

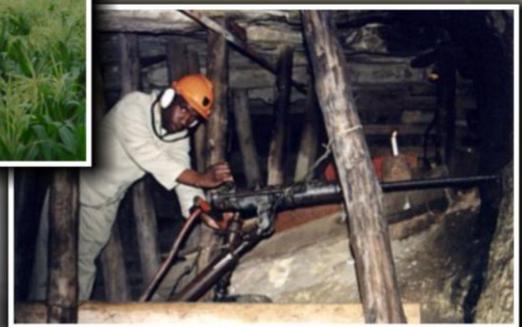


water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA
Directorate: National Water Resource Planning

Vaal River System: Large Bulk Water Supply Reconciliation Strategy

GROUNDWATER ASSESSMENT: DOLOMITE AQUIFERS



DECEMBER 2006

PREPARED BY:





**DEPARTMENT OF WATER AFFAIRS AND FORESTRY
DIRECTORATE: NATIONAL WATER RESOURCE PLANNING**

**VAAL RIVER SYSTEM: LARGE BULK WATER SUPPLY
RECONCILIATION STRATEGY**

GROUNDWATER ASSESSMENT: DOLOMITE AQUIFERS

December 2006

VAAL RIVER SYSTEM: LARGE BULK WATER SUPPLY RECONCILIATION STRATEGY

LIST OF REPORTS

Report No:	Title
P RSA C000/00/4406/01	Urban water requirements and return flows
P RSA C000/00/4406/02	Potential savings through WC/WDM in the Upper and Middle Vaal water management areas
P RSA C000/00/4406/03	Re-use options
P RSA C000/00/4406/04	Irrigation water use and return flows
P RSA C000/00/4406/05	Water resource analysis
P RSA C000/00/4406/06	Groundwater Assessment: Dolomite Aquifers
P RSA C000/00/4406/07	First stage reconciliation strategy

Above list of reports effective as at December 2006

VAAL RIVER SYSTEM: LARGE BULK WATER SUPPLY RECONCILIATION STRATEGY

GROUNDWATER ASSESSMENT: DOLOMITE AQUIFERS

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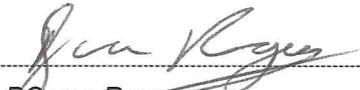
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Vaal River System: Large Bulk Water Supply Reconciliation Strategy Groundwater Assessment: Dolomite Aquifers

TABLE OF CONTENTS

1	Introduction AND TERMS OF REFERENCE	1
2	GROUNDWATER RESOURCE ASSESSMENT	2
2.1	Far East to Far West Rand Dolomites	2
2.1.1	Literature Review	5
2.1.2	Geology	7
2.1.3	Aquifer Development.....	8
2.1.4	Aquifer Hydraulic Parameters	10
2.1.5	Groundwater Levels and Flow	11
2.1.6	Recharge.....	13
2.1.7	Groundwater Quality	17
2.1.8	Existing Groundwater Use	18
2.1.9	The Reserve.....	18
2.1.10	Groundwater Balance.....	20
2.2	North West Dolomites	24
2.2.1	Literature Review	24
2.2.2	Geology	24
2.2.3	Aquifer Development.....	29
2.2.4	Aquifer Hydraulic Parameters	29
2.2.5	Groundwater Levels and Flow	30
2.2.6	Recharge.....	30
2.2.7	Groundwater Quality	31
2.2.8	Existing Groundwater Use	31
2.2.9	The Reserve.....	33
2.2.10	Groundwater Balance.....	33
2.3	Ghaap Plateau Dolomites	33
2.3.1	Literature Review	33
2.3.2	Geology	33
2.3.3	Aquifer Development.....	38
2.3.4	Aquifer Hydraulic Parameters	39
2.3.5	Groundwater Levels	40
2.3.6	Recharge.....	41
2.3.7	Groundwater Abstraction	43
2.3.8	Groundwater Balance.....	45

2.3.9	Groundwater Quality	47
3	Groundwater Management	48
3.1	Concepts.....	48
3.2	Groundwater Exploitation	50
3.2.1	West and Far West Rand	50
3.2.2	North West Dolomites	52
3.2.3	Ghaap Plateau	54
4	Conclusions	55
4.1	Far East to Far West Rand	55
4.2	North West Dolomites	57
4.3	Ghaap Plateau	57
4.4	SUMMARY	58
5	Recommendations	59
5.1	Far East to Far West Rand	59
5.2	North West Dolomites	59
5.3	Ghaap Plateau	59
5.4	general.....	59
6	References	61

List of Tables

Table 2-1:	Lithostratigraphy of the Malmani Subgroup	7
Table 2-2:	Historical spring discharges.....	9
Table 2-3:	Examples of various storage estimates	11
Table 2-4:	Recharge estimates (as percentage of MAP).....	17
Table 2-5:	Groundwater abstraction and spring flow (Million m ³ /a)	18
Table 2-6:	Water Balance	20
Table 2-7:	Water balance summary.....	21
Table 2-8:	NW Dolomite Compartments	24
Table 2-9:	Storativity and Transmissivity (m ³ /day/m) for various geological formations and compartments.....	30
Table 2-10:	Recharge estimates per Compartment.....	31
Table 2-11:	Groundwater Abstraction (Million m ³ /a)	31
Table 2-12:	Groundwater Balance Estimates per Compartment	33
Table 2-13:	Geology of the Ghaap Plateau	35
Table 2-14:	Calculated S-values for the Ghaap Plateau dolomites	40
Table 2-15:	Calculation of groundwater leakage across the Kuruman Dyke.	41
Table 2-16:	Recharge calculation of the Kuruman area based on spring flow, abstraction and evapo-transpiration.....	42

Table 2-17: GRA2 recharge calculations for the Ghaap Plateau dolomites.	43
Table 2-18: Groundwater abstraction from the Ghaap Plateau dolomites.	45
Table 2-19: Calculated groundwater balance for the Ghaap Plateau dolomites (Vaal WMA only).	46
Table 3-1: Volumes of stored groundwater potentially available	52
Table 3-2: Available abstraction.....	54
Table 3-3: Boreholes required in each GMU to exploit 75% of the recharge surplus	54
Table 4-1: Summary of Options	58

List of Figures

Figure 2-1: Dolomitic outcrop areas within the Vaal Basin WMA.....	1
Figure 2-2: Far East to Far West Rand Dolomites	2
Figure 2-3: Far East to Far West Rand Dolomites: Compartments	1
Figure 2-4: Groundwater Flow Directions and dewatered compartments.....	1
Figure 2-5: Dolomitic Groundwater compartments in the Far West Rand	1
Figure 2-6: Water level contours at West Driefontein Mine: Bank Compartment	16
Figure 2-7: Borehole positions from the NGDB	1
Figure 2-8: North West Dolomites.....	1
Figure 2-9: Dolomite Formations	1
Figure 2-10: Dolomite Compartments, Springs and groundwater flow directions.....	1
Figure 2-11: Distribution of Boreholes from the NGDB	1
Figure 2-12: Dolomites of the Ghaap Plateau.....	34
Figure 2-13: Compartment Dykes and Major Faults	37
Figure 2-14: Borehole positions from the NGDB	44

Vaal River System: Large Bulk Water Supply Reconciliation Strategy

Groundwater Assessment: Dolomite Aquifers

1 INTRODUCTION AND TERMS OF REFERENCE

Although there are other aquifers within the Vaal Basin Water Management Area, the ToR specified that the Dolomite Aquifers were the only ones to be investigated in this Study.

Within the study area there are some 26 000 km² of outcrop of dolomitic rocks. Fresh dolomite is impermeable and has no primary porosity. However, structural and geomorphological processes have created a network of joints, faults, fractures, solution cavities and weathering products. These interconnected features give rise to one of the most important aquifers in South Africa.

Attention was first drawn to the water bearing properties of the dolomites in the 1950's as deep gold mining progressed on the West Rand. Until cementation techniques of shaft sinking were perfected, the gold bearing reefs beneath the dolomite were inaccessible due to inrushes of groundwater from the dolomites. By 1956, up to 50 000 m³/day was being pumped from mines such as Venterspost.

During the 1960's and 70's, interest focussed mainly on mining related issues such as dewatering; in the 1980's on emergency groundwater supply to the PWV region and in the 1990's to the present, on quantification of aquifer characteristics. For the current Vaal Basin Study, the emphasis is on quantification of groundwater resources and identification of potential groundwater schemes.

The Terms of Reference as set out in the Inception Report were:

- Selection of most feasible groundwater options from past studies
- Identify options for conjunctive groundwater and surface water use
- Screening of groundwater schemes

Deliverables from the Inception Report were to be:

1. GIS database of hydrogeological information
2. A ranked list of potential (and existing) groundwater schemes, with cost estimates for development
3. Conjunctive use scenarios
4. Numerical model for predictive and management applications

Some compromises to these deliverables have been made in the light of some parallel DWAF, Water Research Commission (WRC) and Department of Minerals and Energy (DME) funded and managed projects on the dolomites in progress. These include fieldwork and are thus able to investigate the hydrogeology of the dolomites in far more detail than is possible under the Vaal Basin Study. Examples include the North West Dolomites (DWAF and WRC), Schoonspruit and

Zeerust Compartments (DWAF), Wonderfontein Spruit Catchment (DWAF and DME) and KOSH (DWAF) studies, to name the main ones (see Chapter 6). Information from these studies has formed an important basis for this study.

2 GROUNDWATER RESOURCE ASSESSMENT

This groundwater resource assessment has been limited to the dolomitic aquifers occurring within the Vaal Water Management Area (WMA). These are divided into three main regional and morphological groups, namely:

- Far East to Far West Rand (Vaal River Type)
- North-West (Plateau Type)
- Ghaap Plateau

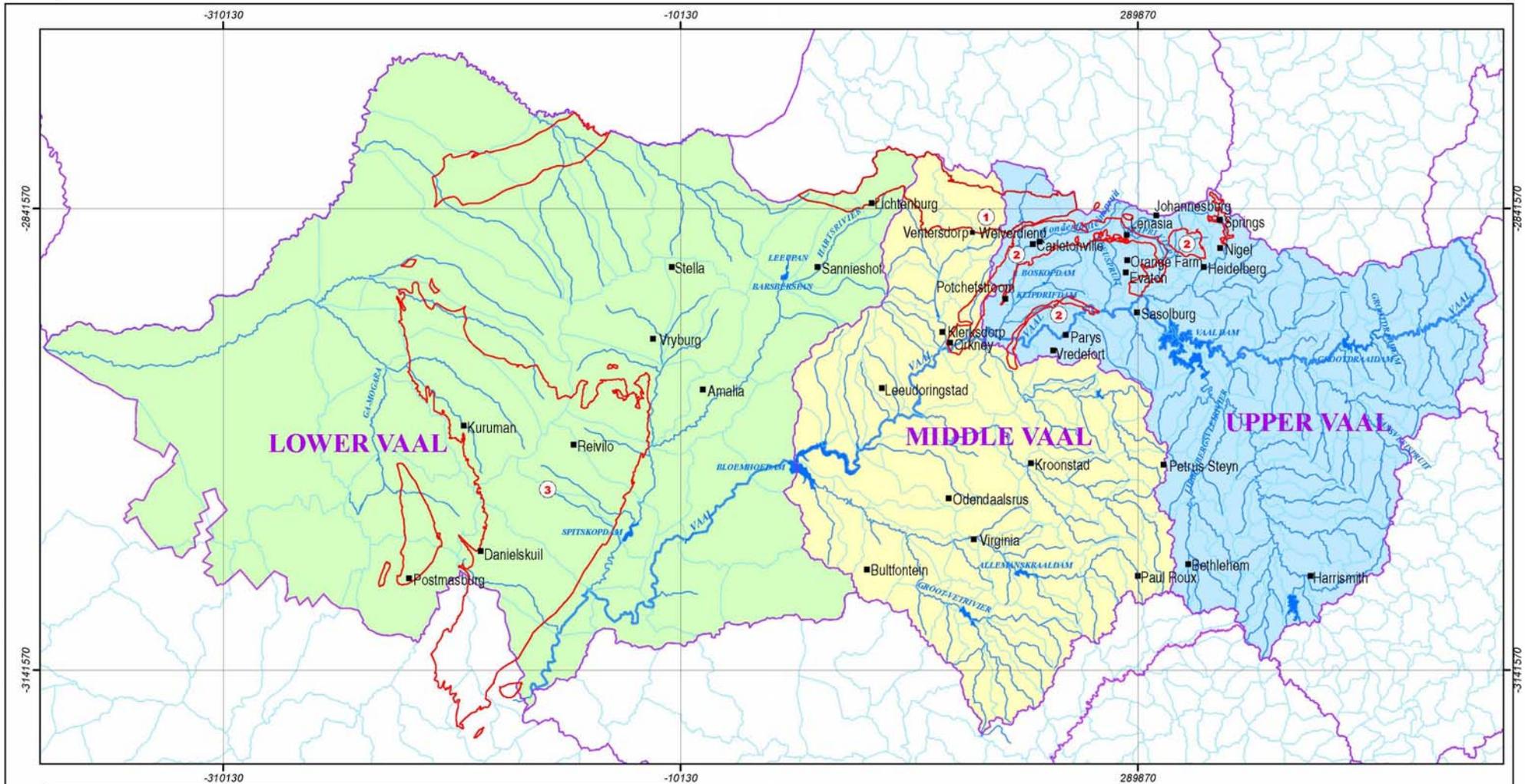
These groups are shown on **Figure 2-1**. The thin arcuate outcrop of dolomite on the North-West margin of the Vredefort Dome is included in the Far East to Far West Rand grouping.

The first two groups occupy diverging arcuate outcrop areas on the southern and northern flanks, respectively, of the Hartebeesfontein Anticline. All three areas are characterised by the development of karst features due to leaching of the dolomite, compartmentalisation of the dolomite by dykes (mainly) and sills, and the presence of strongly flowing cold springs. Each group is discussed individually in the following sections.

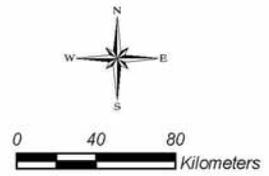
The study covers an area of ~26 000 km² and this assessment is of necessity no more than an overview of the situation.

2.1 FAR EAST TO FAR WEST RAND DOLOMITES

This area extends from the Springs area in the east to Orkney in the south-west (see **Figure 2-2**). It covers an area of ~ 2 850 km². The main outcrop area extends from the Klip River Valley to the Vaal River, with subordinate areas at Springs, north of Heidelberg and between Potchefstroom and Parys. It is unique in that this area comprises South Africa's major aquifer, the Malmani Dolomites. However, mining impacts have had a major influence on groundwater levels, storage and quality. Large areas have been subjected to extreme groundwater level drawdown as a result of an official policy of deliberate dewatering of large parts of the aquifer. Dewatering has been defined as pumping exceeding natural recharge and a compartment is considered to be dewatered when pumping/inflow has reduced to a steady-state equilibrium with recharge (Wolmarans 1986). For example, dewatering of the Oberholzer Compartment began in September 1955 and was accomplished in April 1973 (Hodgson et al, 2001). During this period, pumping rates reached 170 Mℓ/day, while the steady state pumping after dewatering is 50 Mℓ/day.



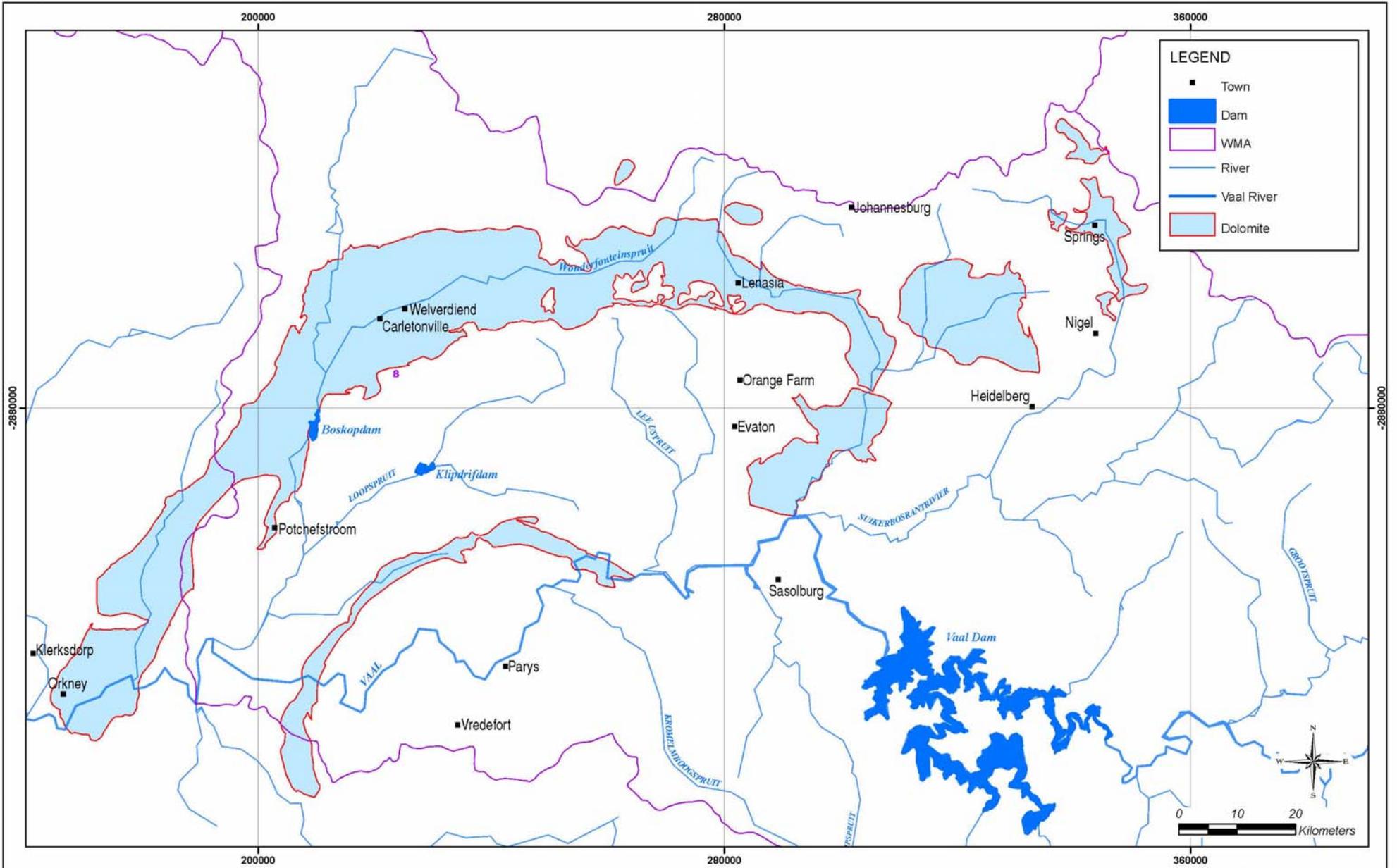
LEGEND		Water management area (WMA)		Dolomite	
■	Town		WMA 8: Upper Vaal		North West
	River		WMA 9: Middle Vaal		Far East to Far West Rand
	Vaal River		WMA 10: Lower Vaal		Ghaap Plateau
	Dam				
	Quaternary catchment				



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335412	ALBERS EQUAL AREA CONIC	
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	WGS	25

VAAL RECONCILIATION STUDY:
DOLOMITE OUTCROP AREAS WITHIN THE VAAL BASIN WMA

DATE	SCALE
DEC 2006	2 500 000
COMPILED BY	FIG NO.
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VAAL RECONCILIATION STUDY:
FAR EAST TO FAR WEST RAND DOLOMITES

DATE	SCALE
DEC 2006	600 000
COMPILED BY	FIG NO.
SCHN	2-2

The Springs area has been excluded from further investigation because of contamination by, mainly, mining activities (Lieskewicz 1986). The Parys area has also been excluded because it is an insignificant area in terms of the Vaal Basin Catchment and the main dolomite outcrop areas.

2.1.1 LITERATURE REVIEW

The dolomites between Lenasia and Welverdiend have been extensively studied due to the importance of gold mining in the area. Initial work in the 1950's and 60's was mainly concerned with the pumping and disposal of large volumes of groundwater entering the mine workings from the overlying dolomites. Pumping rates of 40 000 to 50 000 m³ per day had been reached by 1956 from the Blyvooruitzicht and Venterspost mines, respectively (see **Figure 2-3**).

During the 1960's and 70's interest focussed on mining related issues of control and disposal of inflow water. A policy of dewatering was implemented for the Venterspost and Oberholzer Compartments (1964), Bank Compartment (1969) and Gembokfontein West Compartment (late 1980's). However, the potential of the dolomitic aquifers for large scale groundwater supply was also recognised (Enslin and Kriel, 1967).

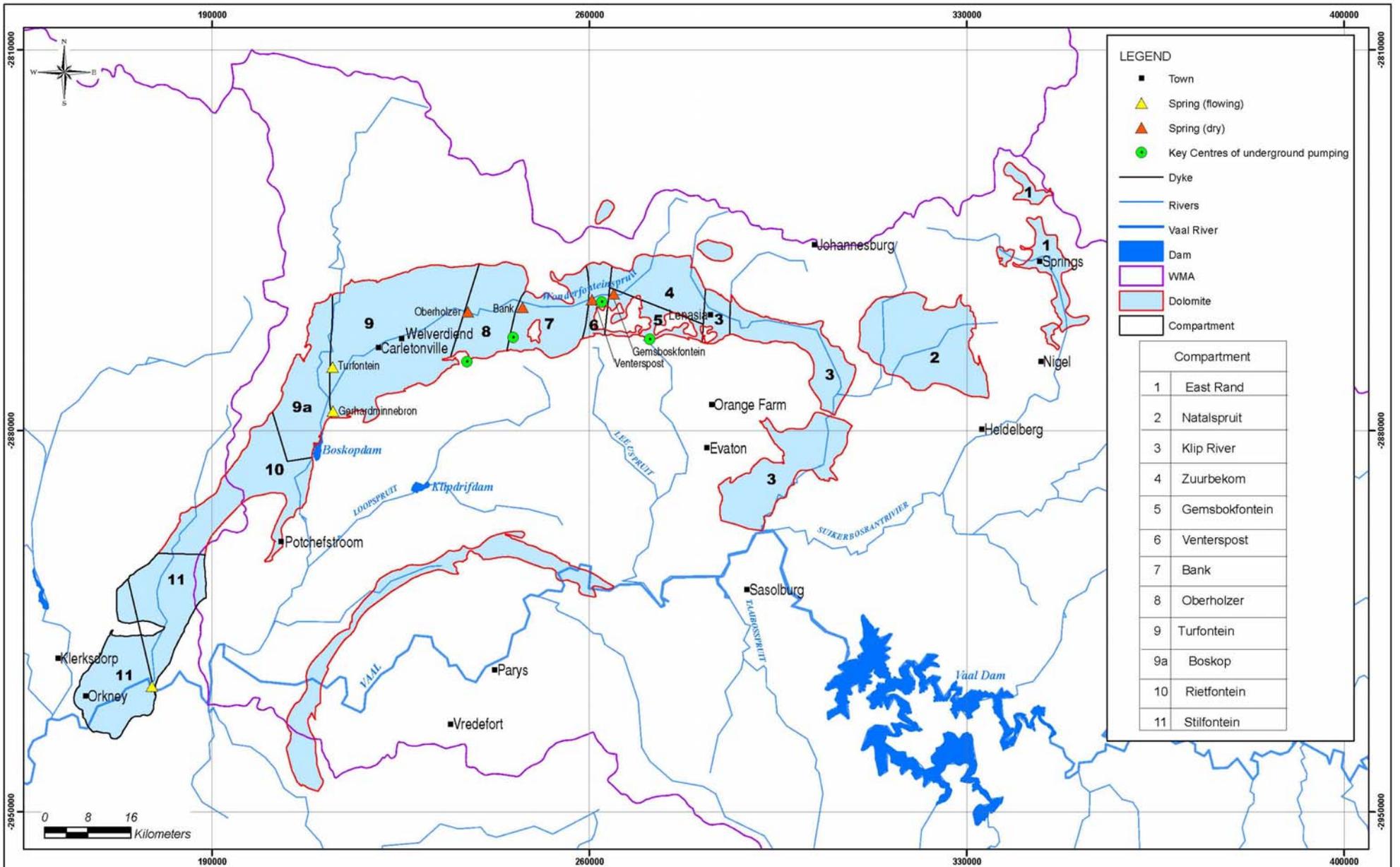
In the early to mid-1980's interest in the dolomites as a large-scale source of groundwater supply was rekindled by the serious drought gripping the PWV area. A sustainable yield of ~240 Mℓ/day (88 million m³/annum) was estimated (Vegter 1983). Extensive exploration drilling and yield testing was carried out in the Zuurbekom Compartment and on the East Rand but production boreholes were never established.

In the late 1990's, further efforts were made to quantify the aquifer hydraulic parameters of transmissivity and storage, and recharge.

From the late 1990's to the present, attention turned to the potential for decanting of contaminated groundwater as mining activities wind-down and underground pumping decreases.

The key sources of recent information were the following:

- The Wonderfontein Spruit Study of the DWAF (Hubert et al 2006). Covers the area from the eastern boundary of Zuurbekom Compartment to the western boundary of Turfontein Compartment (Boskop Dam). The Phase 1 Situation Assessment report was available for review; further work will involve site work to fill in gaps, modelling and preparation of a groundwater and surface water management plan.
- The Groundwater Resource Assessment Phase 2 (GRA2) Project of the DWAF. Compiled June 2005. The main outputs of relevance are quantification of storage, recharge and exploitation potential.
- WRC Report no 699/1/01: Prediction Techniques and Preventative Measures Relating to the Post-Operational Impact of Underground Mines on the Quality and Quantity of Groundwater Resources.



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VAAL RECONCILIATION STUDY:
FAR EAST TO FAR WEST RAND DOLOMITES: COMPARTMENTS AND SPRINGS

DATE	SCALE
DEC 2006	650 000
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SCHN	2-3

- Another key study by the Department of Minerals and Energy (DME), managed by the Council for Geoscience, is investigating the impacts of re-watering of the dolomite aquifer. However, this report was not available for review.

One-on-one meetings were held with Greg Heath and Danel van Tonder of the Council for Geoscience, Eddy van Wyk of the DWAF, Graham Hubert of Golders and Associates and Messrs Winde and Stoch of the Far West Rand Dolomitic Water Association. A full list of references is given in Chapter 6 of this report.

2.1.2 GEOLOGY

The dolomites belong to the Malmani Subgroup of the Transvaal Sequence. They comprise of four Formations, with the subdivision being on the basis of chert content and presence/absence and type of algal structures. From a groundwater perspective, the chert content is the most important, with the chert-rich formations forming the main aquifers. The subdivision and lithostratigraphy is shown in **Table 2-1** and the dolomite outcrop area in **Figure 2-2**.

Table 2-1: Lithostratigraphy of the Malmani Subgroup

Formation	Lithology	Thickness (m)
Eccles	Chert-rich dolomite	380
Lyttelton	Dark, chert-free dolomite	150
Monte Christo	Light coloured, recrystallised dolomite with abundant chert	700
Oaktree	Dolomite, becoming darker upwards; chocolate coloured weathering	200

These formations have not been differentiated on the published geological maps. The dolomite is underlain by the Black Reef Formation and overlain by the Pretoria Group.

A characteristic of the area is a series of cross-cutting lineaments representing faults and dykes. These are discussed in more detail in the next section. The dykes are mostly not 100% impermeable but are at least several orders of magnitude less permeable than the Karstified dolomite. They therefore divide the dolomite into a series of characteristic compartments. From east to west these are (see **Figure 2-3**):

- | | | |
|--------------------------|---|--------------|
| • Springs | } | East Rand |
| • Natalspruit | | Central Rand |
| • Kliprivier | } | |
| • Zuurbekom | | |
| • Gemsbokfontein (E & W) | | |
| • Venterspost | | West Rand |
| • Bank | | and Far West |
| • Oberholzer | | Rand |
| • Turfontein | | |
| • 9a. Boskop | | |
| • Rietfontein | | |
| • Stilfontein | | |

For ease of description the latter two areas are discussed separately, where appropriate.

2.1.3 AQUIFER DEVELOPMENT

The dolomite owes its permeability mainly to secondary fissures such as faults, joints and bedding planes which have provided easy access to circulating groundwater, thus promoting deep weathering of the dolomite, largely by carbonate solution or karstification. The residues of this weathering are mainly brown clays and wad with chert rubble and boulders. The depth of weathering/superficial deposits varies up to ~150 m but is very unpredictable and pinnacles of fresh dolomite are commonplace adjacent to deeply weathered zones.

One of the most important controls on zones of deep weathering is tensional fractures. Interpretation of Landsat Imagery of the Zuurbekom and Gemsbokfontein Compartment (Withers, 1983) reveals four major lineament trends, viz:

- West Rand (NNW-SSE)
- Transkaroo (NE-SW)
- Bank (NW-SE)
- Witpoortjie (NNE-SSW)

The Witpoortjie and Bank lineaments form a conjugate pair and are characteristic deformational trends within the Transvaal Sequence (Brink, 1979). These fractures have only minor displacement and generally penetrate right through the dolomite, may be tens of metres in width and are filled with clayey residual material. They form ready conduits for groundwater flow and on the West Rand are potentially one of the most serious water hazards to mine workings. A

characteristic phenomenon of the Far West Rand is of 'wet' and 'dry' mines. Venterspost and West Driefontein are 'wet' mines characterised by 'dirty' gouge filled faults, i.e. the Bank and Witpoortjie lineaments.

On the other hand Libanon and Doornfontein, although among the most heavily faulted mines in the area, are relatively 'dry' mines due to the mylonitic nature of the faults, i.e. West Rand and Trans-Karoo lineaments. A notable feature of the dolomite of the southern Gauteng is the occurrence of near vertical dykes which intersect the dolomite at intervals of a few kilometres, subdividing the dolomite into compartments (see **Figure 2-3**). These dykes are of diabase or composite syenite-diabase and are up to 60 m thick. The two main dyke trends are approximately N-S and E-W, the former being known as the Pilansberg Dykes (Day, 1980). These N-S dykes occupy major tensional features, as described in the preceding paragraph. They form barriers to groundwater flow of varying effectiveness.

An important feature of the East Rand dolomites is the presence of near horizontal sills. Up to three main sills are present, with the main one being known as the Green Sill.

A third structural feature controlling groundwater occurrence in the dolomite are axes of local folding. Flexure of the dolomite caused a network of fissures which radiate upwards from the axes of these distortions. Collapse of a stope beneath such a flexure at West Driefontein Gold Mine allowed the inrush of 385 Ml/day into the mine in 1968. Such localised folding is mainly detected from detailed exploration borehole records where the boreholes penetrate through the dolomite, allowing a contour map to be drawn up of the base of the dolomite and fold axes to be identified.

A characteristic and important feature of the dolomites is the occurrence of cold springs, several of high magnitude discharge. These generally occur on the upstream side of the compartmentalising dykes, at the lowest topographic point. In the West and Far West Rand, this is along the Wonderfontein Spruit. These springs are shown on **Figure 2-3**. Historical spring discharges prior to mining and large-scale abstraction are shown in **Table 2-2**.

**Table 2-2: Historical spring discharges
(from Hubert et al 2006)**

Spring	Discharge (Million m/a)
Gemsbokfontein	3.1
Venterspost	7.6
Bank	17.9
Oberholzer	19.2
Turfontein	6.7
Gerhardminebron	19.2
Total	73.7 million m³/a

The first four springs have dried-up as a result of the official policy of dewatering of certain compartments to reduce inflows to mines, while the others are still discharging at the above rates.

2.1.4 AQUIFER HYDRAULIC PARAMETERS

The key hydraulic parameters that require quantification to enable the viability of abstraction schemes to be determined in transmissivity (T) and storage (S). Much work has been carried out to try and determine a) methodologies and b) to assign values to these parameters (e.g. Bredenkemp et al, 1991). One of the key problems in this regard is the heterogeneity of the dolomite so that applying average figures across compartments is largely meaningless.

- Transmissivity

Transmissivity (T) is very variable in the dolomite, ranging from nearly impervious to $\sim 30\,000\text{ m}^3/\text{day}/\text{m}$. An interesting feature of the dolomite is the apparent increase in transmissivity toward the N-S dykes. This was noted in the Zuurbekom and Bank Compartments (SRK 1983, de Freitas and Wolmarans, 1978). In the Zuurbekom Compartment, T increased from an average $260\text{ m}^3/\text{day}/\text{m}$ to $25\,000\text{ m}^3/\text{day}/\text{m}$ near the Gemsbokfontein Dyke. In the Bank Compartment, T increased from an average $1000\text{ m}^3/\text{day}/\text{m}$ to $>7000\text{ m}^3/\text{day}/\text{m}$ close to the Bank Dyke.

An interesting finding to come out of the modelling of the Gemsbokfontein Compartment (SRK 1985) was that T in the N-S direction had to be adjusted to 15:1 of that in the E-W direction to obtain a reasonable calibration with observed groundwater levels.

Test pumping of exploration boreholes in the Klip River and Natalspruit Compartments (Kafri et al 1986) gave highly variable results, with T ranging from tens of $\text{m}^3/\text{day}/\text{m}$ to $1000\text{-}2000\text{ m}^3/\text{day}/\text{m}$, with one anomalous value of $9755\text{ m}^3/\text{day}/\text{m}$.

The highly transmissive nature of the dolomite resulted in the original water table being very flat, with a very low gradient from one end of a compartment to the other. Solution cavities and fissures are likely to be being enlarged with time by the rapid and continuous circulation of water from the surface into mine voids, thus increasing transmissivity and storage. This will induce hydraulic erosion of cavity/fracture infillings and chemical dissolution of the dolomite.

- Storage

Most groundwater potential occurs in the first 100 m and particularly, the first 30 m below the original water table. Various estimates for storage or porosity have been put forward. Some examples are given in **Table 2-3** below.

Table 2-3: Examples of various storage estimates

Author	Depth Interval	Storage
Foster	0 – 100 m	6 %
	>100 m	2 %
De Kock	First 30 m	10 %
	Next 30 m	2 %
	>60 m	<1 %
DWAF	First 30 m	15 %
	30 to 150 m	1.5 %
SRK	Average for the Zuurbekom Compartment from a groundwater Balance for the period 1966 to 1983:	1.3 %
Bredenkamp	Dolomites in general	1 – 5 %

The data presented in the above section shows the wide variation in T and S within the dolomite. Because of the nature of karst, these variations cannot be assigned to specific areas or zones and conditions vary greatly over short distances (Hodgson et al). Transmissivity and S values obtained from test pumping can be particularly site specific and also misleading. Water balances offer a better method of obtaining representative S values (Bredenkamp 1995).

2.1.5 GROUNDWATER LEVELS AND FLOW

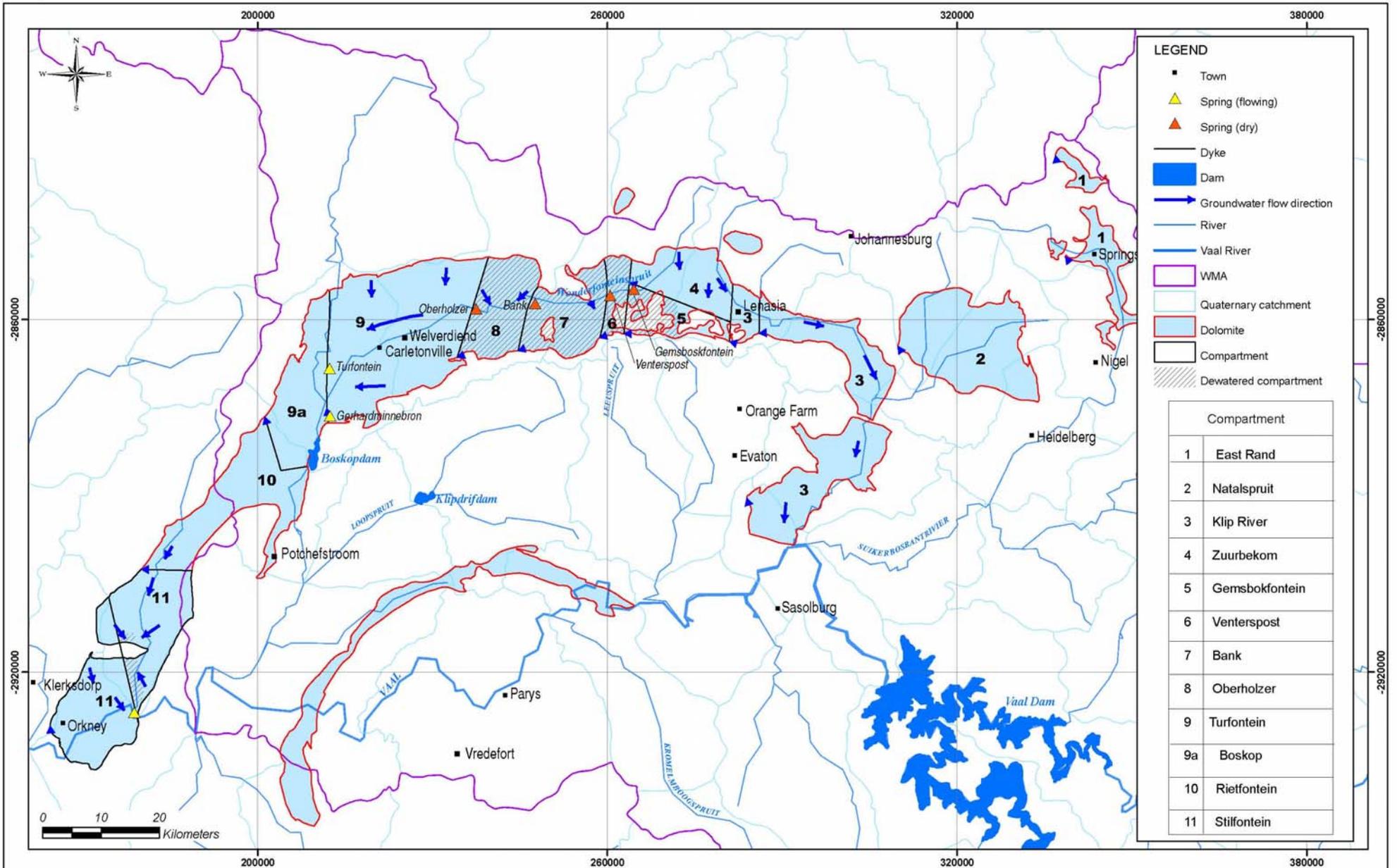
General groundwater flow directions and dewatered compartments are shown in **Figure 2-4**.

- Natalspruit and Klip River

Groundwater levels are characterized by low gradients bounded by 'steps' along known and inferred dykes. At a regional scale, groundwater levels indicate flow converging onto the main drainage channels and southwards towards the Vaal River.

Gradients in the Natalspruit Basin are between 0.2 % and 0.5 %. Groundwater levels converge on the Natalspruit, Elsburgspruit and Rietspruit,.

Groundwater in the Kipriver area can be divided into numerous small compartments on the basis of groundwater levels. These compartments appear to be in connection with the Klip River. Gradients vary from ~0.1 % to ~0.2 %.



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VAAL RECONCILIATION STUDY:
GROUNDWATER FLOW DIRECTIONS AND DEWATERED COMPARTMENTS

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- West Rand

The original, pre-mining water table in this area was very flat. This is a consequence of the highly transmissive nature of the karstified dolomite. Groundwater flow is in a generally westerly direction, with this flow being interrupted to varying degrees at the major compartment forming dykes, e.g. Bank, Oberholzer, etc. This is shown schematically in **Figure 2-5**. The aquifer overflowed at the lowest topographic point along these dykes in a series of springs or 'eyes', such as the Venterspost and Oberholzer Eyes.

Expansion of mining activities beneath the dolomites led to increased inflows and associated pumping costs. A policy of dewatering of dolomitic compartments was therefore followed, starting with Venterspost and Oberholzer in 1964, Bank in 1969 and Gemsbokfontein West in the late 1980's. This has led to the formation of large zones of depression in the water table above the main mine inflow areas. An example from the Bank Compartment (West Driefontein mine) is shown in **Figure 2-6**. The pumped water is discharged via pipeline(s) back into the Wonderfontein Spruit downstream of the Oberholzer Dyke.

Apart from the compartments affected by dewatering mentioned above, the Stilfontein Compartment is also affected. There is a large zone of drawdown immediately to the east of the NNW-SSE trending dyke that bisects the compartment, as indicated on **Figure 2-5**.

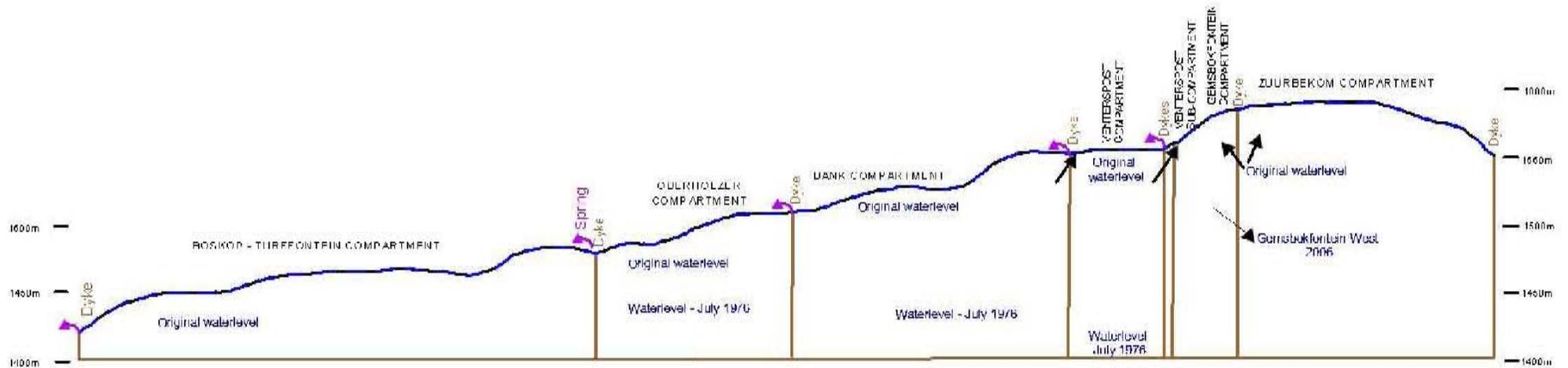
2.1.6 RECHARGE

- Natalspruit and Klip River

Using comparative, chloride mass balance and water balance methods, Kafri (*op cit*) derived recharge figures of 20% and 13% of Mean Annual Precipitation (MAP) for chert-rich and chert-poor dolomites, respectively. Total recharge to the area of $50 \times 10^6 \text{ m}^3/\text{a}$ was estimated.

- West Rand

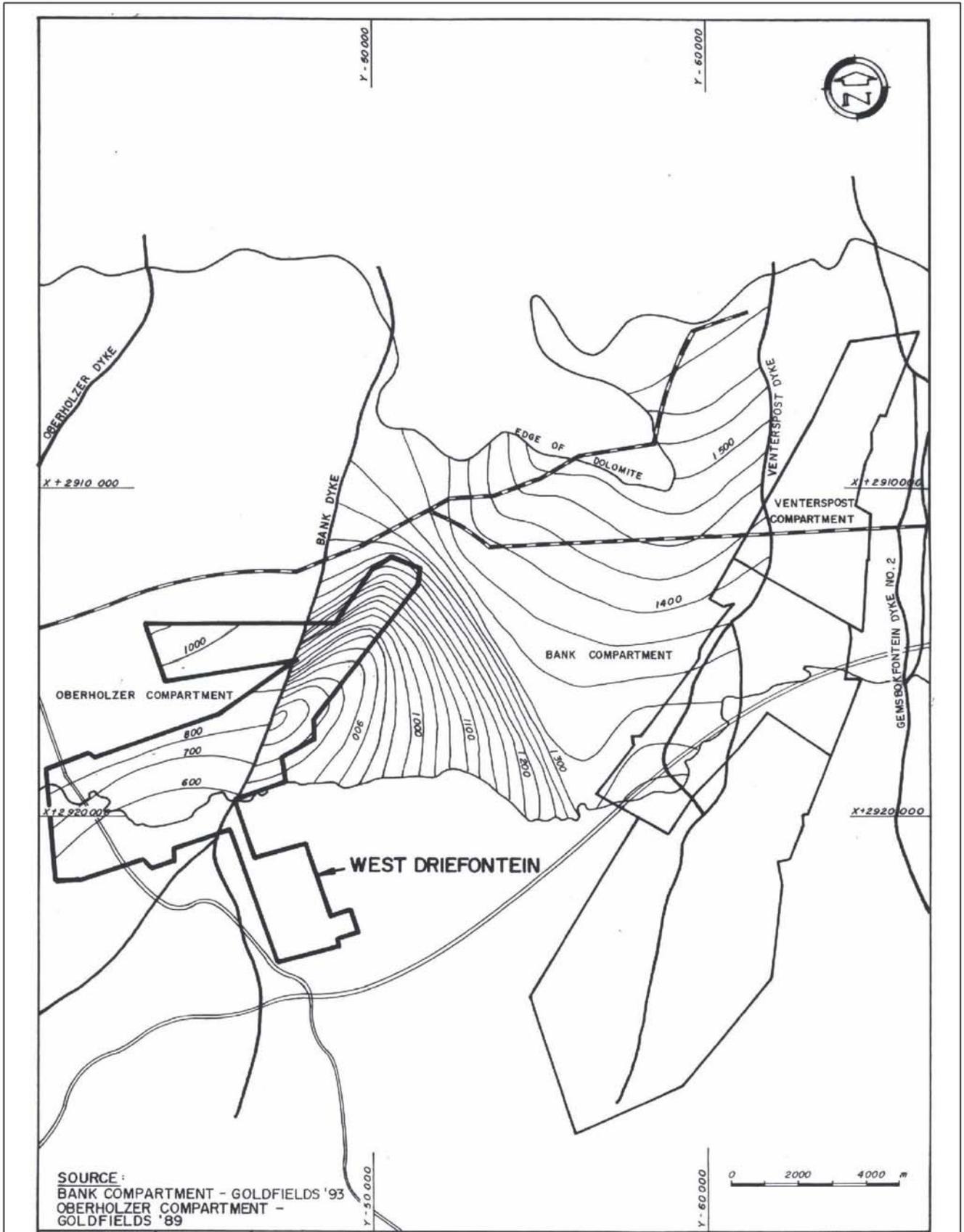
Recharge estimates have been carried out by numerous researchers, using a number of differing techniques. The simplest of these makes the assumption that the pre-mining flow of the various eyes was equivalent to recharge under natural conditions and that the compartment dykes are impermeable. Other approaches have included the chloride mass balance method, hydrogeochemistry and water balances. A summary of recharge estimates, as a percentage of rainfall, is given in **Table 2-4** overpage.



PROJECT NO.	COORDINATE SYSTEM	
335412	SPHEROID	CENTRAL MERIDIAN

DOLOMITIC GROUND-WATER COMPARTMENTS IN THE FAR WEST RAND

DATE	SCALE
JUNE 2006	
COMPILED BY	DWG NO.
DOOK	2.5



PROJECT NO. 335412	COORDINATE SYSTEM		WATER LEVEL CONTOURS AT WEST DRIEFONTEIN MINE (mamsl) BANK COMPARTMENT	DATE DEC 2006	SCALE NOT TO SCALE
	SPHEROID	CENTRAL MERIDIAN		COMPILED BY SCHN	FIG NO. 2-6

Table 2-4: Recharge estimates (as percentage of MAP)

Compartment	Enslin & Kriel (1967)	Fleisher (1981)	Wolmarans (1984)	Foster (1989)	Bredenkamp (1993)	GRA 2 (2005)
Zuurbekom	13	16.8	15		15.8	7
Gemsbokfontein	7.5	12.8	5.3		27	
Venterspost	8.5	27	20	54.6		5.4
Bank	5.8	24	16.3	27.3		6.7
Oberholzer	3.6		18.3	12.9		6.0
Turffontein			5.6			

There is a large spread of estimates for most compartments, with the exception of Zuurbekom. The discrepancies are due to uncertainties and inconsistencies in aspects such as leakage through dykes and surface water losses. The GRA 2 estimates appear to be too low. A further important aspect to be considered is increased/induced recharge owing both to greater available storage being created in dewatered compartments, e.g. Foster's Venterspost estimate of 54.0 % and opening up of additional access paths, e.g. sinkholes, areas of subsidence.

A unique characteristic of the dolomite aquifer of the West Rand is that, owing to its very high transmissivity, the total annual recharge is available for abstraction. The main management limit is that drawdown should not exceed ~ 5 m because of stability concerns as the risk of sinkhole formation increases with drawdowns greater than this where the water table is within 30 m of the ground surface.

The generally flat topography and lack of surface drainage features all point to recharge being relatively high on the dolomites. A further aspect that will affect, i.e. increase, recharge, is the extensive development of sinkholes, subsidence and associated fracturing related to the mine dewatering process.

2.1.7 GROUNDWATER QUALITY

Natural dolomitic groundwater is essentially a Ca/Mg (HCO₃)₂ type, alkaline and with an EC of <70 mS/m. However, the impacts of mining, industrialisation, waste disposal and agriculture have modified this natural water quality to a greater or lesser extent over most of the dolomite area under discussion. The favourable aquifer characteristics of high transmissivity, storativity and rapid recharge mean that the dolomite aquifer is vulnerable to contamination. Contamination is manifested by significant increases in concentration of Total Dissolved Solids, sulphate (acid mine drainage), sodium and chloride, and nitrate. Dissolved radionuclides are also a problem, particularly in the Bank and Oberholzer Compartments.

Surface water and groundwater show very similar characteristics providing further evidence of their close relationship in dolomitic terrain. Boskop Dam is the receiving water body for most of the mining influenced water draining from the West and Far West Rand. Salinity of the dam water has increased over the last 30 years, and sulphate and sodium concentrations have more than doubled (Hodgson et al).

All compartments have been impacted to a greater or lesser extent by mining activities, with the Springs area being ruled out for future groundwater use for this reason.

2.1.8 EXISTING GROUNDWATER USE

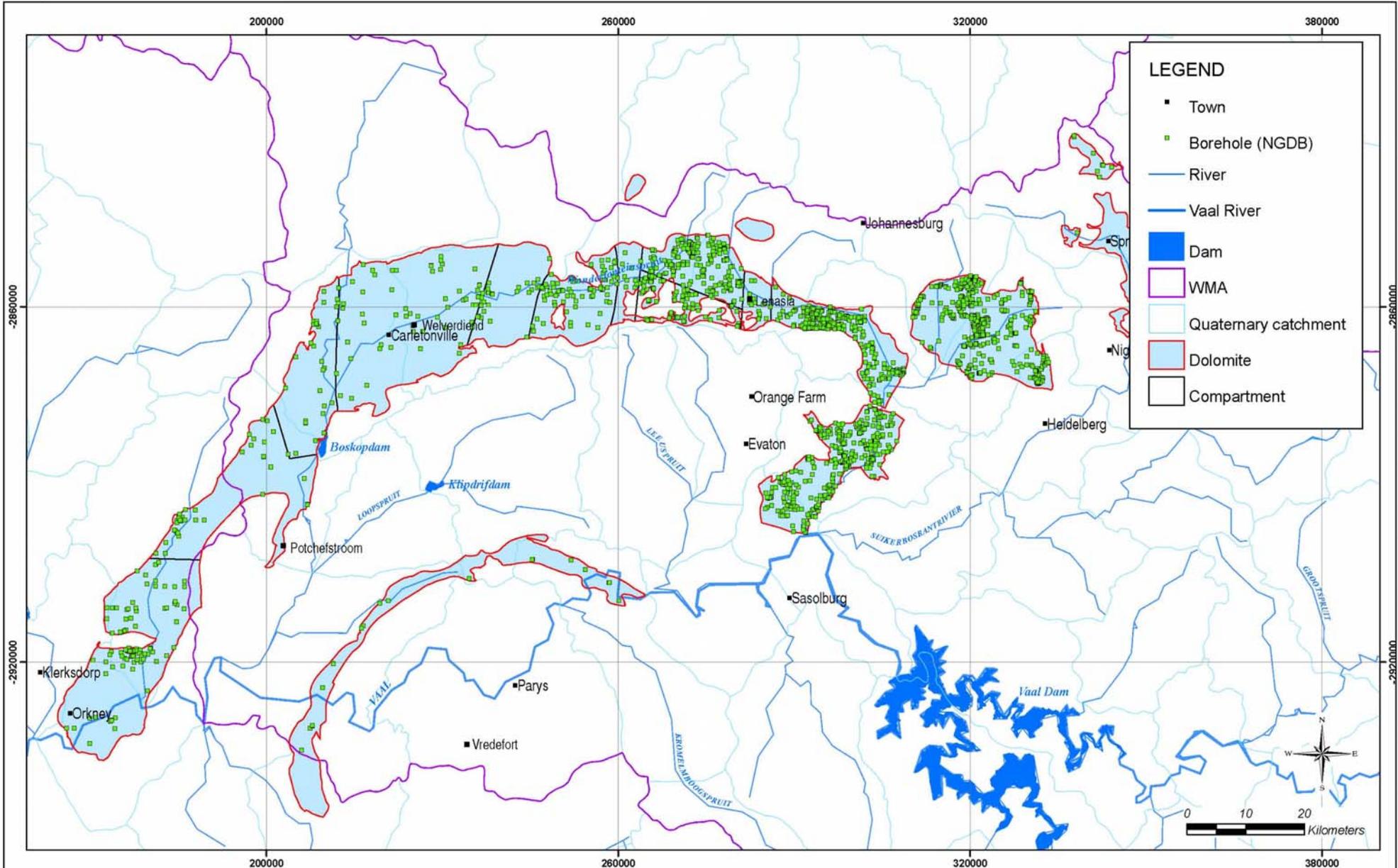
Groundwater is abstracted for domestic and irrigation use and by the mines, the latter two being by far the most important except in Zuurbekom Compartment. A summary of estimated abstraction, obtained from various sources, is shown in **Table 2-5**. The positions of boreholes from the NGDB are shown on **Figure 2-7**.

Table 2-5: Groundwater abstraction and spring flow (Million m³/a)

Compartment	No	Spring Flow	Irrigation	Domestic	Mining	Municipal/ Industrial	Total
Varkfontein/East Rand Basin	1	-	2.5	1.0	24.5	-	28.0
Nataalspruit	2	-	43.4	2.3	-	-	45.7
Klipriver	3	-	23.0	1.3	-	1.0	25.3
Zuurbekom	4	-	-	-	7.6	10.0	17.6
Gemsbokfontein	5	-	1.5	-	43.2	-	44.7
Venterspost	6	-	-	-	27.0	-	27.0
Bank	7	-	-	-	36.0	-	36.0
Oberholzer	8	-	0.4	-	19.0	-	19.4
Turffontein	9	25.2	3.4	2	-	-	30.6
Boskop	9a	-	-	-	-	-	-
Rietfontein	10	4.0	1.5	-	-	-	5.5
Stilfontein	11	0.2	0.1	-	12	-	12.3
Totals		29.4	75.8	6.6	169.3	11.0	292

2.1.9 THE RESERVE

Groundwater Reserve studies have not been completed for any catchments within this study area.



PROJECT NO. 335412	COORDINATE SYSTEM ALBERS EQUAL AREA CONIC	
	SPHEROID WGS	CENTRAL MERIDIAN 25

**VAAL RECONCILIATION STUDY:
BOREHOLE POSITIONS FROM THE NGDB**

DATE DEC 2006	SCALE 600 000
COMPILED BY SCHN	FIG NO. 2-7

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2.1.10 GROUNDWATER BALANCE

The pre-mining flow estimate for springs in the Wonderfontein Catchment (Zuurbekom to Turfontein/Boskop) Dam) is 74 Million m³/a. According to **Table 2-5** there is currently a deficit of ~49 Million m³/a of natural spring discharge compared to the pre-mining situation. The pre-mining flow corresponds to an overall pre-mining recharge of ~9.7 % (EMA 2006). The combined estimated groundwater abstraction and springflow of ~117 Million m³/a (Hubert et al 2006) is much higher than the pre-mining recharge suggested above, which indicates that the Wonderfontein Catchment system is not yet in balance (EMA 2006). This means that dewatering of the dolomite aquifer is still continuing. Alternatively, if the system is in balance or steady state today, recharge is more like 15 %. This could either indicate that recharge has increased during the mining era (highly likely) or that the pre-mining estimates of spring flow or recharge were too low (Hubert et al 2006).

Water levels in DWAF monitoring boreholes are still declining, which supports the hypothesis that the dolomite compartments in the Wonderfontein Compartment are not in balance (Hubert *op cit*).

A groundwater balance is attempted per compartment as per the list in Section 2.1.2. The balance is based on the various figures given in the literature quoted above and is summarized in the table below.

Table 2-6: Water Balance

Compartment	Area (k m ²)	Storage volume (Million m ³ /5 m drawdown)	Existing use (Million m ³)	Recharge (Million m ³)	Surplus* (Million m ³)
Natalspruit	314	78.5	45.7	31	0
Kliprivier	428	107	25.3	42	16.7
Zuurbekom	143	35.5	17.6	15	0
Gemsbokfontein	102	Dewatering	43.2	43.2*#	N/A
Venterspost	52	Dewatered	27	27*#	N/A
Bank	156	Dewatered	36	36*#	N/A
Oberholzer	161	Dewatered	19	19*#	N/A
Turfontein	522	130	30.6	47	16.4
Boskop	211	53	?	19	19?
Rietfontein	257	64	1.1	19	17.9
Stilfontein	415	104	12.3	31	18.7
Total	2761	572	258	329	89

Notes

* Excludes mining of groundwater in storage

Recharge taken as 12 to 15% of the average annual rainfall

S_y taken as 5% for the upper 5 m

#Recharge assumed to = pumping rate to maintain dewatering

Existing use from DWAF 2000. Includes spring flow and pumpage from mines

Comments are made on individual compartments as follows:

- Natalspruit and Klip River

The table above indicates a surplus of ~16.7 Million m^3/a Kafri et al (*op cit*) provided a water balance for this area (including the Klipriver Compartment). Their findings are summarized in **Table 2-7** below.

Table 2-7: Water balance summary

Input/Output	Volume (Million m^3)
Inflows	
Groundwater	Unknown
Surface water	68
Direct recharge	50
Waste disposal	164
Irrigation return flow	13
Total	295
Outflows	
Groundwater	Unknown
Surface water	239
Abstraction	45.7
Evapotranspiration	24.5
Total	305

The above figures are quite different to those in **Table 2-6** and are from a fairly detailed study and appear to show that there is no surplus groundwater available. However, the recharge figure given in **Table 2.6** appears to be on the low side and is ~23 Million m^3 less than that given in **Table 2-4**. Using the latter recharge figure there could be a surplus of ~20 Million m^3/a . This would require 25 production boreholes yielding 25 l/s .

- Zuurbekom

According to the figures presented in **Table 2-4** there is no groundwater surplus in this compartment. There is also the question of contamination by mining activities in parts of the compartment.

- Gemsbokfontein

The western part of this compartment is being actively dewatered and some of this water is used to artificially recharge the eastern part of the compartment. Equilibrium conditions had not yet been attained as at 2001 (Hodgson et al). In 1986/87, the Rand Water Board installed two production boreholes in the Gemsbokfontein East Compartment, a little to the south of the existing RWB pump

station at Zuurbekom. These were designed to yield a total of 20 000 m³/day or 7.3 Million m³/a. However, after pumping at an average of 8 700 m³/day and abstracting 1.83 Million m³ over a period of six months, the water table in this compartment had dropped by over 4 m. On advice from the State Coordinating Technical Committee on Sinkholes, the Board stopped pumping in June 1987.

From the above experience it was concluded that extreme caution should be exercised in estimating the volume of groundwater available for abstraction in any dolomitic compartment (DWAF 1988). Factors that require particular attention were highlighted as being storage, recharge and external factors such as mine dewatering and abstraction from neighbouring compartments, in addition to long-term water level behaviour.

Large-scale exploitation of the Gemsbokfontein compartment is therefore not recommended.

- Venterspost

This compartment is in a dewatered state. Predictions of the time required to rewater vary from 0.42 years (based on mine records of water pumped) to 25 years (based on the former flow of the eye). Water quality ranges from contaminated (SO₄ >300 mg/l) to mixed dolomitic (SO₄ <70 mg/l).

Foster (1989) estimated that the volume of groundwater in storage within 50 m of the then water table elevation was ~21.5 million m³. He also obtained a significantly higher recharge rate of 54%.

Due to its dewatered state, i.e. mostly deep water levels, uncertainties about recovering water levels and the possibility of inflow of contaminated groundwater, exploitation of this compartment is not quantified at this stage. Further conclusions and recommendations can possibly be made once the DWAF's Wonderfontein Spruit study is completed.

It should be noted that recovered water levels could be significantly lower than the previous natural levels owing to mining having taken place through the bordering dykes between the Venterspost Dyke and the Turfontein Dyke. The new post mining recovered level is predicted to be at the level of Turfontein Dyke/Eye, which is ~1 430 m above mean sea level according to the scenario of Hodgson et al 2001. This would mean that groundwater levels would be between ~145 and 160 m below ground surface and would change the economics of groundwater abstraction considerably. Seeing as the most favourable features for borehole siting are karst features in the upper ~50 m or so of the dolomite, establishing high yielding (>25 l/s) production boreholes could also be problematical.

Exploitation of this compartment is not recommended or feasible pending re-watering.

- Bank

This compartment is in a dewatered state and water levels are deep over the main mining areas. However, away from these areas, water levels are relatively shallow. Foster (op cit) estimated that the volume of groundwater in storage within 50 m of the then water table elevation was ~63 million m³. He also obtained a significantly higher recharge rate (~27%) based on the volume of water

pumped from the mines in this area. There would thus appear to be scope to develop groundwater resources in this compartment away from the main mining areas.

Modelling of the Bank Compartment by Hodgson et al (op cit) indicated a time period for rewatering of the compartment of 21 years. However, it is not stated if this is for full rewatering or only to the level of the Turfontein Dyke.

Exploitation of this compartment is not recommended or feasible pending re-watering.

- Oberholzer

This compartment is also in a dewatered state, with deep water levels associated with mining areas. Foster also looked at this compartment and estimated that there was ~38 million m³ of groundwater in storage within 50 m of the water table as at 1989.

More detailed studies are required to investigate Foster's conclusion that groundwater abstraction from this compartment is feasible.

- Turfontein

The water balance indicates that there may be ~ 17 Million m³ of surplus groundwater in this compartment. However, if the scenario of water level recovery to the level of Turfontein Dyke is correct and holes mined through the compartment dykes are not plugged, then all recharging water from the upstream compartments will discharge at Turfontein Eye. This amount of flow has been estimated at ~150 000 m³/day (Hodgson op cit), equivalent to 70 production boreholes yielding 25 l/s. However, groundwater level contour maps appear to show that the compartment dykes do in fact form barriers to groundwater flow and the above scenario may not materialise

Eight production boreholes yielding 25 l/s would be required to abstract the ~6 Million m³/a surplus recharge.

- Rietfontein

Table 4-6 indicates that there may be a surplus of ~18 Million m³/a in this compartment, which is probably the least investigated of all the Far West Rand Compartments. About 22 production boreholes would be required to abstract this 'surplus'.

- Stilfontein

The main groundwater abstraction in this Compartment is from Margaret Shaft at Stilfontein Gold Mine, and ~12.3 Million m³/a is pumped. The surplus groundwater is estimated at 17 Million m³/a. The pumped water is used by DRD-NW operations for process water (7 000 m³/day), supply to a number of plots north of Stilfontein, where dewatering has caused a trough of depression, and by Chemwes for re-working of slimes dams (18 000 m³/day). The balance is discharged to the Koekemoer Spruit. The second largest abstraction is from 'scavenger' boreholes on the northern banks of the Vaal River on AngloGold's property (Unknown quantity – I Dennis pers comm.). This water is used in the gold recovery process.

The estimated surplus groundwater (Million m³/a) can be summarized as follows:

• Natalspruit/Klip River)	:	20
• Turfontein	:	6
• Rietfontein	:	18
• Stilfontein	:	17
Total	:	61

2.2 NORTH WEST DOLOMITES

The north-west dolomites outcrop along the northern edge of the Lower and Middle Vaal WMA. The towns of Lichtenburg and Ventersdorp are situated on the southern edge of the outcrop. The total area of dolomite is ~ 4 050 km² (see **Figure 2-8**).

2.2.1 LITERATURE REVIEW

Studies have been undertaken on this area of dolomite since the 1930's (EMA, 2003). The main sources of information used in this study were that of E Martinelli and Associates (2003) and Bredenkamp (in Stephens et al 2005). The former is an Inception Report on the Project Management and Technical Coordination of North-West Dolomitic Groundwater Region Areas. The latter is a Situational Analysis for the Preparation of Institutional Arrangements for Groundwater Management in the North West Dolomite Water Area. Other relevant reports deal with individual compartments. A list is provided in Section 6.

2.2.2 GEOLOGY

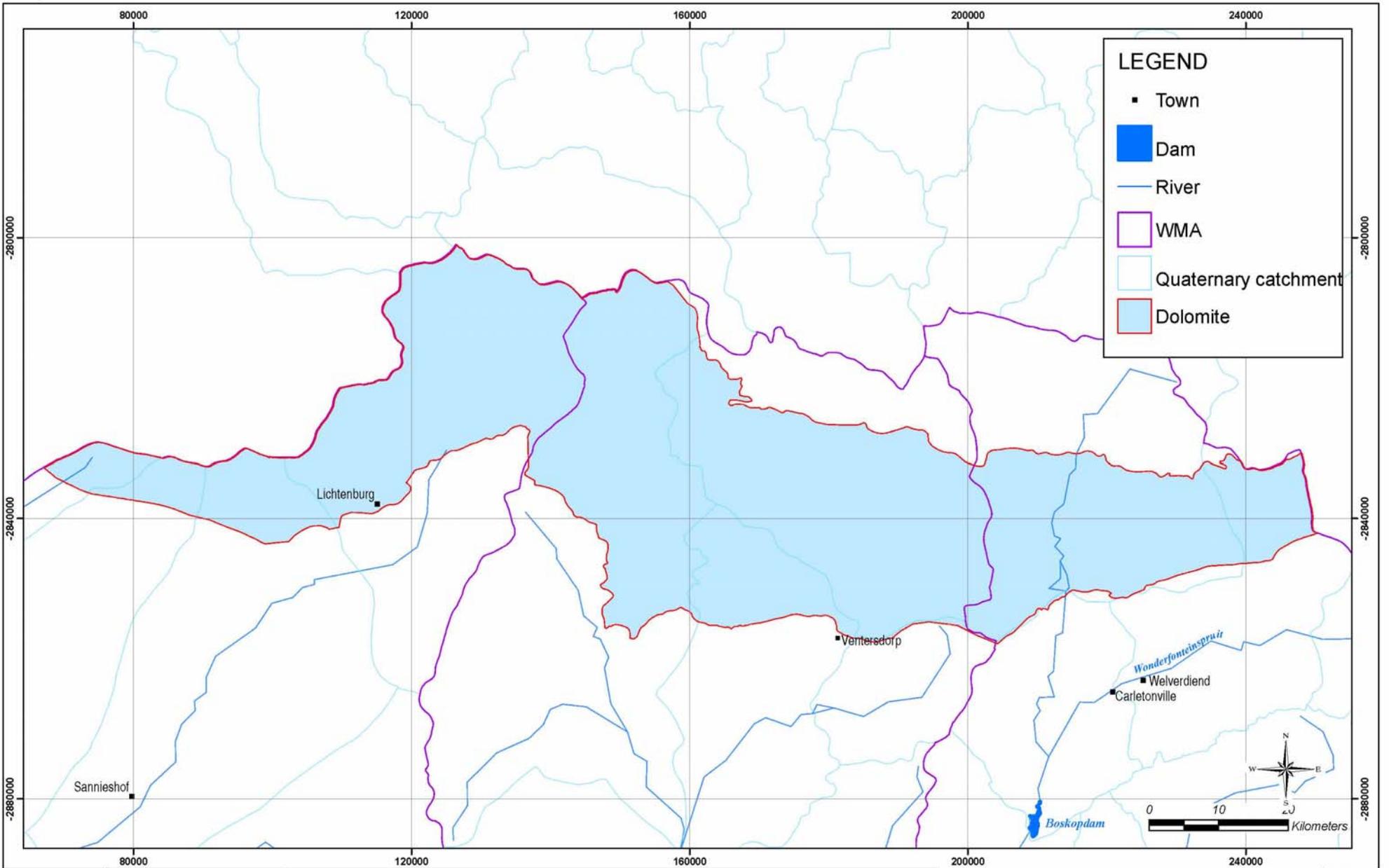
The geological sequence is similar to that of **Table 2-1** for the West Rand and is not repeated here. There is an additional formation at the top of the sequence, the Frisco Formation. This is a dark, chert-poor dolomite. However, the individual formations have been mapped for most of the NW dolomite area, as shown on **Figure 2-9**. There are numerous intrusive diabase dykes which form compartments in the dolomite. These are shown on **Figure 2-10** along with the boundaries between the dolomite formations.

There are six main compartments which are listed in **Table 2-8**.

Table 2-8: NW Dolomite Compartments

Compartment	No	Area (km ²)	Spring
Holfontein	12	99	Holfontein
Moorivier	13	880	Bovenste Oog van Moorivier
Schoonspruit	14	1673	Schoonspruit
Grootpan	15	464	Bokkraal
Lichtenburg	16	698	Lichtenburg

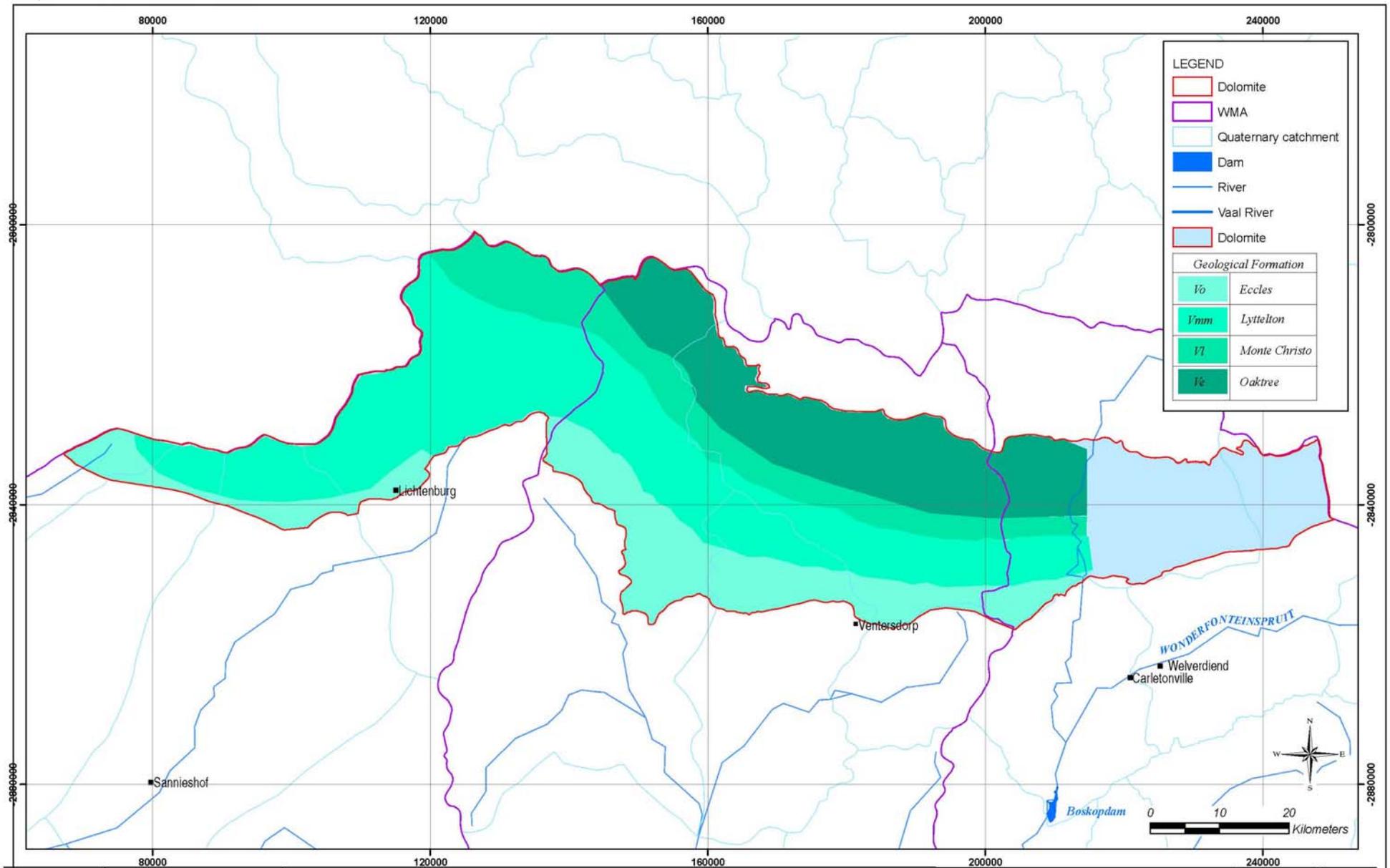
Grootfontein	17		
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PROJECT NO.	COORDINATE SYSTEM	
335412	ALBERS EQUAL AREA CONIC	
	SPHEROID	CENTRAL MERIDIAN
	WGS	25

VAAL RECONCILIATION STUDY:
NORTH WEST DOLOMITES

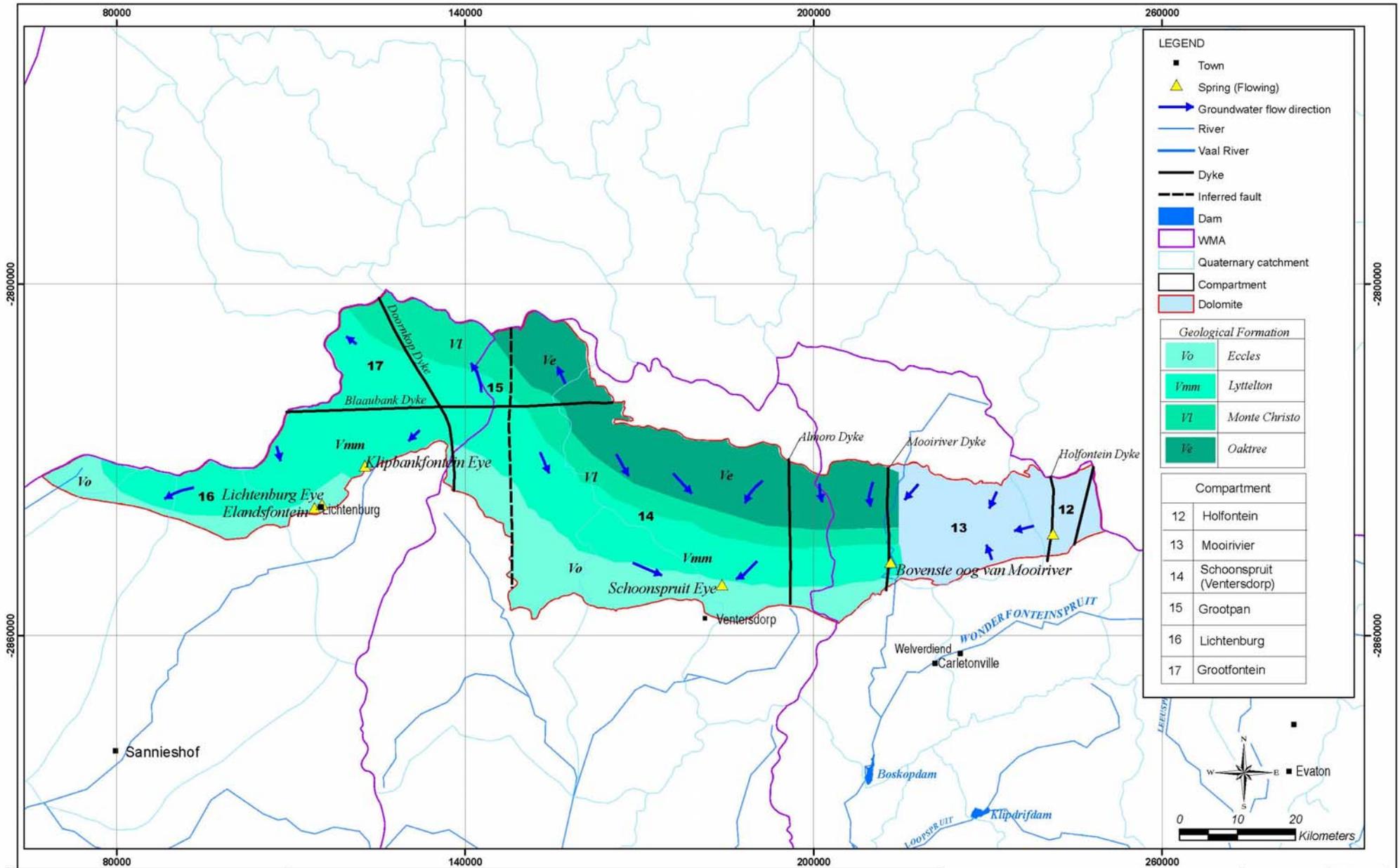
DATE	SCALE
DEC 2006	500 000
COMPILED BY	FIG NO.
SCHN	2-8



PROJECT NO. 335412	COORDINATE SYSTEM ALBERS EQUAL AREA CONIC
SPHEROID WGS	CENTRAL MERIDIAN 25

**VAAL RECONCILIATION STUDY:
NORTH WEST DOLOMITES: GEOLOGY**

DATE DEC 2006	SCALE 500 000
COMPILED BY SCHN	FIG NO. 2-9



PROJECT NO.	COORDINATE SYSTEM	
335412	ALBERS EQUAL AREA CONIC	
	SPHEROID	CENTRAL MERIDIAN
	WGS	25

VAAL RECONCILIATION STUDY:
COMPARTMENTS, SPRINGS AND FLOW DIRECTIONS

DATE	SCALE
DEC 2006	600 000
COMPILED BY	FIG NO.
SCHN	2-10

The NWD compartments are mostly much larger than those of the West Rand, although there are several subcompartments, particularly in the Lichtenburg and Grootfontein Compartments. The major features are the compartmental dykes, which from east to west are the Blaaubank, Doornkop, Almore, Mooirivier and Holfontein Dykes, and a major N-S trending fault (see **Figure 2-10**). The fault appears to act as a groundwater barrier (Bredenkamp *op cit*).

Numerous springs occur in the area, either as a result of dykes or faults, or thinning of lithologies towards outcrop boundaries. The main ones include (see **Figure 2-10**):

- Schoonspruit. Has a low flow of 17.6 Million m³/a, and is strongly affected by groundwater abstraction for irrigation.
- Bovenste Oog van Moorivier. Average flow ~9.5 Million m³/a, low flow ~3.2 Million m³/a.
- Lichtenburg.

Sinkholes are not significant features of the area (the Wonderfontein is just outside the WMA). This is probably due to limited water level fluctuations (EMA, *op cit*).

2.2.3 AQUIFER DEVELOPMENT

Similar comments apply to this area as generalised under Section 2.1.3. In terms of karst development and, therefore, aquifer development, the three divisions of the Monte Christo Formation and the Eccles Formation (see **Figure 2-9**) are most favourable. This is indicated by groundwater occurrence (high borehole yields) and high transmissivity. Karst development appears to be best in the basal unit of the Monte Christo Formation, which is characterized by interbedded oolitic chert.

2.2.4 AQUIFER HYDRAULIC PARAMETERS

Values of storativity and transmissivity for the various geological formations and compartments are indicated in **Table 2-9** below.

Table 2-9: Storativity and Transmissivity (m³/day/m) for various geological formations and compartments

Groundwater Compartments/Formations	Grootfontein	Lichtenburg	Grootpan	Schoonspruit
Oaktree T S	35 0.025			
Monte Christo T S	1200 0.008	0.012	0.028	0.03
Lyttleton T S	1100 0.008		0.044	
Eccles T S	3000 0.12		0.035	0.029

From **Table 2-9** it is evident that the transmissivity and storativity of the Monte Christo and Eccles Formations are highest, which generally applies to all the dolomite of this region (Bredenkamp *op cit*).

Similar findings as to the West Rand are found regarding a decrease in S with depth. For example, in the upper 1 m thickness of the aquifer, storativity values as high as 0.36 are obtained. At a depth of 100 m below surface, S may be only 0.005 (Bredenkemp *op cit*).

2.2.5 GROUNDWATER LEVELS AND FLOW

Groundwater levels and flow directions generally mimic the topography, with 'steps' created by barriers such as dykes and faults. Springs occur at the topographic lows along dykes and towards the edge of the dolomite outcrop area.

All the compartments to the east of the N-S fault and south of the Blaaubank Dyke drain to the east and south-east. The Blaaubank Dyke is a major barrier and separates the Compartments draining to the south (Lichtenburg and Schoonspruit (Ventersdorp) from those draining to the north (Grootpan and Grootfontein). Groundwater flow is generally towards the major springs in each compartment. A simplified flow map is shown in **Figure 2-10**.

2.2.6 RECHARGE

Recharge estimates have been derived by Bredenkamp, using the chloride mass balance method, for the compartments of the Grootfontein, Lichtenburg, Grootpan and Schoonspruit Units (EMA, *op cit*). However, the recharge estimate matches the groundwater use estimate to three decimal places in the Grootfontein, Lichtenburg and Groot Marico/Schoonspruit compartments at 46.397, 36.772 and 60.366 Million m³/a, respectively. The recharge estimates are therefore rejected.

Figures derived from the GRA 2 project are shown in **Table 2-10** along with nominal 10 % estimates. Further comment is given in Section 2.2.10.

Once again the GRA2 figures appear to be too low, while 10% is a reasonable 'average' of the figures obtained by Bredenkamp et al (2005).

Table 2-10: Recharge estimates per Compartment

Compartment	Recharge (m ³ /a)		
	GRA 2 Normal	GRA 2 Drought	10 % of MAP
Holfontein	3 750 400	2 714 400	6 930 000
Moorivier	36 588 000	26 308 900	52 800 000
Schoonspruit	56 297 000	40 000 000	100 000 000
Grootpan	12 138 400	8 690 000	28 768 000
Grootfontein	5 800 000	4 116 600	15 500 000
Lichtenburg	15 500 000	10 960 000	41 880 000
Totals	130,000,000	93,000,000	245,000,000

2.2.7 GROUNDWATER QUALITY

Groundwater quality is reported as being good and mostly in a pristine state. It is a Ca/Mg (HCO₃)₂ type water, alkaline and with an EC of <70 mS/m. Quality concerns relate to informal settlements, concentrations of people near springs and the impact of irrigation (ERM, 2003). Veltman (2003) also reports on high nitrate concentrations in some areas, e.g. Grootpan, which is attributed to livestock wastes at feedlots and drinking sites.

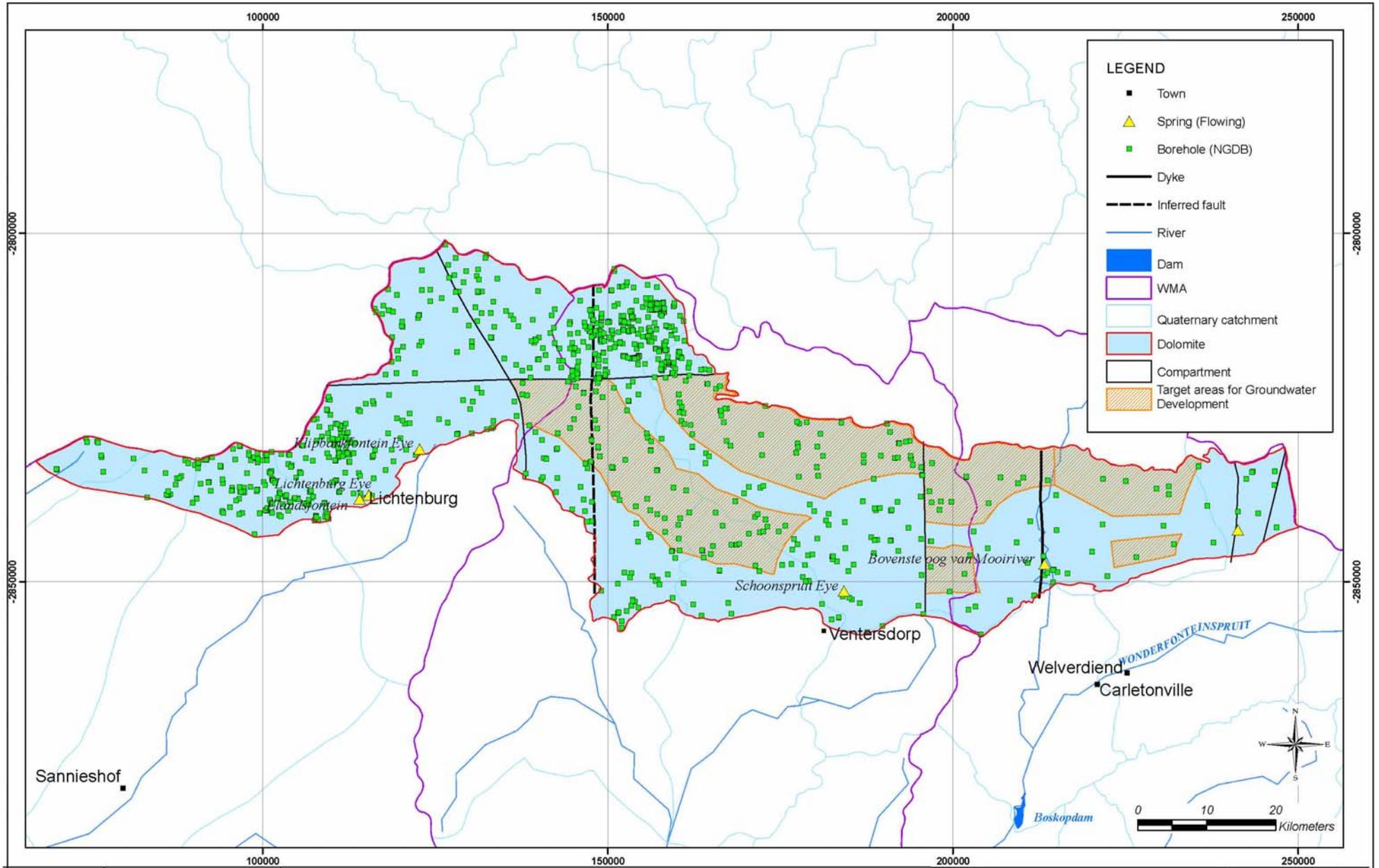
2.2.8 EXISTING GROUNDWATER USE

The distribution of boreholes, as obtained from the NGDB, is shown on **Figure 2.9**. Total abstraction, excluding spring flow is shown on **Table 2-11**.

Table 2-11: Groundwater Abstraction (Million m³/a)

Compartment	Irrigation	Domestic	Municipal/Industrial	Total
Grootfontein	19.0	1.9	-	22
Holfontein	6.0	-	-	6.0
Moorivier	3.0	-	-	3.0
Schoonspruit	26	8.1	0.3	34.4
Lichtenburg	28	8	1.6	37.3
Grootpan	7.0	7.1	-	14.1
Totals	89	25.1	1.9	117

The highest concentration of boreholes is in the Grootpan and Lichtenburg Compartments, as shown on **Figure 2-11**.



PROJECT NO. 335412	COORDINATE SYSTEM ALBERS EQUAL AREA CONIC	
	SPHEROID WGS	CENTRAL MERIDIAN 25

VAAL RECONCILIATION STUDY:
BOREHOLE POSITIONS FROM THE NGDB AND TARGET AREAS FOR GROUNDWATER DEVELOPMENT

DATE DEC 2006	SCALE 500 000
COMPILED BY SCHN	FIG NO. 2-11

2.2.9 THE RESERVE

Groundwater reserve studies have been carried out for catchments C23F and C24C and F. These cover most of the study area. However, copies of these reports were not received by the time of finalisation of this report.

2.2.10 GROUNDWATER BALANCE

A groundwater balance is given in **Table 2-12** based on information obtained from the various references on the area.

Table 2-12: Groundwater Balance Estimates per Compartment

Compartment	Area (km ²)	Storage (Million m ³)	Existing use (Million m ³)	Springflow	Recharge (Million m ³)	Recharge Surplus (Million m ³)
Holfontein	99	25	6.0		9	3
Moorivier	880	220	3.0	16	79	60
Schoonspruit	1673	418	35	50	100*	15
Lichtenburg	698	174	37.3	Dried up	42*	0
Grootpan	464	116	14.1	18	28*	0
Grootfontein	239	60	22	12	14*	0
Totals	4053	1013	117.4	96	272	78

Recharge taken as 15% apart from* @10%

2.3 GHAAP PLATEAU DOLOMITES

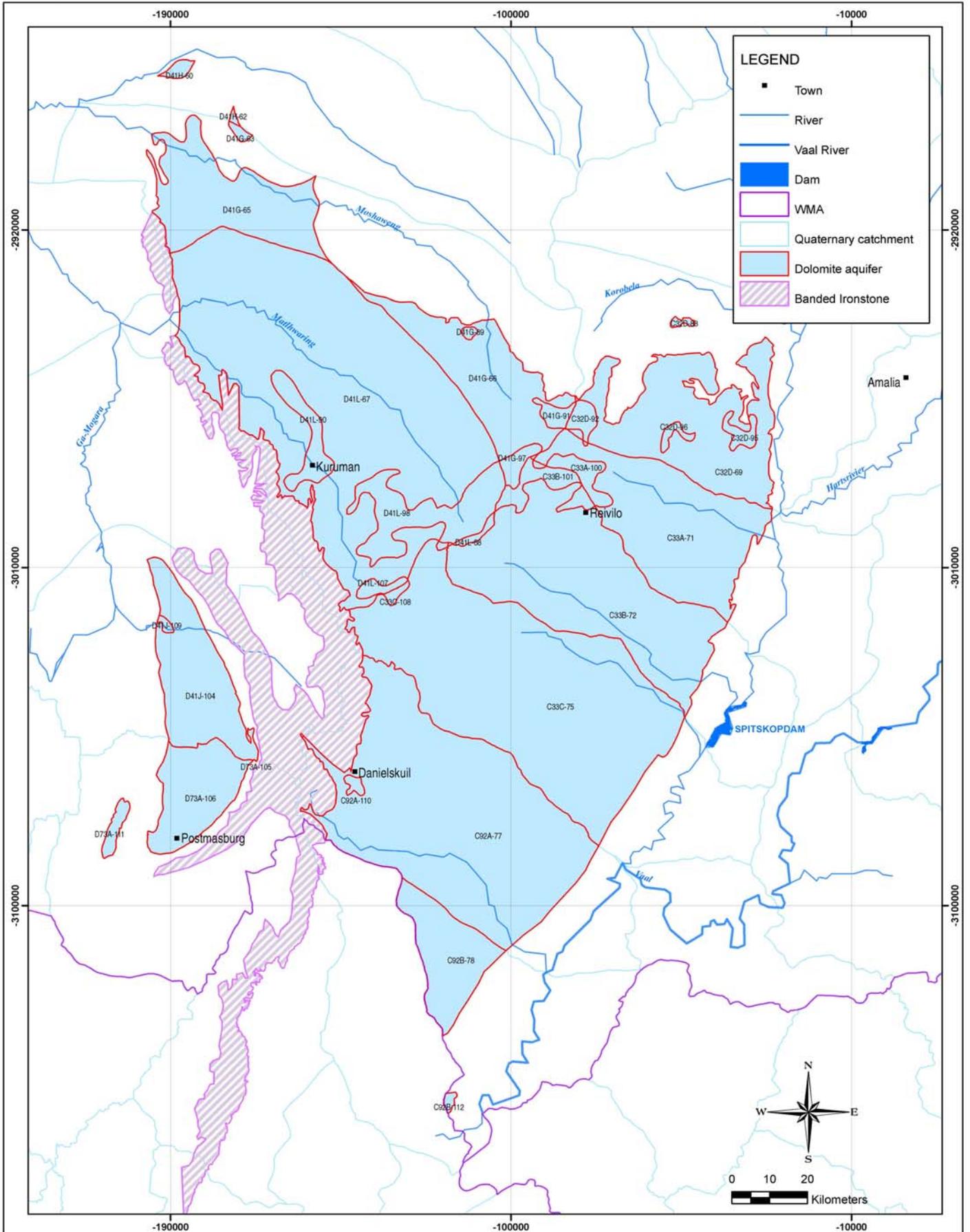
The dolomites of the Ghaap Plateau are indicated on **Figure 2-12**.

2.3.1 LITERATURE REVIEW

Numerous studies have been conducted on the dolomites of the Ghaap Plateau which includes the dolomites of the Ghaap Plateau, the Sishen-Kathu-Postmasburg area and the Pomfret-Tosca-Vergeleë area. The reports reviewed are listed in Section 6.

2.3.2 GEOLOGY

The rocks of the Campbell Group, which is part of the Griqualand West Sequence, underly the flat surface plains of the Ghaap Plateau. These rocks can be divided into the Vryburg Formation at the base, followed by the intermediate Schmidtsdrif Formation and the Ghaap Plateau Formation on top as detailed in **Table 2-13**. The Vryburg Formation consists mainly of quartzite with subordinate conglomerate, grit, flagstone and lava.



PROJECT NO. 335412	COORDINATE SYSTEM ALBERS EQUAL AREA CONIC	VAAL RECONCILIATION STUDY: GHAAP PLATEAU DOLOMITE		DATE DEC 2006	SCALE 900 000
	SPHEROID WGS			CENTRAL MERIDIAN 25	COMPILED BY SCHN

Table 2-13: Geology of the Ghaap Plateau

Sequence	Group	Formation	Member	Lithology
Griqualand West Sequence	Griquatown	Asbestos Hills	Daniels-kuil	Brown jaspilite and crocidolite with shale Three prominent markers - Upper speckled marker; lower speckled marker and flat pebbled conglomerate (potsherd marker) Brown jaspilite and chert (Main marker)
			Kuruman	Banded ironstone with bands of amphibolite and lenses of flat pebble conglomerate, crocidolite, tuff. Ferruginized, brecciated banded ironstone (Blinkklip breccia) at base.
	Campbell	Ghaap Plateau	Lime Acres	Chert breccia at top (manganese marker) Dolomite with lenses of limestone and chert
			Grootfontein	Mainly chert with interbedded layers of dolomite
			Fairfield	Coarsely crystalline recrystallized dolomite Banded ironstone marker - Kanguru layer
			Ulco	Mainly fine grained dolomite and limestone
		Schmidtsdrif	Monteville	Stromatolitic limestone, chert and dolomite with a prominent quartzite layer at the top
			Clearwater	Mainly khaki shale with interbedded dolomite
			Boomplaas	Oolitic, stromatolitic and mat algal limestone with interbedded flagstone and quartzite
		Vryburg	Waterloo	Lava
			Koboya	Quartzite and flagstone
			Rosendal	Lava
			Koboya	Quartzite, grit and conglomerate

A prominent quartzite layer at the top and the first limestone layer at the base defines the Schmidtsdrif Formation. This Formation is subdivided into the Boomplaas Member at the base, followed by the Clearwater Member in the middle and the Monteville Member at the top.

The following Ghaap Plateau Formation consists of the Ulco, Fairfield, Grootfontein and Lime Acre Members. This Formation consists mainly of dolomite, chert and limestone. A prominent banded ironstone marker known as the Kanguru Layer, occurs between the Ulco and Fairfield Members. Boreholes intersecting this layer well below the water table can have high yields. Several thin black shale layers occur in the Lime Acres Member. These layers are not mapped as scree and windblown sand normally cover it. The top of the Lime Acres Member (and the Ghaap Plateau Formation) is defined by a chert breccia. The total outcrop area of dolomitic rocks is ~19035 km².

Rocks of the overlying Griquatown Group, which represent the hilly areas west of Kuruman, are also included in the discussion as most of the groundwater recharge in the Kuruman area occurs in the banded ironstone of this Group. The base of the Kuruman Member of the Asbestos Hills Formation, which forms part of the Griquatown Group, is defined by a brecciated banded ironstone known as the Blinkklip Breccia, while the base of the following Daniëlskuil Member is defined by the first occurrence of jaspilite.

Large areas along the foothills of the Kuruman Hills are covered by recent deposits of windblown sand and scree whilst surface limestone covers large areas of the flat plains to the east. The thick rubble cover immediately east of the hills can be explained by the movement of Dwyka glaciers

from the northwest. These glaciers were lifted by the elevated Kuruman Hills and at the eastern side of these hills vast volumes of debris were deposited to form the rubble and talus cover. Further to the east the glaciers again came in contact with the dolomitic sediments with subsequent limited scree cover. Simultaneously, the upper leached part of the dolomites was eroded away by the glacier movement thus explaining the limited karst development in the central Ghaap Plateau.

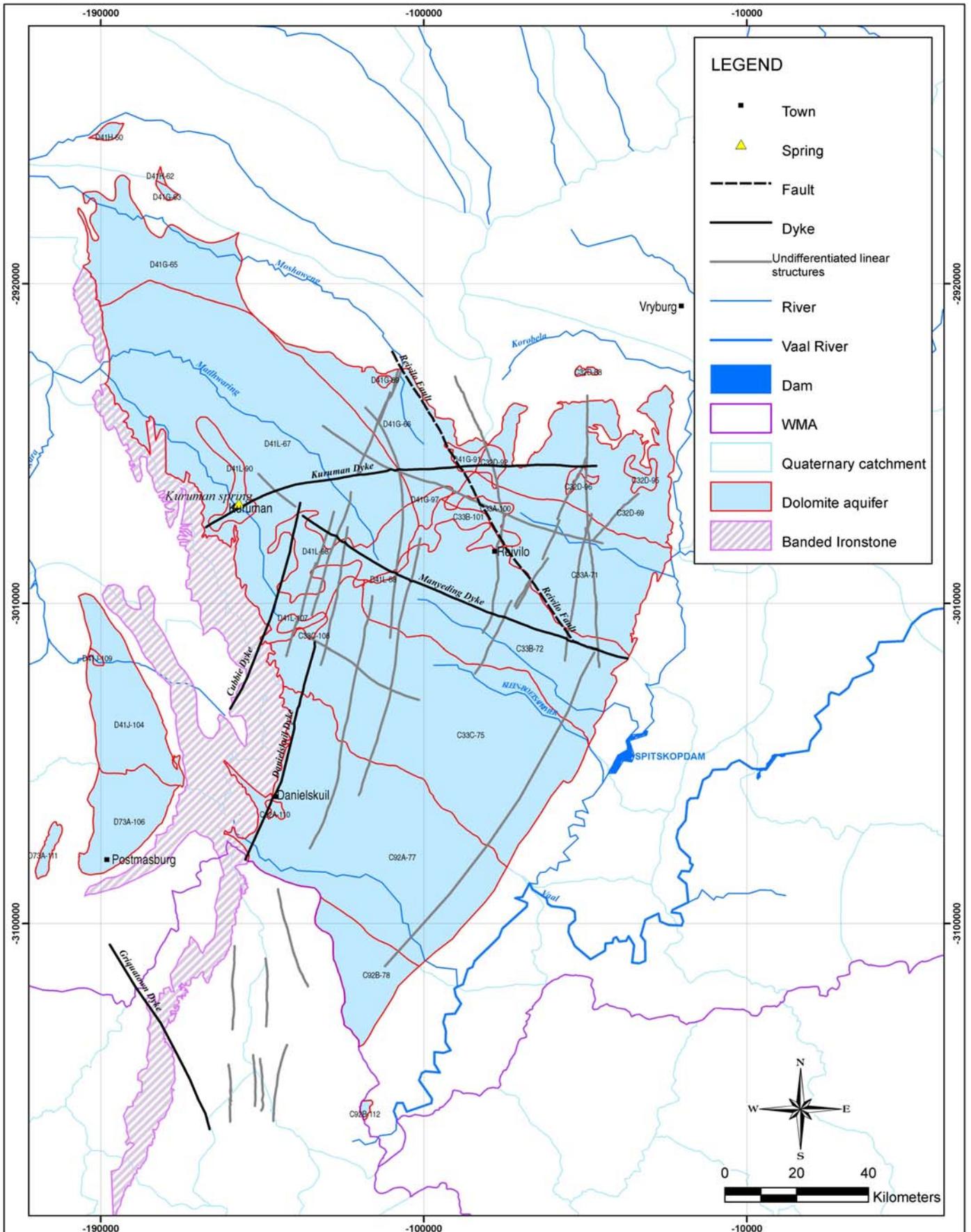
In the Kathu area Kalahari deposits up to 100m thick cover the bedrock. Two outcrops of Dwyka Tillite are known on the Ghaap Plateau, namely:

- Some 35km northwest of Reivilo on the farm Mooifontein, where it was intersected in a borehole in a pan, and
- Some 35km southwest of Daniëlskuil on the cadastral farm 510, where salt was mined in a pan in the past.

The fact that both occurrences are located in pans suggests that these pans represent ancient sinkholes.

Numerous dolerite and diabase dykes are present in the area (see **Figure 2-13**). These dykes vary from a few metres to more than 50m thick and are vertical to near vertical. The general strike of the dykes is either NNW or NNE. Dyke outcrops are rare, but the dyke localities can normally be identified by distinct linear surface limestone ridges elevated some 0.5 to 2m higher than the surrounding areas. These ridges are without exception overgrown with thorn trees. The diabase dykes are normally thickest (more than 10m), coarse grained and olivine rich with a greenish colour. In contrast the dolerite dykes are normally thin, fine grained and with a dark grey colour. In the Kuruman Hills and immediate surrounding areas the dolerite/diabase dykes are normally weathered and this weathered zone can extend to 90m.bgl. as shown by drilling on the farm Mount Carmel some 20km north of Daniëlskuil. Apparently the NNW striking dykes are younger than the NNE ones, as indicated at Maneyding, where a NNE dyke is off-set 300m by a NNW dyke (Maneyding dyke). This also shows that these dykes represent ancient fault zones in certain cases.

Though Smit reported no known recent sinkholes in 1970 (GH1537) several sinkholes developed during heavy downpours in 1988. These sinkholes are restricted to the area within 15km east of the Kuruman Hills. The largest one developed some 25km south of Kuruman on the farm Kono B across the Kuruman-Daniëlskuil road and the final depression was approximately 3.5m lower than the surface.



PROJECT NO. 335412	COORDINATE SYSTEM ALBERS EQUAL AREA CONIC	VAAL RECONCILIATION STUDY: COMPARTMENT DYKES AND MAJOR FAULTS		DATE JUNE 2006	SCALE 950 000
	SPHEROID WGS			CENTRAL MERIDIAN 25	COMPILED BY SCHN

2.3.3 AQUIFER DEVELOPMENT

Good supplies of groundwater can be located on the Ghaap Plateau in fractures and leached zones associated with dykes and faults as well as on the contact with chert beds and the Kanguru Layer. As the dykes normally act as aquitards which divide the aquifer into compartments, open fault and fracture zones, as well as chert beds, are regarded as the best targets for groundwater exploration. The fractured and leached dolomite weathers to a brown clay and wad with chert and banded ironstone rubble. Apparently high yielding boreholes occur some distance away from the thick dykes (40-80m from dyke contact) and closer to the thin dykes (within 10m from contact). The reason for this phenomenon is not clear yet, but is suspected to be linked to the zone of metamorphism caused by the intrusive dykes. This zone has a low permeability and boreholes should be drilled outside this zone in the fractured dolomite. Hydrocensus data indicates that well away from structures the weathered zone on the central and eastern plateaus normally only extends down to between 15 and 20 m.bgl, which implies that where the water level is above this zone the aquifer acts like a primary aquifer and groundwater can be located at random. However, the yields of these boreholes are normally low and prone to decrease rapidly during dry spells.

The Vryburg Formation forms an important aquifer especially in the Vryburg basin where the quartzite was highly fractured during the developing phase of the basin. Detailed hydrocensus data indicates that high yielding boreholes are located along the northern, eastern and southern boundaries of the plateau where boreholes intersect the Vryburg quartzite. These boreholes intersected groundwater at relative great depths and the main water strike in some boreholes are reported to be deeper than 130 m.bgl. During 1992 Vryburg town abstracted more than 7,000 m³/day from this aquifer on the farm Biesjes Vlakte.

The central plateau (Schmidtsdrif Formation and Ulco, Fairfield and Grootfontein Members of the Ghaap Plateau Formation) is characterized by generally lower yielding boreholes with highly variable yields. The higher yielding boreholes tend to run dry during heavy pumping. Normally the main water strike in this area is relatively shallow (less than 50 m.bgl.). The exception in this regard is the Kanguru Layer where springs occur (e.g. Vlakfontein Spring) and some high yielding boreholes are located on this layer. This layer also yields groundwater at relatively great depths (>100 m.bgl.) as indicated by exploration drilling in 1995 on the farm Rooikoppies 495 located approximately 21km east of Griquatown along the road to Campbell (pers. comm. C Esterhuyse).

The best high yielding zones occur along the eastern side of the Kuruman Hills in the cherty Lime Acres Member of the Ghaap Plateau Formation, in the Kathu-Sishen area and in the Vergeleë area, where saturated Kalahari sediments cover the dolomite. (The first zone roughly extends from the foothills of the Kuruman Hills to 15km east thereof.) These are the only areas where the Ghaap Plateau dolomites are highly leached to relatively great depths. The surface covering in the area immediately east of the Kuruman Hills can extend down to 70 m.bgl. in certain localities. A borehole G43646 was drilled by the DWAF in 1994 on the farm Alphen some 11 km south-east of Kuruman along the road to Daniëlskuil. This borehole intersected 70m of rubble followed by 1 m of chert and then a cavity extending to 117 m.bgl. The water level is 86 m.bgl. indicating a saturated thickness of 31 m for the cavity. This borehole is located along a non-magnetic lineament and

approximately 200 m southwest the farmer drilled a dry borehole where he intersected solid dolomite at 30 m.bgl. A similar example is the cave at Boemasgat 20 km north of Daniëlkuil which extends to 243 m below the water level or approximately 280 m below surface and reaches maximum dimensions of 140 m long by 70 m wide. However, the farmer drilled a dry borehole to 120 m.bgl. some 30 m from this sinkhole on the edge of a smaller sinkhole caused by the same structure. In this case the structure (and leached zone) dips slightly to the north with the borehole located on the footwall thereof thus only intersecting solid dolomite/limestone at depth. These examples indicate the crucial correlation between the location of the borehole (relative to a structure) and the yield thereof.

In one of the tunnels in Finch Mine located some 25 km southwest of Daniëlkuil groundwater was intersected in a fracture in the otherwise solid dolomite at 680 m.bgl, which indicates that fractures can extend down to great depths in certain areas. This fracture, although relatively small in size, reportedly yields a constant groundwater flow of 14 l/s at a temperature of 26°C.

2.3.4 AQUIFER HYDRAULIC PARAMETERS

The hydraulic parameters that require quantification to enable the viability of abstraction schemes to be evaluated are transmissivity (T) and storage (S). Several attempts have been made in the past to determine these values (Gilding 1979, Dziembowski 1978, Van Dyk 1995). Due to the heterogeneity of the dolomite both T and S-values vary dramatically temporally so that applying average values for compartments is largely meaningless.

- Transmissivity

The transmissivity (T) is very variable in the dolomite and ranges from almost impervious to >10,000 m³/day/m. Van Dyk (1995) suggests an average T-value ranging from 25 to 60 m³/day/m for the dolomites in the Tosca-Vergeleë area. Generally, the transmissivity decreases with depth due to decreased leaching. The highest transmissivities occur along the eastern side of the Kuruman Hills and in the Kathu-Sishen area. Transmissivities in the latter area are further boosted by fracturing associated with the Maremane Anticline.

The highly transmissive zones associated with fractures, faults and dykes results in a fairly flat water table with a low gradient from the upstream to the downstream side of a compartment. Across the dykes the water level steps down into the next compartment. These steps can be more than 50 m in elevation in those areas with deep water levels.

- Storage

As with transmissivity, storage is highly variable due to the heterogeneous nature of the dolomites. Bredenkamp suggests an average value ranging from 1 to 5%. Controlled yield tests conducted on several boreholes indicate values ranging from 0.01% to 2%. The methodology of the GRA2 project was used to obtain estimates of groundwater storage in the dolomite aquifers.

Table 2-14: Calculated S-values for the Ghaap Plateau dolomites

Quaternary Catchment	Locality	Area	Average Waterlevel	Average Waterlevel Change [median]	Storativity of Wt Zone (Sw)	Storativity of Aquifer
		km ²	m.bgl	m		
C32D	Dry Harts	4,134	14.93	2	0.007	0.000822
C33A	Pering	2,855	12.66	2	0.006	0.000631
C33B	Reivilo	2,831	9.75	0	0.008	0.000903
C33C	Harts River	4,141	12.51	2	0.008	0.000981
C92A	Danielskuil	3,914	14.15	2	0.008	0.000974
C92B	Schmidtsdrif	1,975	17.32	2	0.006	0.000705
C92C	Campbell	1,954	13.21	2	0.010	0.001132
D41C	Vergelee	3,903	51.36	10	0.005	0.000144
D41D	Tosca	4,369	36.33	10	0.005	0.000146
D41G	Lykso	4,305	35.37	10	0.006	0.000467
D41J	Kathu	3,874	29.37	2	0.003	0.000118
D41L	Kuruman	5,375	24.86	2	0.006	0.000528
D71B	Griquatown	2,871	17.55	2	0.005	0.000504
D73A	Postmasburg	3,235	20.09	0	0.002	0.000104
TOTAL/AVERAGE		49,735	22.10	3.43	0.006	0.000583

Generally, boreholes located in the dolomite tap groundwater from the weathered zone where it is saturated, irrespective of the level of groundwater intersection, as deep lying fractures are mostly linked to the weathered zone and thus tap groundwater from this zone if saturated. Therefore S-values calculated from yield tests conducted on these boreholes will be higher than the average. The large water level changes reported for areas D41C, D41D and D41G can be attributed to intensive irrigation in these areas and are therefore not representative of the larger dolomite area. The GRA2 values are considered to be conservative.

2.3.5 GROUNDWATER LEVELS

Groundwater levels vary considerably from less than 10 m.bgl. to 195 m.bgl. Generally, water levels on the central and eastern Ghaap Plateau vary between 0 (springs) and 20 m.bgl. whilst it drops to more than 100 m.bgl. in the Kuruman Hills within the catchment area of the Kuruman Eye. Water levels in the Banded Ironstone Formation south of the Kuruman Eye catchment area are seldom deeper than 30 m.bgl. However, in the Pomfret area these levels drop to a maximum of approximately 90 m.bgl. (1990). This can be partially attributed to abstraction by the former mine and SADF boreholes located in the Banded Ironstone Formation. Local depressions in the water table of up to 60 m occur on the central Ghaap Plateau and in the Tosca area. These are explained by local large scale irrigation, which partially dewateres the small compartments (mine dewatering excluded). However, groundwater levels normally recover close to the original level during periods of no abstraction (winter) as the groundwater slowly flows from the more solid dolomite into the highly transmissive fractured zones and/or across dykes forming compartment boundaries.

Perched water levels occur at several localities (e.g. Farms Rossdale direct south of Kuruman, Woodstock located in BIF south-east of Kuruman, and Kruisfontein some 36 km north of Reivilo). These perched water levels vary from about 9 m higher than normal (Kruisfontein) to approximately 85 m higher than normal at Woodstock. These perched water levels are caused by impermeable shale and/or clay layers in the dolomite and banded ironstone. A well defined zone of deeper water levels extends from the Kuruman Hills south-west of Kuruman along the inlier of banded ironstone that runs towards the Eye. These deep water levels can only be explained by a highly transmissive zone that drains towards the Eye (See also report GH3500).

2.3.6 RECHARGE

Numerous recharge studies were undertaken in the past in order to obtain a clearer understanding of the hydrogeology of the Ghaap Plateau dolomites. Smit (1970) obtained a value of 2.3% of the MAP using the measured spring flows and comparing it to the rainfall. However, Smit assumed that the recharge occurs mainly on the dolomites whilst a later study (Esterhuysen, 2003) indicates that 59% of the outflow at the Kuruman Eye originates in the Kuruman Hills. Though the water levels in this area are deep the many large outcrops of banded ironstone and jaspilite collect rain water and conduct it into the surrounding valleys. These valleys are formed by major faults and exploration drilling has shown that intensively fractured banded ironstone (drill cuttings look like gravel) can be intersected in these valleys up to ~ 200m.bgl. There is thus a highly permeable zone to conduct the run-off rainwater down to the groundwater level. Further proof for this method of recharge is the fact that rainwater run off only reaches the bottom ends of these valleys (where they end on the dolomite) during excessive thunderstorms like the February 1988 flood experienced at Kuruman.

Using Smit's recharge value of 2.3% and adapting it for the BIF area (35% of total groundwater drainage area of the Kuruman Eye) gives a recharge value of 3.88%. However, Smit assumed that there is no leakage across the Kuruman Dyke whilst later excavations have revealed a highly weathered gravely dolerite underlying the main road in Kuruman town. During one excavation approximately 20l/s had to be pumped continuously from the excavated hole ($\pm 20\text{m} \times 10\text{m}$) direct downstream of the Eye to lower the water level about 1m in order to proceed with construction works (pers. comm. Mr. N. Fourie, ex town engineer). The leakage across the 1.2km highly weathered zone of the dyke in town is calculated in **Table 2-15** below.

Table 2-15: Calculation of groundwater leakage across the Kuruman Dyke.

Excavation dimensions in m		Abstr. Rate (l/s) to lower WL 1m	GW gradient from dyke contact to pit	Distance of highly weathered dyke zone (m)	Average GW gradient across dyke	Calculated T value (m ² /d)	Calculated leakage across dyke (l/s)
Length	Width						
20	10	20	0.25	1,200	0.023	440	142.6

With these data the recharge can be calculated as indicated in **Table 2-16** below.

Table 2-16: Recharge calculation of the Kuruman area based on spring flow, abstraction and evapo-transpiration.

Spring Flow (l/s)	Spring Flow (m ³ /a)	Leakage across dyke (l/s)	Leakage across dyke (m ³ /a)	Est. Mun. Abstr. (m ³ /a)	Est. abstr. by farmers in BIF (m ³ /a)	Evapo-transpiration at Eye (m ³ /a)	Total groundwater discharge (m ³ /a)	Discharge from BIF (m ³ /a)	Recharge area (km ²)	Recharge area (m ²)	MAP of Kuruman Hills (mm/a)	Recharge % of MAP
160	5,045,760	143	4,496,800	2,522,880	89,369	232,850	12,387,659	7,345,360	367.5	367,500,000	390	5.12

This table indicates that the effective recharge figure for this area is at least 5.1% of the MAP.

In the Tosca-Vergeleë area Van Dyk used the chloride mass balance method to calculate the recharge. These values vary from 0.1% to 7.3% of the MAP with a mean value of 0.4%. The low recharge values were obtained in areas where the dolomite is covered by thick deposits of Kalahari sediments and windblown sand. The upper value was obtained in an outcrop area of banded ironstone. However, the very low recharge values calculated in some outcrop areas are doubtful and chloride contamination of the groundwater is suspected. As an example, the large variation in the chloride concentration of the groundwater in borehole G39682 (<40 mg/l in 1991 to >160 mg/l in 1997) can only be explained by contamination from other sources (e.g. pollution from septic tanks, kraals, etc. and/or fertilizers used on irrigated lands). Discarding those areas with increased chloride concentrations will raise the average calculated recharge considerably.

The recharge calculations of the GRA2 project for the Ghaap Plateau dolomite area are summarized in **Table 2-17**. This table indicates that groundwater recharge as a percentage of the MAP is 7.5% for the Tosca-Vergeleë area, 10% for the Kuruman area and 6.2% for the Kathu area. Relatively low recharge values of < 5% occur in the Schmidtsdrif, Campbell, Griqua Town and Postmasburg areas. This is due to relatively thick overburden and/or underlying argillaceous clastic sediments. The value for the Tosca-Vergeleë area correlates with the maximum recharge as calculated by Van Dyk with the chloride method, whilst the value calculated for the Kuruman area is twice the value obtained with the spring flow model.

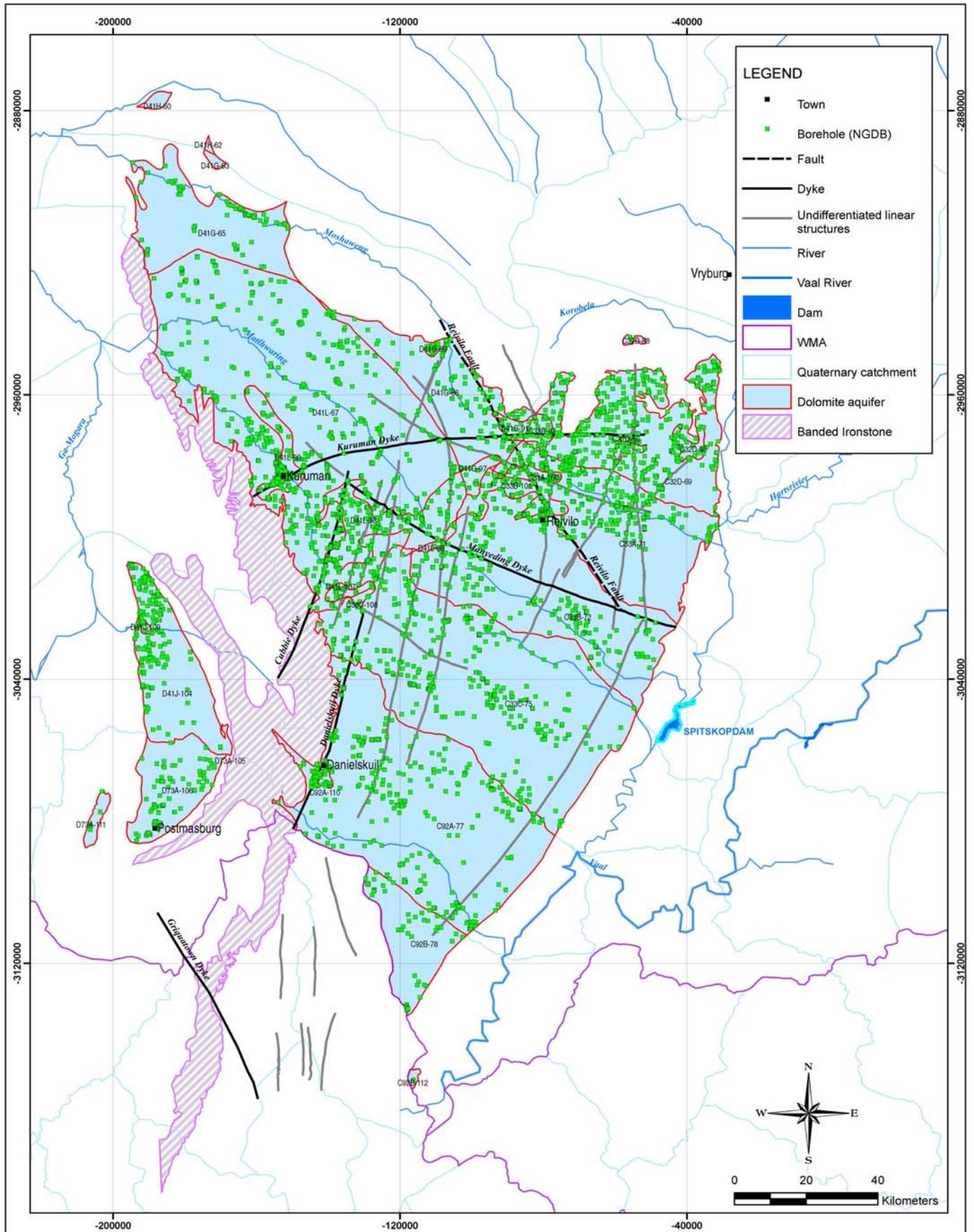
Table 2-17: GRA2 recharge calculations for the Ghaap Plateau dolomites.

QUARTERNARY CATCHMENT	LOCALITY	AREA (km ²)	MAP (mm)	GRA2 GW Use (x10 ⁶ m ³ /a)	REGRESSION	
					Estimated Recharge (mm/a)	Recharge as % of MAP
C32D	Dry Harts	4134	442	4.3011	42.41	9.59
C33A	Pering	2855	432	1.0209	27.47	6.36
C33B	Reivilo	2831	422	0.6825	25.51	6.05
C33C	Harts River	4141	397	0.6428	31.45	7.92
C92A	Daniëlskuil	3914	367	0.8261	23.85	6.50
C92B	Schmidtsdrif	1975	331	0.3232	9.01	2.72
C92C	Campbell	1954	326	0.2375	8.55	2.62
D41C	Vergeleë	3903	396	0.7061	29.43	7.43
D41D	Tosca	4309	380	0.8161	28.95	7.62
D41G	Lykso	4305	366	1.2204	26.04	7.11
D41J	Kathu	3874	358	3.4886	22.02	6.15
D41L	Kuruman	5375	391	3.9896	39.12	10.00
D71B	Griqua Town	2871	315	0.5250	11.41	3.62
D73A	Postmasburg	3235	323	42.7647	13.79	4.27
TOTAL		49676		61.54	24	6.3

2.3.7 GROUNDWATER ABSTRACTION

Existing boreholes as obtained from the NGDB are shown on **Figure 2-14**. Very little groundwater is abstracted on the Ghaap Plateau in areas where the rest water level is > 60m.bgl. This is influenced by financial considerations such as the pumping cost at these levels and the cost of constructing a borehole with a sufficient ID to allow for the installation of a pump capable of a decent yield at these depths. (Note: Most of the boreholes constructed in the BIF are of 125 mm final ID. To install a pump yielding 10 l/s or more at 100 m.bgl. requires a final ID of at least 200 mm which is considerably more expensive to construct.) An estimated total of 1950ha is under irrigation on the Ghaap Plateau with a calculated groundwater abstraction of 15 Million m³/annum. This equates to ~ 7,700 m³/ha/a, which is reasonable taking into account the 300 ha rice fields at Manyeding. Groundwater abstraction by municipalities and mines is estimated at 11.3 Million m³/annum. Evaporation and evapo-transpiration losses are estimated at 0.8 Million m³/annum based on calculations for Kuruman by Smit. Groundwater abstraction in the rural areas for domestic and stock watering purposes is calculated at 13.1 Million m³/annum. This equals to a total groundwater abstraction of 40.2 Million m³/annum for the Ghaap Plateau area.

Van Dyk calculated the groundwater abstraction in the Tosca-Vergeleë area as 14.76 Million m³/annum, whilst the value for the Sishen-Kathu area was calculated as 10.7 Million m³/annum (mine abstraction of 8 Million m³/annum included – SRK Report 336736/DraftV1.3). The volumes of groundwater abstracted in the Kuruman, Kathu and Tosca-Vergeleë areas are significantly higher than the values represented in **Table 2-18**. Subsequently, the calculated groundwater abstraction values for these areas were modified and are represented in **Table 2-18** overpage.



PROJECT NO. 335412	COORDINATE SYSTEM ALBERS EQUAL AREA CONIC		VAAL RECONCILIATION STUDY: BOREHOLE POSITIONS FROM THE NGDB	DATE DEC 2006	SCALE 950 000
	SPHEROID WGS	CENTRAL MERIDIAN 25		COMPILED BY SCHN	FIG NO. 2-14

Table 2-18: Groundwater abstraction from the Ghaap Plateau dolomites.

QUARTENARY CATCHMENT	LOCALITY	AREA (km ²)	MAP (mm)	GRA2 GW Use (Million m ³ /a)	Revised GW Use (Million m ³ /a)
C32D	Dry Harts	4134	442	4.3011	4.3011
C33A	Pering	2855	432	1.0209	1.0209
C33B	Reivilo	2831	422	0.6825	0.6825
C33C	Harts River	4141	397	0.6428	0.6428
C92A	Daniëlskuil	3914	367	0.8261	0.8261
C92B	Schmidtsdrif	1975	331	0.3232	0.3232
C92C	Campbell	1954	326	0.2375	0.2375
D41C	Vergeleë	3903	396	0.7061	0.7061
D41D	Tosca	4309	380	0.8161	14.7600
D41G	Lykso	4305	366	1.2204	1.2204
D41J	Kathu	3874	358	3.4886	10.7000
D41L	Kuruman	5375	391	3.9896	6.3902
D71B	Griqua Town	2871	315	0.5250	0.5250
D73A	Postmasburg	3235	323	42.7647	42.7647
TOTAL		49676		61.54	85.10

The table indicates that the total volume of groundwater abstracted from the Ghaap Plateau dolomite is ~ 85 Million m³/annum (includes area outside of the Vaal WMA).

2.3.8 GROUNDWATER BALANCE

The groundwater balance for each quaternary catchment can be calculated using the modified recharge, abstraction and exploited groundwater potential figures from the GRA2 project. These values are represented in **Table 2-19** overpage.

Spring flow was not taken into account except for evaporation losses and irrigation as most of the spring over flow otherwise recharges into the next groundwater compartment. The table indicates that a groundwater deficit only occurs in the Postmasburg area. In the Campbell and Schmidtsdrif areas the calculated groundwater recharge is close to the current abstraction though the harvest potential indicates a larger surplus. In the Tosca-Vergeleë area the conservative calculated harvest potential still indicates a surplus of groundwater. The total groundwater surplus for the dolomites of the Ghaap Plateau based on the GRA2 calculated planning potential 131-162 Million m³/annum.

D14J is compartmentalised in at least 4, perhaps 5 or 6 compartments and 8 Million m³/a is abstracted from the compartment the Sishen mine is located in, which is ~20-25 % of the quaternary. Abstraction from the Kathu compartment is ~2.5 Million m³/a. The other compartments are relatively pristine with low abstraction and water is abstracted from the BIF and not the dolomites.

Table 2-19: Calculated groundwater balance for the Ghaap Plateau dolomites (Vaal WMA only).

Quaternary Catchment	Compartments/Catchments	Area	Volume of Water stored in Aquifer (Million m ³)	5m Drawdown Storage Volume (Million m ³)	Mean Annual Potential Recharge		Existing Groundwater Use (Million m ³)	Utilisable Potable Groundwater Exploitation Potential ((UPGEP)			
					Million m ³ /a			Million m ³ /a/			
		km ²			Sv	Svr		Wet Season	Dry Season	Wet Season	Dry Season
								Re	Re (dry)	UPGEP	UPGEP (dry)
C32D	Dry Harts	1,335	1,087,704,726	69,444,011	22,969,220	15,672,312	4.30	14,356,774	11,019,313		
C33A	Pering	1,351	1,151,171,768	71,019,338	19,057,363	12,979,574	1.02	9,279,398	6,551,425		
C33B	Reivilo	2,000	1,720,353,859	105,956,110	31,229,545	21,213,479	0.68	18,379,796	13,540,191		
C33C	Harts River	3,131	2,593,515,771	166,536,782	37,882,792	25,473,443	0.64	30,258,428	25,433,704		
C92A	Danielskuil	2,858	2,335,603,566	150,435,085	29,406,188	19,517,230	0.82	30,088,923	26,165,236		
C92B	Schmidtsdrif	505	426,871,232	27,374,276	3,898,736	2,595,250	0.32	5,047,270	4,538,173		
D41G	Lykso	1,794	1,220,085,668	66,654,115	14,485,967	9,650,330	1.22	5,184,908	3,414,650		
D41J	Kathu	744	239,235,927	10,900,083	5,335,306	3,530,054	10.70	0	0		
D41L	Kuruman	4,768	3,106,090,760	166,858,637	54,816,769	36,845,178	6.39	48,419,942	39,937,290		
D73A	Postmasburg	549	55,868,572	4,355,759	4,770,447	3,140,420	47.77	1,533,931	944,096		
Total		19,036	13,936,501,848	839,534,195	223,852,333	150,617,270	73.86	162,549,369	131,544,077		

2.3.9 GROUNDWATER QUALITY

Groundwater quality in the Ghaap Plateau dolomites varies significantly, with Electrical Conductivities (EC) ranging from 6 to > 500 mS/m. The extremely low EC's (<20 mS/m) occur normally in the BIF outcrop areas and can be linked to rapid recharge, whilst the single EC value of 531 mS/m occurs at borehole number 81418260 on the WSM borehole database. This borehole is located immediately east of Kathu next to a pan. Isolated E.C. values of more than 300 mS/m were measured on the central Ghaap Plateau and at Tosca. In almost all the cases these high EC's could be linked to nitrate pollution from kraals, French drains (which are commonly used on the farms) or fertilizers used on irrigated lands. High E.C. values on the farms Mooifontein (northwest of Reivilo) and cadastral farm number 510 also known as Soutpan (southwest of Daniëlskuil) are linked to sub outcrops of Dwyka sediments underlying pans. A deeper borehole drilled in the pan at Soutpan intersected dolomite underneath the Dwyka with relatively fresh groundwater of 100 mS/m. This borehole is also artesian compared to the others, which are sub-artesian, further indicating that it taps groundwater from a different aquifer.

Generally the EC of the groundwater from the dolomite on the Ghaap Plateau ranges from 45-70mS/m. EC values in excess of 100mS/m should be investigated for pollution. EC values of < 30 mS/m are linked to the BIF recharge area whilst values between 30 and 45 mS/m normally indicate a mixture of BIF and dolomite groundwater (e.g. Kuruman Eye at 32 mS/m).

The groundwater quality expressed as the EC of the Kathu area follows a similar pattern as that described for the Ghaap Plateau, with EC values ranging from 8 – 287 mS/m (WSM borehole 81418260 excluded). Generally, the EC values in this area are slightly higher than those recorded on the Ghaap Plateau. This phenomenon is likely due to contamination from the overlying Kalahari Aquifer which generally has a slightly more saline groundwater. Large scale irrigation at Kathu and the Bestwood plots most likely also contributes to increased EC values due to salt concentration in the topsoil as a result of evaporation. During events of local recharge these salts, as well as fertilizers used on the irrigated lands are washed down to the groundwater with a resultant increase in EC. In this area EC values in excess of 150 mS/m are likely to be linked to pollution.

The groundwater quality of the Tosca-Vergeleë dolomite area follows a similar trend to that of the Kathu area. EC values in this area range from 47 – 336 mS/m, with a median value of about 83 mS/m for the north-western part of the area and 115 mS/m for the south-western part of the area. Van Dyk (GH4023) concludes that the more saline groundwater of the south-western part of the area can be associated with the east-west dolerite dykes present in this area which yield older groundwater than the other dyke orientations. EC values in excess of 100 mS/m and 150 mS/m in the north-western and south-western parts of the area respectively, indicate pollution.

3 GROUNDWATER MANAGEMENT

Groundwater management is discussed in general terms initially for dolomitic aquifers. The three main areas are then discussed in detail individually.

3.1 CONCEPTS

The key issues guiding management and therefore use of dolomitic groundwater/aquifers are water level fluctuations and quality. The former impacts on geotechnical/ground stability, spring flows and ecology (wetlands). The latter is of particular importance in areas of mining, agriculture and also point sources, in terms of possible contamination of potable water supplies.

Dolomitic aquifers are unique in South Africa on account of their very high transmissivity. This means that systems/compartments behave in a similar way to an individual production borehole. The total recharge to a compartment is thus theoretically available for abstraction instead of a percentage thereof. This means that recharge (and storage) are the governing factors regarding abstraction.

There is minimal surface water drainage on areas of dolomite outcrop and such as there is is intimately linked to the groundwater system. Surface water flow and discharge from one compartment becomes groundwater recharge to the next compartment downstream. The concept of conjunctive use becomes obsolete in dolomitic areas because of this interaction: any use of surface water or groundwater in such areas is conjunctive use.

The key to developing groundwater resources is to locate zones of high transmissivity, away from the main spring emergences. Successful production boreholes in dolomitic aquifers are assumed to yield >25 l/s or ~0.8 Million m³/a. The most permeable formations in the dolomite are the Monte Curisto and Eccles Formations. These have been mapped for the NW dolomites (see Figure 2-9) but not for the West and Far West Rand.

In the previous Vaal River Study (BKS 1989), it was stated that spring flow had already been factored in to the catchment water balance. However, spring flow represents a minimum aquifer yield, where flow is driven by recharge on the compartment area, which is then driven by the hydraulic gradient towards the spring. To derive maximum aquifer yield, dynamic use of the high storage capacity of the dolomite is required. This is equivalent to the variable storage-draft concept for management of major surface water impoundments.

Dynamic use of storage will not only increase the system yield but should lead to an (substantial) increase in recharge as water levels are lowered. This would be especially the case where there is extreme rainfall above the mean. Even with 'normal' aquifer water levels in the NW dolomites, van Rensburg (2003) found that recharge varies exponentially for rainfall exceeding a certain threshold value – up to 80 % if monthly rainfall is 300 mm.

In the NW dolomites, for example, spring flow only represents ~45 % of the recharge, with the balance being lost to evapotranspiration, lateral outflows and other losses (Bredenkamp, et al 2005).

One of the key aspects of areas of dolomitic terrain is ground stability. This has been found by numerous researchers to be related in large measure to critical variations or fluctuations in the water table. In areas where the original water table is within 30 m of the surface, fluctuations up to ~5 m have been found to be acceptable. Fluctuations beyond this can lead to ground instability and sinkhole development, with sometimes catastrophic results. For this reason, in applying the variable storage draft concept to dolomite aquifer yield, a limit of 5 m is placed on storage drawdown, except in the Kathu area where dolomites are overlain by BIF and Kalahari sediments.

A drawdown or draft of 5 m would seem to be reasonable, apart from stability considerations, in terms of local aquifer thickness or effective storage thickness. Assuming a conservative effective aquifer thickness of 30 m (see Table 4.2), 5 m only represents 17% of the available drawdown. However, this stored water will not be available continuously but could be used for bridging purposes in times of drought or to meet short-term peak demands. Even if increasing available storage by lowering the water table leads to an increase in recharge, this is only likely to replace a small percentage of the drawdown. For example, to replace 1 m of storage will take an increase in annual recharge of 70 to 80 %, depending on the compartment.

A simplistic management approach can be implemented based on the integrated response of water levels using the saturated volume fluctuation (SVF) or cumulative departure (CRD) approaches (Bredenkamp et al 1994). In order to apply such methods, the level of the water table in each compartment will have to be determined and its relation to the pre-exploitation level.

In order to take into account all the variables and some unknowns in the management of dolomitic aquifers, a numerical flow model is required. This approach has successfully been applied in the Zeerust Compartment of the NW dolomites (Hubert et al, 2005). The FEFLOW 3D finite element model was used to simulate the proposed abstraction of 20 000 m³/day. It was shown that this could be achieved with a maximum drawdown of 6 m in compartments away from springs, with only minor reductions in spring flows. Rainfall and therefore recharge of the last 30 years was used as input to the model with the assumption that similar patterns will be repeated.

Such a model can be used to:

- Identify compartments that can be managed as a unit;
- Quantify steady state and temporal water balance flow components spatially (recharge) as well as laterally (leakage through compartment boundaries);
- Quantify steady state and transient drawdown impacts on spring flows and leakage across boundaries.

The Zeerust study is the first phase of the assessment of all compartments within the area delineated by DWAF Water Services from Mafikeng to Ventersdorp as potential sources of bulk water supply. The Zeerust approach should be extended over the entire dolomite area according to EMA, 2003.

Several other modelling studies have been carried out on the dolomite aquifers, with varying objectives. A summary of some of these include:

- Krantz (1997). West Rand area. Model developed to:
 - Identify boundaries and flow conduits;
 - Assess the water level rise in the REGM area;
 - Determine likely decant points;
 - Determine potential decant water quality.
- Hodgson et al (2001). Bank Compartment. Chosen to simulate dewatering, rewatering and pollution as it is data rich and representative of other mining influenced compartments in the area.
- Swart et al (2003). West and Far West Rand area. Analytical model. The model suggests that it will take ~10 years to fill the mine voids and a further 20 years before springs will resume flowing. The model predicts that, although inter-compartmental flux will take place through dykes, hydraulic resistance to flow will allow groundwater levels to recover fully in the dolomite aquifer and thus the now dry springs will flow again.
- DME (current). Development of a numerical model as part of the Study into the effects of rewatering of the West Rand Compartments.

Budget (R225 k) has been set aside for modelling of the Schoonspruit Compartment as part of the DWAF NW Dolomite Study. The FEFLOW model for the Zeerust compartment could be extended to an aquifer-wide model to also incorporate the Grootfontein, Grootpan, Lichtenburg and Schoonspruit Compartments (FMA, 2003). Such an approach could also be followed for the West and Far West Rand area, although this area is complicated by mining and dewatering (and future rewatering). However, the unaffected compartments, such as Turfontein and Boskop, could be modelled.

Existing DWAF/DME studies on the NW Dolomites and the Wonderfontein Spirit Catchment have provision for modelling in later phases of work. However, only the NW dolomites model will be concerned with bulk water supply. The Wonderfontein models will rather be concerned with dewatering/rewatering, decant points and groundwater quality. However, once calibrated, these models could easily be used as a basis for a water supply focus. The only new models that would need to be constructed would be for the compartments downstream of Boskop Dam, and the Ghaap Plateau area. The latter area is so large (~19000 km²) that a number of compartmental models would probably be required to adequately represent groundwater conditions.

3.2 GROUNDWATER EXPLOITATION

3.2.1 WEST AND FAR WEST RAND

There are a number of possible scenarios in this area which relate to mining activities in the Zurbekom, Gembokfontein, Venterspost, Bank, Oberholzer and Stilfontein Compartments. How water pumped from mines in these compartments is disposed of and how these compartments

rewater as mining is phased out will have a direct bearing on water availability, both quantitatively and spatially, and the timing thereof.

In terms of the mining impacted compartments listed above, a number of scenarios arise. These are:

1. Compartments rewater but boundary dykes are not intact. All flow exits at Turfontein Spring. This flow could be of the order of 150 Million m³/a. Quality is uncertain because of various recharge pollution sources. Compensation flows may have to be made for upstream users where springs remain dry. No 'new' water added to the system.
2. Compartment dykes are intact or engineered to be intact. Springs re-appear but flows could be higher than pre-mining because of enlargement of fissures by re-circulation of groundwater and increased recharge through sinkholes and depressions. Swart (2003) estimated that it would take ~30 years for this scenario to develop assuming all mining stopped simultaneously. No new water added to the system unless recharge increases. If recharge increased by 10% there could be ~7 Million m³/a of 'new' water added to the system.
3. Pumping continues from the main mining centers and the water is treated to potable standards and sold to cover costs. This has been investigated for the Central and West Rand area and more recently for the Stilfontein area. In the former the so-called Strategic Water Management Plan (SWAMP) was collectively devised by affected mining houses. This would involve treating the contaminated water currently being pumped from the workings with the two by-products, potable water and gypsum, being sold to cover costs. Approximately 240 Million m³/a of potable water could be produced in this way. Pumping a further 107 Million m³/a over ~4 years would expose currently flooded gold ore reserves.

In the Stilfontein area, plans are currently being formulated to sell ~21 Million m³/a of untreated water that is being pumped from six shafts in the area. This would be sold to Midvaal Water Company, which serves the Klerksdorp-Orkney area.

The above water would not be 'new' water in the true sense of the word but would reduce contaminant loads to surface water and reduce demand on potable water supplies.

A treatment plant to process 20 Mℓ/day of contaminated mine water from coal mines in Mpumalanga has been approved by Anglo Coal and is due to be operational within the third quarter of 2007 (Water, Sewage and Effluent, 2006). This water will be sold to Emalahleni (Witbank) Municipality. Final capacity will be 60 Mℓ/day. The untreated water has high concentrations of sulphate (~2500 mg/ℓ), a pH of <3 and high metals content. This would seem to prove the viability of the SWAMP and Stilfontein proposals.

4. Exploit dolomitic storage

New water could be made available by exploiting the highly favourable storage characteristics of the upper levels of the dolomite aquifers. Drawdown of this storage should be limited to within 5 m of the original compartment water table, as previously discussed. This option is limited to those compartments unaffected by dewatering, i.e. Klip River, Natalspruit, Turfontein,

Boskop and Rietvlei. In addition, abstraction should take place away from springs to minimise impacts of obstruction on flow. Because of this, it is assumed that only the upstream 50 % of each compartment would be exploited. A storage factor of 5% is assumed for this upper 5 m zone. An indication of the volumes of groundwater that could be made available by exploiting storage is given in **Table 3-1** below.

Table 3-1: Volumes of stored groundwater potentially available

Compartment	5 m Storage (Million m ³)	50 % Exploitation (Million m ³)	Production boreholes required
Klip River	107	53	66
Natalspruit	78	38	47
Turfontein	183	91	114
Boskop	53	26	32
Rietfontein	64	32	40
Total	485	240	300

The number of production boreholes required is based on a minimum yield of 25 l/s per borehole. This is a minimum figure and yields much higher than this can be attained. At a yield of 50 l/s per borehole, the number of boreholes required is halved.

This water would not be available on a continuous basis but could be used for emergency or peak demand top-up supplies. Taking this fact into account, the number of boreholes required declines.

If it is assumed that a three year drought period is reasonable, then if abstraction is spread over three years, 80 Million m³/a could be abstracted from 100 x 25 l/s boreholes, or 50 x 50 l/s boreholes. Each production borehole would cost ~R100 000.

Lowering of water levels will reduce losses to the system such as evapotranspiration and leakage. However, the ecological implications of doing this needs to be addressed, which is outside of the scope of this investigation.

Although groundwater use has been taken into account, reference to **Figure 2-7** shows that there is an uneven distribution of boreholes. Excluding the dewatered compartments, the Natalspruit and Klip River Compartments appear to have a fairly dense network of boreholes.

The Turfontein, Boskop, Rietfontein and possibly northern Stilfontein Compartments appear to show the best possibility for exploitation. From Table 5-1, this means a possible 149 Million m that could be factored into the water balance under some form of acceptable abstraction regime.

3.2.2 NORTH WEST DOLOMITES

The North West Dolomite Area Water Resources Management Study (EMA, 2003), “aims to provide the integration and co-ordination of all completed, ongoing and planned studies necessary to obtain a detailed knowledge and understanding of the dolomite aquifer.” The overall objective is stated as, “Developing a definitive assessment of the dolomite such that meaningful management

of the aquifer can be undertaken with confidence.” Some of the key Technical and Aquifer management objectives are highlighted here. These are:

- Definition of the areal extent of aquifers
- Define compartment boundaries
- Quantification of resources per compartment
- Quantify existing use
- Identify areas of over and under abstraction
- Determine recharge
- 3D numerical modelling
- Prepare water balances
- Implement/update monitoring networks
- Reserve determination

A comprehensive study of the Zeerust area was initiated by the Water Services Department of the DWAF Regional Office, Mafikeng. This was scheduled for completion in July 2003. It is mentioned here as the RMA (*op cit*) advocate that the comprehensive resource assessment methodology adopted be extended over the entire dolomite area. This work includes numerical modelling using the FEFLOW 3D finite element package. The model is being used to determine the volume of resources, taking into account recharge, discharge, abstraction and storage and the simulation of various abstraction scenarios.

The budget proposed for the Grootpan, Grootfontein, Lichtenburg and Schoonspruit (modelling only, comprehensive study already done by the DWAF) is ~R9.25 million. This is an 18 month comprehensive study, as the above objectives show, which goes far beyond the scope possible from the Vaal Reconciliation Groundwater Study.

This area is more straightforward in that there is minimal impact of mining on groundwater. Conversely, there is large scale existing dependence on groundwater and spring flow, largely for irrigation but also for municipal supply. The area is subject to a large-scale DWAF project(s) to quantify and manage groundwater resources. Only a brief overview can be given here compared to level of detail being covered in these projects. Largely based on the work of Bredenkamp (*op cit*), available quantities of groundwater are shown in **Table 3-2**.

Table 3-2: Available abstraction

Compartment	Groundwater Available Million m ³	Production boreholes required
Holfontein	3	4
Moorivier	60	75
Schoonspruit	4	5
Lichtenburg	0	-
Grootfontein	0	-
Grootpan	8	10
Total	75	94

The main areas for establishment of production boreholes correspond to areas underlain by the Monte Christo and Eccles Formations, as shown on **Figure 2-11**.

A recurring theme in all studies and compartment water balances is the need to firm-up existing groundwater use. This would seem to be especially true of the Moorivier Compartment. However, reference to **Figure 2-11** indicates that the density of existing boreholes is probably less in this compartment than any of the others.

3.2.3 GHAAP PLATEAU

The number of boreholes required in each GMU to exploit the surplus groundwater in that GMU was calculated based on an estimate of the long term sustainable yield of scientifically selected boreholes. These estimates are based on personal experience of the areas and are summarized in **Table 3-3** below. The table indicates that in total ~271 boreholes would be needed to abstract 131 Million m³/a from the 13 GMU's. It must be stressed that boreholes drilled in the catchment area of the Kuruman Eye will have a negative effect on the spring flow. As this spring is declared as a historical monument, decreased flow caused by upstream abstraction will likely raise concerns from local residents and DWAF. The volume listed in **Table 3-3** for this spring is therefore not 'available'.

Table 3-3: Boreholes required in each GMU to exploit 75% of the recharge surplus

QUARTERNARY CATCHMENT	LOCALITY	GW surplus based on UPGEF (Dry Season) (Million m ³)	Estimated sustainable yield of scientifically selected boreholes (ℓ/s @ 24h/d)	Cost of borehole (R)	No of Bh's required
C32D	Dry Harts	11	10	75,000	35
C33A	Pering	6.5	10	75,000	22
C33B	Reivilo	13.5	10	75,000	45
C33C	Harts River	25.4	10	75,000	85
C92A	Daniëlskuil	26.2	25	125,000	33
C92B	Schmidtsdrif	4.5	12	75,000	12
D41G	Lykso	3.4	15	75,000	7
D41J	Kathu	0	40	150,000	0

QUARTERNARY CATCHMENT	LOCALITY	GW surplus based on UPGEF (Dry Season) (Million m ³)	Estimated sustainable yield of scientifically selected boreholes (ℓ/s @ 24h/d)	Cost of borehole (R)	No of Bh's required
D41L	Kuruman	(40)*	(40)	150,000	(32)
D73A	Postmasburg	0	15	-	0
TOTAL		131	N/A	N/A	271

* See comment in above paragraph

The most expensive boreholes to construct will be in the Kuruman area where thick overburden is expected and boreholes will have to be constructed to a final depth of 300 m.bgl. However, the unit cost per m³ of groundwater is the least for this area due to the expected high sustainable yields of boreholes.

4 CONCLUSIONS

The main conclusions drawn from this investigation are listed under each study area.

4.1 FAR EAST TO FAR WEST RAND

- There are 11 main compartments varying in area from ~52 km² (Venterspost) to ~522 km² (Turfontein).
- Many of these compartments have been severely impacted by mining and other activities. In this regard the Springs, Gemboksfontein West, Venterspost, Bank and Oberholzer Compartments are unsuitable for development of conventional groundwater schemes, i.e. boreholes, at present and for the near future (~20 years). This is due to deep water levels and poor groundwater quality.
- Storage and transmissivity vary by orders of magnitude both areally and with depth, making compartment-wide predictions of groundwater exploitability difficult.
- The chert-rich dolomites have the best groundwater potential, i.e. the Monte Christo and Eccles Formations. Constant re-circulation of groundwater is also causing enlargement of fractures and cavities, thus enhancing groundwater potential. However, this is offset by the negative effects of dewatering and contamination.
- Recharge estimates generally fall in the 10 to 15 % (of MAP) range, with some much higher ones in the 20 to 50 % range. The latter might not be too far fetched as sinkholes and subsidence development, lowering of water levels and widening of conduits will have enhanced recharge potential.
- A unique feature of the dolomite is that, because of its very high transmissivity, the total annual recharge is available for abstraction.

- Groundwater and surface water are intimately related and continual interchange occurs between these phases of the hydrological cycle along the flow path.
- Natural dolomite groundwater is essentially a Ca/Mg (HCO₃)₂ type, alkaline and with an EC of <70 mS/m. Contamination in areas affected by mining, industrialisation and agriculture is manifested by an increase in EC, sulphate, sodium, chloride and nitrate. Dissolved radionclides are also a problem, particularly in the Bank and Oberholzer Compartments.
- Total groundwater abstraction and spring flow is estimated at 292 Million m³/a, 58 % of this being related to mining.
- An approximate water balance indicates that there might be surpluses in the Klip River, Turfontein, Boskop, Rietfontein and Stilfontein Compartments of ~17, 16, 19, 18 and 19 Million m³/a, respectively or 89 Million m³/a. However, much or most of this may already have been factored in to the catchment surface water balance.
- Assuming an allowable drawdown of 5 m in compartments unaffected by mining, and taking into account existing borehole distributions and densities and allowing for 50 % exploitation, there may be ~150 Million m³ of groundwater available under some form of acceptable abstraction regime. This is from the Turfontein, Boskop and Rietfontein Compartments.
- A simplistic assumption of a 25 l/s yield from a typical production borehole means that ~190 such boreholes would be required. However, the number of boreholes would depend on actual yields (could be 50 to 80 l/s) and the manner in which the groundwater is exploited, i.e. continuous, top-up or emergency supply. Each production borehole would cost of the order of R100 000 to drill and construct.
- In terms of the mining impacted compartments, a number of scenarios are possible, viz:
 - All flow exits at Turfontein Spring after rewatering. Flow could be ~150 Million m³/a of uncertain quality;
 - Springs reappear but flow is increased due to increased recharge. If recharge increased by 10% there could be ~7 Million m³/a of 'new' water added to the system. This scenario would take >30 years to materialise;
 - Pumping continues from the main mining centres and the water is treated to potable standards. Approximately 240 Million m³ of potable water could be produced. Pumping a further 107 Million m³/a over a period of ~4 years would expose currently flooded gold reserves;
 - In the Stilfontein area, plans are currently (June 2006) being formulated to sell ~21 Million m³/a of untreated mine water to Midvaal Water Company.

4.2 NORTH WEST DOLOMITES

- There are six compartments varying in area from 99 km² (Holfontein) to 1673 km² (Schoonspruit). These compartments are mostly much larger than those of the previous area, although there are several subcompartments.
- Similar comments on transmissivity and storage apply as per 6.1. In particular, karst development appears to be best in the basal unit of the Monte Christo Formation.
- Taking recharge as 10% of MAP, total recharge could be of the order of 245 Million m³/a.
- Groundwater quality is mostly good and in a pristine state apart from some areas with high nitrates, which is attributed to livestock wastes and irrigation.
- Existing groundwater use is estimated at 117 Million m³/a. The highest concentration of boreholes occurs in the Grootpan and Lichtenburg Compartments.
- Spring flow totals ~96 Million m³/a.
- Water balances indicate that there might be of the order of 75 Million m³/a of surplus groundwater available. This is made up of 3, 60, 4 and 8 Million m³/a from the Holfontein, Mooirivier, Schoonspruit and Grootpan Compartments, respectively.
- About 94 production boreholes would be required to abstract this amount, assuming a yield of 25 l/s per borehole. This would cost R9.5 million for installation of the boreholes only.
- Groundwater development should be concentrated in the Monte Christo and Eccles Formations away from the main spring locations.

4.3 GHAAP PLATEAU

- The groundwater levels in the Ghaap Plateau dolomite areas vary considerably from 0 m.bgl. (spring and artesian boreholes) to more than 150 m.bgl. The deepest water levels occur in the BIF and adjacent dolomite upstream of the Kuruman Eye.
- Groundwater use in the area varies considerably and is controlled by the location of towns (which use groundwater), mines (dewatering) and the availability of suitable soil for growing crops (irrigation).
- The minimum recharge in the Kuruman Eye catchment area is 5% of MAP based on the measured spring flow, calculated leakage across the Kuruman dyke and groundwater abstraction in the area.
- Using the groundwater recharge values calculated in the GRA2 project, recharge varies from 2.6% of MAP in the Campbell area to 10.0% in the Kuruman area. The value for the Tosca-Vergeleë area is 7.5% of MAP which is considerably more than the 0.4% calculated by Van

Dyk using the CMB method. The average groundwater recharge for the Ghaap Plateau dolomite is ~6 % of MAP.

- The CMB method has to be used with great care to ensure that groundwater samples used to calculate the groundwater recharge are not contaminated by fertilizers used on nearby irrigated fields, kraals and French drains. Contamination from these sources will undoubtedly increase the chloride content of the groundwater and hence the CMB method will yield a lower recharge value.
- Total groundwater recharge on the dolomite areas is estimated at ~495 Million m³/a.
- The 'surplus' groundwater potential of the area is ~131 Million m³/a, allowing for droughts. Approximately 271 boreholes would be required to exploit this groundwater.
- Yield per production borehole could range from 10 l/s to 40 l/s.
- Costs per borehole range from R75 000 to R150 000.
- Current total groundwater abstraction in the area amounts to ~68 Million m³/a.
- A groundwater deficit occurs in the Postmasburg/Kathu area.
- Groundwater quality in the Ghaap Plateau dolomites is generally good (SABS Class 0) with more saline water occurring in polluted areas and at two localities where Dwyka Tillite is present in sinkholes.

4.4 SUMMARY

The above options are summarized in **Table 4-1** below.

Table 4-1: Summary of Options

Scenario	Volume of groundwater (million m ³ /a)	Comment
West and Far West Rand		
Compartments rewater – dykes not intact	150 (at Turfontein Spring)	No 'new' water added
Compartment dykes intact or engineering to be intact	Possibly 7	Could take 30 years to develop
Pumping continues, water treated to potable standard	240	No 'new' water but would reduce salt loads and demand on existing potable supplies
Exploit groundwater storage	150-240	Up to 300 production boreholes required (25 l/s each)
North-West		
Increased groundwater abstraction	75	Mainly from the Moorivier Compartment

Scenario	Volume of groundwater (million m ³ /a)	Comment
Ghaap Plateau		
Increased groundwater abstraction	90	Up to 270 production boreholes required. Excludes Kuruman area (40) because of possible impacts on the spring

5 RECOMMENDATIONS

The main recommendations arising from this investigation are indicated in the following sections.

5.1 FAR EAST TO FAR WEST RAND

- Obtain the DME report on the West and Far West Rand and review.
- Carry out a hydrocensus in the areas where existing groundwater use is uncertain.
- Liaise with the DME/Council for Geoscience on groundwater management plans for the West and Far West Rand mining areas.
- Liaise with the DWAF/EMA personnel carrying out the Wonderfontein Spruit study.
- Construct a model (s) of selected compartments, where sufficient data are available, to do scenario modelling of groundwater abstraction and management.

5.2 NORTH WEST DOLOMITES

This area is being covered in detail by parallel DWAF and WRC studies. All aspects of further investigation, quantification and modelling appear to be catered for in future budgets.

5.3 GHAAP PLATEAU

Select a compartment(s) and construct a numerical model to do scenario modelling of groundwater abstraction and management.

5.4 GENERAL

- Extend this study to cover the dolomitic aquifers in the surrounding catchments, particularly those in the Zeerust, Krugersdrop-Pretoria-Delmas and southern Ghaap Plateau areas.
- Investigation the feasibility of Management of Aquifer Recharge and link with the Artificial Recharge Strategy developed.
- Develop an overall monitoring programme to coordinate existing programmes and provide full coverage of the dolomite aquifers.

- Prior to considering development options, the relevant risk assessments, vulnerability, impact and hazard mapping, as well as protection zones, need to be defined.

6 REFERENCES

Barnard H.C. (2000). *An Explanation of the 1:500 000 General Hydrogeological Map.* Johannesburg 2526. Department of Water Affairs and Forestry.

Bredenkamp D.B. (1993). Hydrological evaluation of the West Rand Dolomitic Compartments: Zuurbekom, Gembokfontein East and Gembokfontein West. Department of Water Affairs and Forestry, Technical Report GH3866.

Bredenkamp D.B. (1995). *Dolomitic Groundwater Resources of the Republic of South Africa.* Department of Water Affairs and Forestry, Technical Report GH3857.

Bredenkamp D.B. *et al.* (1986). *Groundwater supply potential of dolomite compartments west of Kurgersdorp.* Department of Water Affairs and Forestry Technical Report GH3440.

Bredenkamp D.B., Van Rensburg H., Van Tonder G.J and Cogho V. (1987). Quantitative estimation of the aquifer storativity and recharge by means of a water balance incorporating a finite element network. Quantity and Quality Conference IAHS, Benidorm, Spain.

Dames & Moore (1984). *Pering Groundwater Investigation Class C Report.*

Du Toit, A.J. (1985). Department of Co-operation and Development. Mothibistadt: Project No P040. Feasibility Study on Groundwater and Site stability. Summary Report No.2.

De Freitas M.H. and Wolmarans J.F. (1978). *Dewatering and settlement in the Bank Compartment of the far West Rand, South Africa.* SAIMOS-78 Conference proceedings, Granada (Spain).

De Villiers, S.B. (1959). *Opname van die fonteine in die dolomiete op die Kaapplato.* DWAF Technical Report No GH1062.

De Villiers, S.B. (1961). *Dolomietiese oë in die gebied Kuruman.* DWAF Technical Report No GH1147.

Duvenhage, A.W.A. & Meyer, R. (1991). Geohydrological and Geophysical investigations in the Tosca-Vergeleë area, 1991. CSIR Report no EMI-C 91179.

Dziembowski, Z.M. (1974). Grondwaterondersoek by Sishenmyn met spesiale verwysing na toestand in groef in Heuwel 2, Distrik Postmasburg. DWAF Technical Report No GH2803.

Dziembowski, (1976). Grondwatertoestande by Sishenmyn Distrik Postmasburg soos op 30 Junie 1976. DAWF Technical Report No GH2912.

Dziembowski, Z.M. (1977). *Grondwatertoestande by Sishenmyn soos op 15 Julie 1977.* DWAF Technical Report No GH2958.

Dziembowski, Z.M. (1978). *Water from Sihen mine as a temporary supply.* DWAF Technical Report No GH2998.

Enslin J.F., Kleywegt R.J., Beukes J.H.T. and Gordon-Welsh J.F. (1976). *Artificial recharge of dolomitic ground-water compartments in the Far West Rand Gold-fields of South Africa*. In Land Subsidence: Proc. 2nd Int. Symp. Anaheim, Publ. 1.

Enslin J.F. and Kriel J.P. (1968). The assessment and possible use of the dolomitic groundwater resources of the Far West Rand, Transvaal, Republic of South Africa. Proc. Int. Conf. Water for Peace, Washington May 1967, Vol. 2.

Esterhuysen, C.J. (1985). Program van ondersoek van die geohidrologie van die Ghaapplato, Noord-Kaap. DWA Technical Report No GH3404.

Esterhuysen, C.J., Fortuin, M. & Visser, D. (2004). Assessment of the groundwater resources of the Kathu Aquifer. SRK Consulting Report No 336736/DraftV1.3.

Ground Water Division of the Geological Society of South Africa. (1988). *Workshop on Dolomitic Ground Water of the PWV Area*.

Hodgson F.D.I, Usher B.H., Scott R., Zeelie S., Cruywagen L-m. and de Necker E. (2001). Prediction Techniques and Preventative Measures relating to the Post-operational Impact of Underground Mines on the quality and quantity of groundwater resources. WRC Report No 699/1/01.

Hubert G. (2003). Project Management and Technical Coordination of North West Dolomitic Groundwater Region Areas. Inception Report No 1061/1.

Hubert G., F Wimberely, N. Bezuidenhout, T.J. Coleman, U. Ramjee, S. Mtshali, Dr J. van Blerk and M. van de Venter. (2006). The Determination and Management of the Interaction between the Surface and Groundwater in Dolomitic Water Resources in the Far West Rand Area. Phase I Situation Assessment. Volume I: Text. DWA.

Fleischer, J.N.E. (1981). Geohydrology of the dolomite aquifers of the Malmani Subgroup in the south-western Transvaal, RSA. Department of Water Affairs and Forestry, Technical Report GH3169.

Foster M.B. (1989). *The dolomitic groundwater resources of the Far West Rand*. Proceedings of the 5th Biennial Symposium of the Ground Water Division, Conference, Geological Society of South Africa, Mintek 1989, pp19-27.

Geldenhuis S.J.T. and Howard J.R. (1988). Quality and pollution of the ground water in the dolomites of the PWV Area. SRK Report.

Gilding, B.H. (1979). A preliminary mathematical model of a confined-watertable aquifer known as the Sishen compartment. DWA Technical Report No GH3129.

Kafri U., Foster M. Detremmerie F. and Simonis J. (1985). *The Hydrogeology of the dolomite aquifer in the Kliprivier-Natalspruit Basin*. Technical Report Gh3408. Directorate Geohydrology. DWA.

Kotze J.C., Dziembowski Z.M. and Botha L.J. (1994). *Schoonspruit eye district Ventersdorp analysis of rainfall, eye flow and water levels*. Drainage area C24. Technical report Gh3842. Directorate Geohydrology, DWAF.

Kuhn C.M. (1986). Geohydrological investigation of the Western and Central Steenkoppies Compartment. Technical report Gh3446. Directorate Geohydrology, DWAF.

Kuhn C.M. (1989). *Hydrogeology of the Midrand-Kempton Park dolomite*. Technical report Gh3501. Directorate Geohydrology, DWAF.

Leskiewicz, A.F. (1981). Groundwater investigation of the Daniëlskuil mining area, Drainage region C39. DWAF Technical Report No GH3167.

Leskiewicz, A.F. (1984b). *Potential supply from dolomitic ground water sources of East Rand*. Technical Report No GH3316. Directorate Geohydrology, DWAF.

Leskiewicz, A.F. (1986). Exploitable potential of the ground water sources of the East Rand dolomite for emergency supplies. Technical Report No GH3463. Directorate Geohydrology, DWAF.

Leskiewicz, A.F. (1989). Preliminary geohydrological survey results of dolomitic compartment of Mooirivier.

Polivka J. (1987). Geohydrological investigation of the Schoonspruit compartment in the dolomite area of Ventersdorp. Technical report Gh3524. Directorate Geohydrology. DWAF.

Rosewarne P.N. (1982). *Extension of the Far West Rand Project – Potchefstroom to the Vaal River*. Report No Gh 3216. Directorate of Geohydrology. Directorate of Water Affairs.

SABS (2001). *Classification of Water for Domestic Use*. SABS 241 – 2001.

Scott J.R. (1995). *Flooding of Central and East Rand Gold-mines*. Water Research Commission. Report No 481/1/95.

Smith, C.P. (1981). The electrical resistivity survey carried out in conjunction with the groundwater investigation of the Sishen/Kathu area, Northern Cape. DWAF Technical Report No GH3183.

Smith C.P. & Erasmus, C.J.H. (1983). *Exploration drilling in the Gathlose area, District Kuruman*. DWAF Technical Report No GH3249.

Smit, P.J. (1970). Grondwatertoestande in omgewing van Sishenmyn, Distrik Postmasburg. DWAF Technical Report No GH1523.

Smit, P.J. (1970). Groundwater recharge on the dolomite of the Ghaap Plateau near Kuruman in the Northern Cape, RSA. DWAF Technical Report No GH1537.

Smit P.J. (1977). Die geohidrologie in die opvanggebied van die Moloporivier in die noordelike Kalahari. Ph-D thesis University of the Free State.

South African Committee for Stratigraphy (SACS) (1980). *Stratigraphy of South Africa. Part 1. Litostratigraphy of the Republic of South Africa, South West Africa/Namibia, and the Republics of Bophuthatswana, Transkei and Venda*. Handb. geol. Surv. S. Afr., 8.

SRK Consulting. *Strategic Integrated Water Management Plan – Gauteng Gold Mines*.

Van der Merwe, J. (1982). Geohidrologiese aspekte van die karbonaatryke gesteentes in Noord-Kaapland met 'n kritiese beskouing van wiskundige evalueringstegnieke. Ph-D thesis, University of the Free State.

Van der Merwe, J. and Hodgson, F.D.I. (1981). *Geohydrological aspects of the Vryburg Compartment, Northern Cape Province*. Bull. 9. Institute for Groundwater Studies, University of the Free State.

Van Dyk, G. S. du T. (2005). Managing the impact of irrigation on the Tosca-Molopo groundwater resource. DWAF Technical Report No GH4023.

Van Rensburg H Janse. (1995). *Management of Southern African aquifers*. Ph D. Thesis, University of the UOFS.

Van Rooyen, L. (1977). Die geologie en geohidrologie van 'n gebied noord van Reivilo, Kapproovinsie. MSc thesis University of the Free State.

Vegter J.R. and Foster M.B.J. (1989). *The geohydrology of dolomite formation in the Southern and Western Transvaal*. Department of Water Affairs and Forestry, Report No GH3643.

Veltman S. (2003). *A methodology for groundwater management in dolomitic terrains with the Schoonspruit compartment as pilot area*. Thesis for M Sc degree in Faculty of Natural & Agricultural Sciences, Department of Geohydrology, University of the Free State, South Africa.

Veltman S. (2004). *Establishment of the regional groundwater monitoring network at KOSH (Klerksdorp-Orkney-Stilfontein-Hartbeesfontein)*. Report no Gh3987. Directorate: Free State Regional Office, Department of Water Affairs & Forestry.

Willeminck, W. (1982). Voorstel vir 'n ondersoek na die grondwateraanvulling in die Kathugebied, Distrikte Kuruman en Postmasburg. DWAF Technical Report No GH3201.

Wolmarans J.F. and Guise-Brown F.H. (1978). The water hazard in deep gold mining of the Far West Witwatersrand – South Africa. SAIMOS-7, Granada, pp329-346.

Wullschleger, N.J. (1998). *Red sands hydrogeological study*. Toens & Partners Report 139.