TECHNICAL SERIES: 2

Dolomite Aquifers of South Africa

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Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

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EXECUTIVE SUMMARY

Dolomites are South Africa's most important aquifers because borehole yields are frequently high and natural water quality good. They are often divided into semi-independent "compartments" by igneous dykes and other features. Water in one compartment is separated, to an extent, from water in adjacent compartments. Whilst water quality in our dolomite aquifers is generally good, there are certain areas that are affected by pollution, including acid-mine drainage, agricultural pollution and discharges from sewage treatment plants. Over-abstraction in some compartments is also a serious concern, since it not only threatens continuity of groundwater supplies (e.g. agricultural users of water) but can also lead to sinkhole development and threaten ecological water flows (e.g. spring flows).

Dolomite aquifers are unusually vulnerable to pollution, and there is a special need to protect these aquifers from pollution. It is usually more difficult and expensive to clean up polluted groundwater than it is to prevent pollution in the first place. A modified version of the COP aquifer vulnerability mapping method, trialled in the Cradle of Humankind and the Sudwala/Pilgrim's Rest areas, is recommended as a first step to systematically assessing vulnerability and risk. Vulnerability mapping informs protection of the wider groundwater resource. Source protection zones for important individual boreholes are recommended as an additional pollution prevention measure.

An equally important consideration in developing groundwater resources in the dolomites is the issue of ground stability and sinkhole risk. This needs to be evaluated in line with current guidelines (see the Dolomite Guideline Booklet – Activity 23 - for more details). Groundwater abstraction can exacerbate the risk of sinkhole formation and ground instability.

Monitoring groundwater in the dolomites is the foundation of managing the resource. There is evidence that groundwater monitoring networks have declined in parts of the dolomites in recent years (for example in the Steenkoppies compartment). Effective monitoring of groundwater encompasses a variety of issues, including availability of and access to monitoring boreholes, institutional capacity to carry out monitoring and interpret the results, and compatibility and availability of various monitoring datasets.

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CHAPTER 1. INTRODUCTION

South Africa's dolomite rocks form some of our most important aquifers (Barnard, 2000) because borehole yields are often high and natural water quality is good. They are used extensively for irrigation (e.g. in the Delmas and Tarlton areas), public water supply (e.g. Mafikeng, Lydenburg and Tshwane), and are vitally important to natural ecosystems as well as thousands of small-scale groundwater users. Dolomite aquifers are threatened in some places by over-abstraction and pollution. Following the 1998 Water Act and other groundbreaking legislation, groundwater in South Africa is now part of a common water resource for the use of all South Africans, the ownership, management and protection of which is vested in the State. New structures and institutions are now specified for water management, with an emphasis on devolution of responsibility to regional and local levels. The Department of Water Affairs (DWA) is leading a number of projects to consolidate and improve management of dolomitic groundwater resources in South Africa.

This Technical Series report is one of the final outputs of the DWA "Geohydrology Guideline Development: Implementation of Dolomite Guideline" Project (IHP Project Number: 14/14/5/2/2). The Dolomite Project began in late 2007, and ended in November 2009. It has been divided into a series of Activities, each one addressing a particular aspect of South Africa's dolomite groundwater resources (see Table 2 1 for a full list of the various activities together with brief descriptions). This report, the main deliverable for Activity 27 of the Dolomite Project, is intended to support the better implementation of the DWA Generic Guideline document ("A Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa" – DWAF, 2008). Deliverables for all of the Activities are available from the Department of Water Affairs.

The DWA Generic Guideline (DWAF, 2008) is based on an earlier document "A Guideline for the Assessment, Planning and Management of Groundwater Resources within Dolomitic Areas in South Africa" (DWAF, 2006). The 2006 Dolomite Guideline is divided into three volumes – a Conceptual Introduction; Process and Related Activities; and Procedures. The Dolomite Guideline provides detailed advice on the institutional and management context for dolomitic groundwater. It also contains an overview of the dolomite groundwater resources in South Africa based on the information available in the relevant Internal Strategic Perspective documents of the Water Management Areas, together with recommendations and templates for topics that include drilling, pumping tests, groundwater exploitation in dolomites and the recommended approaches and procedures for establishing good groundwater management in dolomites. The roles of the various people and organisations involved with groundwater development and management in dolomites are also explained.

This Technical Series report does not replace or duplicate either the Generic Guideline or the Dolomite Guideline. Instead, it will provide further details of the current state of South Africa's dolomite aquifers and describe recent research and specialist techniques related to dolomite aquifers. It will draw on the work done on the DWA Dolomite Project, and is intended to function as an appendix to the Generic Guideline.

Table 1-1 below summarises the various technical activities of the Dolomite project. See **Figure 1-1** for geographical locations. Note that certain numbers have been allocated to routine project management or administrative activities, and therefore do not appear on the list.

Table 1-1: Summary of past Dolomite Project Activities

Activity	Name	Description of deliverable(s)
3	Review of Dolomite Guideline	Report reviewing the Guideline for the Assessment, Planning and Management of Groundwater Resources within the Dolomitic Areas in South Africa, and also reviewing the Guideline for engineering-geological characterisation and development of dolomitic land.
5	North West Dolomites – coordination and integration of projects	Report which summarises and evaluates past groundwater related studies on the North West Dolomites (Zeerust-Lichtenburg-Mafikeng area). Contains a list of 34 recommendations or suggestions for work priorities in the area.
6	Desktop geohydrological assessment of the Delmas / Bapsfontein dolomites	Report which describes geology, hydrogeology, groundwater levels and trends, groundwater quality and evaluates current water use in the dolomites east and north-east of Johannesburg (Rietvlei, Witkoppies, and Elandsfontein compartments, the Bapsfontein-Delmas area, the Varkfontein-Knoppiesfontein area and the East Rand Basin).
7	Ground stability in dolomitic areas - Tshwane	The work derived an inherent ground stability risk classification for the Centurion (Tshwane) CBD area. The report does not display the final risk map, due to the potential sensitivity of the area. The Council for Geoscience has further information, and a copy of the map.
13	Desktop geohydrological assessment of the Tarlton dolomites	Report describes geology, hydrogeology, groundwater levels and trends, groundwater quality and evaluates current water use in the Zwartkrans compartment to the east of Tarlton and the Steenkoppies compartment to the west of Tarlton. Discusses the issues of acid mine drainage and makes management recommendations.
14	Desktop geohydrological assessment of the Tshwane dolomites	Report describes geology, hydrogeology, groundwater levels and trends, groundwater quality and evaluates current water use in the Aalwynkop, Erasmia, East and West Fountains and East and West Doornkloof compartments to the south of Pretoria. Discusses management issues such as pollution, data collection and protection zoning.
15	Desktop geohydrological assessment of the Sudwala / Pilgrim's Rest dolomites	Report describes geology, hydrogeology, groundwater levels and trends, groundwater quality and evaluates current water use in the "escarpment" dolomites of the Blyde River – Pilgrim's Rest – Sudwala area in Mpumalanga Province. The report includes a discussion of instability / vulnerability and a vulnerability map, as well as suggested management

Activity	Name	Description of deliverable(s)
		actions.
16	Desktop geohydrological assessment of the Natalspruit dolomites	Report describes geology, hydrogeology, groundwater levels and trends, groundwater quality and evaluates current water use in the Natalspruit Basin and Klip River Valley dolomites south of Johannesburg. Management actions are suggested.
19	Dolomite compartment maps	Series of A0 size maps summarising groundwater conditions and management units in the Tshwane, Natalspruit, Tarlton, North West and Ghaap Plateau dolomites areas, aimed at planners and managers at the various levels. There is also a lower resolution map covering the entire area from Delmas in the east to Zeerust in the west, and including the KOSH area in the south.
20	Desktop study of future research priorities for the North West dolomites	Refined and prioritised the list of recommendations arising from Activity 5, in collaboration with dolomite experts Mr Frans Wiegmans and Dr David Bredenkamp. The report contains a summary of technical and management recommendations.
21	Implementation of Generic Dolomite Guidelines	Report that recommends management activities and actions, particularly as they apply to two study areas (Tshwane and Sudwala / Pilgrim's Rest). Includes technical and policy background material to groundwater management in South Africa, and a summary of current management issues.
22	Data Collation	DVD with all data used in the various Activities, accompanied by a short report describing data processing and format.
23	Dolomite Guideline Booklet: A short guide to available documents on procedures for developing dolomitic land.	Professionally laid out and printed information booklet, giving the reader a brief introduction to the various documents that have information on building developments on dolomite land. Includes an introduction to ground stability, and a section on why groundwater management is important to ground stability.
25	Geohydrological assessment of the Steenkoppies dolomite compartment	Technical assessment of groundwater conditions in the Steenkoppies compartment near Tarlton, with particular reference to low flows at the Maloney's Eye spring and associated disputes. Includes analysis of rainfall in the area and correlation of rainfall with spring flows, a review of previous work, and recommendations for management interventions.

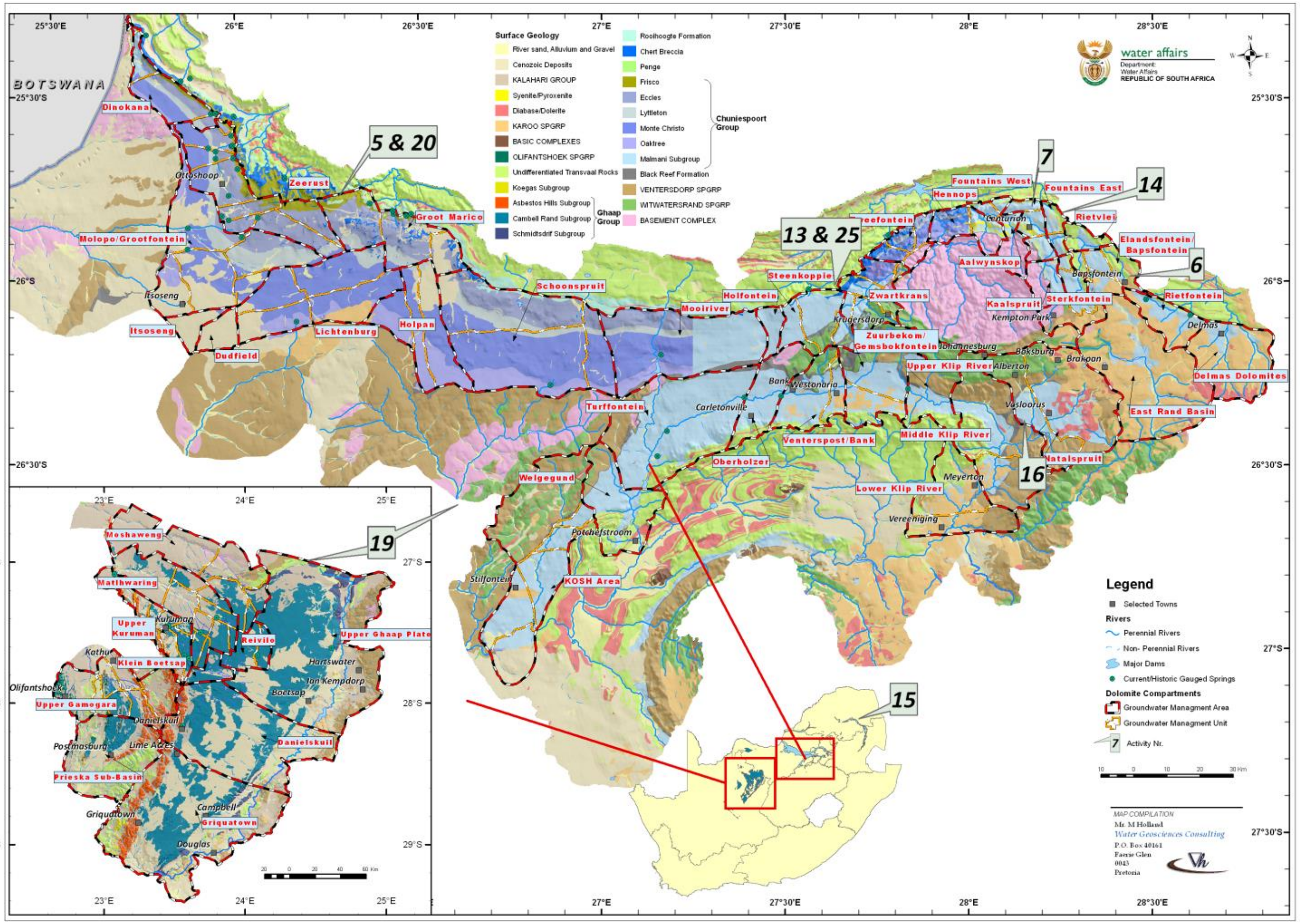


Figure 1-1: **Map showing locations of Dolomite Project Activities**

CHAPTER 2. SOUTH AFRICA'S DOLOMITE AQUIFERS

2.1 Introduction

Strictly speaking, "dolomite" is a carbonate mineral ($CaMg(CO_3)_2$), but the word is often taken to mean a particular type of limestone rock which contains the mineral dolomite – the meaning used in this report. This report discusses the dolomites of the Transvaal Supergroup (where the largest groundwater resources are found), and does not include younger limestone rocks found in the Western Cape Province and elsewhere (e.g. Cango Caves area near Oudtshoorn). The Transvaal Supergroup dolomites form curved outcrops to the east and west of Gauteng Province (Malmani Subgroup of the Chuniespoort Group) as well as a triangular plateau east and south of Kuruman in the North Western Cape Province (Ghaap Group). Formed around 2.7 billion years ago and as much as 2 km thick in places, the dolomites have been tectonically deformed and faulted, and are intruded by volcanic dykes and other structures (Johnson et al, 2006). They are divided into different formations based partly on the chert content. They are thought to have been deposited in shallow marine environments as a chemical precipitate and also in association with algal mats and structures called stromatolites (some of the earliest recorded life on earth). In outcrop, dolomite is a fairly hard, greyish to brown rock which may weather to a surface "elephant skin" texture.

From a groundwater point of view, fresh and unweathered dolomite has very little permeability or porosity. Dolomite weathers easily however in the presence of water and carbon dioxide, which can combine to produce weak carbonic acid. Joints, fractures and other features are enlarged by dissolution to form highly permeable conduits (sometimes even caves), and these together with weathered and leached horizons can transform the rock into an excellent aquifer. (The same mechanisms can lead to serious ground instability in dolomitic areas.) Insoluble material such as silica and metal oxides remain as structurally weak and porous "wad". In some cases, weathered and permeable dolomite areas are classed as "karst" areas, with sinkholes, dolines and other distinctive features present. Storativities of South African dolomite aquifers generally vary between 1 and 5 % (Barnard, 2000), but this property depends greatly on the extent of weathering and dissolution. Transmissivities can be several hundred m2/day or more. Groundwater movement in dolomites can, via permeable conduits, be several metres per day or faster. Groundwater flow can be unpredictable, due to the discrete networks of channels, fissures and void spaces. Recharge values as high as 14 % of annual rainfall have been derived (Barnard, 2000).

The dolomites are divided into groundwater units or "compartments" by features such as igneous dykes, faults and contacts with adjacent rocks. These compartments are often used as the basis for hydrogeological characterisation and groundwater management. Compartment boundaries are rarely completely impermeable however, particularly in the upper weathered sections, but the extent of groundwater movement across compartment boundaries may be difficult to quantify. Compartment boundaries are normally marked by a distinct change in water levels, and in some cases force groundwater to the surface as springs or seeps. High yielding springs (e.g. Maloney's Eye) found at geological/compartment boundaries or topographic lows are a feature of the dolomite aquifers. The water table or piezometric surface within a compartment may be relatively flat. Defining compartment boundaries, followed by an assessment of the groundwater conditions (flow direction, water levels and water quality) within the compartment, is an important task in dolomite hydrogeology.

This report briefly describes the following dolomitic areas in turn:

- Far West and KOSH areas
- Natalspruit area
- North West area
- West Rand area
- Delmas area
- Tshwane area

The chemistry values shown are taken from the National Groundwater Database, managed by the Department of Water Affairs. The chemistry values may not reflect the effects of local pollution, nor reflect changes across the different compartments in each area. For more detail on the chemistry, groundwater levels and compartment boundaries, refer to the dolomite compartment maps (Activity 19) produced as part of this project.

2.2 Description of the Far West and KOSH Areas

- **Morphology and Drainage**

  The topography of the area is flat, which influences the surface water drainage and occurrence of wetlands during the rainy seasons.

- **Climate and Rainfall**

  The climate is typical South African Highveld, with warm to hot, rainy summers, and cold, dry, sunny winters. The summers are hot with daily maximum temperatures ranging from 27 to 30 ºC with extremes of 35 to 40 ºC. More than 80 % of the mean annual precipitation occurs in the six month period October to March. Rainfall occurs mainly in thunderstorms and showers, with an annual average of between 600 and 625 mm.

- **Geology and hydrogeology**

  The regional geology of the area (**Figure 3 2**) consists largely of Vaalian lithologies, particularly the Pretoria and Chuniespoort Formations of the Transvaal Supergroup. Rocks of the Witwatersrand and Ventersdorp Supergroups are also present. Large parts of the area also consist of basement rock of Swazian age, largely made up of granite and gneiss. The Malmani Subgroup dolomites plunge regionally northward and are overlain by the Pretoria Group. Outcrops of the Witwatersrand Supergroup appear along the southern boundary of the dolomites. The Malmani Subgroup is described as dolomite, banded iron formation, chert and shale. This series consists mostly of layered strata of calcium magnesium carbonates (CaMgCO3), some layers massive and some with chert bands.

  Unweathered Malmani dolomite has a low permeability. The joints and faults and bedding planes have served to develop the secondary permeability of the rock mass, particularly in chert-rich units such as the Monte Christo and the Eccles

Formations .Groundwater movement within the dolomite aquifer in this area is known to be associated with north-south trending joints and faults which have experienced preferential dissolution.

○ **Chemistry**

Although the average EC value of 107 mS/m (**Table 2-1),** and the mean pH value of 7.6, indicate generally good quality groundwater, some element/parameters are elevated beyond acceptable limits (SSA, 2006). These suggest the presence of contamination in some of the groundwater in the area.

Table 2-1: Chemistry of groundwater samples from the Far West Rand area.

Parameter/ Element	Total sample	Minimum value	Mean value	Maximum value
Ca (mg/l)	280	1.80	114.4	635.1
Cl (mg/l)	280	1.50	40.8	573.0
EC (mS/m)	279	3.50	107.0	575.0
F (mg/l)	280	0.05	0.2	1.2
K (mg/l)	278	0.15	6.7	46.7
Mg (mg/l)	280	0.50	61.9	333.7
NH_4 (mg/l)	278	0.02	1.8	35.6
NO_3 as N (mg/l)	280	0.02	3.5	49.8
Na (mg/l)	279	1.00	40.9	609.1
PO_4 (mg/l)	278	0.00	0.0	0.2
SO_4 (mg/l)	279	2.00	427.6	4279.8
Si (mg/l)	279	0.20	9.7	27.7
Total Alkalinity (mg/l $CaCO_3$)	279	2.00	157.2	369.0
pH	280	6.02	7.6	11.0

2.3 Description of Natalspruit Area

○ **Morphology and Drainage**

The dolomitic formations of the Natalspruit Basin form an outlier surrounded by higher ground formed by pre-Chuniespoort Group formations. The topography of this Basin is relatively subdued, with the higher ground in the eastern half of the Basin associated with the outcrop of Karoo age dolerite sills. Higher ground in the western half of the Basin coincides with the occurrence of chert. The Natalspruit area extends over quaternary catchments C22B and C22C, and forms part of the Vaal River sub-system located within the Upper Vaal Water Management Area.

The Klip River area occupies a broad flat-bottom valley which follows the outcropping area of the Malmani dolomites. It is bounded to the north and south by higher ground occupied by the Black Reef quartzite and pre-Transvaal formations and to the southwest by the ridges of the Pretoria Group.

- **Climate and Rainfall**
  The climate in the area is typical South African “Highveld”, characterised by warm summers, dry winters and hot, wet summers when 80 % of the rainfall is experienced as thunderstorms. Frosts are experienced for up to five months of the year and hail falls often. Average annual rainfall for the region is 700 mm with higher rainfall occurring on the high ground surrounding the area

- **Geology and hydrogeology**
  The dolomite of the Natalspruit Basin forms a shallow outlier of the Malmani Subgroup lying in a synclinal trough where only the Oaktree Formation and lower part of the Monte Christo Formation remain. The Natalspruit dolomitic outcrop is underlain by the Klipriviersberg Group and part of the Ventersdorp Supergroup, comprising mainly of andesitic lava and tuff. The outcropping Klip River Valley dolomites are the most western portion of an arcuate belt that lies from Zuurbekom to Vereeniging, east of the Klip River dyke. In the Klip River area, all four dolomitic formations occur.

  The Natalspruit and Klip River dolomitic aquifers (**Figure 2-1**) are distinguishable based on their chert content. The chert-poor formations have low storage potential compared to chert-rich formations. Dykes, lineaments, lithology and sills are responsible for ‘compartmentalisation’ of aquifer units.

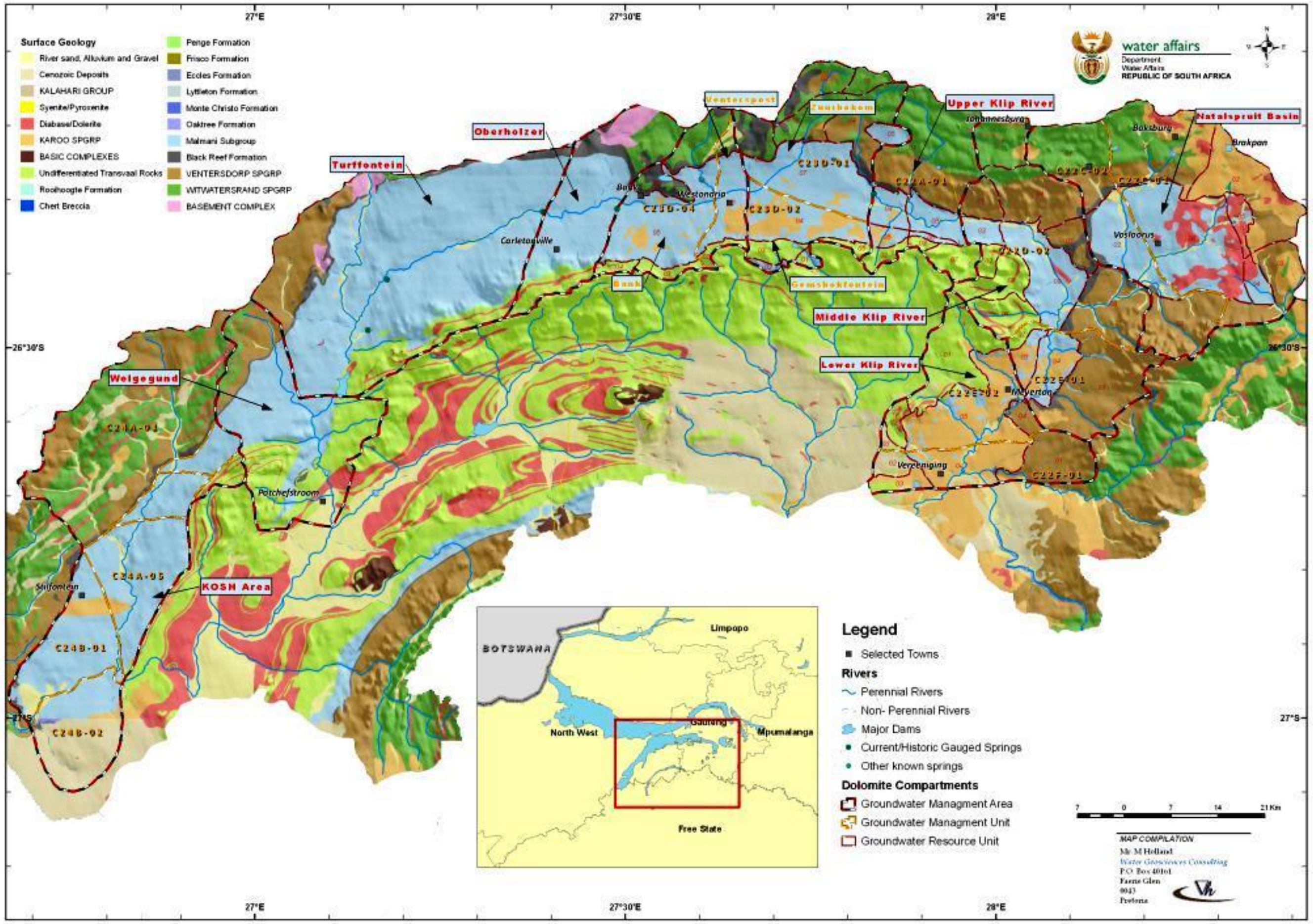


Figure 2-1: **Dolomitic aquifers of the Natalspruit / Klip River, KOSH and Far West areas**

- **Chemistry**
  Although the average EC value of 50 mS/m, and the mean pH value of 7.5, indicate that the quality of groundwater is generally good, some elements/parameters (e.g. maximum values, Table 2-2) are elevated beyond the drinking water standard (SSA, 2006). This suggests the presence of contamination in some of the groundwater in the area.

Table 2-2: Chemistry of groundwater samples from the Natalspruit/Klip River area

Parameter/ Element	Total sample	Minimum value	Mean value	Maximum value
Ca (mg/l)	714.0	0.5	41.8	398.6
Cl (mg/l)	714.0	1.5	23.0	461.5
EC (mS/m)	714.0	2.9	49.9	440.0
F (mg/l)	714.0	0.1	0.1	2.4
K (mg/l)	707.0	0.2	2.0	163.0
Mg (mg/l)	714.0	0.5	27.1	231.9
NH_4 (mg/l)	707.0	0.0	0.4	110.0
NO_3 as N (mg/l)	714.0	0.0	4.5	211.4
Na (mg/l)	713.0	1.0	16.9	221.0
PO_4 (mg/l)	707.0	0.0	0.0	6.2
SO_4 (mg/l)	713.0	2.0	68.0	1 679.4
Si (mg/l)	707.0	0.2	10.5	35.9
Total Alkalinity (mg/l $CaCO_3$)	714.0	2.0	121.9	723.2
pH	714.0	4.0	7.5	9.6

2.4 Description of North West Area

- **Morphology and Drainage**
  The topography of the area varies from plains which have moderate to low relief to more complex lowlands, hills and mountains, to closed hills and mountains with relief varying from moderate to high. Groundwater units to the east of the fault and south of the Blaauwbank Dyke drain to the east and southeast, and units west of the fault drain to the west, south and north.

- **Climate and Rainfall**
  The climate is temperate in the east and drier in the west. Rainfall is strongly seasonal, with most rainfall occurring as summer thunderstorms. Mean annual rainfall ranges from 400 to 800 mm and decreases from the east to the west. The mean annual temperature ranges between 18 and 20 °C. Maximum and minimum temperatures are experienced during January and July respectively.

- **Geology and Hydrogeology**

  The North West dolomite aquifer is made up of the Eccles, Lyttelton, Monte Christo and Oaktree Formations, which comprise the Chuniespoort group. Both the Eccles and Monte Christo Formations are chert-rich, whilst the Lyttelton Formation is chert free. The entire sequence dips to the north underneath the Pretoria Group.

  The chert-rich Eccles and Monte Christo Formations have higher coefficients of storativity and transmissivity. The dolomitic aquifer (**Figure 2-2**) is subdivided into compartments by the intrusion of dykes, which act as groundwater barriers.

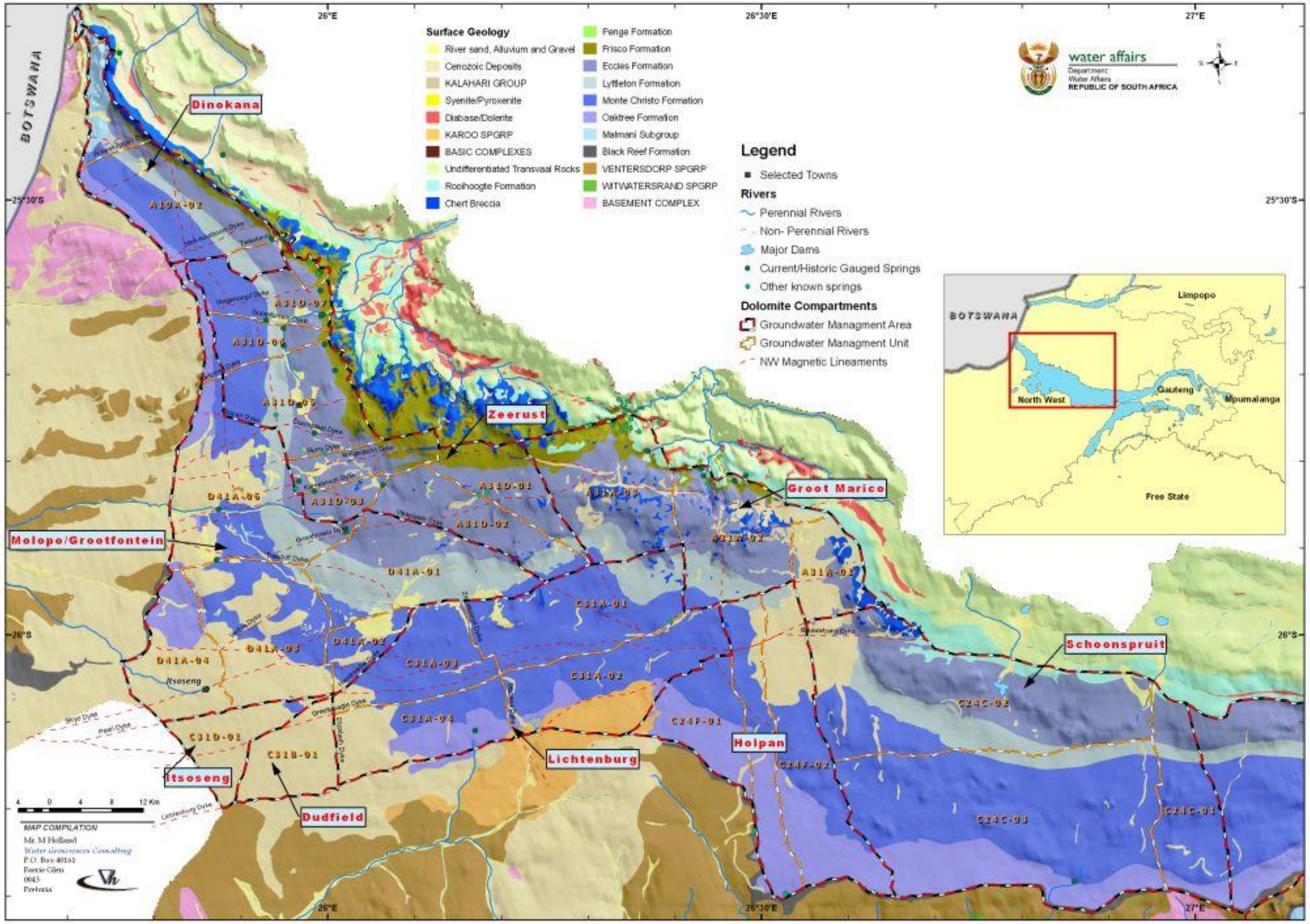


Figure 2-2: **Dolomitic aquifers of the North West area**

- **Chemistry**

  The chemistry data (**Table 2-3**) indicates generally acceptable groundwater quality, with an average EC value of 52.8 mS/m and an average pH value of 7.9. Some of the nitrate and chlorides concentrations (maximum values) are slightly elevated beyond the drinking water standards (SSA, 2006).

Table 2-3: Chemistry of groundwater samples from the North West area

Parameter/ Element	Total sample	Minimum value	Mean value	Maximum value
Ca (mg/l)	923	0.5	49.9	217.0
Cl (mg/l)	923	1.5	21.7	699.0
EC (mS/m)	924	2.0	52.8	313.6
F (mg/l)	923	0.1	0.2	2.8
K (mg/l)	923	0.2	1.9	94.7
Mg (mg/l)	923	0.5	33.3	194.0
NH_4 (mg/l)	923	0.0	0.5	13.9
NO_3 as N (mg/l)	923	0.0	5.0	58.1
Na (mg/l)	923	1.0	7.7	698.3
PO_4 (mg/l)	923	0.0	0.0	0.4
SO_4 (mg/l)	923	2.0	9.4	265.9
Si (mg/l)	923	0.2	8.4	26.5
Total Alkalinity (mg/l $CaCO_3$)	923	2.0	219.7	602.0
pH	924	2.0	7.9	9.0

2.5 Description of West Rand Area

- **Morphology and Drainage**

  The topography of the study area (**Figure 2-3**) is generally flat to gently undulating, and is virtually devoid of surface drainage features. Towards the upper reaches of the Zwartkrans compartment there are significant topographical differences, attributed to different erosion and weathering characteristics of the dolomites and their associated breccias. The chert-poor units weather to a smooth topography covered by red silty type clayey soils devoid of chert. The chert-rich units weather to an uneven topography characterised by dissolution openings and a permeable chert residue with red silty and brown manganiferous soils.

  The Steenkoppies and Zwartkrans dolomite compartments form part of the upper Crocodile River sub-system and are located within the Crocodile (West) and Marico Water Management Area. The tertiary drainage region is A21 with the Steenkoppies compartment falling within the upper reaches of quaternary drainage region A21F and the Zwartkrans compartment almost completely within drainage region A21D. The Zwartkrans compartment is drained towards the north-east by the perennial Blaauwbankspruit and the Steenkoppies compartment is drained in its upper most reaches by the Rietspruit.

- **Climate and Rainfall**
  The climate in the area is typical South African “Highveld”, characterised by warm summers, with 80 % of the rainfall experienced as thunderstorms, and cool dry winters with cold nights. Frosts are experienced for up to five months of the year and hail falls often.

- **Geology and hydrogeology**
  The formations of the dolomites are distinguishable based on their chert content. The chert poor formations weather evenly to produce a low storage potential residue of silty clay. The dolomite weathers faster than the chert leaving the rock supported by chert structures. Chert rich formations develop a greater concentration of fissures and fractures, which will enhance the process of weathering. These chert rich formations are generally favourable for large-scale development of groundwater. Dolomitic compartments are formed by crosscutting dykes that act as barriers to groundwater flow, creating isolated hydrogeological compartments.

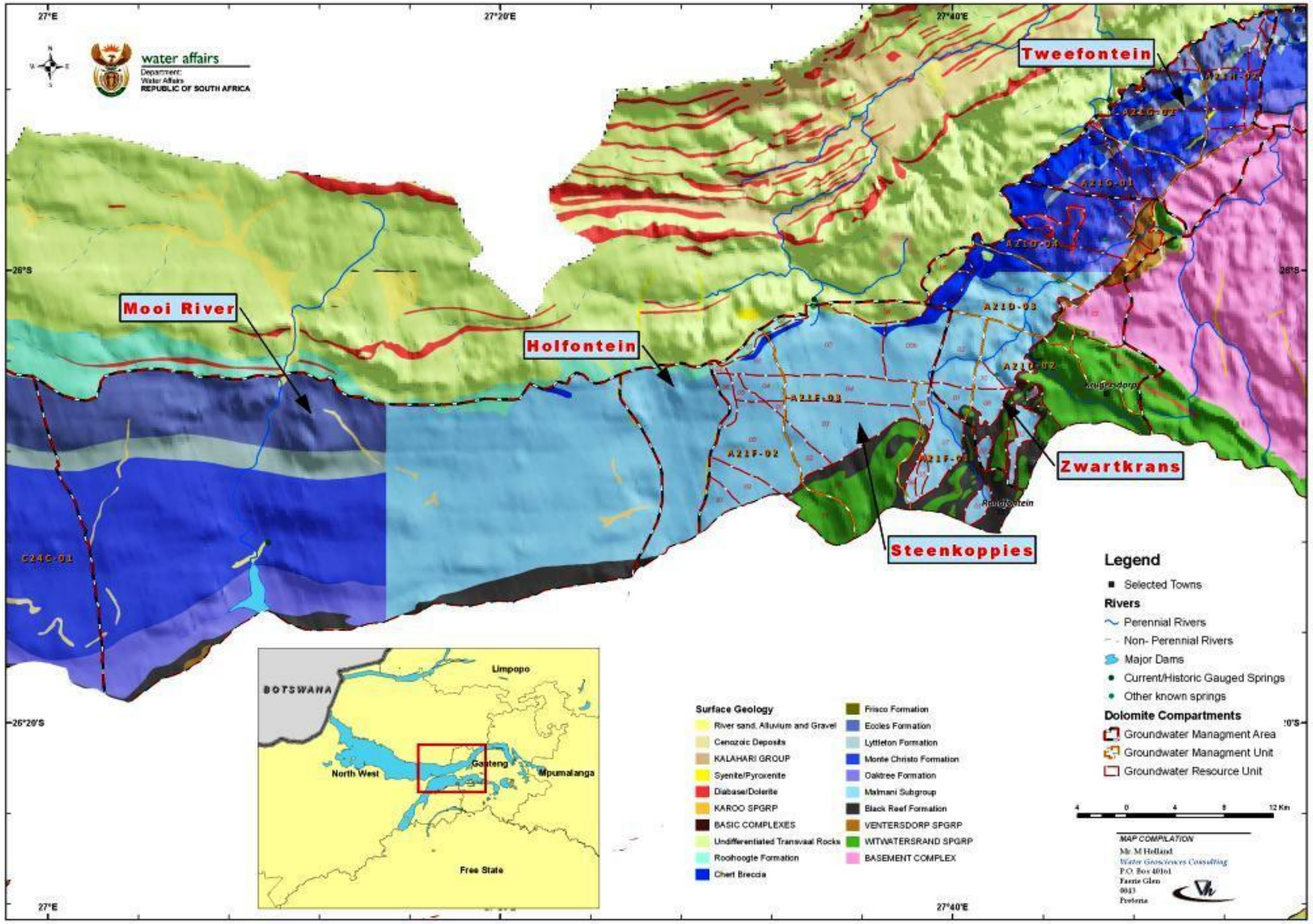


Figure 2-3: **Dolomitic aquifers of the West Rand area**

- **Chemistry**
  Although the average EC value of 39 mS/m, and the mean pH value of 7.0, indicate that the quality of groundwater is generally good, the maximum values of some elements/parameters (**Table 2-4**) are elevated beyond the drinking water standard (SSA, 2006). These suggest the presence of contamination, probably from mining, sewage treatment and agricultural activities in the area, and this should be considered before usage.

Table 2-4: Chemistry of groundwater samples from the West Rand area

Parameter/ Element	Total sample	Minimum value	Mean value	Maximum value
Ca (mg/l)	252	0.5	33.3	563.4
Cl (mg/l)	252	1.5	15.7	148.1
EC (mS/m)	252	1.8	39.3	558.0
F (mg/l)	246	0.1	0.1	1.0
K (mg/l)	252	0.2	1.3	16.1
Mg (mg/l)	251	0.5	16.9	225.5
NH_4 (mg/l)	250	0.0	0.2	8.4
NO_3 as N (mg/l)	246	0.0	1.9	26.4
Na (mg/l)	252	1.0	14.4	182.6
PO_4 (mg/l)	250	0.0	0.1	8.1
SO_4 (mg/l)	251	2.0	110.6	3929.3
Si (mg/l)	250	0.2	6.0	38.3
Total Alkalinity (mg/l $CaCO_3$)	250	2.0	78.9	312.7
pH	252	2.7	7.0	9.1

2.6 Description of Delmas Area

- **Morphology and Drainage**
  The topography of the study area is generally flat to gently undulating, with plains, slopes and several scattered hill crests. A prominent ridge crest capped with resistant quartzite (striking northwest to southeast) is situated along the northern part of the study area north of the R50 road. The dolomite dips regionally north-northeast beneath the Pretoria Group.

  The study area extends over quaternary catchments A21A, C21D, B20B and B20A of the Crocodile (West) and Marico, and Olifants Water Management Area (WMA) respectively. The main surface drainage in the northern part of the study area is the Rietvlei.

  To the southeast of Bapsfontein non-perennial streams drain the dolomite in an easterly direction and eventually flow north into the perennial Koffiespruit stream

- **Climate and Rainfall**

  The climate in the area is typical South African "Highveld", characterised by warm summers, with 80 % of the rainfall experienced as thunderstorms, and cool dry winters with cold nights. Frosts are experienced for up to five months of the year and hail falls often.

- **Geology and hydrogeology**

  The dolomite occurring in the study area (**Figure 2-4**) is part of the Malmani Subgroup overlying the Black Reef Formation and underlying the Timeball Hill Formation of the Pretoria Group. The Pretoria Group rocks in the northeast act as hydrogeological boundaries with numerous pre- and post-Karoo age impervious dykes subdividing the dolomite into 'compartments' isolated hydrogeologically from each other, especially north-west of the study area. The area south of the dolomitic outcrops is extensively covered by younger Karoo sediments

  The hydrogeological properties of the dolomite are determined by geologic and geomorphological controls such as structure, stratigraphy and morphology. The water-bearing properties of the dolomite stem from carbonate dissolution along structural and lithological discontinuities such as faults, fractures, joints and bedding planes. Chert-poor formations weather to produce low storage potential compared to chert-rich formations. Dolomitic compartments are formed by cross-cutting dykes that act as barriers to groundwater flow, creating isolated hydrogeological compartments.

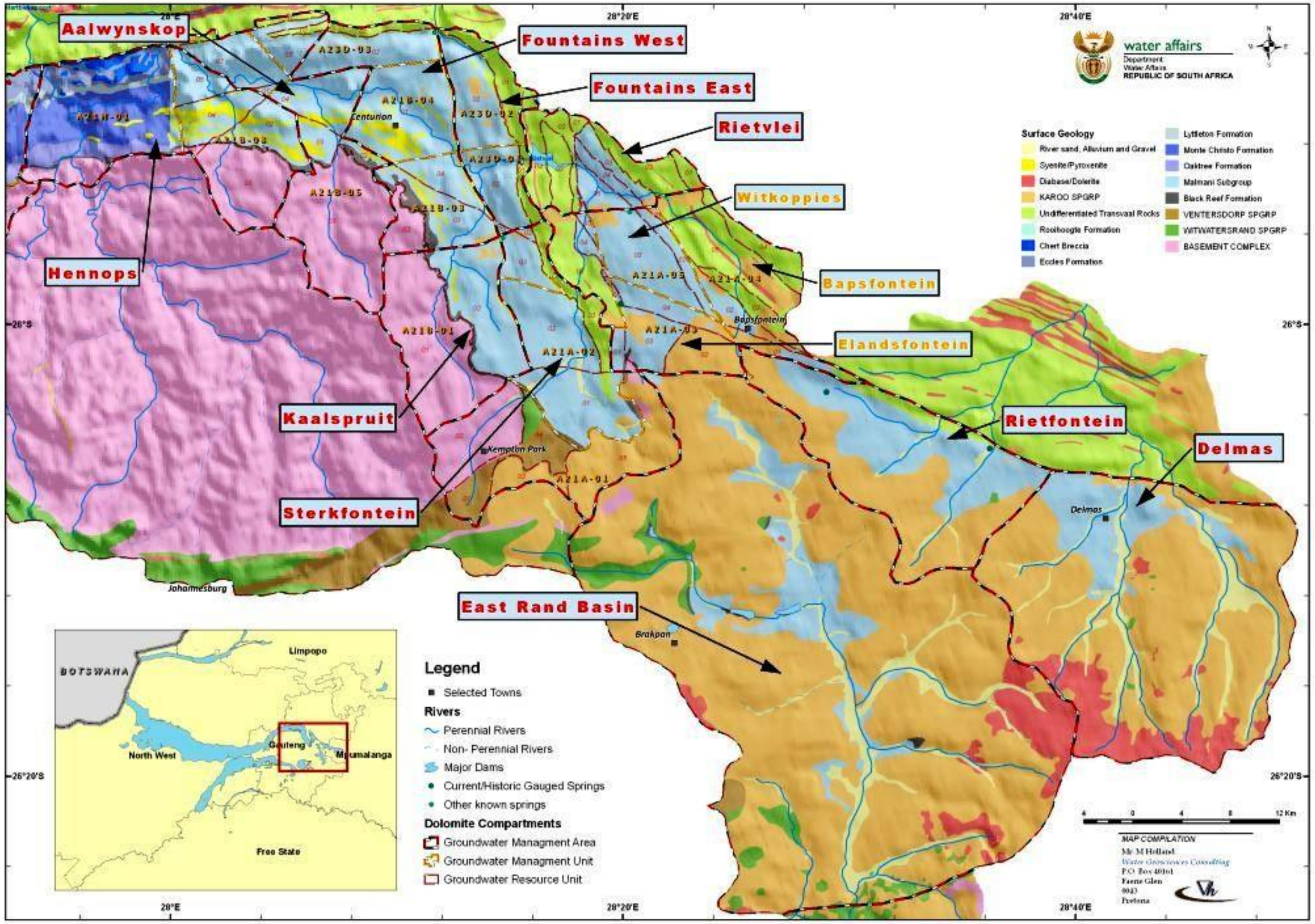


Figure 2-4: **Dolomitic aquifers of the Delmas and Tshwane areas**

- **Chemistry**

  The chemistry data (**Table 2-5**), indicates that the quality of groundwater in some of the boreholes is not suitable for human consumption without treatment. Some of the elements are elevated beyond the drinking water standard (SSA, 2006).

Table 2-5: Chemistry of groundwater samples from the Delmas area

Parameter/ Element	Total sample	Minimum value	Mean value	Maximum value
Ca (mg/l)	145	1.00	26.49	395.20
Cl (mg/l)	145	1.50	24.88	942.40
EC (mS/m)	145	4.80	146.40	418.80
F (mg/l)	145	0.05	17.65	1.83
K (mg/l)	144	0.15	1.57	64.41
Mg (mg/l)	145	1.00	9.52	246.80
NH_4 (mg/l)	144	0.02	8.09	0.56
NO_3 as N (mg/l)	145	0.02	0.93	69.34
Na (mg/l)	144	1.00	11.30	277.90
PO_4 (mg/l)	144	0.00	10.44	0.65
SO_4 (mg/l)	144	2.00	9.02	554.40
Si (mg/l)	145	0.20	13.66	40.00
Total Alkalinity (mg/l $CaCO_3$)	145	9.00	63.34	363.00
pH	145	5.89	7.55	9.39

2.7 Description of Tshwane Area

- **Morphology and Drainage**

  The topography of the study area is subdued, with a general drop in altitude from the south to the north. The dolomitic rocks tend to form flatter ground, with ridges being composed of the adjacent Pretoria Group quartzites. The study area is contained mainly within the quaternary catchment A21B, with small portions of A21H and A23D. The area is drained by the Hennops River and its tributaries, including the Sesmylspruit, Olifantspruit, Kaalspruit and the Rietspruit.

- **Climate and Rainfall**

  The Tshwane area has a typical South African "Highveld" climate, with warm summers during which 80 % of the rainfall falls as thunderstorms (often with hail) , and cool dry winters with cold nights.

- **Geology and hydrogeology**

  The oldest rock types in the study area (**Figure 2-5**) are represented by various granites of Archaean age, together called the Basement Complex, and which include the Halfway House Granite in this area. Quartzites of the Black Reef Formation overlie the Basement Complex, and are in turn overlain by dolomites and cherts of the Chuniespoort Group. The dolomites in the study area belong to the Malmani Subgroup of the Chuniespoort Group, and are dated between 2600 and 2500 Ma.

- **Chemistry**
  The chemistry data (**Table 2-6**) indicates that the quality of unpolluted groundwater in the area is generally suitable for human consumption according to the drinking water standards (SSA, 2006). Nitrates and sulphates concentrations are slightly elevated, which may indicate anthropogenic pollution.

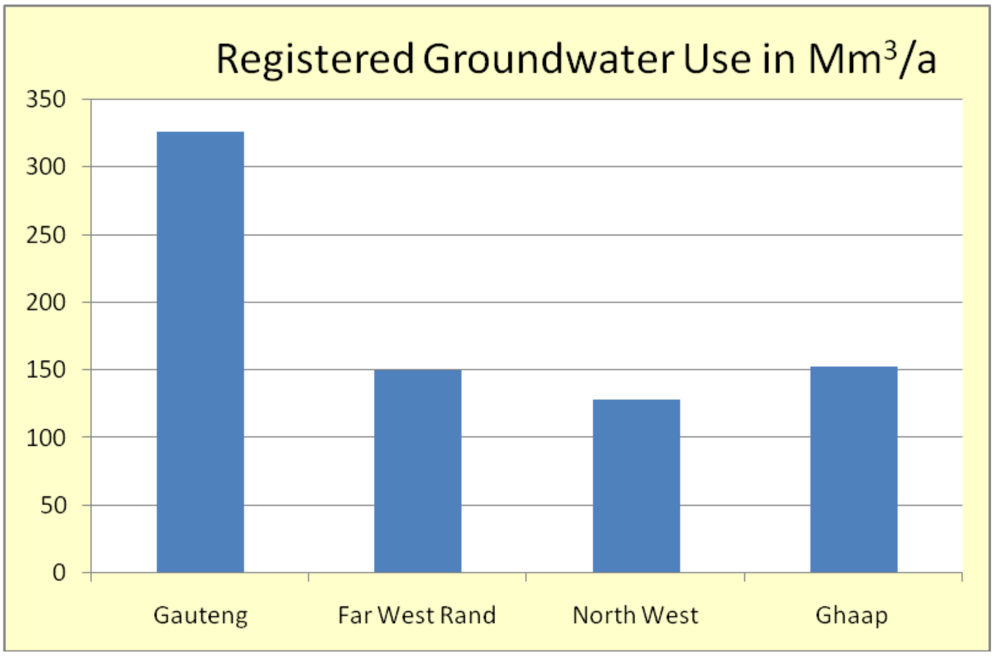
Table 2-6: Chemistry of groundwater samples from the Tshwane area

Parameter/ Element	Total sample	Minimum value	Mean value	Maximum value
Ca (mg/l)	338	0.50	36.3	162.8
Cl (mg/l)	338	1.50	18.4	154.1
EC (mS/m)	338	2.40	43.0	144.0
F (mg/l)	338	0.05	0.2	9.3
K (mg/l)	338	0.15	1.5	39.3
Mg (mg/l)	338	0.50	23.7	102.4
NH_4 (mg/l)	338	0.02	0.2	38.3
NO_3 as N (mg/l)	338	0.02	2.4	23.6
Na (mg/l)	338	1.00	14.6	121.1
PO_4 (mg/l)	338	0.00	0.0	4.4
SO_4 (mg/l)	338	2.00	20.9	633.6
Si (mg/l)	338	0.20	10.5	30.2
Total Alkalinity (mg/l $CaCO_3$)	338	8.40	155.3	560.0
pH	338	5.01	7.5	10.2

2.8 Dolomite groundwater abstractions

The WARMS data represents the volume of water use registered and not actual use. However, in some cases it can give a general idea of groundwater use. Based on the WARMS data obtained, there are a total of 1 962 registered water users in the Gauteng, North West and Ghaap Plateau dolomites, with a registered volume of approximately 600 Mm3/a. See **Figure 2-5** below for the volume of registered use for each dolomite region.

Figure 2-5: Volume of registered groundwater use in each dolomite region



2.9 Monitoring

Monitoring of groundwater (both water levels and water quality) is a vital first step in managing the resource, providing "early warning" of problems. Despite evidence of increasing pressure on dolomitic groundwater resources in recent years (e.g. over-abstraction and pollution), there is evidence that groundwater monitoring networks may be declining (for example in the Steenkoppies compartment). Effective monitoring of groundwater encompasses a variety of issues, including availability of and access to monitoring boreholes, institutional capacity to carry out monitoring and interpret the results, and compatibility and availability of various monitoring datasets. Monitoring of groundwater in dolomite aquifers needs to take into account possible high spatial variations in water quality and water levels, due to preferential flow pathways, compartmentalisation, and other physical features.

2.10 Strategic value of the dolomites

The potential strategic value of the four dolomite aquifer compartments in the Tshwane area is considerable. Following the severe drought in the early to mid 1980s, Vegter (1986) estimated that more than 1 500 litres per second would be available from these compartments, on at least a temporary basis. As far as is known, no current estimates of total groundwater potential from the dolomite aquifers have been made, or "residual" potential less current legal use. The value of groundwater in the dolomites is higher than most people realise – in the Steenkoppies area alone, groundwater supports an agricultural industry worth hundreds of millions of rands, employing thousands of people.

CHAPTER 3. VULNERABILITY IN DOLOMITE AQUIFERS

3.1 Introduction

The conduits and weathered zones in dolomites can allow pollutants to move quickly and easily in the aquifer, and relatively little physical filtering of water occurs. Karst landforms such as sinkholes and dolines together with thin soils also allow surface pollutants rapid access to the aquifer. Together, these characteristics make the dolomites very vulnerable to surface pollution of various types. Once polluted, the dolomites are difficult and expensive to clean up, in common with other aquifers. Although often used in the context of water quality, vulnerability can also refer to the quantity of a groundwater resource and the likelihood of this diminishing (e.g. drought vulnerability). Except where specified, the following sections refer to vulnerability to pollution, rather than to over-abstraction.

There have been only limited attempts to date to assess the vulnerability of South Africa's dolomite aquifers. Various options are open to the groundwater planner, ranging from the simple characterisation of all dolomite aquifers as "vulnerable", to the determination of groundwater protection zones, to more sophisticated methods which differentiate between different areas of dolomite aquifers depending on their physical characteristics. Some combination of these is also possible. It is generally easier and cheaper to protect groundwater from pollution than it is to remediate or "clean up" the pollution once it has occurred.

Aquifer protection may be divided into "resource protection" methods (e.g. mapping the vulnerability of a whole aquifer) and "source protection" methods that protect individual boreholes or springs (e.g. source protection zones). A combination of the two is recommended for South African dolomite.

3.2 The COP Vulnerability Assessment Method

The COP aquifer vulnerability mapping method, developed by Vías et al. (2003), was modified with respect to South African karst terrains by the University of Pretoria (Water Research Commission Project No: K8/669) in the wider Cradle of Humankind area near Krugersdorp. The method is based on the determination of the protection offered by the unsaturated zone of the aquifer against a contaminant event, i.e. the capability of the unsaturated zone to filter or attenuate contamination by different processes. The protection provided by the overlying layers (the O factor) is modified by surface settings that control water flow towards areas of rapid infiltration (the C factor) and the characteristics of the transport agent (water), that transfers the contaminants through the unsaturated zone (the P factor). The three factors are multiplied to obtain a final vulnerability index, which is classified into five vulnerability classes, ranging from "very low" to "very high", known as the VUKA index.

The COP/VUKA method was applied in the course of the Dolomite Project to the dolomites of the Sudwala / Pilgrim's Rest area (Activity 15). A final vulnerability map was produced that is intended to give general guidance to planners for the area. The method is data intensive however, and decisions regarding specific developments should not rely on the regional vulnerability assessment.

3.3 Protection Zones in Dolomite Aquifers

Source protection zones are commonly used world-wide to help protect important boreholes from surface pollution. Protection zones are areas around groundwater abstraction points (and sometimes well fields and even whole aquifers too) within in which activities that may pollute groundwater are controlled. They are often used with other methods (such as monitoring networks and vulnerability maps) to contribute to groundwater protection policy. Vulnerability mapping is often done before protection zoning. Ideally a combination of resource and source protection should be implemented to ensure the optimal protection of groundwater within a catchment. Once a protection zone has been defined, it is necessary to enforce the restrictions or rules that are made for activities within the protection zone.

Protection zones can range from simple circles drawn around boreholes (assuming a homogeneous, isotropic aquifer and no regional groundwater gradient) to zones of complex shape derived using numerical groundwater modelling and taking into account aquifer properties, topography, groundwater flow direction and recharge. They vary in size from a few tens of metres around a borehole to hundreds of square kilometres protecting an entire recharge area. The final protection zone or zones that is decided will depend not only on the physical properties of the aquifer and the presence of potential hazards, but also on the skills and resources available to enforce the protection zones and the existing land use in the area to be protected. The “NORAD” documents (DWAF, 2004) recommend that four source protection zones can be defined in South Africa, with the first zone being the “radius of influence of the borehole”, and the successive three zones being based on travel times of contaminants to the source. Other countries adopt slightly different categories.

Determining travel times is difficult in dolomite aquifers with preferred flow-paths. If groundwater flow velocities in conduits are especially high, the concept of travel time reaches its limits and a resource rather than a source protection strategy should be implemented.

3.4 Recommendations

It is recommended that vulnerability maps of all of our dolomite aquifers be derived. This will assist with planning decisions and allow better estimates to be made of data gaps. The maps will also function as data layers which can be added to the existing compartment maps developed as part of Activity 19 of the Dolomite Project.

The most important boreholes (e.g. those currently supplying the Tshwane and Johannesburg metropolitan municipalities) should have their protection zones reviewed. Where no protection zones exist, these should be defined, taking into account the constraints imposed by existing land-use activities. A policy on protection zoning needs to be developed, and it is recommended that some “pilot” zones be implemented to test the policy, and to inform technical staff and the general public.

3.5 Vulnerability to Over-abstraction

Declining groundwater levels due to over-abstraction is a problem in some dolomite areas (e.g. the Tarlton and Delmas areas), and is just as important an issue as pollution. Over-abstraction threatens spring and river flows, and can cause serious ground instability. Boreholes may dry up, causing great inconvenience and potentially threatening valuable industries (e.g. irrigated agriculture). Control of over-abstraction relies on good data collection together with the control of abstractions. This is best done in collaboration with groundwater users and other stakeholders, e.g. through a Water User Association. Although there may be a short-term advantage to individuals who pump too much groundwater, unsustainable abstractions ultimately harm all.

The Steenkoppies dolomite aquifer compartment near Tarlton falls under the jurisdiction of the Mogale City Local Municipality and the West Rand District Municipality. Large-scale irrigation using groundwater from the Steenkoppies compartment is thought to have begun in the 1970s and in 1997 it was estimated that lawful abstraction of groundwater in the Steenkoppies compartment amounted to about 19 Mm3/a. Groundwater from the compartment drains mainly via the Maloney's Eye spring, which flows at an average rate of about 13 Mm3/a (± 472 L/s) and is the origin of the Magalies River. Flow records for the Eye are available for the past century. In recent years the flow at the Eye has declined in comparison to the long-term average, and in early 2007 the Eye reportedly ceased to flow for the first time. Water users downstream of the Eye have complained that the irrigation is resulting in decreased flows to the Eye and consequently low flows in the Magalies River. That the low flows in the Magalies River were caused by groundwater abstraction was disputed by a group of irrigators in the Steenkoppies Compartment.

The value of agricultural activities in the greater Tarlton area is very large, both in net value and employment terms. At present the total area under irrigation is about 2600 hectares, although an accurate figure for current groundwater abstraction in the compartment is not yet available. In terms of the Water Act, a Water User's Association (WUA) is an appropriate vehicle for managing local water resources in a cooperative manner (DWAF, undated). In 2007 a group of irrigation farmers started negotiations aimed at the establishment of a WUA for the area, to be known as the Steenkoppies Aquifer Management Association. Negotiations are currently (October 2009) underway. If the situation with regard to groundwater over-abstraction is not managed cooperatively, a future drought could easily lead to great reductions in flow at Maloney's Eye again, and to expensive and time-consuming legal action.

Box on low flows at Maloney's Eye

CHAPTER 4. TECHNICAL ASPECTS OF DOLOMITE AQUIFERS

4.1 Introduction

This section discusses some technical points regarding groundwater in dolomites. The Dolomite Guideline (DWAF, 2006) has a more comprehensive account of many of these points, together with step-by-step procedures or actions for groundwater assessment, planning and management in South African dolomite aquifers. In particular, Appendix D of the Dolomite Guideline (DWAF, 2006) gives details for the drilling, development, testing, completion and sampling of boreholes in dolomites.

4.2 Borehole Siting

Boreholes in dolomite aquifers can have very high yields, but dry boreholes are also possible. This is because successful boreholes need to intersect groundwater conduits, weathered zones or other water-bearing features. The gravity geophysical method is commonly used for siting boreholes in dolomites in South Africa. Weathered areas (including areas with lots of groundwater conduits) have lower gravity readings compared with unweathered areas. Gravity surveys are time-consuming and expensive to carry out. In certain cases, gravity surveys have already been carried out by DWA or by consultants, although data may be difficult to obtain. Gravity data is also very useful for defining particular areas of high transmissivity, with implications for monitoring and groundwater management.

4.3 Borehole Drilling, Construction and Pumping

Most boreholes in dolomites today are drilled using rotary percussion drills. Drillers experienced in dolomite drilling are recommended - certain features of dolomite can make drilling difficult, can add to difficulties and expenses, and should ideally be discussed with the driller beforehand:

- Dry boreholes are possible, particularly where unscientific borehole siting is used. Dry boreholes can be close to boreholes with good yields, due to preferential flow paths.
- Loss of air-flush returns when fissures or conduits are intersected. The driller may add foam or some other substance to the borehole to regain pressure, but in serious cases the borehole may have to be abandoned.
- Substantial amounts of water may be encountered, which the compressor may be unable to lift out of the hole. Such boreholes may have to be completed short of the original depth.
- Chert layers in the dolomite can be very hard, wearing down drilling bits quickly and even deflecting the drill string.
- Rapid circulation of water discharged during drilling or testing back into the hole is possible, via karst conduits. This can lead to ground instability as the water leaches and erodes the rock in the vicinity of the borehole (DWAF, 2006). In serious cases, sinkholes can form near the borehole. Water should be piped some distance from the drilling / testing site, and care should be taken with long tests.
- Boreholes in dolomite are often “telescoped”, with successively smaller diameters used as the borehole deepens. The starting diameter should be big enough to

accommodate the desired diameter at depth. Boreholes are often left open (no casing) in stable rock.

Boreholes need to be completed with a secure sanitary seal and lockable steel cap, to protect both the borehole and the groundwater resource. Interpretation of pumping tests should be carried out with care, since many of the assumptions necessary for standard methods (e.g. uniform, isotropic aquifer) are not valid for the dolomites. All data from boreholes drilled should be submitted to the Department of Water Affairs for incorporation into their database.

4.4 Tracer Tests

Tracer tests are a common technique for estimating groundwater flow vectors in aquifers with preferential flow pathways, such as dolomites. A tracer is added to groundwater at one point, and points down-gradient are monitored to see when and how much tracer appears. Tracers can be liquids such as fluorescent dyes, or solids such as tiny spores or even harmless bacteria. Tracer tests can be considered in dolomites where flow vectors need to be estimated accurately (e.g. in determining impacts from mining, in defining source protection zones or in apportioning liability for pollution). Tracer tests can be complicated to carry out and interpret, and collaboration with the Water Research Commission or a university is recommended - the tracer test could form part of a research project.

4.5 Adaptive Management

In common with most aquifers, it is very difficult to predict the extent of the groundwater resource, or estimate impacts, before some degree of exploitation has started. This is partly because vast amounts of data are needed to model such things accurately, and partly because the act of exploitation itself changes aquifer properties (e.g. induced recharge, altered flow patterns, aquifer compaction, etc), and which may be impossible to predict. Adaptive management means that the technical and conceptual model of an aquifer is refined, and management interventions (such as irrigation abstraction restrictions) developed or “tuned” as new data becomes available (Seward et al, 2006). This is generally what happens anyway in all groundwater schemes, but acknowledging it in the first place avoids unrealistic expectations.

4.6 Stakeholder Participation

The Dolomite Guideline (DWAF, 2006) emphasises the need for the collaboration and participation of all stakeholders in using and managing water resources. Since dolomite aquifers are often close to major urban centres where pollution, over-abstraction and land-use can be problems, they have a relatively high potential for conflict between different groups, and consequently a greater need for stakeholder participation and decision-making processes.

- **Water user associations**
  An important form of cooperative local management of water resources provided for in the law is Water User Associations - cooperative bodies of local water users. They allow better control of joint finances and equipment; simplify negotiation with regulators and other stakeholders; facilitate debate and collective decisions; and consolidate joint interests. In several dolomite compartments where over-abstraction is a problem and there is potential for conflict between different groups of water users (e.g. Steenkoppies compartment), a WUA would help to resolve problems before they arose. However, a current problem with WUAs is the time and effort needed to set one up. It is recommended that DWA do everything possible to facilitate the WUA process where stakeholders are motivated. In areas where conflict may occur, but a user forum has not yet coalesced, the advantages of WUAs should be explained. It is preferable for users to take early decisions to avoid crises and problems in a "bottom-up" manner, rather than have directives imposed from above at a late stage.

> A Water User Association (WUA) is "a co-operative association of individual water users who wish to undertake water-related activities for their mutual benefit." (DWAF, undated). A WUA is regarded in law as a body corporate, able to borrow money, open bank accounts and enter into legal proceedings. WUAs may represent one sector (e.g. irrigating farmers), or many sectors (e.g. farmers, miners and forestry workers). The Minister of Water Affairs must establish a WUA, once he or she is satisfied that it is in the public interest and that wide public consultation has taken place. WUAs are generally funded through charges to their members, although in certain circumstances the state may assist with funding. Former subterranean water control boards are required to become WUAs, and this process must incorporate a measure of transformation in terms of management structure (DWAF, 2004). The final powers and functions of a WUA, once established, are delegated by the Minister, who may also remove functions and even dissolve the WUA under certain circumstances.

Box on Water User Associations

- **Partnership with research institutes**
  Resolving many of the potential problems in dolomite aquifers rests partly on a sound scientific understanding ("conceptual model") of the resource. Without broad scientific consensus, endless arguments over issues such as compartment boundaries, liability apportionment for pollution, sustainable abstraction volumes, or "natural" water levels and spring flows can clog up the planning and management process and result in conflict and periodic crises. Not all of this applied scientific research can be carried out by government departments due to shortage of time and resources. South African institutions such as the Water Research Commission, the CSIR, Mintek, the Council for Geoscience and the universities which have a considerable research capacity are able to resolve pressing technical questions if asked and mandated to do so.

- **Inter-agency cooperation**
  Historically, management of groundwater resources, and the associated problems such as mine water pollution, have been handled by a variety of government departments and institutions. Today, although the Department of Water Affairs is the legal "guardian" of all water resources, the problem still remains. Groundwater stakeholders naturally include the various government departments with responsibility for issues that affect groundwater – better cooperation is needed (perhaps facilitated by a forum) between key departments to resolve complex problems such as acid mine drainage.

CHAPTER 5. CONCLUSIONS

The dolomite aquifers in South Africa supply large quantities of good quality water to towns, farms, informal settlements and others, and also have critical environmental functions. Assessment, planning and management of the groundwater resources in dolomitic aquifers is improved by an understanding of the technical features of these aquifers. Protection of the dolomite aquifers is a priority, since pollutants can move quickly and easily through these rocks. Cooperation between institutions (e.g. government departments, research institutes), businesses (e.g. private consultants) and individual groundwater users is likely to be a key requirement for more efficient long-term management.

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