CENTRAL DISTRICT MUNICIPALITY

CONTRACT No. RPW1 / 2003

WELBEDACHT BULK WATER SUPPLY GROUNDWATER RESOURCE AUGMENTATION PHASE 1

REPORT NO. 2005/0076-02

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DATE: FEBRUARY 2005

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Reg No. 1995/012155/07

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1 INTRODUCTION

1.1 General

The Central District Municipality (CDM) in Mafikeng, had in April 2003 commissioned production from a well field situated on the farm Uitvalgrond 60 JO some 6km southwest of the Town of Zeerust. This well-field comprises of 4 production boreholes delivering a daily abstraction of 30l/s to supply the Welbedacht area.

The normal exploitation of the well field as per recommended abstraction, following the commissioning, continued until March 2004 when problems began with some of the production boreholes failing necessitating reduction of the abstraction. By early September 2004 exploitation of the well field was completely discontinued as all production boreholes had failed. The failing of the well field negatively affects water supply to the beneficiary communities thus prompting the CDM to urgently rectify the situation.

The CDM has engaged Bogare Consultants Consortium (BCC), a consortium of consulting firms currently appointed on the Rural Water Supply Programme - Contract No. RPW1/2003, to undertake a geohydrological investigation for the re-evaluation of the groundwater resource in the Uitvalgrond area and further groundwater resource augmentation from other nearby dolomite compartments. The total water demand for the Welbedacht Bulk Water supply was specified by CDM as 40 l/s for a 24 hour pumping period, equivalent to 3456 m^3/day. Khulani GeoEnviro Consultants (KGC) a member of BCC is entrusted with the responsibility of the investigation. To fully comprehend and address the detail and level of expertise required in the investigation, KGC has sought involvement of associated consultancies VSA Geoconsultants Group and AquiSim Consulting.

1.2 Background

The existing high yielding boreholes in chert-rich dolomite formations on the farm Uitvalgrond 60 JO (also known as Wolvekoppies 60 JO) lead to the appointment of Africon Engineering (Africon) in 2001 to 2002 to investigate and develop the groundwater resource for augmentation purposes of the water supply to the Welbedacht area. A well field comprising of 4 production boreholes to deliver 30l/s was hence established by Africon on the farm (Uitvalgrond). The Uitvalgrond farm comprises of one of the dolomite compartment units (DCU) referred to as the Klaarstroom compartment and is the closest to the Zeerust area. It covers a surface area of 13 km^2 with a piezometric groundwater level of 1361mamsl, and is underlain by the upper

Eccles (chert-rich dolomite) and Frisco (Banded Ironstone and shale) Formations. These formations have been intruded by diabase dykes resulting in the formation of dolomite groundwater compartments.

The production boreholes from this well field started to fail almost a year after commissioning. Recorded water level draw-downs of the boreholes were in excess of 12 metres indicating that the compartment was over utilized and unable to sustain 30l/s. Although the available groundwater abstraction and water level monitoring data from the well field are inconsistent, indications for the long term sustainable supply potential of this compartment is expected to be in the order of 10 to 15l/s (> 1 l/s per 1 km^2 of dolomite compartment surface area).

During 2002 a PMA Consortium (comprising the geohydrological consultants VSA, Africon, and EMA) commenced with a detailed regional study of the Zeerust Dolomite compartments. This study entailed detailed delineation of over 50 dolomite compartments, including the Dinokona, Doornfontein and Rietpoort well fields. A comprehensive and very detailed 3 dimensional numerical model was compiled to study the rainfall recharge relationships, fountain flows, water level fluctuations and sustainable water supply potential within the various compartments over a 30-year rainfall period. The objective of the study was to identify groundwater resources where an additional 230 l/s could be developed on a sustainable basis to augment water supplies to the larger Zeerust area. From this study the Vergenoegd Compartment Unit was identified where 40 to 45 l/s could be abstracted on a sustainable basis, with the impact on long-term water level draw-downs predicted at less than 5 metres.

The Vergenoegd DCU forms the southern boundary of the Klaarstroom compartment and covers a surface area of 34 km^2. It is mainly underlain by chert-rich dolomite of the Eccles Formation and chert-poor dolomite of the Lyttelton Formation with the springs Vergenoegd and Paardenvallei discharging groundwater from the compartment. Monthly spring flow data over a 30 year period, monitored by the Department of Water Affairs, indicate an average flow of 80 l/s for the Vergenoegd springs (October 1960 to July 1992) and 66 l/s for the Paardenvallei springs (October 1975 to September 2002). The Vergenoegd DCU was subsequently proposed as the main target area to augment groundwater resources for the Welbedacht Bulk Water Supply.

The Tweefontein DCU, located north of the Vergenoegd compartment, forms the western boundary of the Klaarstroom compartment and covers a surface area of 38 km^2. It is underlain by chert-rich dolomite of the Eccles Formation and chert-poor dolomite of the Lyttelton Formation with the Tweefontein Upper spring discharging groundwater from the compartment. Monthly spring flow data over a 30 year period, monitored by the Department of Water Affairs, indicate an average flow of 22.7 l/s (October 1960 to February 1993). The Tweefontein compartment acts as a groundwater divide, with groundwater out-flow to the north (Dinokana compartment) and east (Klaarstroom compartment) and south (Vergenoegd compartment). The southern portion of the Tweefontein DCU was, in addition to Vergenoegd, proposed for the augmentation of groundwater resources.

A locality map of the investigation area is shown in Figure 1, depicting the present study area, location of springs and weirs which monitor spring flow, the four production boreholes of the Uitvalgrond well field, relevant dolomite compartments as defined during the Zeerust dolomite regional study (2003), and DWAF monitoring boreholes.

1.3 Investigation Approach

The approach adopted for the investigation included:

- a desk study to review all existing data including geohydrological reports, in particular the Africon report on the development of the Uitvalgrond well field, rainfall, groundwater level and spring flow monitoring data,
- survey of an extensive gravity grid over an area of 45 km^2 and combination thereof with the existing Africon gravity survey to determine the spatial distribution and depth extent (depth to bedrock or aquifer thickness) of leached dolomite zones in target dolomite compartments,
- hydrocensus survey of all existing boreholes and springs within the gravity survey area to obtain additional, updated and reliable water level information,
- leveling of surface elevations above mean sea level (mamsl) of boreholes and springs, using the surveyed gravity grid as reference to refine compartment boundaries,
- identify major saturated leached dolomite zones in the different compartments and potential boundaries to groundwater flow related to shallow bedrock zones,
- identify exploration drilling to fill critical information gaps and/or establish monitoring boreholes,
- propose drilling programme to establish additional production boreholes to ensure a sustainable water supply of 40 l/s and limit the impact on water level draw-downs in dolomite compartments and spring flows,
- supervise exploration drilling and test pumping of new boreholes,
- update and refining of the regional 3D groundwater dynamic model of the Zeerust Dolomite Compartments to determine the long term impact of the recommended groundwater abstraction on water levels and spring flows, and
- compile investigation report.

This report discusses the results obtained to date (prior to the planned drilling) and further provides recommendations for the proposed resource augmentation. Liaison with the client was maintained throughout the investigation and further liaison with landowners was conducted.

2 DESK STUDY

2.1 Uitvalgrond Well Field

The discussion on the Uitvalgrond well field is presented in two sections with regard to the development and subsequent groundwater abstraction.

2.1.1 Development of Well Field

The report by Africon (Final Report on the Evaluation of the Groundwater Resources at Uitvalgrond 60 JO, Zeerust – Report 14261CH/G2/2002) recommended a daily abstraction of 30l/s achieved by alternating pumping at two weekly intervals from 4 production boreholes. The approach adopted by Africon in developing the well field included a gravity survey albeit on a small grid, geophysical survey, drilling of 4 monitoring and 5 boreholes for abstraction purposes , pump testing, water quality analysis and 3D steady state as well as transient state groundwater flow modeling.

The approach by Africon was appropriate and similar to the approach adopted for the current investigation. The limitation with the Africon investigation was the limited aerial extent of the investigation conducted in the Klaarstroom compartment covering a surface area of 13 km^2. The investigation was confined to a small (1.1 km^2) narrow area of the Klaarstroom compartment, comprising highly fractured dolomite, and located north and south of a faulted intrusive dyke. The ingress of water into the fractures in the dolomite in this small area resulted in extensive weathering/leaching or karstification of the bedrock to depths up to 80 metres below surface.

Dolomite aquifers consist of a series of solution cavities below the water table that may or may not be interconnected with zones of solid dolomite and chert not contributing to groundwater flow. Hydraulic properties of dolomite aquifers may therefore vary over short distances in all directions. In modeling of dolomite aquifers a porous media approach is used by specifying regional representative aquifer parameters (hydraulic conductivity, aquifer thickness and storativity). In addition to representative regional aquifer parameters and reliable estimates of groundwater recharge from rainfall, information on the piezometric heads (water level elevations) of the aquifer system and known water flux is critical.

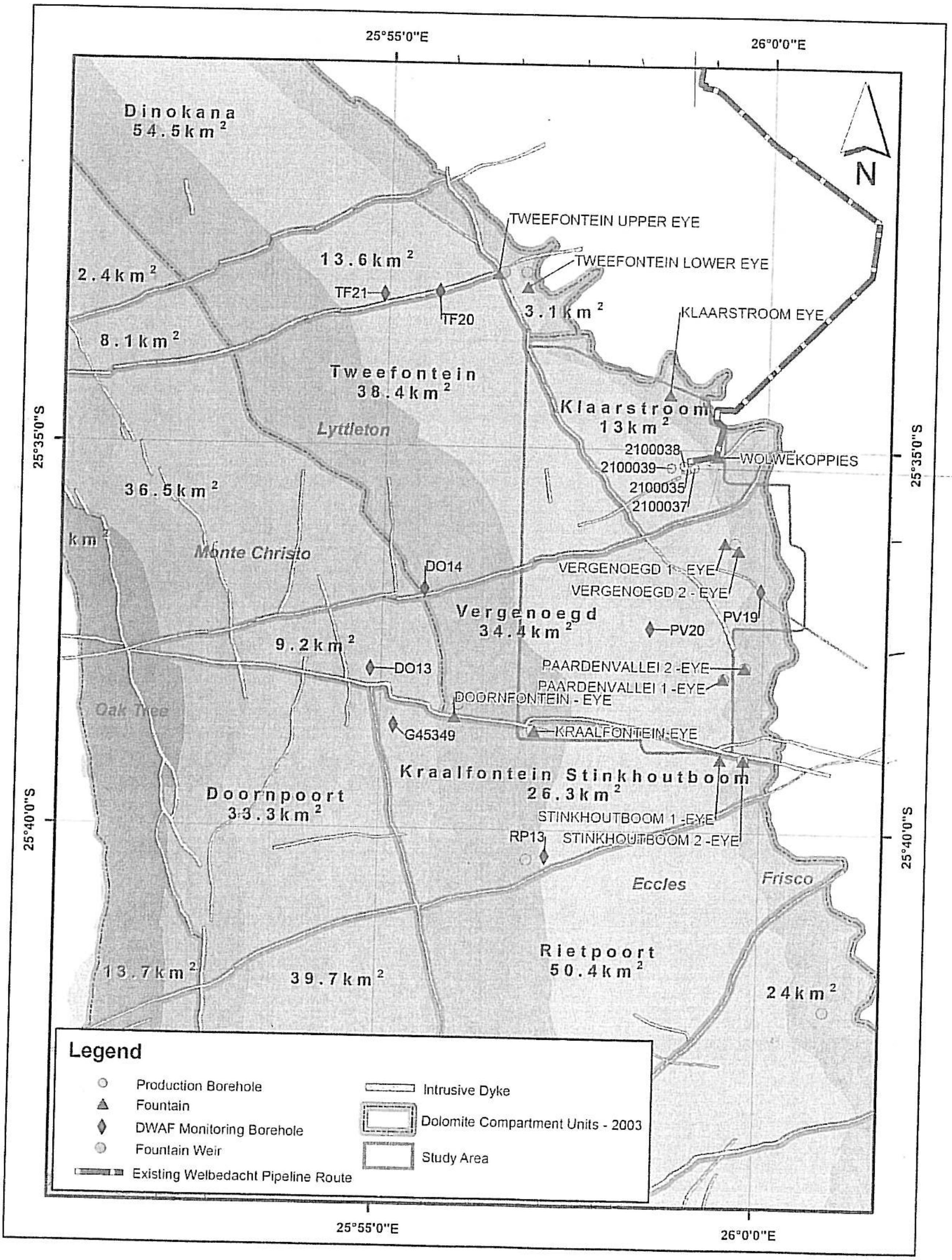


Figure 1 Locality Map depicting Study Area, Boreholes, Springs and Dolomite Compartments.

The groundwater flow in the Klaarstroom compartment (based on surface topography and water levels) is from the southwest/northwest to the east/southeast. Rainfall recharge is discharged through two springs located on the eastern edge of the compartment, namely the Wolvekoppies (8 l/s) and Klaarstroom (23 l/s) springs. Discharge from the system also occurs towards the east, through the Frisco Formation's contact, with a specified constant head of 1340 mamsl.

The flow elevations for these springs (Wolvekoppies and Klaarstroom) were estimated at 1360.5 and 1360 mamsl, respectively. The estimate of the flow elevation for Wolvekoppies was based on nearby accurate surveyed water levels in exploration boreholes, and considered reliable. The estimate of the flow elevation of 1360 for the Klaarstroom spring was based on map interpolation from topographic maps, as it was not surveyed during the Africon investigation. The similar estimates of flow elevations for both the springs, limited information on depth to bedrock and lack of boreholes located towards the Klaarstroom spring (in which water level elevations could be measured) resulted in the assumption that aquifer parameters (hydraulic conductivity and aquifer thickness) determined from aquifer testing of potential production boreholes could be extrapolated towards the Klaarstroom spring. An average aquifer thickness of 60 metres was used for the aquifer model.

The representative or range of aquifer parameters obtained from aquifer testing at potential production boreholes and modeling by Africon is as follows:

Borehole Number	T-Value (m^2/day)	Storativity
2100037	1430 to 1620	0.0353
2100036	836 to 992	0.0258
2100035	1380 to 13600	0.0561
2100038	6410 to 14500	0.0382
2100039	2300 to 3200	0.0187

Transmissivity values range from 836 to 14500, typical of the varying nature of leached dolomite aquifers and the storativity from 1.8 to 5.6 per cent, with an average storativity in the order of 3.5 per cent.

The water balance flow components obtained during steady state calibration of the aquifer model by Africon is as follows:

Component	m^3/day	l/s
Recharge (65mm)	4048	46.85
Klaarstroom Spring	1930	22.34
Wolvekoppies Spring	683	7.91
Natural outflow losses	1435	16.61

From the above it is evident that groundwater recharge from rainfall is the driving force and only inflow component and exploitable resource. It should be noted that a long term average recharge of 65 mm was used (approximate 12 % of Mean Annual Precipitation - MAP) and variations in recharge related to below or above average rainfall not evaluated since no suitable monitoring data related to water levels, groundwater abstraction and spring flow was available.

Results form the transient aquifer modeling by Africon indicated that spring flow is very sensitive to water level draw-down, and that for a draw-down of 1 meter the Wolvekoppies spring will diminish from 8 to 2 l/s, and stop flowing at a 2 meter water level draw-down. Optimum well-field yield (31 l/s) is obtained with draw-downs in the order of 3m, at which time the Klaarstroom spring will also stop flowing.

Borehole management recommendations by Africon, to supply an optimum yield of 30 l/s, from four production boreholes, pumping on a two weekly rotating basis is as follows:

Borehole Number	Depth (m)	Water Level (m)	Yield (l/s for 12 hrs / day)
2100037	42.8	17.6	10 – south of dyke
2100035	67.6	22.3	10 – south of dyke
2100038	45.5	27.4	20 – north of dyke
2100039	43.5	30.6	20 – north of dyke

The water level depths listed above were measured on 2 May 2002, and represent static water levels prior to well-field abstraction for future reference in monitoring water level draw-downs.

2.1.2 Groundwater Abstraction from Well Field

The Central District Municipality commissioned production from the Uitvalgrond well field in April 2003 as per recommended abstraction listed above. Water meters were installed to measure groundwater abstraction from each production borehole as well as piezometer tubes to enable measurement of water level depths within production boreholes.

Groundwater abstraction following the commissioning continued until March 2004 when problems began with some of the production boreholes failing necessitating reduction of the abstraction. Recorded water level draw-downs of the boreholes were in excess of 12 metres indicating that the compartment was over utilized and unable to sustain 30l/s. By early September 2004 exploitation of the well field was completely discontinued as all production boreholes had failed.

Aquifer monitoring data for the well field during groundwater abstraction is limited. One set of meter readings in m^3, dated 19 May 2004, was obtained from CDM for the four production boreholes. Water level draw-downs in the order of 12 meters were reported in May 2004, with some production boreholes failing. Monthly water levels were measured by CDM since November 2004 to monitor the water levels since pumping stopped early in September 2004.

The recommended groundwater abstraction for each production borehole and the meter readings on 19 May 2004 were used (13 months) to estimate the total groundwater abstraction as well as average daily abstraction rate from each borehole as listed below. It is possible that some of the flow meters got stuck, with lower recorded abstraction than actual. These production boreholes were equipped according to recommended discharge rates, in which for example two boreholes should be pumped alternatively at 10 l/s for two weeks, equivalent to 5 for 24 hours per day. To estimate the total groundwater abstraction over a period of 17 months the larger meter reading is used for boreholes with the same recommended abstraction rate.

Borehole	**Abstraction Based on Meter Reading**		**Estimated Total Abstraction – 17 months**	
Number	**Volume m^3**	**Daily Abstraction l/s**	**Volume m^3**	**Daily Abstraction l/s**
2100037	80,052	2.4	193,880	4.4
2100035	148,050	4.4	193,880	4.4
2100038	281,848	8.4	370,138	8.4
2100039	67,949	2.0	370,138	8.4
Total	**577,101 m^3**	**17.2 l/s**	**1,128,038 m^3**	**25.6 l/s**

Monitoring of water levels in the well field was measured approximate monthly since 8 November 2004. The water level draw-downs measured in production boreholes, using the static water level depths measured on 2 May 2002 as reference is listed below.

Borehole	**Water Level Draw-down (m)**			
Number	**20041108**	**20041223**	**20050118**	
2100037	-13.94	-14.24	-13.24	1.0 m recovery since 20041223
2100035	-12.94	-13.34	-12.54	0.84 m recovery since 20041223
2100038	-13.28	-13.48	no data	
2100039	-13.06	-13.36	-12.36	1.0 m recovery since 20041223

The draw-down data indicate a continued lowering of water levels during November and the larger portion of December 2004. This was over a period of 6 weeks and in the absence of groundwater abstraction. The residual drawdown over 6 weeks in the four boreholes ranged from 0.2 (Bh 2100038) to 0.4 (Bh 2100035), with an average of 0.3 m. The minimum residual draw-down is observed in Bh 2100038 which can be expected as it has the lowest water level elevation of 1346.72 mamsl of all four boreholes. This water level elevation is 6.7 metres above the constant head boundary specified for natural flow losses to the east across the Frisco Formation – Refer Section 2.1.1. The average water level drop of 0.3 m over the 6 week period is considered as a result of natural flow losses during a period of insignificant or no recharge from rainfall.

During the period end December to mid January (approximate 4 weeks) a rise in water levels ranging from 0.84 to 1.0 metres is observed, indicating a net inflow from rainfall recharge. The average water level rise measured in three boreholes is 0.95 m.

The observations made on the water level monitoring data and estimated total abstraction is used in later sections of this report to assess the sustainable yield of the well field at Uitvalgrond.

2.2 Regional Study of Zeerust Dolomite Compartments

During 2002 a PMA Consortium (comprising the geohydrological consultants VSA, Africon, and EMA) commenced with a detailed regional study of the Zeerust Dolomite compartments. This study entailed detailed delineation of over 50 dolomite compartments, including the Dinokona, Doornfontein and Rietpoort well fields. A comprehensive and very detailed 3 dimensional aquifer model was compiled to study the rainfall recharge relationships, fountain flows, water level fluctuations and sustainable water supply potential within the various compartments over a 30-year rainfall period.

In the study of the Zeerust Dolomite Compartments, high resolution airborne magnetic surveys enabled detailed and accurate identification of intrusive dykes. The accurate location of dykes combined with 317 water level elevations (within an accuracy of 3 metres) enabled for the first time reliable identification of dolomite compartment boundaries. The defined compartment boundaries made it possible to improve the effective recharge from rainfall relationship. Extensive transient modeling was done using fountain flows, water level fluctuations and monthly rainfall data for a period of 30 years (1970 to 2000). The transient modeling showed that the effective recharge, using monthly rainfall data, has an exponential relationship and a cut-off value of 65 mm at which no or very limited recharge occurs. The final recharge equation used is as follows:

$$\mathrm{Re} = (R - 65) \times (01 \times EXP^{0.02(R-65)}) \qquad \text{.......... 1}$$

$$\begin{aligned} \mathit{Where}: \mathrm{Re} &= \text{Effective Recharge (mm)} \\ R &= \text{Rainfall (mm)} \end{aligned}$$

The objective of the study was to identify groundwater resources where an additional 230 l/s could be developed on a sustainable basis to augment water supplies to the larger Zeerust area. From this study the Vergenoegd Compartment Unit was identified where 40 to 45 l/s could be abstracted on a sustainable basis, with the impact on long-term water level draw-downs predicted at less than 5 metres. The steady state water balance components were abstracted from the aquifer model and listed below. The approach of this investigation is to spread the specified water demand of 40 l/s in different compartments to minimize the impact on the Vergenoegd and Paardenvallei springs. A 25 l/s abstraction is targeted for the Vergenoegd-Paardenvallei Compartment, which represents 13 percent of the total inflow of 194.1 l/s.

Component	**m^3/day**	**l/s**
Recharge	6,691	77.4
Net Inflow across Boundaries	10,087	116.7
Total Inflow	**16778**	**194.1**
Vergenoegd Spring	8,809	102.0
Paardenvallei Spring	7,223	83.6
Natural outflow losses	746	8.5
Total Outflow	**16,778**	**194.1**

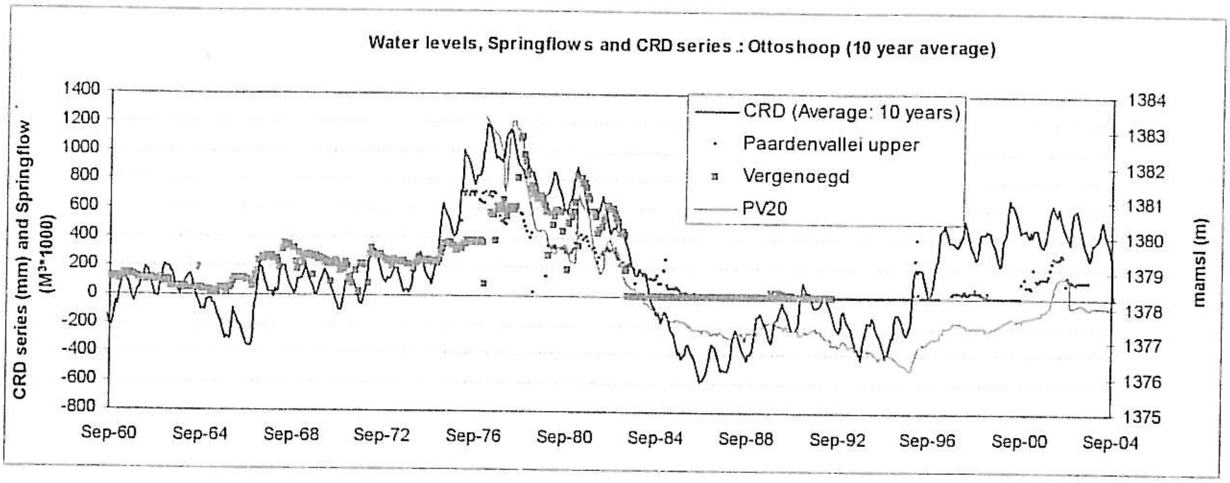
The Vergenoegd compartment further contains substantial surface depressions (2.49 km^2), with no surface run-off, which represent areas of very high rainfall recharge and extensive leaching of the dolomite with well-developed groundwater storage and borehole yield potential, presently not considered in the aquifer model. The Malmanie surface drainage further runs through the compartment, which will result in additional groundwater recharge during rainfall storm events (flush floods).

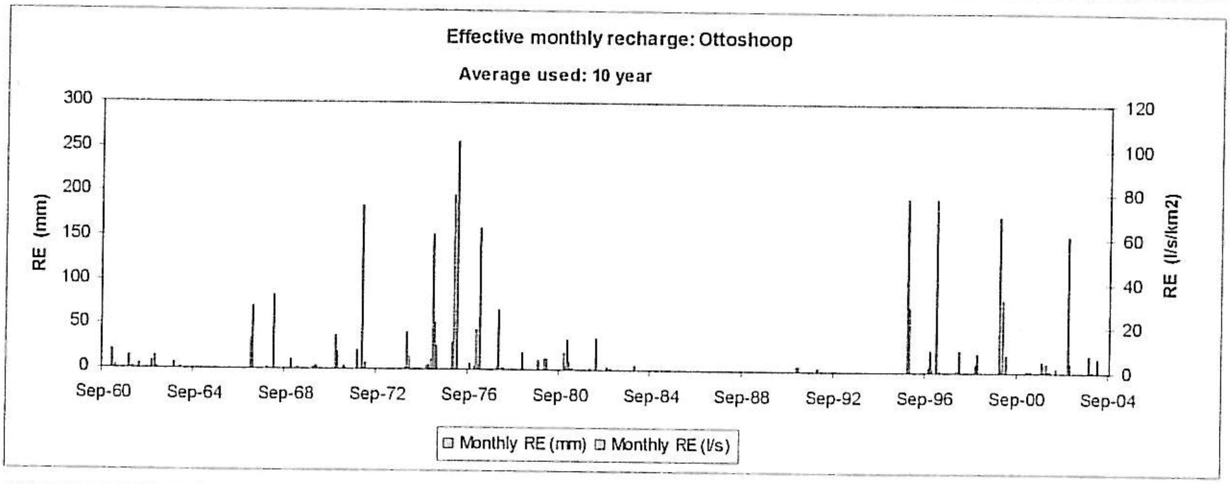
2.3 Evaluation of Effective Recharge

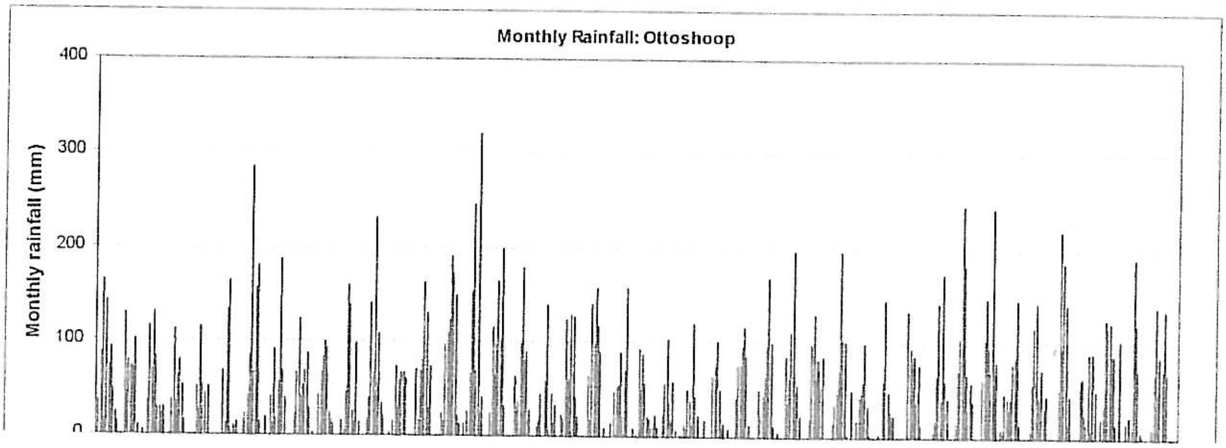
The evaluation of effective recharge is presented in two sections, one specifically on rainfall data and the other on estimations of effective recharge.

2.3.1. Rainfall

The closest rainfall station to the dolomite compartment units under investigation is the Ottoshoop rainfall station, for a period of 100 years. The rainfall at this station is high over the summer months and lowest over the winter months (Figure 2). A minimum amount of monthly rainfall (65mm) is required before groundwater recharge occurs. Consequently effective recharge only occurs (on average) during the months from November to March.







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The rainfall station has large variations in rainfall from year to year, from 300 up to 900 mm, with a mean annual rainfall of 539 mm (Figure 3). There are some consecutive years of extremely high rainfall > 800 mm (A in Figure 3) and also long periods of moderate to very low rainfall where rainfall seldom reaches the average let alone exceeds it (B in Figure 3).

Table 1 Rainfall Statistics for Ottoshoop Rainfall Station

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Mean	99.0	83.5	79.9	39.2	15.6	5.3	3.6	4.0	14.0	42.1	68.6	88.7	539
Median	86.9	72.2	70.5	26.5	5.8	0	0	0	3.6	38.1	64.5	79.3	512
10 Percentile	38.5	23.8	13.6	0	0	0	0	0	0	7.3	15.2	34.1	356
90 Percentile	179.7	159.1	171.7	91.7	44.7	18.0	9.5	14.0	47.8	82.9	129.1	159.6	760
No. of years	99	96	97	100	101	101	101	101	101	97	98	97	100

Rainfall is the driving force of the long term exploitation potential of the groundwater resource. The large variation in monthly rainfall will result in significant variations in effective groundwater recharge, with a negative impact on groundwater levels and spring flows during low rainfall periods.

2.3.2 Effective Groundwater Recharge Estimates

The Africon (2002) calculated effective recharge for Uitvalgrond as 12% of mean annual rainfall or 65mm annually. However, no assessment of the pattern of recharge with time was made which is elucidated in this investigation, targeting a similar 12% recharge of mean annual rainfall, using the exponential rainfall-recharge relationship developed during the Zeerust dolomite compartment study (refer equation 1) in conjunction with a CRD (cumulative rainfall departure) analysis.

First, rainfall data for Ottoshoop and Slurry rainfall stations were checked for quality and a CRD analysis performed. The CRD analysis, which is explained in detail in Bredenkamp et al. (1995), involves finding the accumulated departure of rainfall from the average rainfall over time (Equations 2 and 3).

$$CRD_i = CRD_{i-1} + R_i - R_{av} \quad \text{....................} 2$$

$$CRD_i = CRD_{i-1} + R_i - \frac{\sum R_{i-n}^{i}}{n} \quad \text{....................} 3$$

$$\begin{aligned} Where: CRD &= \text{Cummulative Rainfall Departure Series} \\ R_i &= \text{Current monthly rainfall} \\ R_{av} &= \text{Average monthly rainfall} \\ \text{n} &= \text{Number of months included in average} \end{aligned}$$

The analysis can be thought of as a debt-credit analysis with debts building up over consecutive dry periods and credits in the form of recharge to the groundwater system over wet periods. Hence, the CRD series should correspond well with fluctuations in groundwater level (see Figure 5)

The CRD series was used to identify monthly rainfall that could potentially contribute to effective recharge. If the CRD value was negative the system was still in debt and groundwater levels were below equilibrium. Any effective recharge during the negative CRD period was mainly restoring the aquifer system to equilibrium conditions. When the CRD series was positive the system could, if there was sufficient monthly rainfall, begin recharging or filling the aquifer above equilibrium levels. In other words, effective recharge only occurred if both of the following conditions were met.

1. The CRD series was positive
2. More than 65mm (The minimum monthly rainfall required to effect recharge) of rainfall occurred within a month.

Equation 4 was used to calculate effective recharge. The equation implicitly excludes rainfall below 65mm satisfying condition 2. To satisfy condition 1 recharge was assigned a value of zero when the CRD series was negative.

$$\mathrm{Re} = (R - 65) \times (01 \times EXP^{0.02(R-65)}) \quad \text{.......................4}$$

$$\textit{Where}: \mathrm{Re} = \text{Effective Recharge (mm)}$$
$$\mathrm{R} = \text{Rainfall (mm)}$$

A number of recharge estimates were calculated using equations 2, 3 and 4. In equation 2 the long term average rainfall over the whole record is used whereas in equation 3 a moving average over a number of preceding years was used. A range of different lengths from 6 to 12 years were evaluated for the moving average. The CRD series relating to these estimates was compared to water level data from borehole PV20.

It was found that the moving averages (Equation 3) were in general more suitable than the long term average (Equation 2). The moving averages CRD series correlated better with water level data than the long term average. The long term average CRD method also resulted in an unrealistic median recharge of 0 as well as very long periods of zero recharge (Figure 4). Other researchers such as Jacob (1944) also found that a shorter average was more appropriate for CRD analysis and pointed out that it allowed the weight assigned to early rainfall to be progressively reduced while realistically eliminating the impact of future rainfall.

Finally a 10 year moving average was used (overall the best fit to water level data) on the Ottoshoop rainfall station (the closest rainfall station). Recharge and rainfall patterns correlate very well and both showed high variability over time (Figures 4 and 5). The final recharge pattern corresponded well with water level fluctuations suggesting that recharge, and thus rainfall, is the major driving force for fluctuations in water levels and spring flows (Figure 5).

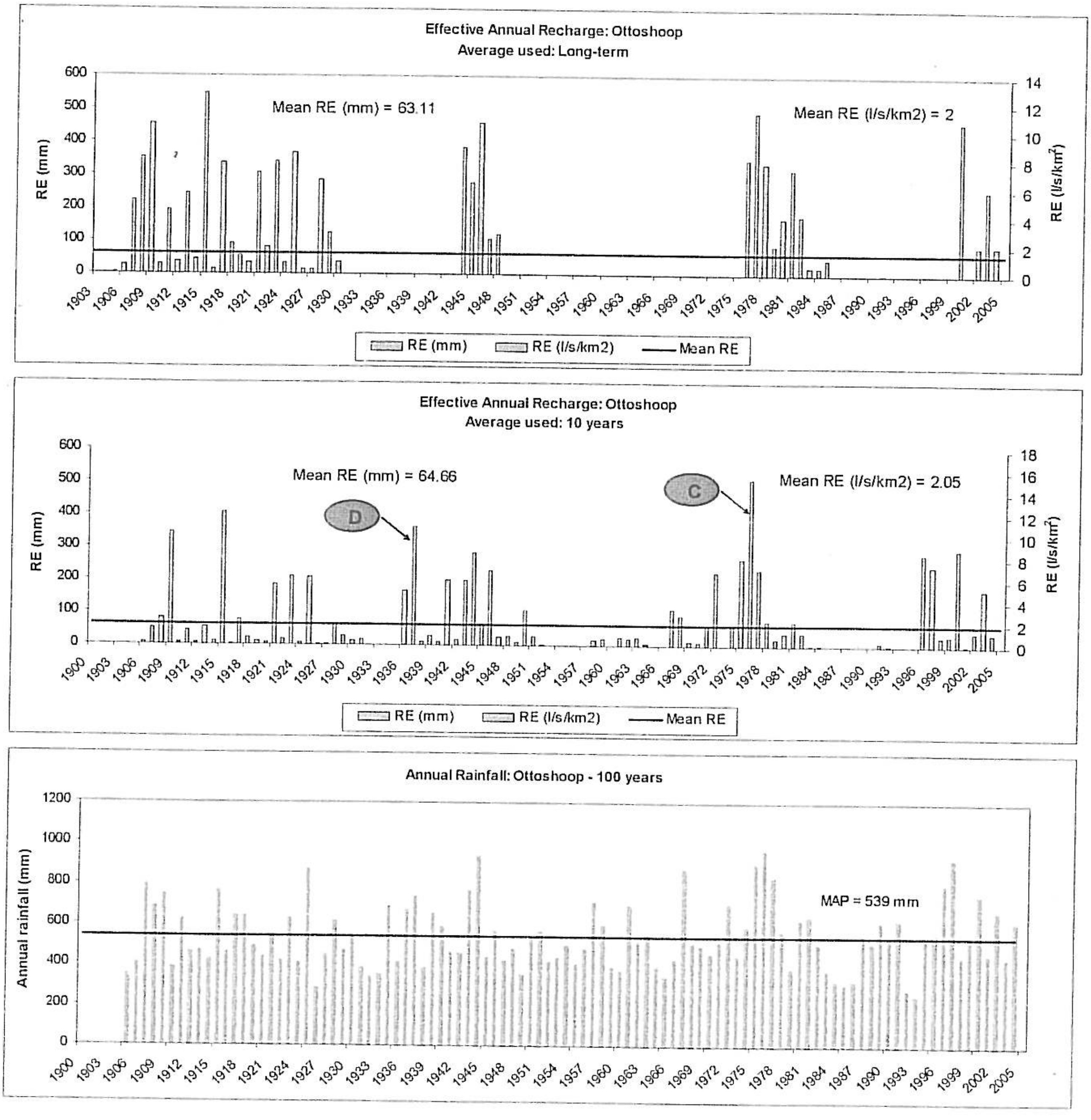

Figure 4. Annual recharge and rainfall for Ottoshoop

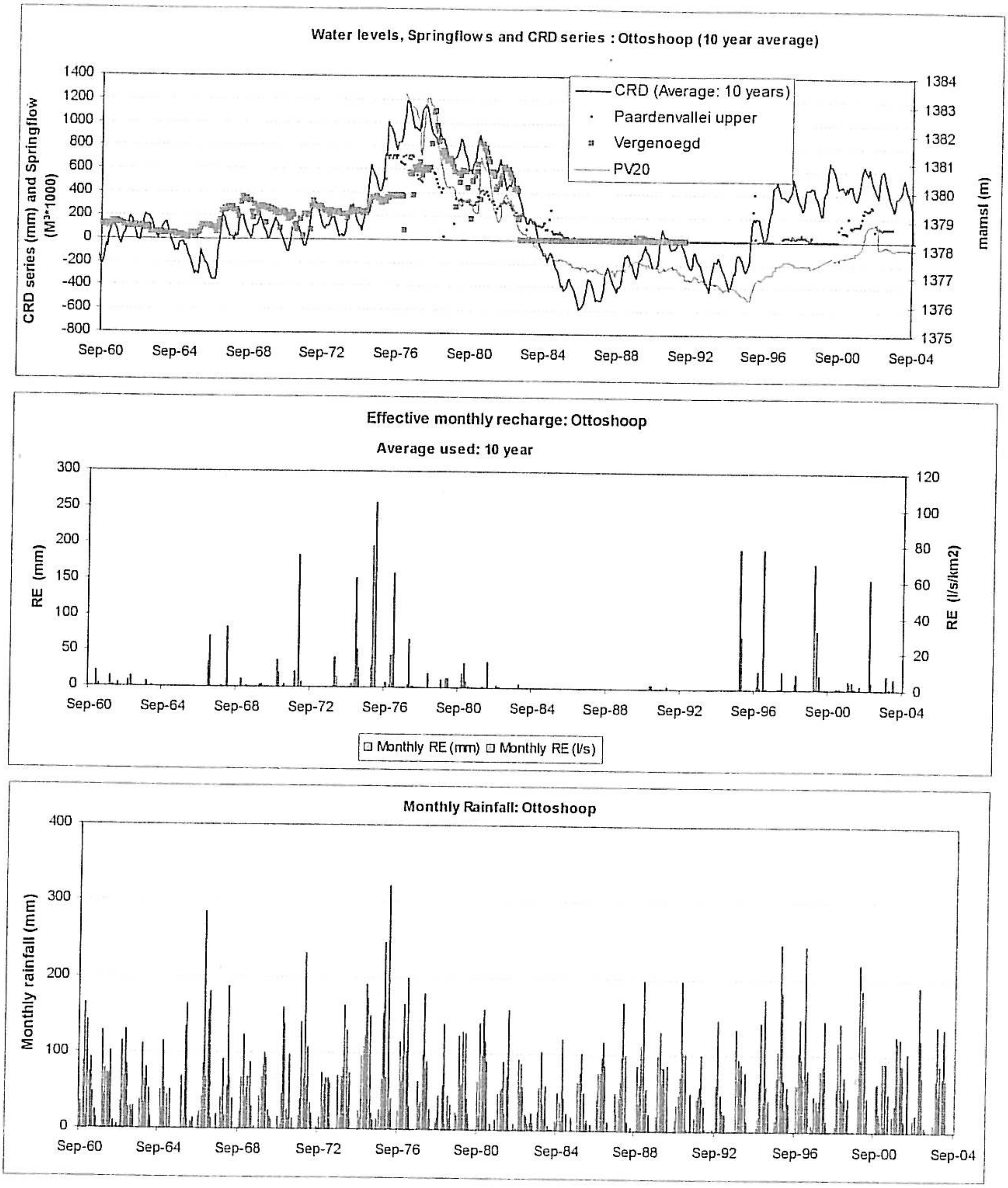

Figure 5. Monthly water levels, CRD, recharge and rainfall

The final mean value for effective recharge was 63 mm (2.01 l/s per km^2) or almost 12% of mean annual rainfall (Table 2). However, the system is highly variable and there was still a large difference of 44 mm between mean and median recharge (Table 2). This is because large peak events (eg. C & D in Figure 4) raise the mean value unrealistically. Physically, these events probably mitigate low rainfall periods such as during 1992 to 1995. The mean annual effective recharge represents the absolute maximum that could be exploited over the long term, however during periods of lower rainfall spring flows will drastically reduce and only recover after a major rainfall event. In evaluating sustainable abstraction from dolomite compartments it is proposed that the 70 percentile effective annual recharge value of 55mm is used, equivalent to 1.75 l/s per km^2. The 70 percentile value represents a 30 per cent probability that in any one year the effective recharge will be above 55 mm, for the target 12 % recharge of MAP.

The effective recharge over the period of pumping from the Uitvalgrond well field (April 2003 – September 2004) was 40mm.

Table 2 Recharge Statistics for Ottoshoop

MAP = 539 mm *% Re =12%*

	Annual RE (mm) >65 mm	Annual RE (l/s/km^2) >65 mm
Mean	63	2.01
Median	19	0.60
70 Percentile	55.4	1.75
90 Percentile	216	6.84
No. of years	85	85

The Zeerust regional dolomite study indicated that recharge varies for different dolomite formations, ranging from 1.5 % to 19 % of MAP. Note that the result in Table 2 is for a 12 % recharge of MAP only.

2.4 Variations in Spring Flow and Water Levels

Borehole water level and spring flow data from DWAF was updated until 2004 and 2003, respectively. The comparisons between variations in borehole water levels and variations in spring flow (in the same dolomite compartment unit) showed a strong relationship between the two. Variations in both parameters also show a clear similarity to variations in recharge for most boreholes and springs (Figure 6 and 7). In particular for the period during which there was almost no recharge (1983 to 1995 – 12 year period) there is a similar corresponding period of declining or low water levels for PV19, PV20, DO14, TF20, TF21 and RP13. There were also no flow conditions in Vergenoegd during this period and low flow conditions followed by no flow conditions for Paardenvallei, Kraalfontein, Tweefontein Upper Eye and Stinkhoutboom. Although it appears that there are no flow conditions since 1983 in Kraalfontein, it is not the case as spring flow is merely below the weir height.

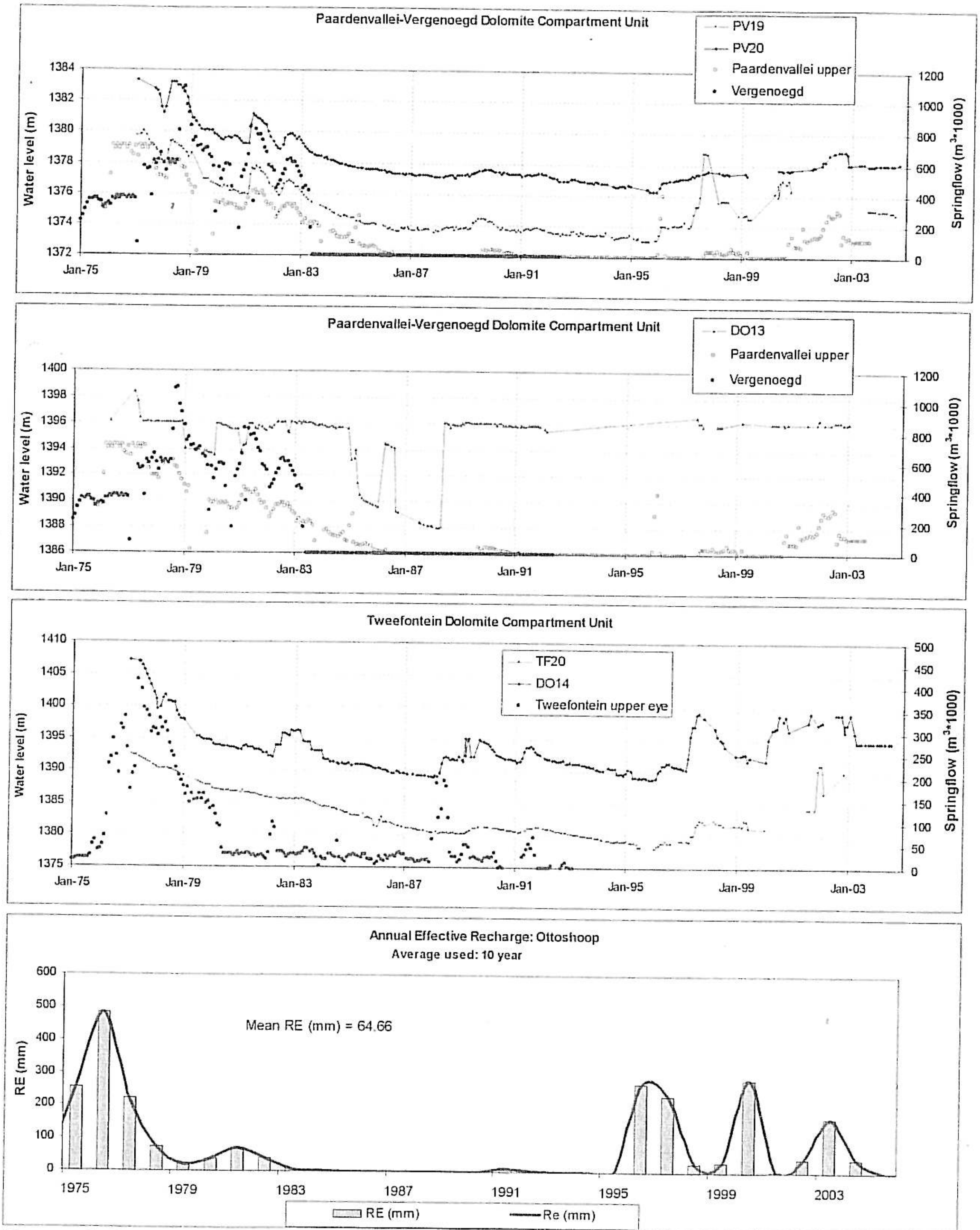

Figure 6 Water Level and Fountain Flow Variations for Paardenvallei-Vergenoegd and the Tweefontein DCUs

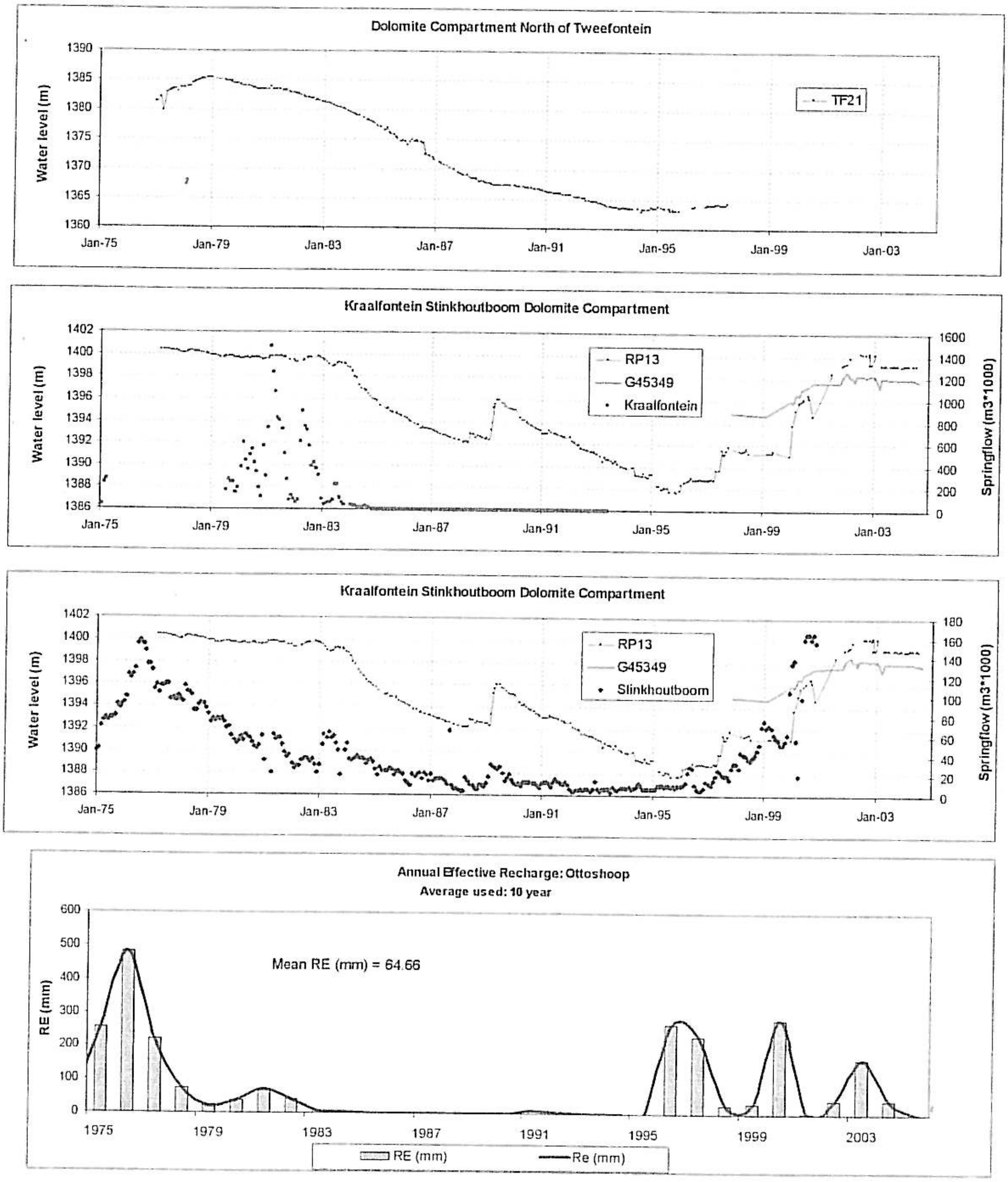

Figure 7 Water Level and Fountain Flow Variations for the Kraalfontein Stinkhoutboom DCU

The Paardenvallei Vergenoegd DCU was evaluated in more detail by comparing flow volumes at the Paardenvallei (upper or eye 1) fountain to water levels in borehole PV20. This borehole was chosen since it has a good record and considered the most representative of flow conditions in the DCU. The Paardenvallei Eye 1 spring was also chosen since it is close to the weir that measures flow, meaning that the weir receives little water besides that from Paardenvallei.

There is higher variability in flow at the Paardenvallei spring (Figure 8) producing an order of magnitude difference between the mean flow of 57.5 l/s (149 000 m^3/month) and the median flow of 13.5 l/s (35 000 m^3/month). There were also long periods with no spring flow and these correspond with low groundwater levels (A and B on Figure 8). In fact, for 40% of the record there was no flow which constitutes roughly 11 out of the 27 years recorded. Similar results were obtained for the nearby spring Vergenoegd, where the mean flow was 81 l/s (210 000 m^3/month) and the median flow was 50 l/s (129 000m^3/month).

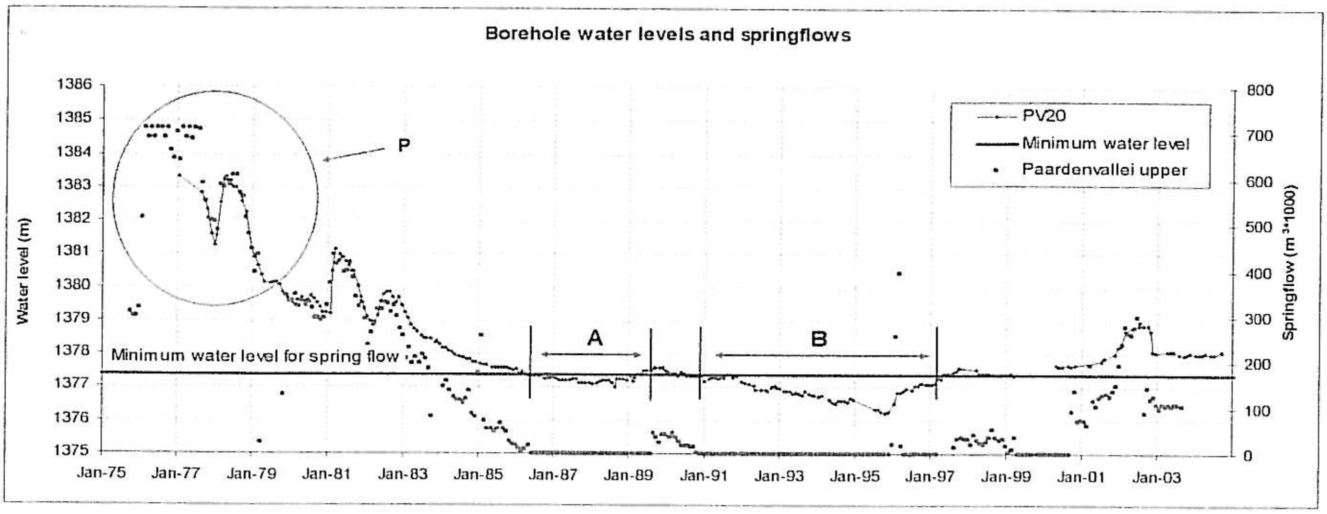

Figure 8 Critical Water Level Evaluation for Spring Flow in the Paardenvallei Vergenoegd DCU

Peak flows occurred very rarely in the Paardenvallei Upper spring (Eye 1). The highest spring flow (P on Figure 8) peaked above 270 l/s (700 000 m^3/month), almost 5 times higher than the mean, but flow only exceeded 193 l/s (500,000 m^3/month) for 10% of the record. The peak flows corresponded with peak rainfalls and subsequent recharge values.

The spring flow at Paardenvallei correlates well with water levels in PV20 (Figure 8). <u>The strong relationship between groundwater levels and spring flows allows us to predict what critical water level elevation will result in no flow conditions for the spring, which was calculated as 1377.3 mamsl.</u> The spring flow stops within a few months of groundwater in PV20 dropping below the critical level (A&B in Figure 8). When water levels rise above the critical level, the spring responds by commencing flow within a few months.

The critical groundwater elevations were also estimated for springs in the other compartments (Table 3). The Kraalfontein fountain weir reports zero flow conditions well before the critical level is reached (Figure 7) but this is because the fountain was flowing at such a minimal flow that it did not exceed the minimum flow capacity of the weir and thus no flow was recorded. Instead a minimum flow water level was deduced from site measurements of the flow height of the spring. This water level is also assigned to Stinkhoutboom Eye 2 or lower eye, since both fountains lie in the same dolomite compartment unit, and have measured flow heights within 0.1 metres. The weir measuring the Stinkhoutboom lower spring never reports zero flow over the whole record, but this is because the weir also receives water from the Stinkhoutboom upper spring (Eye 1), fed by perched water levels.

The Tweefontein upper fountains minimal water level of 1380.8 was found by comparing zero flow records with concurrent water level records. The times when the fountain flowed despite lower than critical water levels can be explained by a high surface water component contributing to this weir.

Table 3 Summary of Critical Water Levels in DWAF Monitoring Boreholes for Fountain Flows

Spring	Critical water level	Relevant borehole
Paardenvallei	1377.3	PV20
Tweefontein upper	1380.8	TF20
Kraalfontein	1392.5	RP13
Stinkhoutboom	1392.5	RP13

3 FIELD INVESTIGATIONS

Field investigations comprised surveying of an extensive gravity grid within the study area, covering an area of 45 km^2, and a hydrocensus survey of all existing boreholes and springs within the gravity survey area to obtain additional, updated and reliable water level and spring flow elevations.

3.1 Gravity Survey and Results

Regional gravity surveys lines (at 100m intervals) conducted during the PMA Consortium investigation in the Vergenoegd compartment indicated zones of shallow (0 to less than 10m deep) dolomite bedrock to very deep (60 to 90m) bedrock zones. It is essential in the resource development of the Klaarstroom compartment and present compartments targeted for resource development that the depth to bedrock (aquifer depth) is defined.

This was best cost effectively done by conducting a gravity survey along north-south (E) and east-west (S) lines at a 300 m line interval, and 50 m station interval along lines – Refer Map 1. A gravity survey area, totaling 5483 stations, targeting the most productive chert-rich Eccles dolomite formations within the relevant compartments, was identified as a minimum requirement to optimally locate drilling targets, delineate major saturated leached dolomite zones and determine dolomite bedrock elevations.

From the dolomite bedrock and water level elevations, zones of solid dolomite bedrock above the water table can be identified. These zones represent dolomite aquifers with very low transmissivity, which in addition to intrusive dykes can act as barriers to groundwater and impact on the compartmentalizing of dolomite aquifers. The depth to bedrock determinations will further be used to refine the spatial aquifer thicknesses used in the Zeerust regional groundwater model, which presently is based on assumed average thicknesses for various dolomite formations, and limits the reliability of estimates of near surface aquifer storage (within 5m water level drawdown) and hydraulic connectivity between various major leached dolomite zones.

The gravity grid was laid out at predetermined co-ordinates using handheld GPS's and elevations of gravity stations leveled (within an overall accuracy of 0.15 m) to obtain surface elevations above mean sea level. The leveling network was referenced to the accurate elevations of DWAF monitoring boreholes and tied into the existing gravity survey by Africon (2002). No discrepancy between DWAF borehole elevations and gravity station elevations surveyed by Africon were found. The gravity grid was later used as reference to effectively survey elevations of boreholes and spring flow during the hydrocensus survey. Gravity observations were made with a Sodin gravity meter.

Data reduction to obtain relative Bouguer gravity values followed normal procedures, applying corrections for surface elevations and latitude. A density of 2.4 g/cm^3 was used for the elevation correction. The relative Bouguer gravity data is affected by near surface and deep seated density variations. Residual gravity data, which represents only near surface density variations, were compiled by subtracting a regional gravity field from the Bouguer data to obtain zero residual gravity values where dolomite bedrock outcrops at surface. A regular regional gravity field was determined and digitized to ensure that a smooth regional gravity field is removed and residual gravity values obtained are free of gridding artifacts.

The gravity survey results are depicted in detail on Map 1 in relation to existing boreholes, springs, production boreholes at Uitvalgrond, location of fountains, dolomite formation boundaries and dykes. Map 1 is split into four map sections and contains the surface elevation, relative Bouguer gravity, regional gravity and final residual gravity maps. Estimates of depth to bedrock in metres from the residual gravity contour map can be obtained by multiplying the residual gravity value in mgal by 45. This implies that a residual gravity value of -1.0 mgal represents an estimated depth to bedrock of 45 metres.

The residual gravity values in the Klaarstroom compartment mainly range from 0.0 to -0.4 mgal indicating shallow dolomite bedrock, with limited leaching or karstification of the upper two thirds of the Eccles Formation as well as the Frisco Formation. This indicates general limited groundwater storage potential and low transmissivity of the dolomite aquifer.

A prominent but localized highly leached or weathered dolomite zone is mapped at the existing production boreholes of the Uitvalgrond well field. Residual gravity values in the vicinity of the production boreholes range from -1.6 to -1.9 mgal with estimated depths to bedrock of 70 to 85 metres, which correlates with the reported bedrock depth of 80 metres for the production boreholes by Africon – Refer section 2.1.1. This implies a major but localized dolomite aquifer that relates to intensive leaching of fractured dolomite associated with the intrusive and faulted diabase dyke.

The residual gravity map further indicates a prominent east-west zone of solid dolomite with limited depths to bedrock (<14m; 0.0 to -0.3 mgal residual gravity values) located between the Wolvekoppies and Klaarstroom springs. This east-west solid dolomite zone indicates poor hydraulic connectivity between the two fountains, and may act as a compartment boundary. A similar solid bedrock zone is present, located to the south of the production boreholes, which limits potential groundwater flow from the Vergenoegd compartment towards the Uitvalgrond well field.

Prominent (>-1.0 mgal) and interconnected residual gravity anomalies exist in the Vergenoegd-Paardenvallei dolomite compartment. These zones represent major leached dolomite aquifers with very high aquifer transmissivities and increased storage potential, as well as major conduits for groundwater flow towards the Vergenoegd and Paardenvallei Springs – refer Map 1.

The identified drilling sites (for potential production and monitoring boreholes) were selected in or near the centre of gravity low anomalies as indicated on the residual gravity map.

3.2 Hydrocensus of Boreholes and Springs

On completion of the gravity survey a hydrocensus of boreholes and springs was conducted within the gravity survey area, to obtain additional and accurate groundwater level elevations required to identify any potential barriers to groundwater flow. The current spring flow elevations or altitudes and borehole surface elevations were leveled and referenced to the gravity station elevations to an absolute accuracy of 0.2 metres above mean sea level. Water levels were measured in all accessible boreholes and present groundwater use identified.

The measured flow elevations or altitude of springs are indicated in Map1 and listed below.

Spring	Flow Altitude (mamsl)
Kraalfontein	1392.8
Stinkhoutboom Eye 1 (upper)	1398.7 – Perched water level
Stinkhoutboom Eye 2 (lower)	1392.7
Paardenvallei Eye 1 (upper)	1378.1
Paardenvallei Eye 2 (lower)	1376.3
Vergenoegd Eye 1	1377.4
Vergenoegd Eye 2	1377.8
Wolvekoppies Eye	1359.6 – presently not flowing
Klaarstroom Eye	1369.4

The Kraalfontein and Stinkhoutboom springs discharge water from the Kraalfontein-Stinkhoutboom DCU - refer Maps 1 and 2. Note that the flow height of the Stinkhoutboom Eye 1 is 6 meters higher than the other two springs and represents a perched water level. The Stinkhoutboom springs discharge water to the east, across the Frisco formation and do not contribute flow to the Vergenoegd-Paardenvallei DCU. The Kraalfontein spring discharges groundwater to the north (located next to the Malmani Loop surface drainage), and flows into the Vergenoegd-Paardenvallei DCU.

The measured flow altitudes of the Paardenvallei and Vergenoegd springs listed above are within 0.5 metres similar to the altitudes finally used in the regional aquifer model of the Zeerust dolomite compartments. Both these springs discharge water from the Paardenvallei-Vergenoegd DCU to the east, across the Frisco formation.

The flow elevation of 1359.6 for the Wolvekoppies is similar to the estimated flow height of 1360.5 by Africon – refer section 2.1.1. The measured flow height for the Klaarstroom eye of 1369.4 is however 9 metres higher than the estimate during the Africon investigation. The Klaarstroom flow height is about 10 meters higher than the flow height for Wolvekoppies, indicting that a significant flow boundary exists between these springs. The presence of a significant flow boundary between these two fountains is the main reason for failure of the Uitvalgrond well field, as the flow of the Klaarstroom eye at 23 l/s was assumed to be in hydraulic continuity to the well field during the Africon study.

The hydrocensus of existing boreholes in the gravity survey area, excluding the Uitvalgrond exploration and production boreholes and DWAF monitoring boreholes (PV20 and PV19), identified 17 boreholes. The location of these boreholes and their respective water level elevations are depicted on Map 2. Summary information regarding existing borehole equipment, owner, reported borehole yield, present use application and estimated abstraction for 24 hours per day is listed below. The majority of these boreholes are used for domestic, gardening, stock and game watering.

The landowner, a Mr. F Geldenhuis, reportedly has a registered irrigation use of 30 ha, of which presently 10 ha is irrigated (10 l/s) from borehole KA9 equipped with a mono pump. Borehole KA11 has a yield of 50 l/s and was used in the past for domestic water supply to Zeerust (pumping at 50 l/s from the Paardenvallei-Vergenoegd DCU). The approximate boundaries of the major landowners are indicted in Map 2.

Borehole Number		Owner	Reported Yield (l/s)	Present Use	Estimated Abstraction (l/s)
VG15	Windpump	J Bhyat	-	Not used	0.0
WK102	Submersible	J Bhyat	-	Standby Bh	0.0
WK103	Mono	J Bhyat	-	Domestic	1.5
KA9	Mono	F Geldenhuis	37	Irrigation	10
KA11	No Equipm.	F Geldenhuis	50	Not used	0.0 supplied Zeerust in past
KA13	Submersible	F Geldenhuis	-	Domestic	1.5
WK100	Windpump	F Geldenhuis	-	Stock	0.5
WK101	Mono	F Geldenhuis	-	Standby Bh	0.0
KA100	Mono	SF Breytenbach	-	Domestic	1.0
PV102	Mono	SF Breytenbach	-	Stock	1.0
PV13	Windpump	SF Breytenbach	-	Not used	0.0
PV100	Mono	J van Staden	-	Domestic	1.0
PV101	Mono	J van Staden	-	Domestic	1.0
WEV204	Submersible	Tiempie	-	Domestic	1.0
VG1	No Equipm.	WF Pelser	Artesian in wet period	Not Used	0.0
VG2	Submersible	WF Pelser	14	Domestic	2.5
VG3	No Equipm.	WF Pelser	Collapsed Bh	Not used	0.0

The estimated existing groundwater use application, in l/s for 24 hours per day, for the target DCU's Paardenvallei-Vergenoegd and Tweefontein South is as follows

DCU	Domestic all purposes	Stock/Game watering	Irrigation	Total
Paardenvallei-Vergenoegd	4.5	1.0	10	15.5
Tweefontein South	1.5	0.0	0.0	1.5
Total:	**6.0**	**1.0**	**10**	**17.0**

The Vergenoegd Irrigation farmers utilize water from the Vergenoegd Spring for irrigation of cultivated land, located some 2 km's to the east and downstream of the Paardenvallei-Vergenoegd Dolomite compartment unit. The Vergenoegd Irrigation farmers have a reported irrigation allocation of 58 l/s and have expressed concerns that groundwater abstraction from the Paardenvallei-Vergenoegd DCU for domestic water supply to

Welbedacht will negatively impact on their irrigation allocation. The farmers indicated that the Vergenoegd spring had already stopped flowing or had minimal flows insufficient for irrigation in the recent past, for a period of up to 17 years. No flow conditions for the Vergenoegd spring (refer section 2.4) occurred during the period 1983 to 1995 (12 years) which corresponds with a period during which there was almost no effective recharge from rainfall. The Vergenoegd spring stopped flowing mainly as a result of an extended period of drought with below average rainfall.

4 DOLOMITE COMPARTMENT UNITS AND MAJOR AQUIFER ZONES

The regional study of the Zeerust dolomite compartments, identified compartment boundaries based on the location of detailed mapped intrusive dykes and water level elevations with an accuracy of 3 metres, as indicated in Figure 1. From the gravity survey data (surface elevations and residual gravity data) shown in Map1 a dolomite bedrock elevation map was compiled and contoured at 5 metres interval as shown in Map 2.

Based on the dolomite bedrock elevation, elevations of spring flows and groundwater levels in boreholes, the Tweefontein and Klaarstroom DCU's indicated in Figure 1 were each split into two DCU's as listed below with adjusted surface areas and indicated on Map2. The names of DCU's were also changed to clearly indicate which fountains discharge water from the dolomite compartment as indicated below.

Zeerust Study DCU	Revised DCU or/and New Names
Klaarstroom (13 km^2)	Klaarstroom (5 km^2)
	Wolvekoppies (7.1 km^2), with Uitvalgrond well field
Tweefontein (38.4 km^2)	Tweefontein (22.3 km^2)
	Tweefontein South (16.1 km^2)
Vergenoegd (34.4 km^2)	Paardenvallei-Vergenoegd (34.3 km^2)
Kraalfontein Stinkhoutboom (26.3 km^2)	Kraalfontein Stinkhoutboom (26.3 km^2)

Based on the dolomite bedrock and groundwater elevations 13 major aquifer zones within the gravity survey area, represented by major saturated leached (SL1 to SL13) dolomite zones, were identified for the different DCU's and varying water level elevations. The surface extent of these zones are indicated in Map 2 and tabulated with reference to the representative static water level and surface area in km^2.

The Uitvalgrond well field is located in SL 8 of the Wolvekoppies DCU. Resource augmentation for bulk water supply to Welbedacht is targeted in the major aquifer zones SL1, SL2, and SL3 in the Paardenvallei-Vergenoegd DCU and SL5 in the Tweefontein South DCU. Using the average storativity of 3.5 per cent, determined from aquifer testing during the Uitvalgrond investigation – refer section 2.1.1, and the volume of water stored in the upper 5 metres (limit used for water level draw-downs in dolomite aquifers for foundation stability purposes) of the aquifer can be estimated as presented below. Note that the gravity survey did not cover the full surface extent of the Tweefontein South and Paardenvallei-Vergenoegd DCU's towards the western boundary, and the volume of water stored in the upper 5 metres of the aquifer is therefore larger for SL5, SL1 and SL2 as indicated below.

DCU	**Aquifer (SL) Zone**	**Area (km^2)**	**Volume (m^3) 0 to 5 m**
Wolvekoppies	SL8	1.1	192,500
Tweefontein South	SL5	>2.68	>469,000
Paardenvallei-Vergenoegd	SL1	>8.9	>1,557,500
	SL2	>2.53	>442,750
	SL3	1.35	236,250
Total		**>16.56**	**>2,898,000**

The total groundwater stored in the upper 5 metres of the targeted aquifer zones is in excess of 2,898,000 m^3, sufficient to supply the water demand of 3456 m^3/day for an abstraction period of 3.2 years.

Effective groundwater recharge from direct rainfall for the target DCU's, using the 70 percentile effective annual recharge value of 55 mm (1.75 l/s/km^2), is listed below. In the Paardenvallei-Vergenoegd DCU major surface depressions exist covering an area of 2.49 km^2 – refer Map 2. In these depression zones no surface run-off occurs and the effective recharge form direct rainfall is expected to be at least 30 per cent of MAP. An additional recharge of 63 mm or 2 l/s/km^2 was estimated for these surface depression zones.

DCU	**Surface Area**	**Annual Recharge from Direct Rainfall**		
	km^2	**mm**	**m^3/day**	**l/s**
Wolvekoppies	7.1	55	1,071	12.4
Tweefontein South	16.1	55	2,436	28.2
Paardenvallei-Vergenoegd	34.3	55	5,184	60.0
Vergenoegd Surface Depressions	2.49	63	0,432	5.0
Total	**60.0**		**9,123**	**105.6**

The water demand of 40 l/s for Welbedacht represents 38 % of the total annual recharge from direct rainfall of 105.6 l/s estimated for the target DCU's. It should be noted that this excludes the net groundwater inflow from surrounding dolomite compartments, across boundaries into the Paardenvallei-Vergenoegd DCU of 116.7 l/s – refer section 2.2 page 10.

The 90 percentile of effective annual recharge, listed in Table 2, is 216 mm or 6.84 l/s/km^2 which amount to a recharge of 410 l/s during high rainfall periods. This represents 10 % of the rainfall record for Ottoshoop. Groundwater abstraction from storage in the target DCU's, would be recharged rapidly during such high rainfall periods.

5 SUSTAINABLE YIELD OF UITVALGROND WELL FIELD

The Uitvalgrond well field is located in a major dolomite aquifer zone of only 1.1 km^2, within the Wolvekoppies DCU with a surface area of only 7.1 km^2 in relation to the initial adjusted 13 km^2.

The natural flow losses from the well field can be estimated from the average water level decline of 0.3, over a period of 45 days with no abstraction, and storativity of 3.5 per cent for the main aquifer zone of 1.1 km^2. The natural outflow to the east across the Frisco formation during the 45 day period was 11,550 m^3, equivalent to 3 l/s. This represents a minimum flow loss as water levels were drawn down by 13.5 m.

The well field was pumped for a period of 17 months (March 2003 to September 2004) during which period the effective recharge from rainfall was calculated as 40 mm. This yields a recharge of 312,400 m^3 from direct rainfall. For the 17 month abstraction period the minimum natural flow loss is estimated at 129,950 m^3. The volume of water pumped from storage within the main dolomite aquifer zone of 1.1 km^2 is 519,750 m^3 for a 13.5 m water level drop.

Water balance components in m^3 for the abstraction period are:

Out Flows and Abstraction	
Natural flow losses	129,950
Estimated total abstraction	1,128,038
In Flows and Storage	
Recharge from direct rainfall	312,400
Volume pumped from storage	519,750
Net inflow to well field	425,838

The net inflow to the well field was 835 m3/day or 9.7 l/s for maximum water level draw-downs. The present sustainable yield of the Uitvalgrond well field is estimated at 6 l/s. This may be increased to 9 l/s once water level draw-downs have recovered to within 5 metres.

6 PROPOSED RESOURCE AUGMENTATION

The proposed resource augmentation is aimed at spreading the groundwater abstraction of 40 l/s over the Wolvekoppies, Tweefontein South and Paardenvallei-Vergenoegd DCU's to limit the impact on water level draw-downs and spring flows. The target yield of additional production boreholes is 45 l/s. This will establish a spare capacity in excess of 10 l/s for the optimal management of the resource to limit water level draw-downs and impact on spring flows.

A total of 8 new production borehole sites (P1 to P8, in order of priority) were subsequently identified, with secondary consideration to limit the total length of new pipelines. The locality of these sites are indicated on and tabulated on Map 2; listing co-ordinates, surface altitudes, gravity station numbers and target borehole yield, in l/s for a 24 hour pumping period. The proposed new pipeline route is indicated in Map 2, to minimize pipeline length, avoid major solid dolomite bedrock and run along property boundaries. The total pipeline length is 8.1 km.

Borehole sites P1, P2, P3 and P8 target a maximum abstraction of 25 l/s in the Paardenvallei-Vergenoegd DCU, located upstream of the Vergenoegd and Paardenvallei springs. Borehole sites P2 and P3 (10 l/s) target the aquifer zone SL2. Between SL2 and the two springs a flow boundary may exist which will reduce the impact of abstraction from P2 and P3 on spring flow. No boreholes exist in SL2, and therefore no water level information which is critical to assess the presence of the potential flow barrier.

Borehole site P7 targets a maximum abstraction of 5 l/s in the Paardenvallei-Vergenoegd DCU, located downstream of the Vergenoegd spring and at the main northern outflow zone across the dyke boundary.

Borehole sites P4, P5, and P6 target a maximum abstraction of 15 l/s from the Tweefontein South DCU, located in the main dolomite aquifer zone SL5.

The conceptual groundwater flow directions, indicating major flow direction within DCU's and leakage zones across dykes are indicated in Map 2. Critical gaps exist in water level information to finalize the conceptual groundwater flows and determine the presence of a potential flow boundary between SL2 and SL1. To obtain this information and establish essential future monitoring boreholes 5 borehole sites M1 to M5 were identified as tabled and indicated on Map 2. These boreholes must be drilled prior to the drilling of new production boreholes. On completion of the monitoring boreholes and test pumping thereof the 3 dimensional aquifer model must be updated and refined for quantitative estimates of the impact of the proposed abstraction on water levels and sprig flows.

The estimated drilling depths for production boreholes range between 35 to 45 metres and for monitoring boreholes from 35 to 50 metres.

Fountain flows are highly sensitive to abstraction within the DCU from which the fountains discharge water. The impact of the target abstraction of 25 l/s upstream of the Vergenoegd and Paardenvallei springs is presently allocated in equal proportions to both springs, with an expected reduction in spring flow of 12.5 l/s.

7 CONCLUSIONS

7.1 Uitvalgrond Well Field

The investigation approach by Africon was appropriate and similar to the approach adopted for the current investigation. The limitation with the Africon investigation was the limited aerial extent of the investigation conducted in the Klaarstroom compartment covering a surface area of 13 km^2. The investigation was confined to a small (1.1 km^2) narrow area of the Klaarstroom compartment, comprising highly fractured dolomite, and located north and south of a faulted intrusive dyke. The ingress of water into the fractures in the dolomite in this small area resulted in extensive weathering/leaching or karstification of the bedrock to depths up to 80 metres below surface.

The measured flow elevation of 1359.6 for the Wolvekoppies spring is similar to the estimated flow height of 1360.5 by Africon. The measured flow height for the Klaarstroom eye of 1369.4 is however 9 metres higher than the estimate during the Africon investigation. The Klaarstroom flow height is about 10 metres higher than the flow height for Wolvekoppies, indicting that a significant flow boundary exists between these springs. The presence of a significant flow boundary between these two fountains is the main reason for failure of the Uitvalgrond well field, as the flow of the Klaarstroom eye at 23 l/s was assumed to be in hydraulic continuity to the well field during the Africon study.

Transmissivity values range from 836 to 14500, typical of the varying nature of leached dolomite aquifers and the storativity from 1.8 to 5.6 per cent, with an average storativity in the order of 3.5 per cent.

The Uitvalgrond well field was pumped for a period of 17 months (March 2003 to September 2004) during which period the effective recharge from rainfall was calculated as 40 mm. Water balance components in m^3 for the abstraction period are:

Out Flows and Abstraction

Natural flow losses	129,950
Estimated total abstraction	1,128,038

In Flows and Storage

Recharge from direct rainfall	312,400
Volume pumped from storage	519,750
Net inflow to well field	425,838

The present sustainable yield of the Uitvalgrond well field is estimated at 6 l/s. This may be increased to 9 l/s once water level draw-downs have recovered to within 5 metres.

7.2 Rainfall and Effective Recharge

The closest rainfall station to the dolomite compartment units under investigation is the Ottoshoop rainfall station, with a monthly rainfall record length of 100 years. The rainfall at this station is high over the summer months and lowest over the winter months. A minimum amount of 65 mm monthly rainfall is required before groundwater recharge occurs. Consequently effective recharge only occurs (on average) during the months from November to March. The rainfall station has large variations in rainfall from year to year, from 300 up to 900 mm, with a mean annual rainfall of 539 mm. There are some consecutive years of extremely high rainfall > 800 mm and also long periods of moderate to very low rainfall where rainfall seldom reaches the average let alone exceeds it.

The CRD series (Cumulative Rainfall Departure) was used to identify monthly rainfall that could potentially contribute to effective recharge. If the CRD value was negative the system was still in debt and groundwater levels were below equilibrium. Any effective recharge during the negative CRD period was mainly restoring the aquifer system to equilibrium conditions. When the CRD series was positive the system could, if there was sufficient monthly rainfall, begin recharging or filling the aquifer above equilibrium levels. In other words, effective recharge only occurred if both of the following conditions were met.

1. The CRD series was positive
2. More than 65mm of rainfall occurred within a month.

The exponential recharge equation 4 below was used to calculate effective recharge. The equation implicitly excludes rainfall below 65mm satisfying condition 2. To satisfy condition 1 recharge was assigned a value of zero when the CRD series was negative.

$$\mathrm{Re} = (R - 65) \times (01 \times EXP^{0.02(R-65)}) \quad \text{..........} 4$$

Where : Re = Effective Recharge (mm)
R = Rainfall (mm)

A 10 year moving average was used for the CRD method on the Ottoshoop rainfall station, which yielded overall the best fit to water level data. The final recharge pattern corresponded well with water level fluctuations suggesting that recharge, and thus rainfall, is the major driving force for fluctuations in water levels and spring flows. The large variation in monthly rainfall results in significant variations in effective groundwater recharge, with a negative impact on groundwater levels and spring flows during low rainfall periods.

The final mean value for effective recharge was 63 mm (2.01 l/s per km^2) or almost 12% of mean annual rainfall. However, the system is highly variable and there was still a large difference of 44 mm between mean and median recharge. This is because large peak events raise the mean value unrealistically. The mean annual effective recharge represents the absolute maximum that could be exploited over the long term, however during periods of lower rainfall spring flows will drastically reduce and only recover after a major rainfall event. In evaluating sustainable abstraction from dolomite compartments it is proposed that the 70 percentile effective annual recharge value of 55mm is used, equivalent to 1.75 l/s per km^2. The 70 percentile value represents a 30 per cent probability that in any one year the effective recharge will be above 55 mm, for the target 12 % recharge of MAP

7.3 Water Level and Spring Flow Fluctuations

Borehole water level and spring flow data from DWAF was updated until 2004 and 2003, respectively. The comparisons between variations in borehole water levels and variations in spring flow (in the same dolomite compartment unit) showed a strong relationship between the two. Variations in both parameters also show a clear similarity to variations in recharge for most boreholes and springs. In particular for the period during which there was almost no recharge (1983 to 1995 – 12 year period) there is a similar corresponding period of declining or low water levels for PV19, PV20, DO14, TF20, TF21 and RP13. There were also no flow conditions in Vergenoegd during this period and low flow conditions followed by no flow conditions for Paardenvallei, Kraalfontein, Tweefontein Upper Eye and Stinkhoutboom.

7.4 Existing Groundwater Use

The estimated existing groundwater use application for the DCU's Paardenvallei-Vergenoegd and Tweefontein South is as follows:

DCU	Domestic all purposes	Stock/Game watering	Irrigation	Total
Paardenvallei-Vergenoegd	4.5	1.0	10	15.5
Tweefontein South	1.5	0.0	0.0	1.5
Total:	**6.0**	**1.0**	**10**	**17.0**

The landowner Mr. F Geldenhuis reportedly has a registered irrigation use of 30 ha, of which presently 10 ha is irrigated (10 l/s) from one borehole equipped with a mono pump. Borehole KA11 has a yield of 50 l/s and was used in the past for domestic water supply to Zeerust (pumping at 50 l/s from the Paardenvallei-Vergenoegd DCU).

The Vergenoegd irrigation farmers utilize water from the Vergenoegd Spring for irrigation of cultivated land, located some 2 km's to the east and downstream of the Paardenvallei-Vergenoegd Dolomite compartment unit. The Vergenoegd irrigation farmers have a reported irrigation allocation of 58 l/s and have expressed concerns that groundwater abstraction from the Paardenvallei-Vergenoegd DCU for domestic water supply to Welbedacht will negatively impact on their irrigation allocation. The farmers indicated that the Vergenoegd spring stopped flowing or had minimal flows insufficient for irrigation for a period of up to 17 years. The Vergenoegd spring stopped flowing mainly as a result of an extended period of drought with below average rainfall.

7.5 Revised Dolomite Compartment Units (DCU)

From the gravity survey data a dolomite bedrock elevation map was compiled. Based on the dolomite bedrock elevation, elevations of spring flows and groundwater levels in boreholes, the original Tweefontein and Klaarstroom DCU's were each split into two DCU's. The names of DCU's were also changed to clearly indicate which fountains discharge water from the dolomite compartment as indicated below.

Zeerust Study DCU	**Revised DCU or/and New Names**
Klaarstroom (13 km^2)	Klaarstroom (5 km^2)
	Wolvekoppies (7.1 km^2), with Uitvalgrond well field
Tweefontein (38.4 km^2)	Tweefontein (22.3 km^2)
	Tweefontein South (16.1 km^2)
Vergenoegd (34.4 km^2)	Paardenvallei-Vergenoegd (34.3 km^2)
Kraalfontein Stinkhoutboom (26.3 km^2)	Kraalfontein Stinkhoutboom (26.3 km^2)

7.6 Proposed Resource Augmentation

The proposed resource augmentation is aimed at spreading the groundwater abstraction of 40 l/s over the Wolvekoppies, Tweefontein South and Paardenvallei-Vergenoegd DCU's to limit the impact on water level draw-downs and spring flow. The target yield of additional production boreholes is 45 l/s. This will establish a spare capacity in excess of 10 l/s for the optimal management of the resource to limit water level draw-downs and impact on spring flows

Based on the dolomite bedrock and groundwater elevations 13 major aquifer zones within the gravity survey area, represented by major saturated leached (SL) dolomite zones, were identified for the different DCU's and varying water level elevations. The Uitvalgrond well field is located in SL 8 of the Wolvekoppies DCU. Resource augmentation for bulk water supply to Welbedacht is targeted in the major aquifer zones SL1, SL2, and SL3 in the Paardenvallei-Vergenoegd DCU and SL5 in the Tweefontein South DCU.
The total groundwater stored in the upper 5 metres of the targeted aquifer zones is in excess of 2,898,000 m^3, sufficient to supply the water demand of 3456 m^3/day for an abstraction period of 3.2 years. The water demand for Welbedacht represents 38 % of the total annual recharge from direct rainfall (105.6 l/s) estimated for the target DCU's. The net groundwater inflow from surrounding dolomite compartments, across boundaries into the Paardenvallei-Vergenoegd DCU was modeled at 116.7 l/s during the Zeerust regional dolomite study.

Fountain flows are highly sensitive to abstraction within the DCU from which the fountains discharge water. The impact of the target abstraction of 25 l/s upstream of the Vergenoegd and Paardenvallei springs is presently allocated in equal proportions to both springs, with an expected reduction in spring flow of 12.5 l/s.

8 RECOMMENDATIONS

Monitoring of water levels in and groundwater abstraction from the existing 4 production boreholes at Uitvalgrond is essential and should be measured and recorded every two weeks until water levels draw-downs are less than 5 metres, after which a monthly interval will be sufficient. Borehole 2100036 should be equipped for continuous water level monitoring and included into the DWAF monitoring programme. A resource monitoring report of the Uitvalgrond well filed should be compiled every six months.

Groundwater abstraction from the Uitvalgrond well field can commence once water levels have recovered to within a residual drawdown of 10 metres, at a monthly abstraction rate not exceeding 15,500 m^3/month or 6l/s. This abstraction rate is expected to allow water levels to continue to recover. Once water levels have recovered to within 5 metres the abstraction rate may be increased to a maximum of 23,330 m^3/month or 9 l/s. Abstraction from the well field should be operated within a maximum allowable water level drawdown of 5 metres.

The water use from the Uitvalgrond production boreholes should be registered with DWAF and the water use from the well field licensed for a maximum abstraction of 10 l/s or 25,920 m^3/month.

The DWAF monitoring borehole PV20 should be equipped with a continuous water level monitoring facility, and a rain gauge installed for monitoring rainfall. Monitoring of spring flow at the Vergenoegd weir (DWAF monitoring station A3H011) was closed in 1992 and should be reopened as soon as possible.

Drilling of the proposed 5 monitoring and/or exploration boreholes to obtain critical water level information should commence as soon as possible. These borehole sites are all located on private land owned by F Geldenhuis with whom a suitable agreement should be made for exploration drilling, borehole pump testing and access to boreholes for future water level monitoring.

The existing 3 dimensional aquifer model compiled for the Zeerust study, should be updated with results from this investigation, re-calibrated and the proposed groundwater abstraction simulated to preliminary quantify the potential impact on water levels and springs. Once results from the monitoring boreholes are obtained the model can be up-date for a final assessment of the aquifer response and recommendations with regard to optimal management to limit impact on the resource.

An Environmental Impact Assessment of the proposed groundwater abstraction for water supply to Welbedacht should be compiled in terms of Government Notices R1182 and R1183 of 5 September 1997 to comply with the relevant procedures contained in the EIA Regulations, Implementation of Sections 21, 22 and 26 of the Environment Conservation Act (no. 73 of 1989).

The existing law full groundwater use from the Paardenvallei-Vergenoegd DCU should be investigated and verified as well as the legal status of the allocated irrigation rights from the Vergenoegd and Paardenvallei Springs.

On approval of the EIA report and finalization of agreements with the landowners Messrs F Geldenhuis and G van Vuuren drilling of all 8 production boreholes should proceed.

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9 REFERENCES

Africon Report (2002). *Final report on the evaluation of the groundwater resources at Uitvalgrond 60 Jo, Zeerust,* Department of Water Affairs and Forestry

Bredenkamp, DB et al. (1995). *Manual on quantitative estimation of groundwater recharge and aquifer storativity,* Pretoria, Water Research Commission.

Jacob, CE (1944). *Correlation of groundwater levels on Long Island,* New York, Trans. Amer. Geophysical Union, Vol. 25.