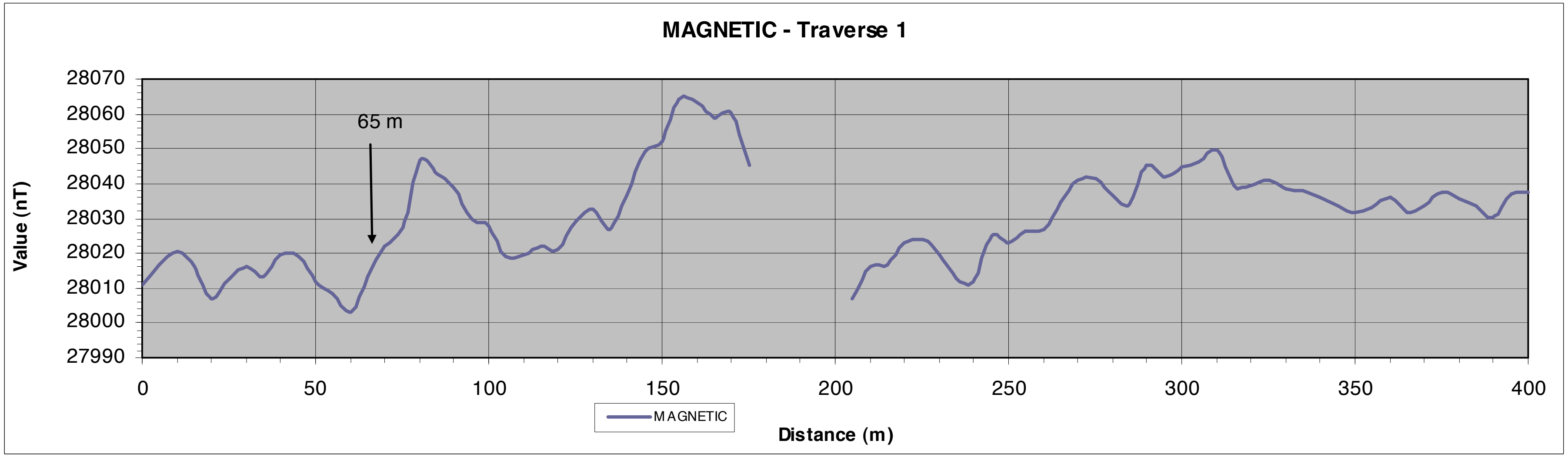

Figure 6-8: Magnetic profile of Traverse 1

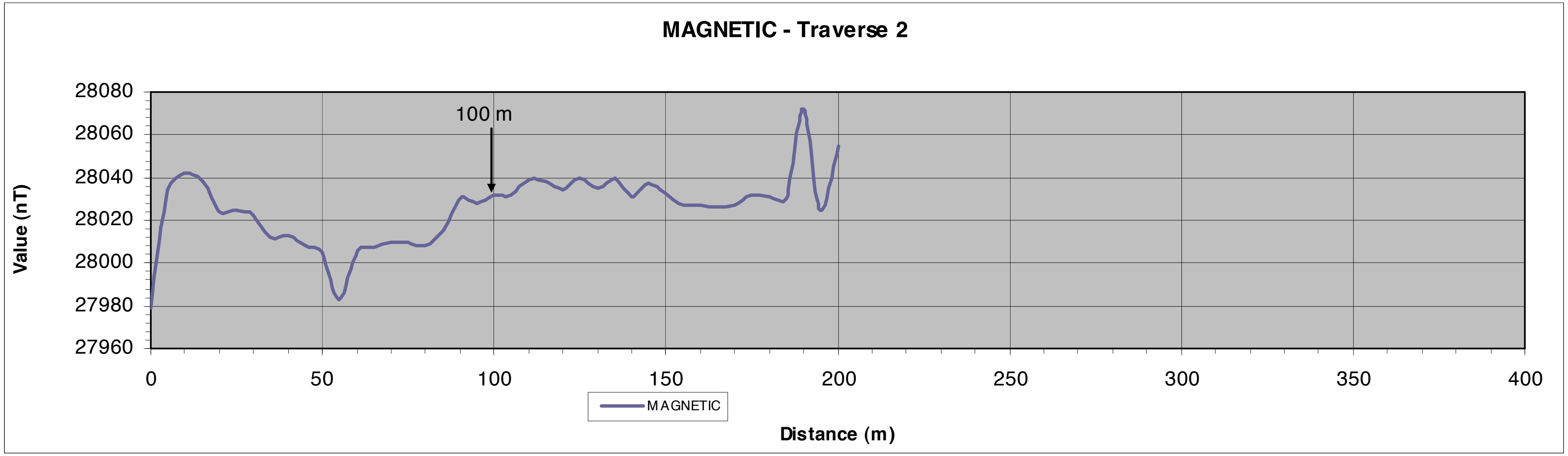

Figure 6-9: Magnetic profile of Traverse 2

7 SUMMARY AND CONCLUSIONS

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 FWR. The direct link between groundwater fluctuations and sinkhole formation was then realised.

Since sinkholes in residential areas can lead to injury and loss of life, the management of the associated risk on dolomite is important. Groundwater (geohydrology) therefore forms an integral part of the Dolomite Risk Management Plan (DRMP).

The geohydrological character of the focus area is not independent of the regional geohydrology of the areas surrounding it. Therefore the Welgegund GMA 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:

Karst Type (dolomite) aquifer	**Intergranular/Fractured Type aquifer**
High groundwater potential	Low to medium potential
High Transmissivity	Low Transmissivity
High yielding boreholes (5-20 L/s)	Low to medium yielding boreholes (<5 L/s)
Shallow (flat) hydraulic gradient	Steeper, more defined hydraulic gradient
Major Aquifer	Minor Aquifer

Groundwater use in the area consists of agricultural, industrial, mining related and domestic use. 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. The hydraulic gradient was found to be flat in the dolomite, signifying high permeability. 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.

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 flags

Quantity flags have to do with the addition (ingress) or abstraction of groundwater. 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 tailings dam. Not only can the groundwater abstraction from the Boitshoko borehole create daily 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, but monthly monitoring of the quality is recommended. It is further 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 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 TCC engage with DWA on the licensing of this use, and ensure that proper steps are followed and the necessary studies are done.

Although located off the dolomite, Potch-Industria has been included in the critical zone due to the large scale water use associated with industrial use. Several boreholes have been identified in this area prior to 2003, but the use has not been verified. The current use must be verified, as well as the possible combined 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.

Since any ingress of water into underground cavities can lead to sinkhole formation by the erosion of weathered material overlying cavities, these flags was highlighted. Seepage from the KGTD unto the underlying dolomite aquifer is believed to take place, although at an unknown rate. The tailings dam was designed to limit runoff and can be seen as a perched aquifer from which water either evaporates, seeps out horizontally or vertically into the dolomite. This flag needs to be investigated further.

Similarly seepage can occur from old infrastructure like reservoirs and water supply, sewerage and storm water pipelines. For this reason old residential areas with older infrastructure overlying high risk zones must be investigated for leakages. Leakages have been observed from the old Sonderwater reservoirs. It is unclear whether any leakages occur from underneath the reservoirs, but this can be determined by installing flow meters on the inlet and outlet pipes, and reconciling the volumes.

Lack of storm water management and ponding of water in the critical zone, especially on high risk dolomitic areas are raised as a flag to be further investigated. The Sarafina sinkhole can partly be attributed to the ponding of water. In this regard it is recommended that the areas be inspected for water ponding after heavy rains. Areas where excessive ponding occurs can be rectified by implementing proper storm water management.

Quality

The Kynoch Gypsum Tailings Dam was identified as the main and an important quality flag in the area. This dam still contains highly polluted water that seeps out into the surface water bodies north of the dam, or into the underlying aquifer. 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.
- 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 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 to flow from the Gerhard Minnebron once gold mining on the FWR ends and dolomite dewatering ceases, 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 EIA's containing specialist geohydrological investigations that consider the impact on the focus area and the critical zone dolomites.

8 RECOMMENDATIONS

8.1 Completion of monitoring borehole network

The proposed monitoring boreholes still to be drilled must be sited, drilled and tested for aquifer parameters. They must be equipped with lockable borehole caps and incorporated into the monitoring network.

8.2 Groundwater abstraction

The abstraction of groundwater from Boitshoko High School must be replaced with municipal water supply. This borehole can also be incorporated into the monitoring network. In the interim the quality of groundwater from this borehole must be monitored on a monthly basis to detect possible pollutants from the KGTD that the pupils might be exposed to.

The groundwater abstraction by OMV as a flag situation on dolomite must be assessed; either by ascertaining whether a geohydrological study was conducted to investigate the impact of the abstraction on the aquifer, or by requesting a similar investigation to be conducted.

8.3 Municipal bylaws

A borehole moratorium must be placed in the critical zone by issuing a bylaw, restricting the drilling of new abstraction boreholes. New boreholes must be approved by the TCC after comparing the proposed location with the dolomite risk zone map, and the proposed yield of the boreholes. New boreholes must be registered on the TCC borehole database.

8.4 Kynoch Gypsum Tailings Dam

As a major flag from a groundwater quality perspective, the impact of the Kynoch gypsum tailings dam on the underlying aquifer needs to be defined in more detail. Therefore the following needs to be addressed as a separate phase:

- Obtain and interpret monitoring reports from OMV.
- EC logging of the monitoring boreholes.
- 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 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.
- Perform a detailed water balance on the KGTD.
- Interpretation and risk quantification.

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10 APPENDIX A: KARST GEOLOGY

Karst as a term refers to a style of landscape containing caves and extensive underground water systems that is developed on especially soluble rocks (limestone, gypsum, dolomite etc.) (Ford and Williams, 2007). Dolomite as a karst forming rock type will be discussed in more detail.

10.1 Origin and character of dolomite

Dolomite as a term refers to both the mineral and the rock type. The rock type consists of the minerals dolomite ($CaMg(CO_3)_2$) mixed with calcite (calcium carbonate, $CaCO_3$) and magnesite (magnesium carbonate, $MgCO_3$) in various ratios (Wagener, 1984).

Dolomite is a chemical sedimentary rock, formed by the accumulation of precipitated dolomite, or skeletal remains of small marine organisms.

Dolomite is tested for in the field by applying a few drops of acid to the rock. It is readily dissolved by acid and the dissolution process of dolomite (or other carbonate rock types) can be observed physically. It is this dissolution process that led to the development of underground cavities. These cavities when close to the surface can collapse under certain conditions to form sinkholes and other forms of subsidence. The effects of sinkholes on dolomite can be more devastating than other rock types in South Africa (Brink, 1996).

- The following karst features give rise to problems in towns and related infrastructure development (Brink, 1996):
- The development of sudden and catastrophic sinkholes (a subsidence that appears suddenly as a cylindrical and steep-sided hole in the ground)
- Gradual subsidence of the surface during the formation of dolines (a surface depression which appears slowly over a period of years)
- The occurrence of highly compressible WAD frequently present in dolomite

Sinkholes and dolines occur as a natural feature within karst areas, but the occurrences thereof is advanced through human interference as indicated by the sinkhole development in urban areas as from the early sixties in the Witwatersrand area.

10.2 Groundwater and cave formation

Some 750 caves occur in the Transvaal basin. This is 80% of all the caves known in South Africa. It is stated that of these 750, most occur in a stretch between

Pretoria and Potchefstroom. Apparently the largest known cave system in South Africa is located in this area: A cave north of Carletonville known as Apocalypse Pothole contains passages that have been mapped for over 20km (Jacobs, 2011).

Most of the caves in the area are fissure caves which are strongly controlled by jointing. Fissure type caves in the Far West Rand (FWR) formed in a horizontal zone 40 m above the natural water table. Many of the fissure type caves stretch horizontally across several stratigraphic layers, leading to the conclusion that their origin is of phreatic (groundwater) origin (Martini and Kavalieris, 1976and Martini, 2006). Other than fissure caves thought to be controlled by water table fluctuation, large cavities have been reported below the water table. In the case of Bushmansgat between Kuruman and Daniëlskuil, the cavity extends to 265 m below the water table (Martini, 2006).

The traditional theory on cave formation is that low concentrations of CO_2 dissolved in rainwater to form a weak carbonic acid that percolated into the ground to slowly dissolve carbonate rocks like dolomite. The presence of flow stones like stalactites decorating the roofs of caves shows that rainwater quickly becomes oversaturated in calcium carbonate, and precipitates minerals dissolved in the vadose zone. The ability of weakly acidic rainwater to dissolve solid carbonate bedrock is therefore quickly neutralised. Taking this into account it is therefore clear that the movement and chemistry of groundwater strongly influenced cave formation in the past.

Recent studies suggest that at least 10% of the caves in the Guadalupe Mountains in Texas and New Mexico were formed primarily by sulphuric acid in groundwater. This includes the famous larger caves like Carlsbad Caverns and Lechuguilla Cave. The hypothesis is based on the discovery of reaction products of sulphuric acid dissolution in the caves which includes elemental sulphur, gypsum, hydrated halloysite, allunite and other minerals. Based on this it is further thought that 10% of major known caves around the world were formed this way. (Polyak et. al, 1998, Oard, 1998).

10.3 History of mining related sinkholes in South Africa

One of the most expensive environmental lessons learned in South Africa had to do with the link between groundwater occurrence and sinkhole formation.

Gold was initially discovered in the Witwatersrand where the gold bearing conglomerate layers (called 'reefs') outcrop on surface. The outcrops have a regional east-west strike, dipping to the south. As the early prospectors and miners followed the southerly dipping reef, depth of mining increased up to a point where vertical shafts had to be sunk further south to develop haulages below the reef horizons. The reasoning was practical: freshly mined gold ore from the southerly dipping stopes could be gravity fed into the haulages from where it was easily transported to the shaft.

As mining continually ventured deeper, the first outcrops of the water bearing Malmani dolomite were encountered on surface. This presented a problem for shaft sinkers since any vertical shaft development had to deal with the dangers of intersecting subsurface fractures, joints and even cavities that were filled with water under enormous regional hydraulic pressure. Much like the hydrostatic pressure in a water strike within a surface borehole drilled on the dolomite would cause the intersected groundwater to push up into the borehole from the fracture; water intersected during shaft development caused the shafts to be flooded.

It was not until the 1930's when a new technique (called 'cementation') was developed to seal off any water bearing fractures that a shaft was successfully sunk through the Malmani dolomite and underlying Ventersdorp lava into the Witwatersrand rocks (Winde and Stoch, 2010). This enabled mines to sink shafts even further south to mine at even deeper levels.

Groundwater contained in the Malmani dolomite in great volumes still managed to percolate through cracks and joints into the newly developed mining voids. Gold mines were again faced with the risk of flooding, and groundwater entering the mining voids had to continually be pumped out to surface. This increased production costs which lead to the decision to dewater the overlying dolomite compartments from above rather than risk lives and production underground by escalating groundwater influx.

A four year environmental impact study was conducted after West Driefontein Gold Mine sought permission from the Government to dewater the overlying dolomite compartment. Permission was finally granted in 1964 to dewater two compartments by pumping out more water than the volume needed to recharge the compartment (while in fact mines commenced with dewatering some years before). The environmental study only predicted the drying up of springs and production boreholes located on the dolomite compartment, and failed to foresee the development of thousands of sinkholes located on the dolomite, some with catastrophic results: A sinkhole swallowed the crusher plant at West Driefontein Gold Mine in December of 1962 in which 29 people were killed, and in 1964 a family of five died when their house disappeared down a sinkhole in

Blyvooruitzicht village (Winde and Stoch, 2010).

Studies into the ground instability experienced which lead to the loss of lives linked sinkhole formation directly to the dewatering of the dolomite compartments (Jennings et. al, 1965 as cited in De Bruyn et. al, 2000).

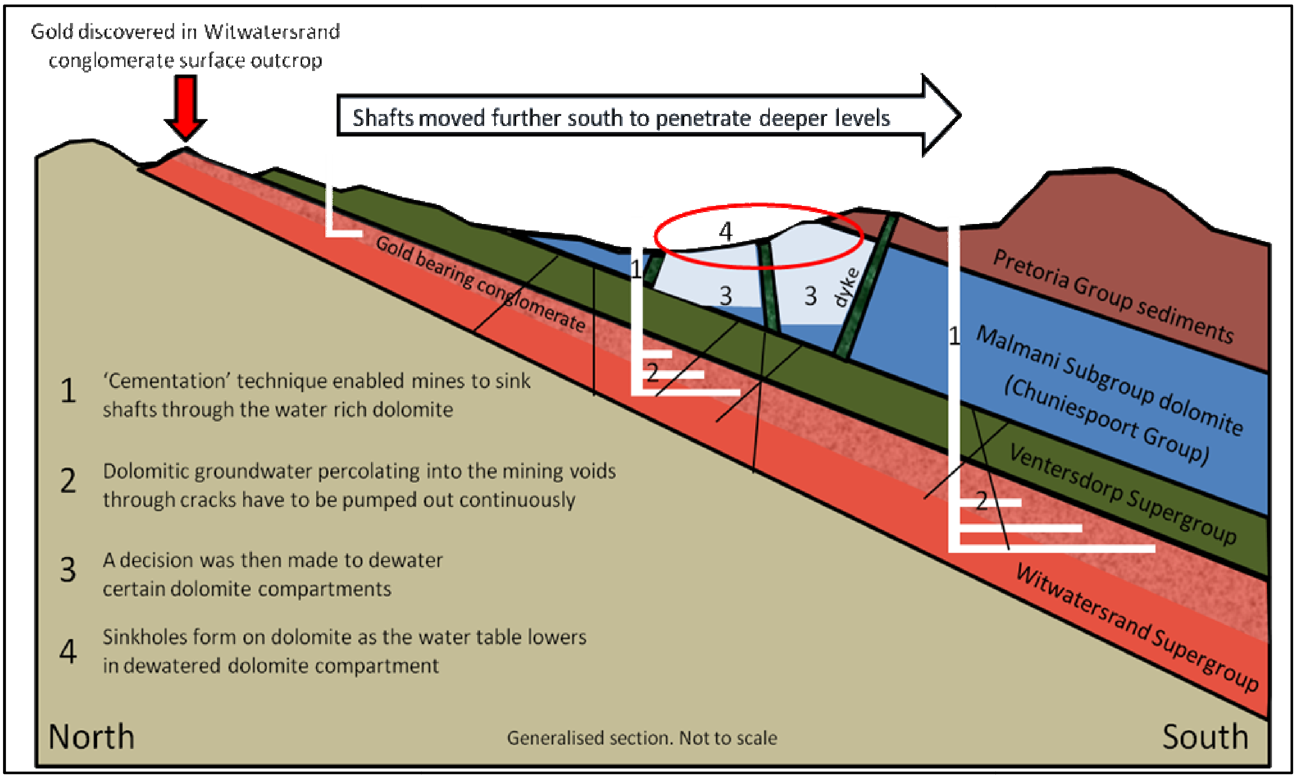


Figure 10-1: Schematic cross section indicating mining related compartment dewatering and subsequent sinkhole formation

10.4 Natural sinkhole formation

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 too great or the material too 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 30 m of the surface.
- The topography should consist of steeply incised valleys underlain by well-jointed, shallow, soluble bedrock. (The topography of the majority of the Malmani dolomite on the FWR is relatively flat).
- 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 initiate 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 characterised 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 paleo-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 blown/washed into the sinkhole. Palaeo karst structures contribute to the heterogeneity 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 paleo-karst features that were later partially filled with transported (gravel) or collapsed material (GeoCon, 2003).

From diagram 1 (Figure 10-2) it can be seen that the cavity (c) within the dolomite

(d) enlarges as water saturates (w) the residual soil zone (s). In diagram 2 the water causes erosion of residual soil into the cavity, which creates a similar collapse of residual soil overburden (diagram 3) until eventually a sinkhole appears (diagram 4) which can lead to increased erosion.

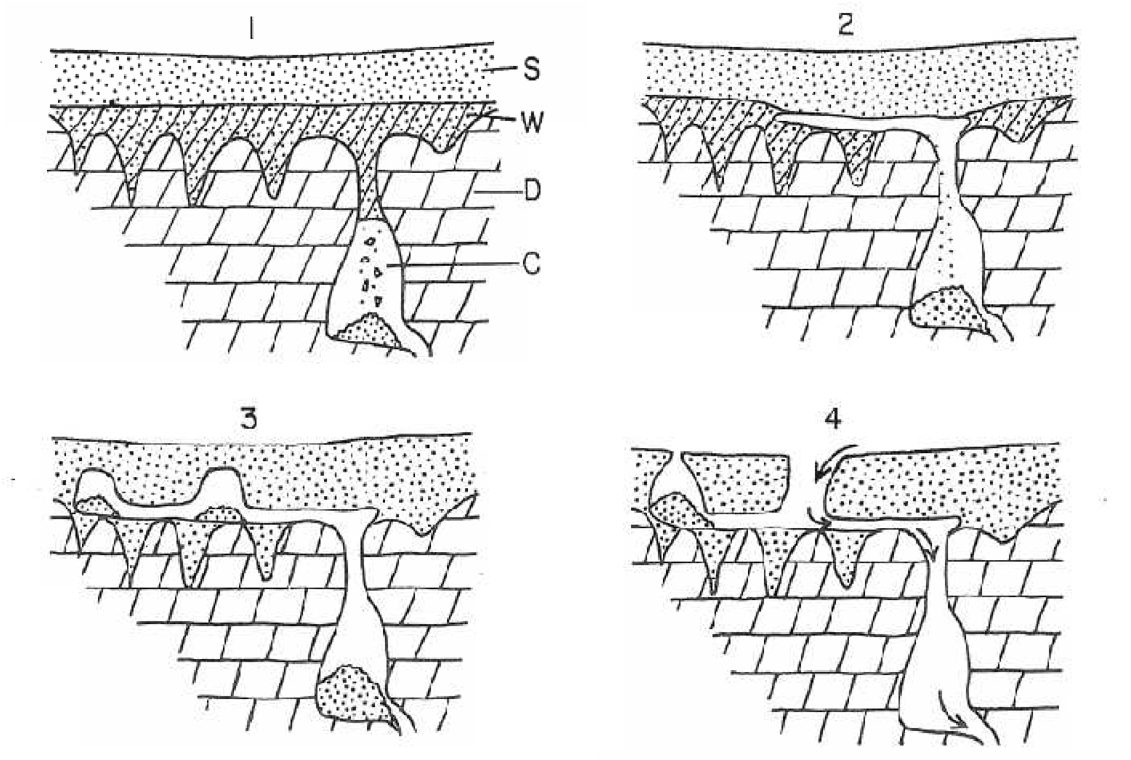


Figure 10-2: Diagram illustrating sinkhole development (Martini and Moen, 1996)

10.5 Induced sinkhole formation

10.5.1 Dewatering

There are three apparent (interconnected) methods 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 (Martini and Moen, 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 (see diagram)

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; DWA, 2006).

From a dolomite stability perspective in Ikageng it is therefore not only important to determine the scope and extent of subsurface cavities, 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.

10.5.2 Water ingress from old infrastructure

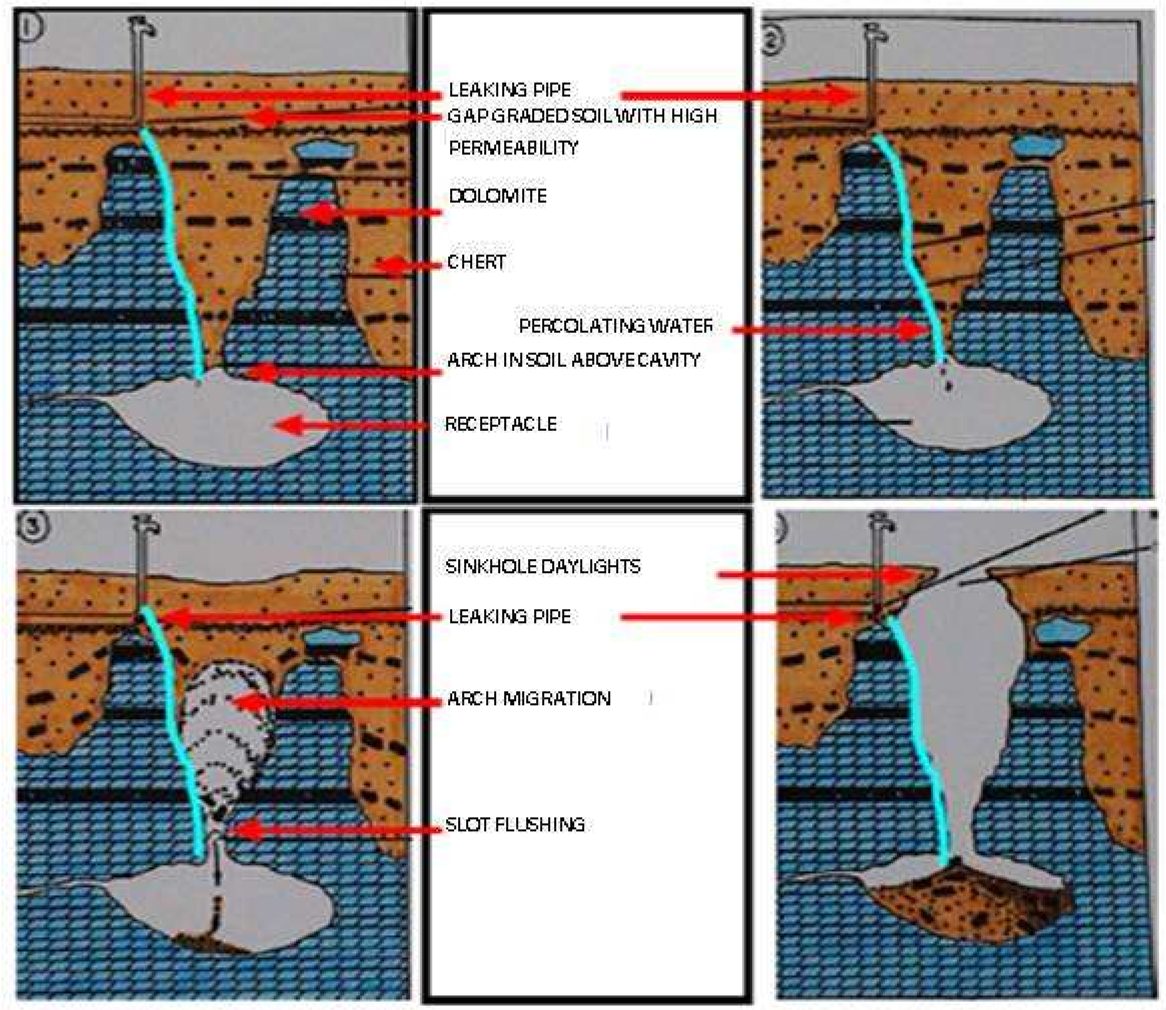


Figure 10-3: Subsoil erosion of dolomitic ground by leaking water infrastructure.

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 and 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 10-3 by the Department of Public Works (2003):

10.5.3 Ponding of water

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 erosion of weathered material as described above. It has been documented that sinkholes form due to the ponding of water. One of the identified sinkholes in Ikageng, the Sarafina sinkhole, can be attributed to this process.

10.6 Evidence of heterogeneity in the study area

There is some evidence of heterogeneity in the dolomite within the study area. This could be seen as sinkholes and cavities as well as variation in the character of the dolomite. The detail evidence is described in AGES (2010b). A few examples include:

- Drilling logs show heterogeneous ground conditions
- Sinkholes in the study area have been identified
- Variation in character of dolomite outcrops

11 APPENDIX B: LEGAL FRAMEWORK

Several laws in South Africa are applicable to development on dolomitic land, and groundwater abstraction from dolomite aquifers.

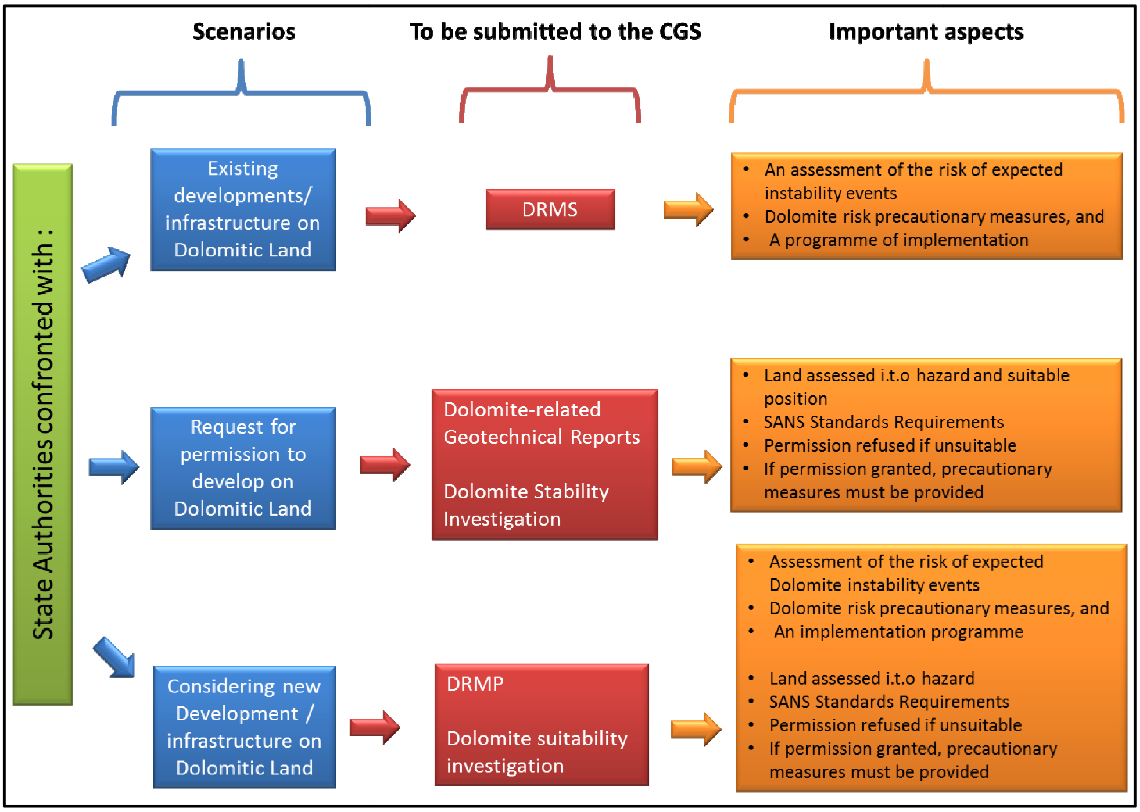
11.1 Constitution of South Africa

According to the Constitution of South Africa (Act 108 of 1996), the local authority has a responsibility towards the health and safety of its inhabitants:

> Section 24 states: "*Everyone has the right to an environment that is not harmful to their health or well-being"*
>
> while section 152 (1)(d) states that *"the objective of local government is to promote safe and healthy environments"*

This is confirmed by the Local Government Municipal Systems Act (No. 32 of 2000, Section 11(3) where the Council of a municipality "… *has the duty to … (l) promote a safe and healthy environment in the municipality*".

The Geoscience Amendment Act, 16 of 2010, more directly addresses the responsibility of the state authority with areas underlain by dolomite in three scenarios indicated in Figure 11-1. Depending on the situation, documents must be submitted to the CGS for advice to minimise the risk of dolomite instability



events.

Figure 11-1: Geoscience Amendment Act requirements for development on dolomitic land

The responsibility of the local authority is addressed in Chapter 4 of the Geoscience Amendment Act (2010) where it states:

- *"All State authorities that are directly considering* ***development or infrastructure of their own on dolomitic land****, must prior to authorisation for development, submit to the Council for Geoscience an appropriate* ***Dolomite Risk Management Strategy*** *for advice to minimise the risk of dolomite instability events occurring;*
- *All State authorities that are* ***approached for permission to develop*** *on* ***dolomitic land*** *under their jurisdiction must, to minimise the risk of dolomitic instability events occurring, ensure that the relevant* ***dolomite-related geotechnical reports*** *(in terms of the guidelines in Annexure E) are submitted to the Council for Geoscience for review and evaluation prior to authorisation by the relevant state authority for development;*
- *All State authorities that have* ***existing developments or infrastructure*** *of their own* ***on dolomitic land*** *shall develop and submit to the Council for Geoscience an appropriate* ***Dolomite Risk Management Strategy*** *for advice, to minimise the risk of dolomite instability events occurring"*

The Tlokwe Local Municipality has a combination of all three scenarios in different areas and it is of critical importance that all will be addressed whilst complying with the requirements indicated in Figure 11-1.

A Dolomite Risk Management Strategy for the Regional Project area, indicated in **Error! Reference source not found.**, must be submitted to the CGS. There will be legal liabilities in terms of the following acts as stated in Volume 1 (AGES, 2010b):

- The Occupational Health and Safety Act (Act 85 of 1993)
- Section 12 of Act 95 of 1998 (NHBRC)
- Act 103 (1977) National Building Regulations
- SANS 10400-B

11.2 Special Reference to the National Environmental Management Act

In the principles of chapter 1 of the National Environmental Management Act (NEMA), 107 of 1998, section 2(2) it states that environmental management must place people and their needs at the forefront.

The term environment refers to humans and the surroundings within which we live and co-exist and that is made up of among other the land, water and atmosphere of the earth and the inter-relationship between them. When applying environmental management to dolomite, it must be noted that dolomite as a rock is not managed, but rather the behaviour and activities of people that may affect dolomite (especially when it comes to geohydrology). Environmental management is therefore directed at regulating or directing the behaviour of people in a given society through a legal framework. Where dolomite and related uncertainties are concerned, the Precautionary approach is followed.

11.3 Special reference to the National Water Act

In Chapter four of the National Water Act (Act 36 of 1998), the usage of water based on abstraction from resources whether from underground or above ground are explained. This is particularly significant when dolomite occurs in the region due to the good groundwater potential associated with dolomitic aquifers. In Subsection 1 below, the act defines the way the public may use water.

Subsection 1:

A person may only use water - (a) without a license -

(i) If that water use is permissible under Schedule 1;

- *(a) Take water for reasonable domestic use in that person's household, directly from any site, water resource to which that person has lawful access;*
- *(b) Take water for use on land owned or occupied by that person, for ...*
- *(c) Store and use run-off water from a roof;*
- *(d) In emergency situations, take water from any water resource for human consumption or fire fighting;*
- *(e) For recreational purposes and;*
- *(f) Discharge*
  - *a. Waste or water containing waste; or*
  - *b. Run-off water, including storm water from any residential, recreational, commercial or industrial*
  - *c. Into a canal, sea outfall or other conduit controlled by another person authorised to undertake the purification, treatment or disposal of waste or water containing waste, subject to the approval of the person controlling the canal, sea outfall or other conduit.*

(ii) If that water use is permissible as a continuation of an existing lawful use;

or

(iii) *If that water use is permissible in terms of a general authorisation issued under section 39; (b) if the water use is authorised by a licence under this Act; or (c) if the responsible authority has dispensed with a licence requirement under subsection (3).*

A person who uses water as contemplated in Subsection (1) –

a) *Must use the water* ***subject to any condition*** *of the relevant authorisation for that use;*

b) *Is subject to any limitation, restriction or prohibition in terms of this Act or any other applicable law*

All water use that do not fall under Schedule 1 must be authorised, albeit under a General Authorisation or a formal water use licence. Therefore, the authority has the right to grant or prohibit water use (outside Schedule 1 use) where it is safe or unsafe to do so and subject to any condition. Subject to subsection (4), chapter 4 of the NWA, the minister may make regulations –

(a) Limiting or restricting the purpose, manner or extent of water use;

(b) Requiring that the use of water from a water resource be monitored, measured and recorded;

(c) Requiring that any water use be registered with the responsible authority.

In the case of dolomite occurrences it is especially important that the authority has all measures in place to limit unnecessary water use in such areas and that water use is monitored from a dolomite perspective as over abstraction of ground water can cause sinkholes. In the absence of the these measures it could be fatal to a community and would not be in accordance to Constitution of South Africa (Act 108 of 1996). When it comes to the issuing of licenses the following regulations 29 (1)(a) and (b) must be considered:

A responsible authority may attach conditions to every general authorisation or license –

(a) Relating to the protection of -

(i) *The water resource in question;*

(b) Relating to water management by -

(i) *Specifying management practices and general requirements for any water use, including water conservation measures.*

(ii) ***Requiring the monitoring and analysis of and reporting on every water use*** *and imposing a duty to measure and record aspects of water use, specifying measuring and recording devices to be used.*

11.4 Special Reference to the National Environmental Management Waste Act 59 of 2008

When referring to the National Environmental Management Waste Act, 59 of 2008 (NEMWA), licensing should be particularly cautious due to the impact of polluted groundwater on dolomite. A "waste treatment facility" is any site that is used to accumulate waste for the purpose of storage, recovery, treatment, reprocessing, recycling and sorting of waste.

When considering a license for a waste treatment facility, Section 48 (d) of the NEMWA should be taken into consideration where it states that the licensing authority must take into account all relevant matters such as increased health and environmental risk that may arise as the result of the location where the waste management activity will be undertaken.

According to the NWA, waste includes any solid material or material that is suspended, or dissolved in water such as those in tailings dams and which is spilled or deposited on land or into a water course in such volume, composition or manner as to cause or to reasonably likely cause, the water resource to be polluted.

This issue is more intensified when waste like effluent from mines is pumped into lagoons or tailings dams. According to GN R718, this can trigger a basic environmental assessment and responsible authorities should be cautious when these facilities exist on dolomitic areas.

11.5 The right of the public to be informed about the risk according to the Promotion of Access to Information Act 2 of 2000 (PAIA)

According to the Constitution of the Republic of South Africa of 1996 section 32, everyone has the right of access to information held by the state (Public body) and any information held by another person and that is required for the exercise or protection of any rights. As the subject matter is concerned with the environmental rights, people whether natural or juristic should be informed about the environmental dangers that exist in their area. This is also emphasised in the Promotion of Access to Information Act 2 of 2000 (PAIA). A requester of information must be given access to information or a record of a public body, regardless of reason if he or she complies with procedural requirements.

When it is therefore a right for a person to know about the safety of his or her environment; and it is being challenged by areas underlain by dolomite, that person needs to know by what extent he or she is being influenced by the situation.

11.6 Geotechnical requirement from the Transvaal Provincial Ordinance 15 of 1986

This ordinance came into effect on 10 June 1987 and applies to township applications submitted since that date. According to Van Schalkwyk (1998):

> *This ordinance does not specifically mention dolomite land, but in terms of Regulation 18(1), "an application for the establishment of a township in terms of section 69 or 96 of the Ordinance shall be accompanied by… (b) A detailed report with comprehensive motivation relating in the township with special reference to… (cc) how the township will be affected by…(bbb) geotechnical conditions…*

Provision is therefore made in the Ordinance for the appointment of local authorities with powers to administer the Ordinance and approve town-planning schemes in their areas of jurisdiction.

11.7 The current Spatial Planning Land Use Management Bill (SPLUMB) 2012 on environmental sustainability

The Spatial Planning Land use Management Bill that was revised in 2012 will repeal the removal of restrictions Act 84 of 1967, Physical Planning Act 88 of 1967 and 125 of 1991 and the Development Facilitation Act (67 of 1995). When the Bill becomes an Act, its intent is to provide a framework for spatial planning and land management in the country.

In Chapter 2 of the SPLUMB Section 6, it states that the following principles will apply to spatial planning, land use management and land development. (b) The principle of spatial sustainability, whereby spatial planning and land use management systems must; (V) promote land development in locations that are sustainable… (vi) result in communities that are viable.

The sustainability of building on specific areas underlain by dolomite should first be established.

In Section 20 of the SPLUMB, it refers to the content of a Strategic Development Framework (SDF). According to Section 20 (j) a regional SDF should include a strategic assessment of the environmental pressures and opportunities within the municipal area, including the spatial location of environmental sensitivities applicable. It does not refer to dolomite specifically but as dolomite contribute to an environmental sensitive area for development; it should be taken into consideration.

11.8 The Development Facilitation Act 67 of 1995 (DFA) with policy reference to geotechnical research

According to Section 3 of the DFA "*the following general principles apply on the basis set out in Section 2, to all land development... (h) Policy, administrative practice and laws should promote sustainable land development at the required scale in that they should-... (v) Ensure the safe utilisation of land by taking into consideration factors such as **geological formations** and hazardous undermined areas...*"

Section 4, which deals with general principles of decision making and conflict resolution, contains the following subsections:

*"(1) The general principles set out in Subsection (2) apply-... (b) without derogating from the generality of paragraph (a) to any decision-... (iii) Relating to the level or standard of engineering services that are to be provided in respect of land development... (2) The decisions contemplated in Subsection (1) shall be taken in accordance with the following general principles... (b) The decision shall be made by at least one appropriate official in the service of a provincial administration or local government body, and experts in the field of agriculture, planning, engineering, **geology**, mining, environmental management, law, survey or such other field as may be determined by the Premier"*.

Regulations in terms of Section 46 that contain more specific instructions in connection with the required geotechnical assessment appear in Government Gazette no. 17395 of 30 August 1996 (Republic of South Africa 1996).

Section 26, which deals with the geotechnical assessment, includes the following subsections:

(j) The depth to which the profile can probably be excavated with a backhoe;

(k) The permeability of the soils and their performance in the transport of wastewater;

(l) The occurrence of areas of outcrop and sub-outcrop and their affect on excavation;

(m) Whether structures will require modification/ reinforcement and/or special foundations."

11.9 National Home Builders Registration Council (NHBRC)

The NHBRC is a statutory body established in terms of Section 2 of the Housing Consumers Protection Measures Act, (Act No 95 of 1998) as amended, with the mandate, amongst others, *to establish and promote ethical and technical standards in the home building industry*. The NHBRC is also mandated to provide warranty protection to housing consumers against defined defects in new homes and to regulate the home building industry. In terms of Section 12(1) of the Act, the Council of the NHBRC publishes a Home Building Manual containing the NHBRC's technical requirements and guidelines.

11.10 Municipal bylaws

The currently active General Authorisation (GA) for groundwater abstraction from quaternary catchment C23H allows for 75 m^3/ha/a to be abstracted without a licence. Since the study area is located mainly in this catchment, there is a general allowance for groundwater abstraction from Ikageng. Although it might be too drastic to revise the GA for the whole of the catchment comprising 451 km^2, it is necessary to restrict uncontrolled groundwater abstraction from Ikageng for reasons stated earlier. Therefore the issue of municipal bylaws is raised:

11.10.1 Groundwater abstraction control

An area was delineated where it is considered necessary to place a moratorium on the drilling of groundwater abstraction boreholes (Figure 5-3). This must be done for the following reasons:

- Anyone who wishes to drill a borehole (for groundwater abstraction) must apply for permission from the TCC. Permission to drill will be dependent on the following:
    - **The area in which the borehole is located**: the area must be compared to the geology and risk zone map. Certain areas might be allowed while others are already at risk.
    - **The volume to be abstracted**
- Tlokwe City Council must act as custodians of the local groundwater resources in order for the Risk Management Plan to be effective. Uncontrolled groundwater abstraction cannot be allowed.
- Effective control over the groundwater abstraction from within the study area must be centralised and will be a function of the Risk Management Plan. This will include records of borehole locations, abstraction volumes and water application.
- Any unexplained water level fluctuations in the groundwater table (as measured by the monitoring network) can then be measured against the

database of controlled abstractions in Ikageng.

Due to the good municipal water supply network, few boreholes were identified in the area. Nevertheless it is necessary for TCC to incorporate the existing boreholes into the groundwater abstraction control database as well.