

# **Groundwater Reserve Determination for Current and Potential Wellfield Development of TMG Aquifers**

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Water Research Commission

by  
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## ABBREVIATIONS

°C	-	Degrees Celsius
%	-	percent
a	-	annum
BHN	-	Basic Human Need
BRBS	-	Breede River Basin Study
CDSM	-	Chief Directorate: Surveys and Mapping
DAGEOS	-	Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply
Da	-	Traka Subgroup
Db	-	Baviaanskloof Formation
Dbo	-	Boplaas Formation
DES	-	Desired Ecological Status
Dg	-	Gydo Formation
Dga	-	Gamka Formation
Dh	-	Hex River Formation
Dt	-	Tra-Tra Formation
Dv	-	Voorstehoek Formation
DWA	-	Department of Water Affairs
DWAF	-	Department of Water Affairs and Forestry
EC	-	electrical conductivity
ES	-	Ezeljacht Syncline
<i>et al.</i>	-	and others
e.g.	-	for example
EWR	-	Environmental Water Requirements
GRA II	-	Groundwater Resources Assessment Phase 2
GRDM	-	Groundwater Resource Directed Measures
i.e.	-	that is
km	-	kilometre
km <sup>2</sup>	-	kilometre squared
l	-	litre
m	-	metre
m <sup>3</sup> /a	-	cubic metre per annum
Ma	-	millions of years
mamsl	-	metres above mean sea level
MAP	-	Mean Annual Precipitation
MAR	-	Mean Annual Runoff
mm	-	millimetre
Mm <sup>3</sup>	-	million cubic metres
mS/m	-	milli Siemens per metre
No.	-	number
NGDB	-	National Groundwater Database

Ope	-	Peninsula Formation
OR	-	Outeniqua Recharge
OU	-	Oudtshoorn Basin
PES	-	Present Ecological Status
RDM	-	Resource Directed Measures
RQO	-	Resource Quality Objective
RU	-	Resource Unit
Sg	-	Goudini Formation
Ss	-	Skurweberg Formation
SVF	-	Saturated Volume Fluctuation
TMG	-	Table Mountain Group
WA	-	Witkliprug Anticline
WARMS	-	Water Use Allocation and Registration Management System
WR90	-	Water Resource Assessment Study 1990
WMA	-	Water Management Area
WRC	-	Water Research Commission
ZS	-	Zebra Syncline

# 1 INTRODUCTION

## 1.1 Background to DAGEOS

Umvoto Africa was contracted in April 2000 to undertake a study of Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply (DAGEOS). The town of Oudtshoorn is situated in a semi arid region in the Klein Karoo, 55 km north of the coastal town of George in the Western Cape Province of the Republic of South Africa. The DAGEOS project focuses on groundwater circulating within the fracture system of the Table Mountain Group (TMG), the geological unit that forms the high mountains in the north and south of the Klein Karoo region, as well as which underlies the Gouritz River basin.

The main aim of the DAGEOS project is to secure deep groundwater as a long-term option to augment the water supply to the greater Oudtshoorn Local Municipality and to contribute to a conjunctive surface and underground water augmentation scheme. The Oudtshoorn Local Municipality, the Department of Water Affairs (DWA), the Water Research Commission (WRC) and the Development Bank of South Africa support the DAGEOS project.

The DAGEOS project is divided into six phases:

- PHASE A – Inception Review and Data Scoping
- PHASE B – Regional Hydrogeological Survey
- PHASE C – Financial and Business Planning
- PHASE D – Target Generation and Borehole/Wellfield Siting
- PHASE E – Exploration Drilling and Resource Assessment
- **PHASE F – Wellfield Establishment and Licensing**

This phased approach to the DAGEOS project has been implemented in order to minimise the financial expense and risk associated with exploration. Additional work has been undertaken in order to increase the scientific confidence in the potential success of deep drilling as a long-term water supply to the greater Oudtshoorn Local Municipality. At present four of the six phases have been completed and the DAGEOS project is currently on the fifth and sixth Phases (Phase E and F), with this report falling into the licensing objectives of Phase F.

Four target zones and sixteen potential exploration target sites were defined during Phase D (Umvoto Africa, 2005):

- Target Zone A: Four sites – A1 to A4
- Target Zone B: Four sites – B1 to B4
- Target Zone C: Two sites – C1 and C2
- Target Zone D: Six sites – D1 to D6

The highest priority targets zones are C and D, located south of Oudtshoorn. These zones contain three sites that access the most extensive Outeniqua compartments of the Table Mountain Group (TMG).

The initial exploration drilling effort, which commenced in 2001, focused on Target Site C1 in the Blossoms area, about 25 km south of Oudtshoorn. Three percussion boreholes (C1a1p, C1b1p and C1c1p) were drilled into the Skurweberg Formation aquifer across the major Witkliprug Anticline, at its intersection with the Klip River. Two deeper, narrow-diameter, diamond-drilled boreholes (C1b2c and C1c2c) were subsequently completed to access the Peninsula Formation aquifer. A 600 m-deep, wide-diameter, production-testing borehole (C1b3p) into the Peninsula Formation aquifer was completed in February 2008.

## **1.2 Background to Reserve Determination**

A licence application was submitted to the DWA in December 2008 for abstraction of 11 million m<sup>3</sup>/a from wellfields in the C1 and C2 target areas, following the results of Phase D and further exploration drilling in the C1 target area.

Since the municipality requires an urgent decision on the licence application, DWA was approached to facilitate a way to expedite the Reserve determination process. Furthermore, there was concern that the standard Resource Directed Methods (RDM) methodology was not applicable to the DAGEOS situation where the proposed groundwater abstraction would occur in an artesian basin.

At a meeting between DWA RDM office, DWA regional office and Umvoto Africa on 4 September 2008, DWA agreed to the hydrogeological consultant undertaking the Reserve determination for this application. DWA approached the WRC for financial support for this Reserve determination.

The present methodology for the Reserve determination does not satisfy hydrogeological conditions in artesian basins. Due to the deep confined nature of aquifers in artesian basins, recharge, discharge and groundwater use processes and patterns are different to those in shallow unconfined aquifers, upon which the Reserve determination methodology is based. Hence the Reserve determination methodology has been modified in determining the Reserve for the Oudtshoorn artesian basin.

It is important to build a conceptual flow model and water balance model to understand pathways and fluxes. This should be a prerequisite for determining the elements required to be estimated for the Reserve determination and Resource Quality Objectives (RQOs). However, it was agreed with the DWA that a rapid Reserve determination would be sufficient and hence numerical modeling would not be required.

The objectives of this report are to:

- Document the methodology for the groundwater Reserve determination,
- Report the findings on the preliminary Reserve determination, and
- Recommend further investigations that may be required.

It is the intention of DWA to incorporate the findings of this study into the proposed review and revision of the Groundwater Resource Directed Methods (GRDM) methodology.

### 1.3 Available Data and Information

Although it was agreed that a rapid Reserve determination would be sufficient for considering the licence application by the Oudtshoorn Municipality, this Reserve determination is based on extensive field work, monitoring data and data analysis, which is summarised in this report. However, this report should be read in conjunction with the following reports, which contain more detailed data analysis:

Umvoto Africa. (2005). Deep Artesian Groundwater Supply for Oudtshoorn Municipal Supply (DAGEOS) **Phase D Report**: Target Generation and Borehole/Wellfield Siting using Structural Geology and Geophysical Methods. Water Research Commission Report No. 1254/1/05. September 2005.

Umvoto Africa. (2008). Updated Geology and **Water Balance Model Report**. Prepared for Oudtshoorn Local Municipality as part of Phase E of the Deep Artesian Groundwater Exploration for Oudtshoorn Supply (DAGEOS) project, Report No. 603/E.09/01/08 (December 2008), 59pp.

Willmot, E. (2008). Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply (DAGEOS) – Estimation of sustainable yield of the deep artesian aquifer through hydraulic testing and numerical modeling. Unpublished MSc thesis, University of Birmingham.

Oudtshoorn Municipality (2008): License Application for C1 & C2 wellfields – **Geohydrology Summary Report**. Prepared by Umvoto Africa as part of Phase E of the Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply (DAGEOS) project. Report No. 603/E.10/01/2008. December 2008.

Umvoto Africa (2008): Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply (DAGEOS) – **Eco-hydrological Monitoring Protocol**. Compiled by CJH Hartnady, A Mlisa, K Riemann, M Smart and W Roets, 37 pp.

Umvoto Africa (2008): Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply (DAGEOS) – **Monitoring Report 2005-2007**. Compiled by C.J.H. Hartnady, A. Mlisa, L. Groenewald and K Riemann for Oudtshoorn Municipality (October 2008), 27 pp.

Umvoto Africa (2009): Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply (DAGEOS) – **Monitoring Report 2008-2009 Update**. Compiled by C.J.H. Hartnady, A. Mlisa and K Riemann for Oudtshoorn Municipality (October 2009), 43 pp.

## 2 STUDY AREA DESCRIPTION

### 2.1 Locality

The DAGEOS project area and Oudtshoorn Local Municipality are situated within the Klein Karoo region of the Western Cape Province of South Africa. The Klein Karoo is a wide east-west trending valley that lies between the parallel east-west trending Outeniqua and Langeberg Mountains in the south (which form the divide between the Klein Karoo and the southern Cape coastline), and the Swartberg Mountains in the north (which form the divide between the Klein and Groot Karoo) (see **Figure 2-1**). The Kammanassie and Rooiberg Mountains (to the southeast and southwest of Oudtshoorn respectively) are also situated within the Klein Karoo valley (see **Figure 2-1**), but fall outside of the area considered for the Reserve determination. The Reserve determination area is dominated in the south by the Outeniqua Mountains, and extends northwards to approximately 5-10 km south of the Olifants River, including the hilly to lower relief areas within the Ezeljacht and Zebra Synclinal basins and the Witkliprug Anticline (see **Figure 2-1**).

The study area overlaps with the study area of the Outeniqua Reserve study (DWA, 2009), results of which are considered and taken into account, where applicable.

### 2.2 Topography

The Oudtshoorn Local Municipality is topographically dominated by rolling hills (approximately 65 % of the total municipal area), which generally range in elevation between 400 and 600 mamsl. Mountainous areas form up to approximately 25 % of the total municipal area, and can reach elevations from 800 mamsl (parts of the Outeniqua Mountains) to 1800 mamsl (the Swartberg Mountains watershed). Flat plains, which are generally associated with the flood plains of the Olifants River, make up 10 % of the total municipal area.

### 2.3 Drainage

The main river in the study area is the Olifants River, which drains from east to west within the Klein Karoo valley. The Olifants River is fed by mountain streams from the Swartberg, Kammanassie and Outeniqua Mountains, and merges with the Gamka River to form the Gouritz River, which flows south towards the sea. Oudtshoorn itself is situated at the confluence of the Grobbelaars, Olifants and Kammanassie Rivers.

The entire study area lies within the Gouritz Water Management Area (WMA), with the drainage network of the selected area covering 29 quaternary catchments in the J and K primary drainage basins (see **Figure 2-2** and **Table 2-1**). The town of Oudtshoorn is located north of the area in the J35A (Grobbelaars River) catchment, and the town of George is located near its southern border on the divide between the K30B and K30C basins. Quaternary catchments J34E, J34F, J35B, J35C, K10E, K20A, K30A, K30B, K30C and K30D fall within the Reserve determination area (see **Figure 2-2** and **Table 2-1**).

**Table 2-1 DAGEOS study area quaternary catchments. Catchments within the Reserve determination area highlighted in light blue.**

Water Management Area	Quaternary Catchment	Catchment Size (km <sup>2</sup> )	MAP (mm) [WR2005]	MAR (Mm <sup>3</sup> ) [WR2005]	EWR * (% MAR)
Gouritz Water Management Area	J25A	353.65	289	6.3	15.45
	J25B	396.86	326	11.2	15.55
	J25C	180.56	288	6.1	15.56
	J25D	210.38	365	12.3	16.06
	J25E	286.54	245	6.4	15.66
	J33B	590.8	437	7.5	10.01
	J33E	328.77	446	24.3	10.04
	J33F	365.77	343	11.3	15.29
	J34D	354.28	471	8.0	15.44
	J34E	258.06	427	4.5	15.55
	J34F	320.09	415	4.9	15.6
	J35A	427.55	418	63.7	12.82
	J35B	651.44	411	10.2	15.09
	J35C	264.63	373	3.1	15.8
	J35D	507.22	407	38.3	14.73
	J35E	215.29	270	6.3	11.58
	J35F	500.36	341	26.2	14.58
	J40A	453.61	418	40.7	18.05
	J40B	221.99	431	21.7	18.67
	K10C	159.04	493	8.9	24.06
	K10D	163.97	454	7.1	23.1
	K10E	132.57	679	15.4	29.46
	K10F	105.78	502	5.8	26.28
	K20A	168.48	722	28.2	33.52
	K30A	196.02	753	40.3	28.05
	K30B	138.64	787	42.9	31.36
	K30C	190.12	805	51.0	33.5
	K30D	177.87	724	31.6	33.07
K40A	87.48	706	11.9	31.05	

\* EWR = Environmental Water Requirements; List was compiled by T Belcher for the DWA All Town Reconciliation Strategy Study (unpublished), based on information from the RDM Directorate's database, SPATSIM and Rivers Database

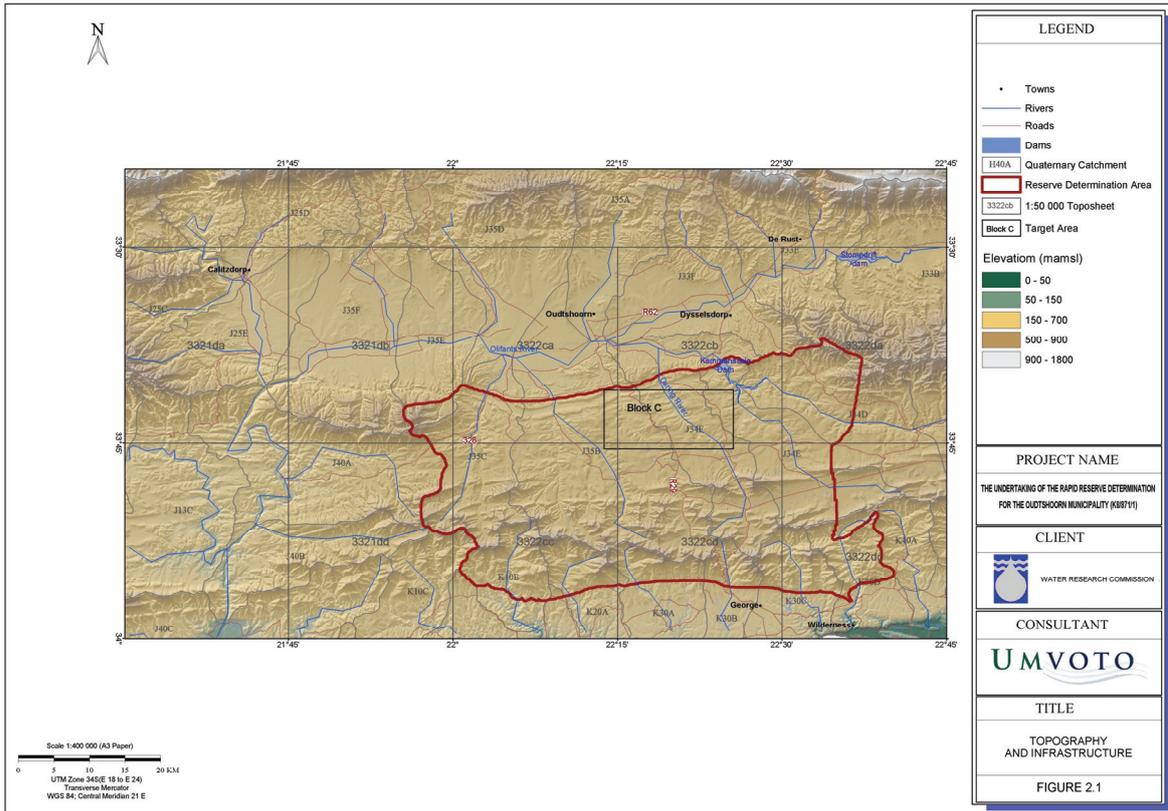


Figure 2-1 Topography of the study area with Reserve determination area boundary.

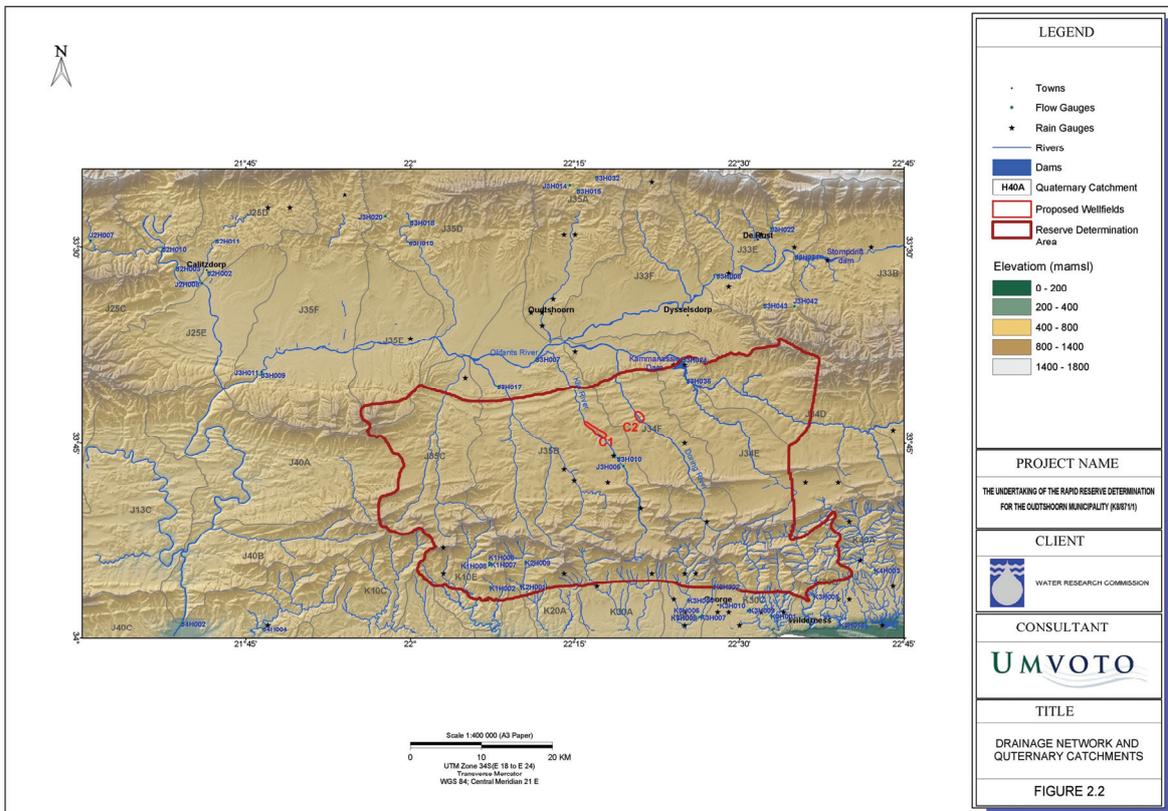
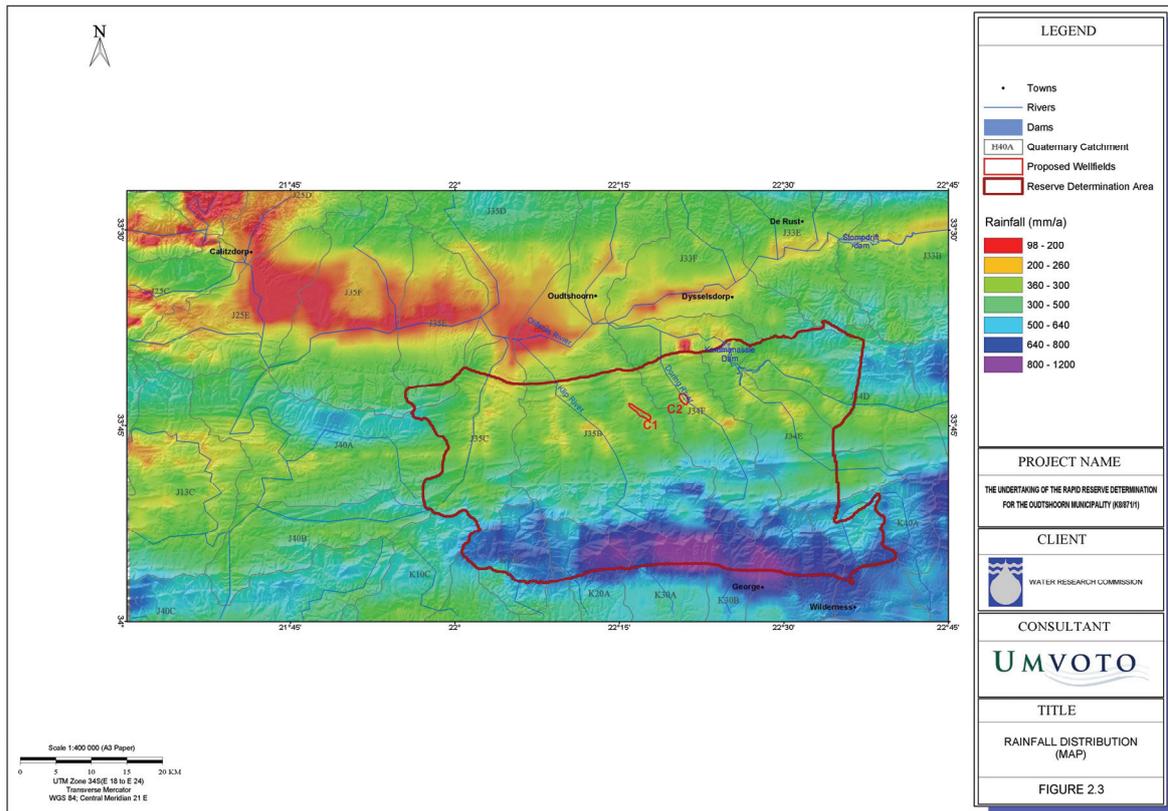


Figure 2-2 Study area drainage network and quaternary catchments.



**Figure 2-3 MAP distribution.**

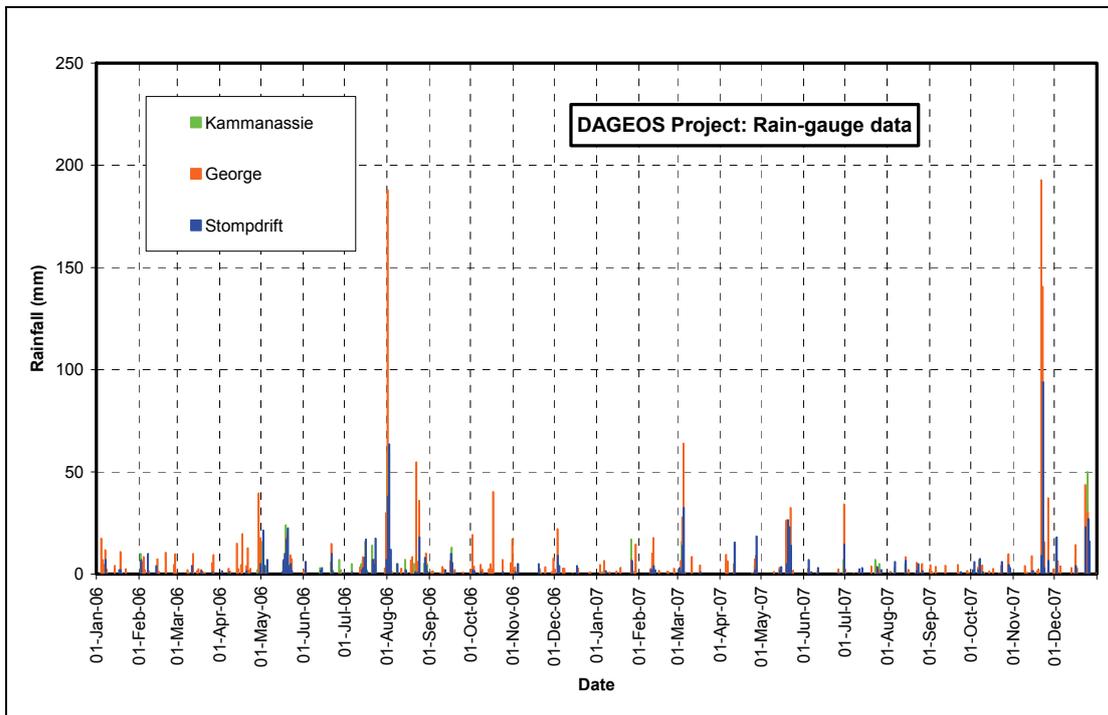
## 2.4 Climate

The geographic distribution of mean annual precipitation (MAP) illustrates the general aridity of the Klein Karoo area, with a major proportion of the region receiving less than 500 mm/a (see **Figure 2-3**). The average precipitation within the Oudtshoorn Local Municipality ranges between 280 and 360 mm per annum. This is in contrast to the surrounding mountain ranges, which receive much higher amounts of precipitation (see **Figure 2-3**). The south-facing slopes of the Outeniqua Mountains receive a MAP of ~1300 mm, whereas the Kammanassie and Swartberg Mountains receive MAPs of approximately 800-1000 mm and less than 900 mm (except in patches along the summit ridge and parts of the south-facing slopes) respectively (see **Figure 2-3**).

During the summer months, daily temperatures within the region average between 26 and 33°C, with maximum temperatures reaching as high as 40°C. Winter days are generally mild and sunny, with maximum temperatures of between 18 and 20°C.

**Figure 2-4** shows the rainfall records for three rain gauge stations (Kammanassie, George and Stompdrift) in the Oudtshoorn and George area between 1 January 2006 and 31 December 2007. All three stations see four major peaks in May 2006, August 2006, February 2007 and December 2007. The peak in August 2006 corresponds to a major flooding event in the Western and Southern Cape that occurred from 31 July 2006 to 3 August 2006 as a cold front passed over the area, which resulted in heavy rain and flooding from Montagu to Storms River and into the Eastern Cape. A cut off low in late November 2007 caused flooding in the Southern Cape, which is reflected in the George and Stompdrift gauge stations. The Kammanassie station received little rain over the two-year period shown in **Figure 2-4**, being especially dry during summer between September 2006 and January 2007. The Stompdrift station shows considerable rainfall between May and September 2006, with very little rainfall between July and November 2007 (see **Figure 2-4**). George receives the largest amount of rainfall of all three stations over the

two-year period as it is the closest to the coast, and is not within the rain shadow of the Outeniqua Mountains compared to the other two stations (see **Figure 2-4**).



**Figure 2-4** Rainfall data for three gauge stations in the Oudtshoorn and George area between 1 January 2006 and 31 December 2007 (Willmot, 2009).

## 2.5 Hydrology

The hydrology differs significantly between the rivers flowing from the Outeniqua Mountains to the north into the Klein Karoo Basin, and those draining towards the south and to the coast. Flow records from the following gauging stations (see **Figure 2-2**) were analysed to evaluate the hydrological conditions of the different regions:

- J3H005 (Klip River; J35B – 1926 to 1947 – 95 km<sup>2</sup>),
- J3H010 (Klip River; J35B – 1972 to 1973 – 98 km<sup>2</sup>),
- J3H017 (Kandelaars River, J35B – 1969 to 2008 – 348 km<sup>2</sup>),
- K1H002 (Beneke River; K10E – 1959 to 2008 – 3.8 km<sup>2</sup>),
- K2H009 (Great Brak River; K20A – not suitable),
- K3H002 (Rooi River; K30B – 1961 to 2008 – 1.04 km<sup>2</sup>),
- K3H004 (Malgas River, K30B – 1961 to 2008 – 34 km<sup>2</sup>),
- K3H005 (Touws River; K30D – 1969 to 2008 – 78 km<sup>2</sup>),
- K3H006 (Rooi River; K30B – 1987 to 1993 – 6.2 km<sup>2</sup>),
- K3H007 (Rooi River; K30B – 1989 to 2008 – 6.3 km<sup>2</sup>),
- K3H008 (Rooi River; K30B – 1987 to 1993 – 6.33 km<sup>2</sup>), and
- K3H010 (Swart River; K30C – 1961 to 2008 – 35.6 km<sup>2</sup>).

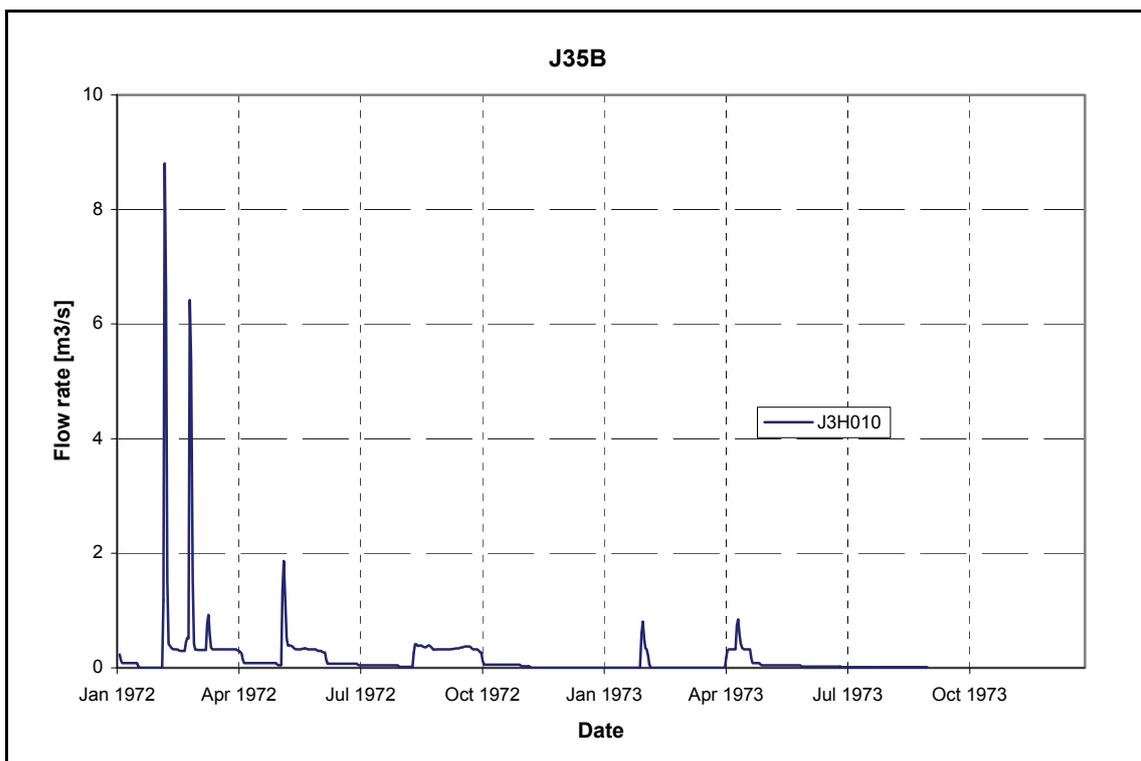
The gauge records indicate that the rivers draining into the Klein Karoo are ephemeral and only flow during and after rainfall events (see **Figure 2-5**), while most rivers draining

towards the coast are perennial (see **Figure 2-6** and **Figure 2-7**). However, the Swart River in K30C also appears to be ephemeral. The impact of heavy rainfall events and the subsequent flooding of rivers can be observed in all records, showing exceedingly high peak flows at certain events.

The low-flow period is usually early winter for both areas (see **Figure 2-8**), but the low-flow rates and volumes vary significantly. The seasonal variation is higher at the flow gauging stations that are located at higher altitudes and having smaller catchment areas (Beneke and Roois River), while the seasonal variation and monthly flow is significantly less for the flow gauging station at the Touws River, which is placed further downstream.

The average low flow on the southern side of the Outeniqua varies between 0.002 m<sup>3</sup>/s at the Roois River (K30B) and 0.08 m<sup>3</sup>/s at the Touws River (K30D). This translates to annual baseflow between 36 mm/a (Touws River) and 138 mm/a (Roois River) for the upper reaches of these catchments.

The Environmental Water Requirements (EWR; see **Table 2-1**) for catchments in the Klein Karoo Basin and on the southern slopes of the Outeniqua are usually higher than the baseflow values, since the EWR includes maintenance low flow and flood releases. Hence, the catchments require more water to sustain the ecological integrity of the rivers than is provided by the groundwater contribution.



**Figure 2-5** Flow records at gauging station J3H010 on the Klip River (J35B) between January 1972 and October 1973.

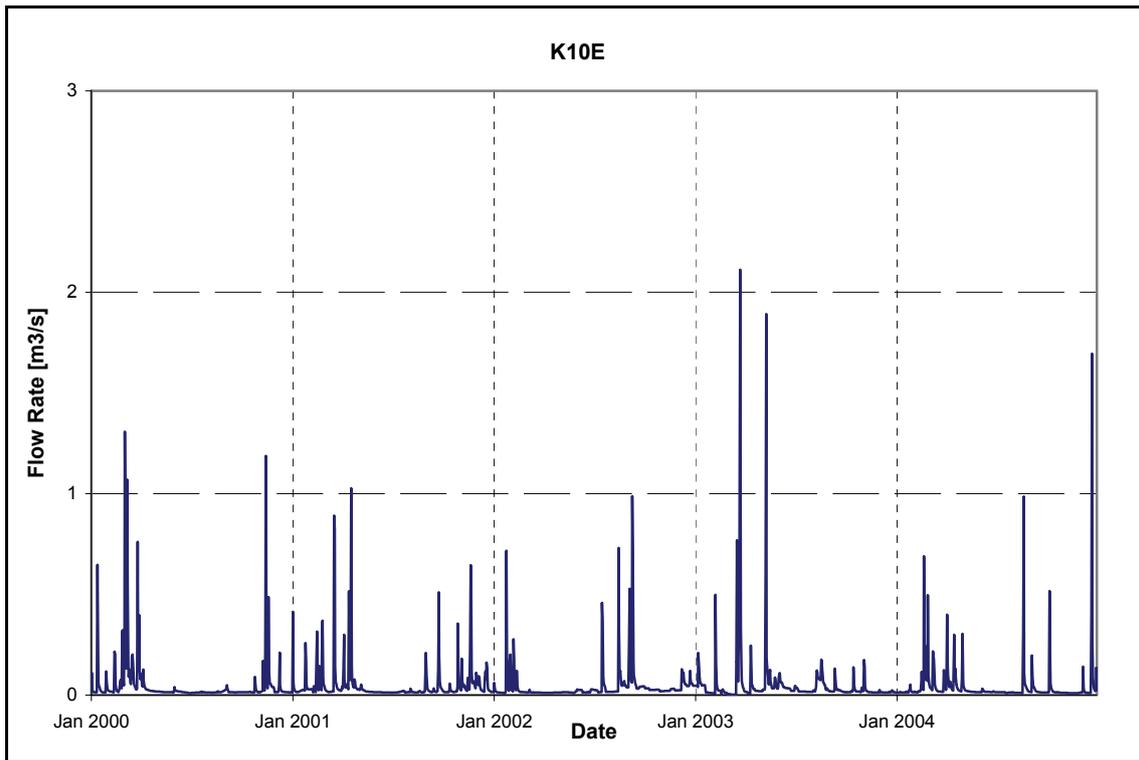


Figure 2-6 Flow records at gauging station K1H002 on the Beneke River (K10E) between January 2000 and January 2005.

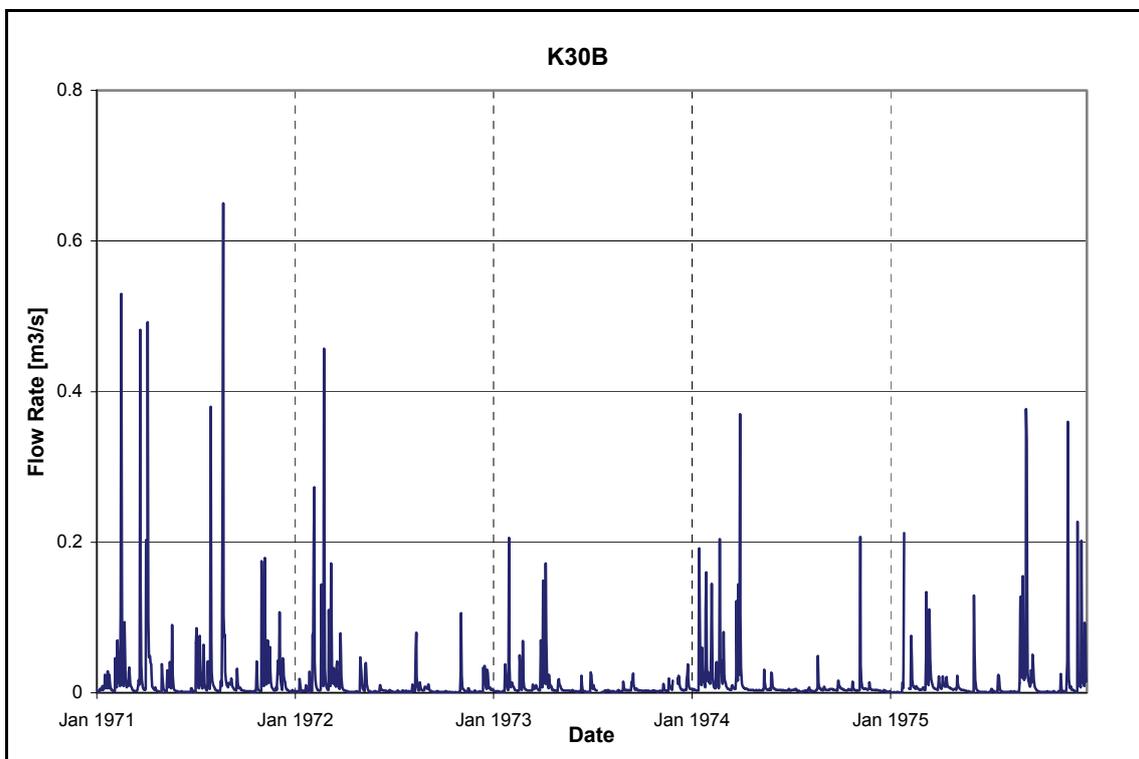
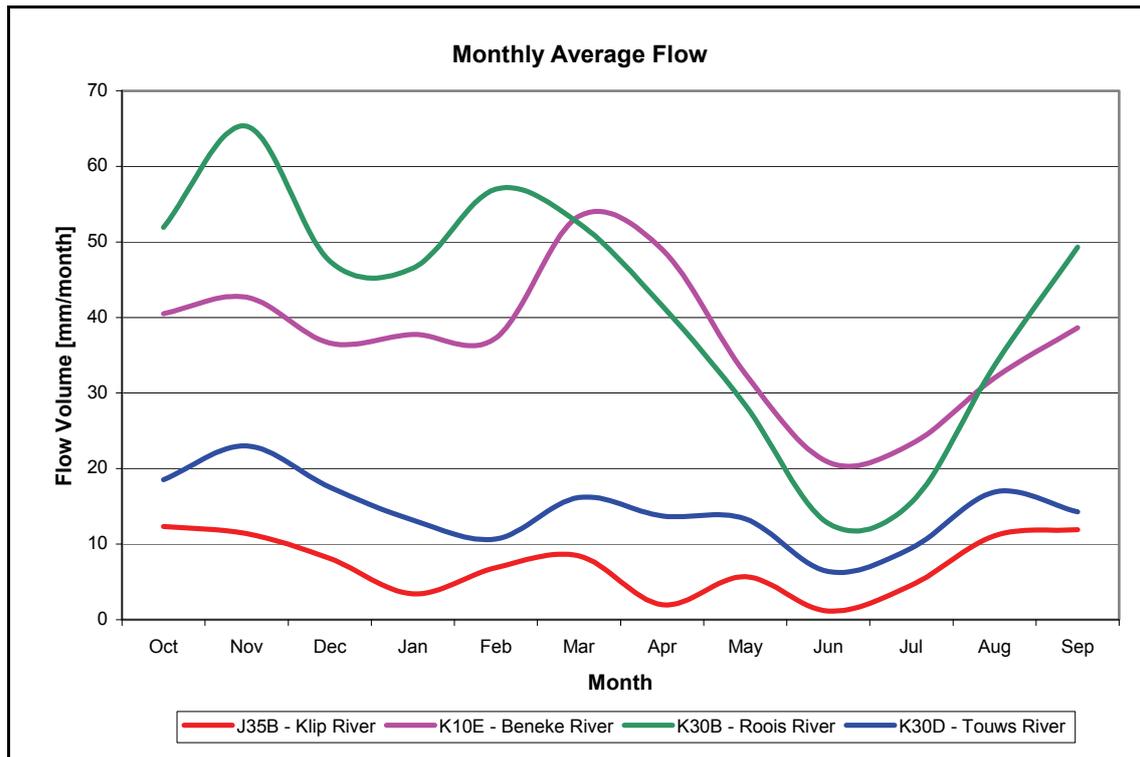


Figure 2-7 Flow records at gauging station K3H002 on the Rooi River (K30B) between January 1971 and January 1976.



**Figure 2-8 Monthly average flow at flow gauging stations in four selected quaternary catchments**

## 2.6 Vegetation

The vegetation of the region is remarkably diverse. Most species flower in spring, although many protea species flower in early autumn. The four main vegetation types encountered are Mountain Fynbos, Arid Fynbos, Succulent Karoo and Succulent Thicket. Mountain Fynbos is the most secure vegetation type as a result of it occurring in steep mountain areas, which are not suited to cultivation. Commercial forestry on the southern slopes of the Outeniqua Mountains, and alien invasive trees and shrubs are a threat though (see **figure 2-9**). Succulent Thicket occurs along major river courses, whereas Succulent Karoo and Arid Karoo occur along lower relief to hilly areas. Both Succulent Thicket and Succulent Karoo are threatened by commercial agriculture along the flood plains of the major river systems in the area (see **Figure 2-9**).

## 2.7 Geology

### 2.7.1 Regional geology

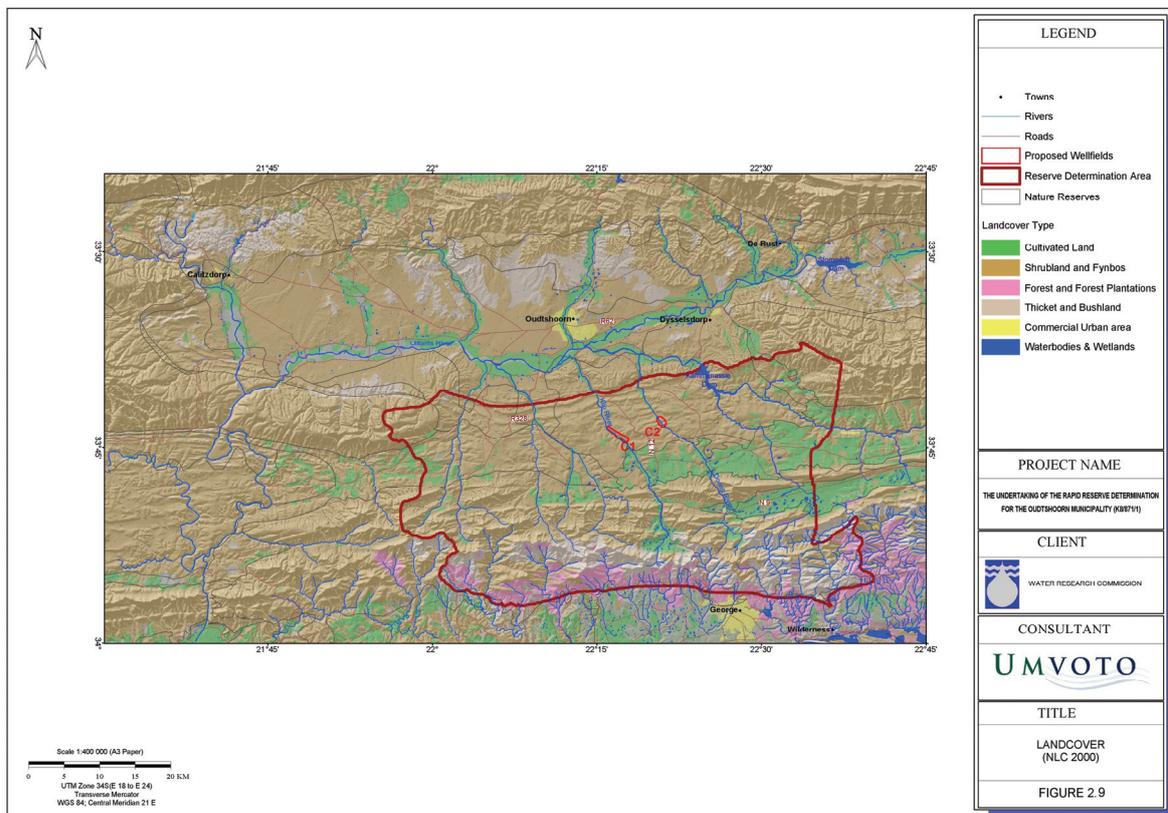
The Table Mountain and Bokkeveld Groups of the Cape Supergroup underlie the study area (see **Figure 2-10** and **Figure 2-11**). The age of the Table Mountain Group (TMG) ranges from Early Ordovician to Early Devonian, i.e. approximately 495-416 Ma, and that of the Bokkeveld Group from Early to Late Devonian, i.e. approximately 416-359 Ma (see **Table 2-2**). The TMG is comprised of the Peninsula (Ope), Goudini (Sg), Skurweberg (Ss) and Baviaanskloof (Db) Formations in the area.

The Cape Supergroup rocks make up the Outeniqua Mountain Range (part of the Cape Fold Belt), which was formed by a regional-scale deformation event of late Carboniferous to Permian-Triassic (~ 320-250 Ma) age that resulted in the large-scale folding of the

Cape Supergroup rocks (Booth *et al.*, 2004).

The study area shows overfolding in the southern Table Mountain Group strata and open folding in the northern Bokkeveld Group strata due to the compressive stress decreasing from south to north. Five kilometres north of Waboomskraal, the Bokkeveld Group conformably overlies the Table Mountain Group. The Gydo (Dg), Gamka (Dga), Voorstehoek (Dv), Hex River (Dh), Tra-Tra (Dt) and Boplaas (Dbo) Formations of the Ceres Subgroup, and the Adolphspoot, Karies and Sandpoort Formations of the Traka Subgroup (Da) constitute the Bokkeveld Group. The Gydo and Gamka Formation strata of the Bokkeveld Group form the Perdepoort Anticline, Zebra Syncline and Witkliprug Anticline, the latter coinciding with the location of Target Zone C (see **Figure 2-10**,

and **Figure 2-12**). Of the four target zones, Target Zone C and Target Sites C1 and C2 have the greatest potential for future development of a deep groundwater borehole as they allow for the shortest vertical drilling distance before intersecting the Peninsula Formation of the Table Mountain Group.



**Figure 2-9** Landcover and vegetation map of the study area.

### 2.7.2 Updated geology

The following changes to the previously reported regional geology were observed through core boreholes and new remote sensing imagery and recorded in Umvoto (2008):

- The Cedarberg Formation is generally absent within the study area. In well-exposed ridge-sections the reddish-weathering Goudini Formation sandstones are observed to be in direct stratigraphic contact with the massive white-weathering Peninsula Formation quartzites, with no sign of any intervening shale exposure or characteristic vegetated band. Field observations and borehole logs show no evidence of this being

a tectonic contact, and instead suggest non-deposition and/or intraformational erosion of the Cedarberg Formation.

- The Skurweberg Formation in Target Zone C, which with appropriate dip correction, cannot be greater than 165 m in thickness. This estimate of the formation thickness is substantially lower than all previous estimates in the Oudtshoorn region (e.g. 370 m in the Wabooms River stratotype section near Joubertina (Theron *et al.*, 1989)). This downward revision of aquifer thickness has negative wider implications for the groundwater resource in the Skurweberg, but positive implications for greater accessibility of the Peninsula Aquifer over a much larger extent within Target Zone C.
- The apparent vertical thickness of the Baviaanskloof Formation has been estimated up to ~ 96 m from core and remote-sensing analyses. Remote sensing studies have also allowed for the calculation of the true thicknesses of various Bokkeveld Group formations, namely the Gydo (~165 m), Gamka, (~170 m), Voorstehoek (~98 m), Hex River (~60 m), Tra-Tra (~70 m) and Boplaas (~130 m) Formations. This has assisted estimation of drilling depth.

**Table 2-2 Stratigraphy of the GRDM and DAGEOS study area as a whole.**

Age	Supergroup	Group	Sub-group	Formation	Lithology	
Quaternary (~ 5 Ma-present)					alluvial sediment	
Jurassic – Cretaceous (~ 200-66 Ma)		Uitenhage		Buffelskloof	conglomerate	
				Kirkwood	sandstone and siltstone	
				Enon	conglomerate	
<i>Unconformity</i>						
Carboniferous – Permian (~ 330-250 Ma)	Karoo	Beaufort	Adelaide	Abrahamskraal	shale	
		Ecca			shale and sandstone	
		Dwyka			tillite (glacial diamictite)	
Ordovician – Devonian (~ 490-360 Ma)	Cape	Witteberg	Weltevrede	Swartruggens	shale and siltstone	
				Blinkberg	sandstone	
				Wagen Drift	siltstone and shale	
		Bokkeveld	Ceres	Traka		shale and siltstone
				Boplaas		feldspathic sandstone and siltstone
				Tra-Tra		shale and siltstone
				Hex River		feldspathic sandstone
				Voorstehoek		shale and siltstone
				Gamka		feldspathic sandstone and siltstone
				Gydo		shale and siltstone
		Table Mountain	Nardouw	Baviaanskloof		feldspathic sandstone and siltstone
				Skurweberg		fractured quartzite
				Goudini		sandstone and siltstone
				Cedarberg		shale and siltstone
				Pakhuis		tillite (glacial diamictite)
		Peninsula		fractured quartzite		
<i>Unconformity</i>						
Namibian – Cambrian (~ 800-540 Ma)	Saldanian	Cape Granite Suite			granite	
		Kansa			metasediments	
		Cango Caves				
		Kaaimans				

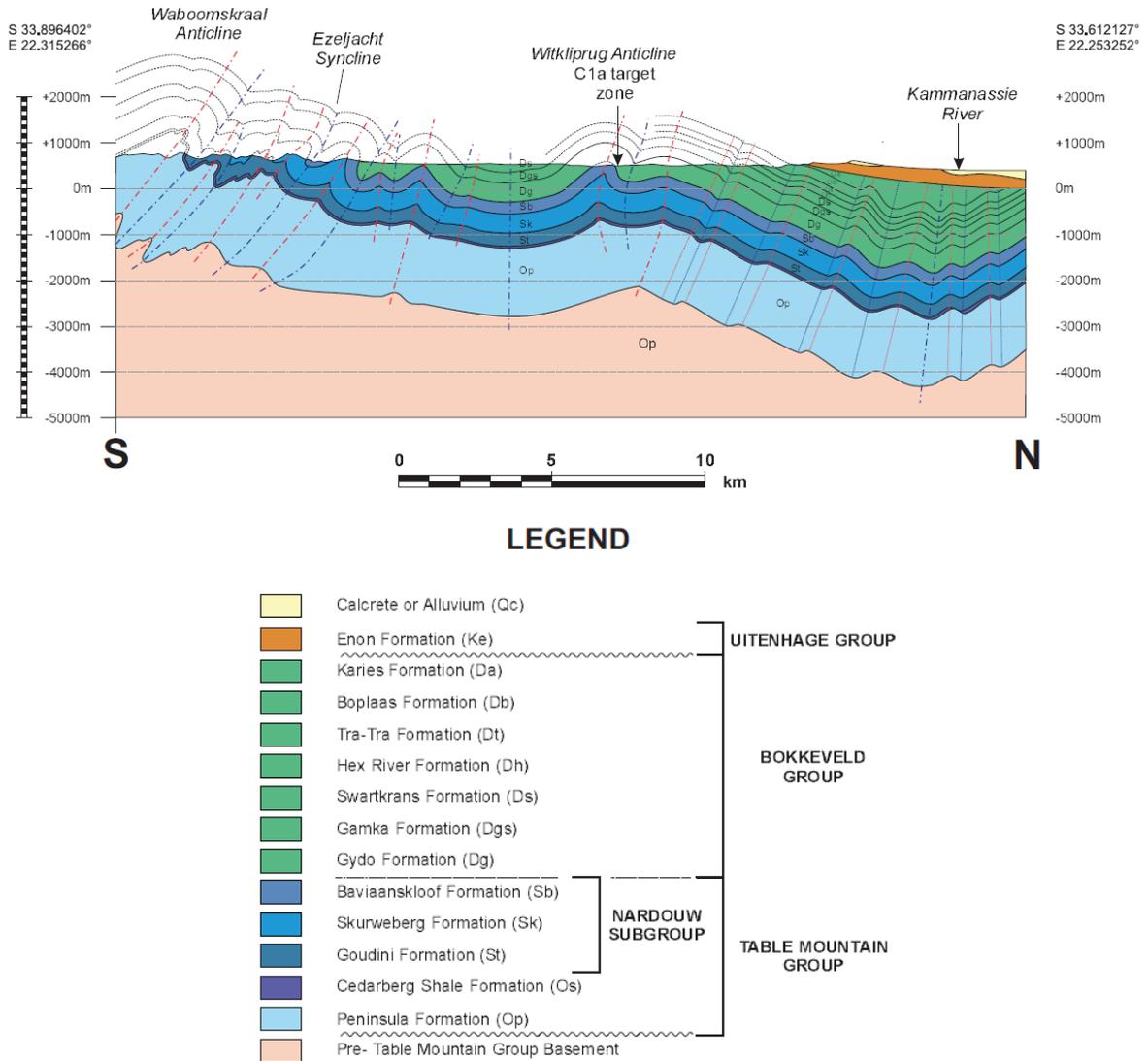


Figure 2-10 Regional N-S cross section through the DAGEOS study area (Umvoto, 2005).

## 2.8 Hydrogeology

### 2.8.1 Aquifer types

Only one aquifer type is dealt with in this groundwater Reserve determination assessment, namely the fractured (or type b aquifers described in Meyer, 1999) unconfined and confined portions of the Peninsula Formation aquifer.

The Peninsula Formation is the topographically dominant unit, building most of the high mountain ranges, and is hydrogeologically most important in that it has the widest extent in the areas of maximum precipitation and recharge potential and the greatest subsurface volume of permeable fractured rock.

The permeability of the rock is an important factor for the capacity of the aquifer to store water, while the occurrence of fractures or fault zones are necessary to transmit the stored water in a sufficient amount to the borehole or another abstracting system.

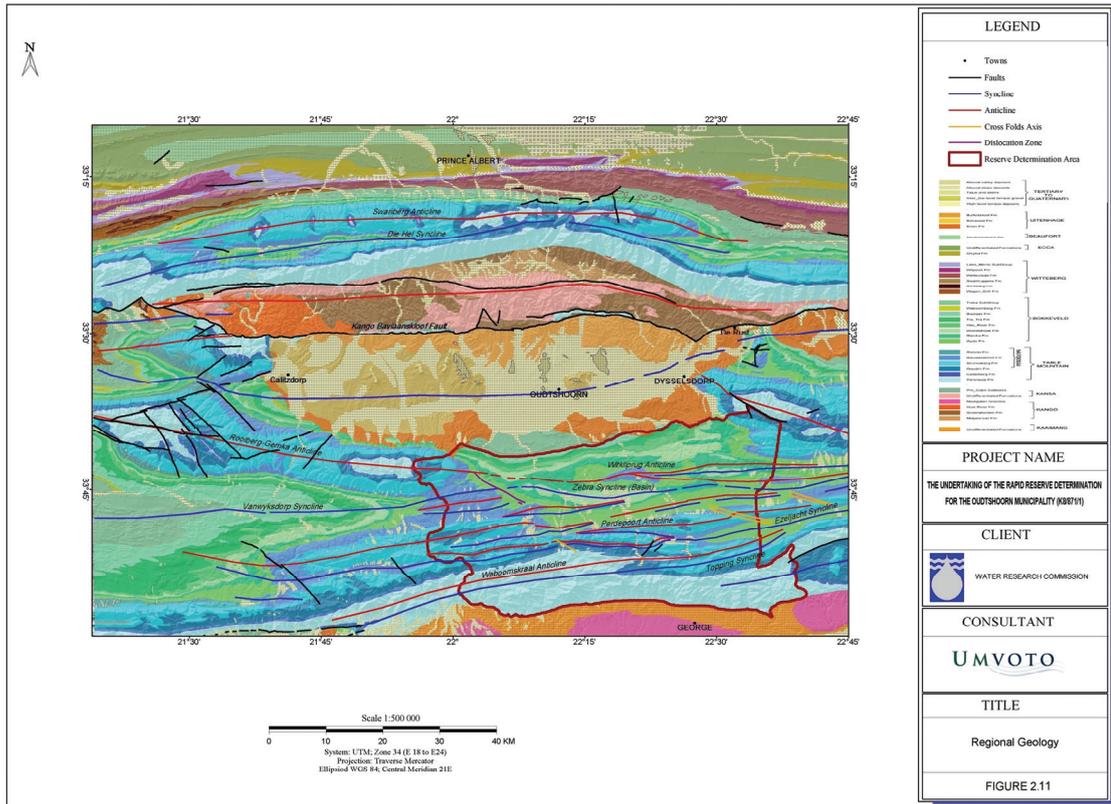
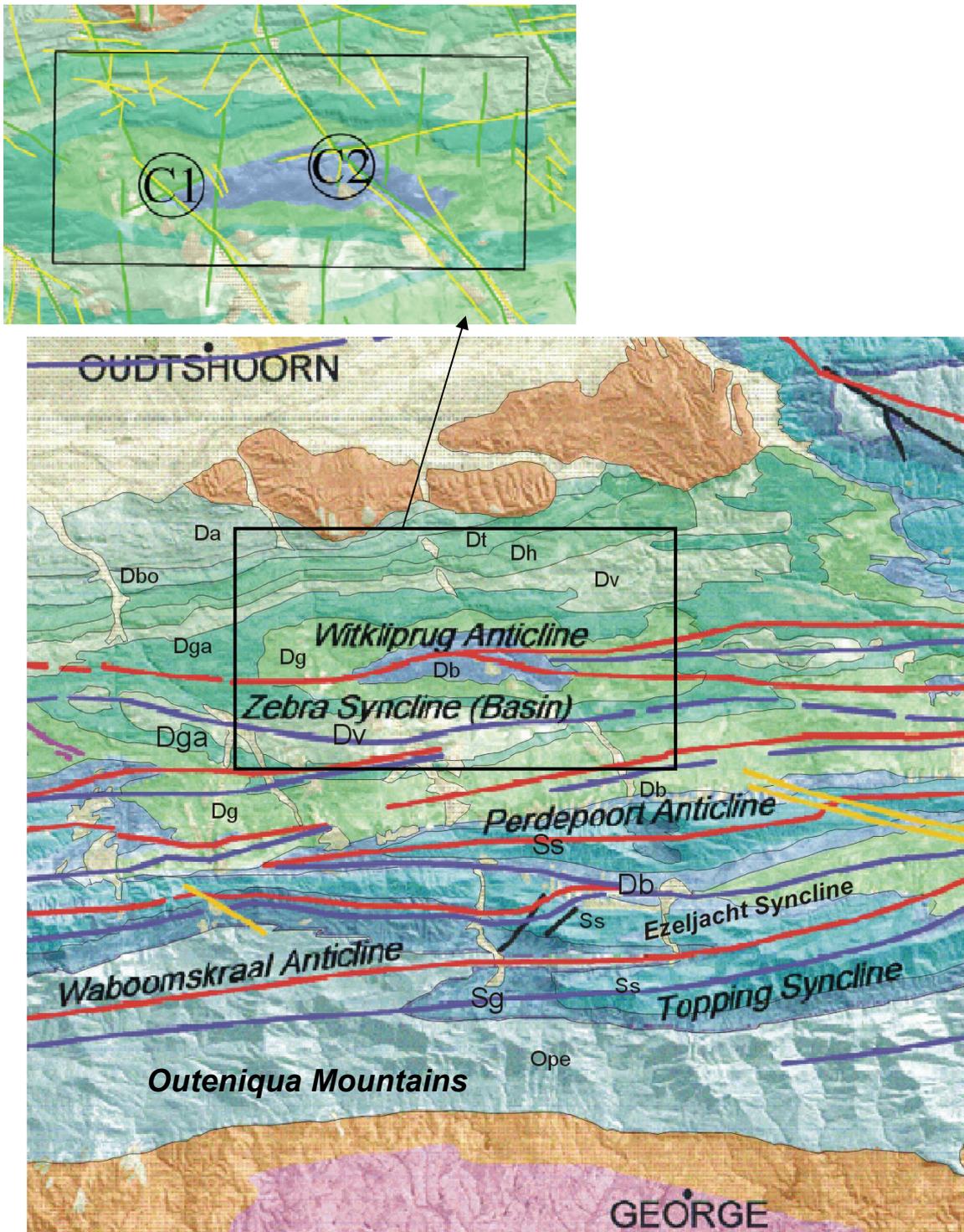


Figure 2-11 Regional geology of the DAGEOS study area.



**Figure 2-12 Target area geology**

Background colours: (see text for geological abbreviations), faults (in black), fractures (green and yellow in inset) and other structures (anticlines in red, synclines in purple, dislocation zones in orange) of the study area superimposed on a Landsat 7 image (after Umvoto, 2005). Inset indicates Target Zone C, with Target Sites C1 and C2.

### 2.8.2 Storage

As part of the groundwater evaluation, storage modelling was conducted for the confined portion of the Peninsula Formation aquifer, to give an indication of the storage capacity of the aquifer for management purposes (Umvoto, 2008). Five model sub-domains were delineated based mainly on geological and structural features, namely the Oudtshoorn Basin (OU), Witkliprug Anticline (WA), Zebra Syncline (ZS), Ezeljacht Syncline (ES) and the Outeniqua Recharge (OR) (see **Figure 2-13**). These model domains incorporate Target Zones (and associated target sites) B, C and D (main groundwater exploration areas) and exclude Target Zone A, identified during Phase D of the DAGEOS project.

The exposed, unconfined portions of the respective aquifer compartments, where the apparent vertical thickness of the Peninsula Formation is reduced by erosion, are ignored in the calculations of **Table 2-3**, which specifically relate to the confined portions of the aquifer with a thickness of 2000 m. The total confined rock volume (of the five model sub-domains) is 270 152 million m<sup>3</sup>. The calculated confined pore volume, and resulting yield values generated by various spatially averaged drawdown in head across the aquifer, is summarized in **Table 2-3**. For a conservative estimate a porosity of 5 % has been used.

**Table 2-3 Yield results from preliminary storage modelling**

Confined Peninsula Aquifer	Area	Rock Volume	Pore Volume	Volume per head decline of:					
				1m		5m		20m	
	km <sup>2</sup>	Mm <sup>3</sup>	Mm <sup>3</sup>	Mm <sup>3</sup>	%	Mm <sup>3</sup>	%	Mm <sup>3</sup>	%
OU	1 412.59	2 753 286	137 664	16.52	0.01	82.60	0.06	330.39	0.24
WA	646.68	1 294 893	64 745	7.77	0.01	38.85	0.06	155.39	0.24
ZS	427.03	855 644	42 782	5.13	0.01	25.67	0.06	102.68	0.24
ES	248.98	499 217	24 960	3.00	0.01	14.98	0.06	59.91	0.24
OR	0.00	0	0	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total</b>	<b>2 735.28</b>	<b>5 403 039</b>	<b>270 152</b>	<b>32.42</b>	<b>0.01</b>	<b>162.10</b>	<b>0.06</b>	<b>648.37</b>	<b>0.24</b>

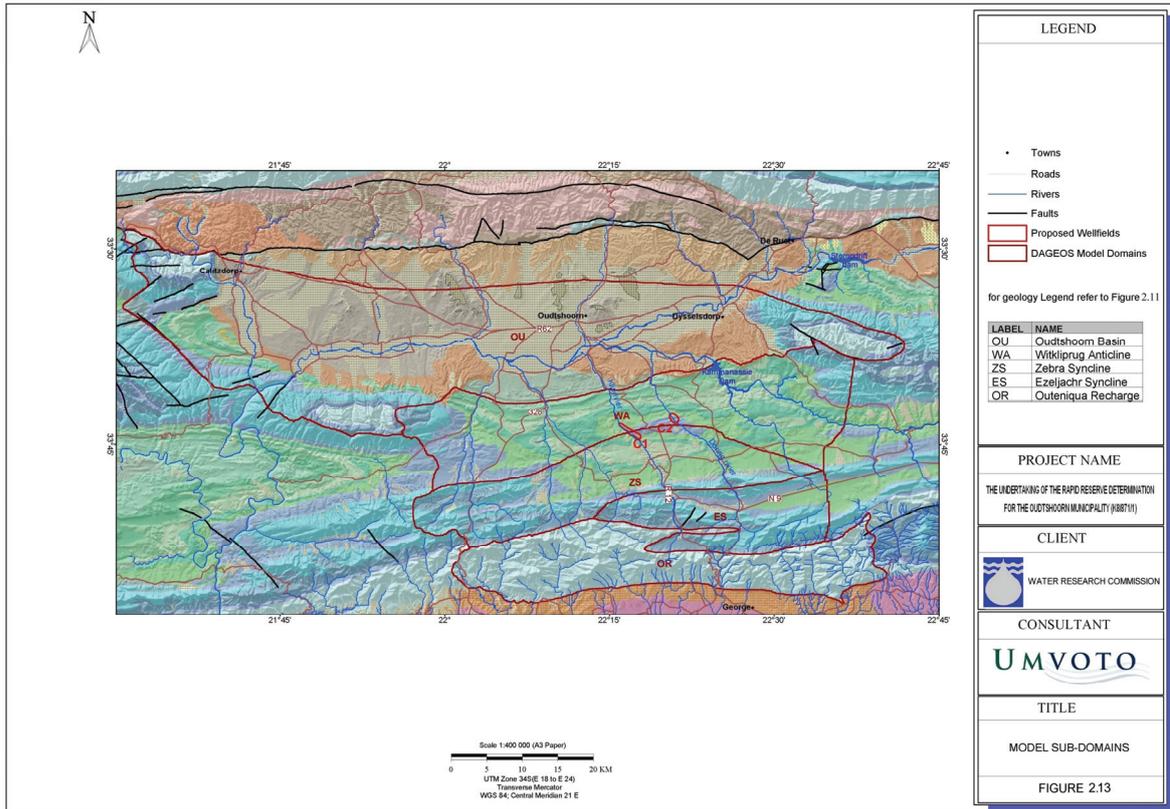


Figure 2-13 Storage modelling sub-domains (Umvoto, 2008).

## 3 RESOURCE UNITS

### 3.1 Definition and standard process

Due to the large size of the study area, it is not feasible to determine a groundwater Reserve for the entire area. Therefore the study area is divided into two smaller sub-regions, called resource units. Resource units are areas of similar physical or ecological properties that are grouped or typed to simplify the Reserve determination process. A 'groundwater resource unit' (or 'groundwater unit') is defined as a groundwater system that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit.

By definition, quaternary catchments are used as the primary delineation of water resource units in Resource Directed Measures (RDM) assessments. In the case of desktop or rapid assessments, insufficient information will be available for refining resource units further, and most assessments will therefore be based on quaternary catchments. Basic information about quaternary catchments can be obtained from the Groundwater Resource Directed Measures (GRDM) assessment software (DWAf, 2006b).

Groundwater resource units relate specifically to hydrogeological characteristics, but may coincide with other significant water resource units or eco-regions, or parts thereof. In some instances, subsurface conditions could play an influential role in controlling hydrological and ecological conditions. Because of the number of factors to be considered, setting resource unit boundaries is an iterative process, requiring modification until all component requirements have been accommodated. However, it is necessary to delineate zones of similar hydrogeology and ecology within the study area.

Three additional criteria are recognized that could be used as the basis for delineation; namely, physical, management or functional criteria. These could be used singularly, or in conjunction with other criteria. It is necessary to specify which criteria or characteristics were used in the delineation process, and motivate why the particular characteristic was considered the most appropriate.

### 3.2 Delineation and revised methodology

#### 3.2.1 Delineation

The resource units delineated for the study area have been based on whether the Peninsula Formation aquifer (which is the targeted aquifer) within the study area is confined or unconfined. The quaternary catchments have not been taken into account, as the surface water delineation is irrelevant for the artesian basin. Hence, two resource units have been defined, viz. one for the unconfined portion and one for the confined portion of the Peninsula Aquifer (see **Figure 2-12** and **Figure 3-1**).

#### Resource Unit 1

Resource Unit 1 is comprised of unconfined Peninsula Formation along the Waboomskraal Anticline, which forms the Outeniqua Mountains in the south of the study area, and forms the major recharge zone in the study area (see **Figure 2-12** and **Figure 3-1**). The smaller unconfined Peninsula Formation outcrops just northeast of Calitzdorp, along the Kammanassie Anticline forming the Kammanassie Mountains, and along the Rooiberg-Gamka Anticline in the vicinity of Bakenskop peak are ignored (see **Figure 3-1**).

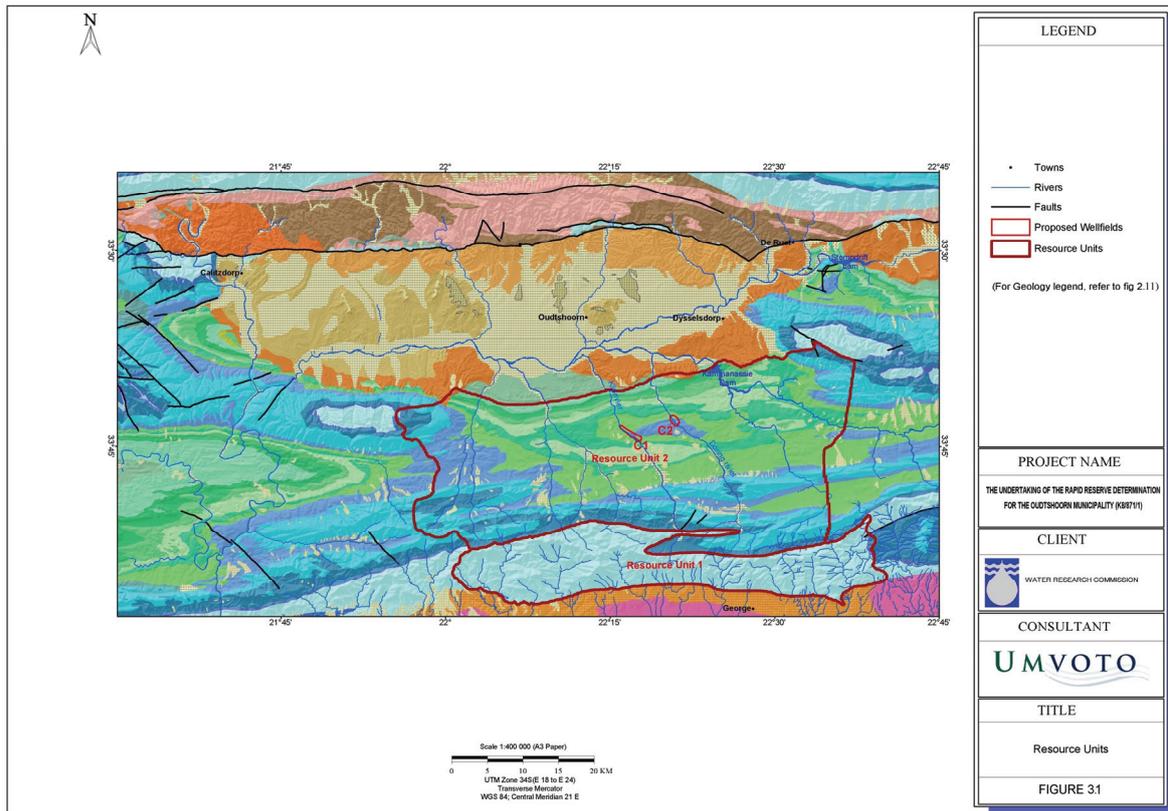


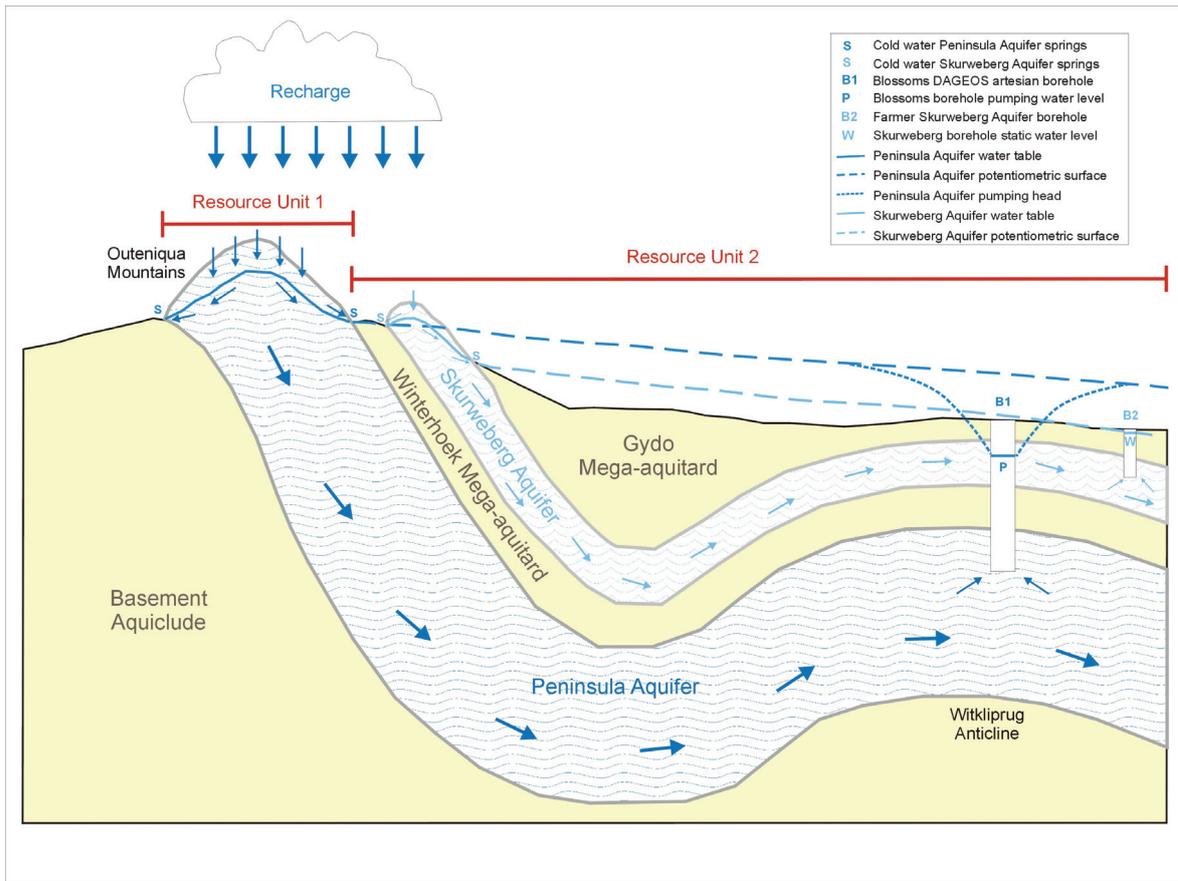
Figure 3-1 Delineated resource units within the DAGEOS study area.

### Resource Unit 2

The confined Peninsula Formation (i.e. Peninsula Formation that is covered by other geological units) north of Resource Unit 1 is termed Resource Unit 2 (see **Figure 3-1**). Resource Unit 2 is deeply confined within the Ezeljacht and Zebra Synclinal basins, as well as below the Witkliprug Anticline (see **Figure 2-12** and **Figure 3-1**). The large Oudtshoorn Basin further north is ignored.

### 3.2.2 Conceptual flow model

A basic conceptual model was developed in order to describe the groundwater flow in both resource units (see **Figure 3-2**). Recharge enters the unconfined Peninsula Formation (**Resource Unit 1**), and exits on either side of the Outeniqua Mountains as cold spring overflow, where the Peninsula Formation is in contact with the Kaaimans Group and Cape Granite Suite (Basement Aquiclude – southern lower Outeniqua slopes) and Goudini Formation (Winterhoek Mega-aquitard – northern lower Outeniqua slopes). Spring overflow only recharges the surface regolith aquifers on these lower slopes, and groundwater does not feed directly into either aquiclude or aquitard. Groundwater recharge flows from the unconfined Peninsula Formation (**Resource Unit 1**) into the deep confined Peninsula Formation aquifer system (**Resource Unit 2**).



**Figure 3-2 Conceptual flow path model for the GRDM study area.**

Proposed water abstraction for the Oudtshoorn Municipality is from the Blossoms artesian borehole, which has been drilled into the deep confined Peninsula Formation at the Witkliprug Anticline. Free artesian flow and/or pumping at the Blossoms borehole causes the development of a drawdown cone around the borehole and a lowering of the potentiometric surface for the Peninsula Formation aquifer, which is elevated above ground level due to the highly pressurised, confined nature of groundwater within the Peninsula Formation aquifer in that region. Lowering of the potentiometric surface of the Peninsula Formation has no affect on the potentiometric surface or groundwater level of the Skurweberg Formation aquifer, due to both aquifers being separated by the Winterhoek Mega-aquitard (the Goudini Formation, and Pakhuis and Cedarberg Formations where present).

The conceptual model for the Outeniqua Reserve determination study (DWA, 2009) is based on quaternary catchment delineation and hence incorrectly presumes that all water recharged in the unconfined Peninsula Formation aquifer in the Outeniqua Mountains, that form part of the K10E, K20A, K30A, K30B, K30C and K30D catchments, moves southwards topographically down gradient, across the Peninsula Formation – basement contact (whether it be Kaaimans Group or Cape Granite Suite), and is transported towards the ocean through the basement rocks where it is lost through evapotranspiration or feeds wetlands in the area. Hydrogeologically, the basement rocks of the area are aquicludes, and do not transmit or store groundwater in any large amounts. The only groundwater present is usually in the shallow weathered regolith zone along the surface of the basement rocks, especially at contact zones between the Cape Granite Suite and Kaaimans Group or fractured areas.

Based on the conceptual model used in this study, only a small percentage of recharge into the Peninsula Formation aquifer exits on the southern side of the Outeniqua Mountains as cold spring overflow, where the Peninsula Formation is in contact with the Kaaimans Group and Cape Granite Suite (Basement Aquiclude – southern lower Outeniqua slopes). Spring overflow only recharges the surface regolith aquifers on these lower slopes, and groundwater does not feed directly into either aquiclude or aquitard.

### 3.2.3 Revised methodology

This is due to the methodology for the Reserve determination for artesian basins not being defined yet and the need for the artesian basin methodology to differ from the standard procedure. The following considerations for the Reserve determination in the Oudtshoorn artesian basin need to be taken into account:

- The recharge area for the Peninsula Formation aquifer is situated in the Outeniqua Mountains and crosses the main watershed between the south flowing rivers and the north flowing rivers.
- Rejected recharge and overspill in the Peninsula Formation outcrop area contributes to river flow, which might be impacted upon by abstraction if the zone of influence reaches the unconfined portion of the aquifer; however, rivers at the northern side are mostly ephemeral (see **Section 2.5**).
- Discharge zones from the deep artesian basin are limited to hot springs (where flow paths can be mapped) along with possible diffuse discharge along the northern boundary of the artesian basin.
- The storage capacity for the confined Peninsula Formation is sufficient for managing the aquifer over a longer time period than 1 or 2 years, as usual for unconfined aquifers and dams, without impacting on the environment.
- The elastic behaviour of the aquifer “lid” influences the estimation of Resource Quality Objectives (RQOs).
- Basic Human Needs can be neglected as this need is catered for from shallower unconfined aquifers (primary alluvial aquifers and the fractured Skurweberg Aquifer, as well as regolith Bokkeveld aquifers).
- Groundwater use within the confined portion of the Peninsula Formation aquifer is zero and can be ignored, as there are no known deep boreholes present other than the currently proposed C1/C2 wellfields.

The following steps are considered necessary:

- Conceptual flow model identifying recharge areas, possible flow paths, discharge areas and specific discharge points (i.e. springs) (see **Figure 3-2**).
- Water balance model for estimation of recharge, storage and discharge volumes.
- Numerical model for quantifying flow rates and time lags (not required for this study).
- Numerical model for scenario testing and impact testing (not required for this study).
- Operational procedures to develop RQOs.

For **Resource Unit 1** the standard procedure of Reserve determination, as outlined by Parsons and Wentzel (2007), applies.

The revised methodology for **Resource Unit 2** takes the above-mentioned considerations into account in that Basic Human Needs and the Ecological Reserve are set to zero.

It is further assumed that groundwater flows from Resource Unit 1 to Resource Unit 2,

whereas the inflow into Resource Unit 2 depends upon the effective recharge to and groundwater abstraction from Resource Unit 1.

### 3.3 Resource Unit 1 hydrogeology

#### 3.3.1 Recharge

Recharge towards the Peninsula Formation aquifer is one of the main parameters in the resource evaluation and Reserve determination process. For the rapid Reserve determination undertaken in this study, available sources of recharge estimations were utilised, and results of the GIS-based aquifer-specific recharge calculations were compared to other approaches and results from other studies (namely Umvoto Africa, 2008) (see **Table 3-1**). Rainfall recharge was only considered for Resource Unit 1, namely the unconfined portion of the Peninsula Formation aquifer, which forms the Outeniqua Mountains.

During Phase D of the DAGEOS study (Umvoto Africa, 2005), a simple and robust approach to evaluating the unused groundwater potential was adopted. An aquifer specific GIS based evaluation of recharge using three different approaches (Riemann, Mlisa and Hay, 2004) was undertaken in-house using the MAP data from the WR90 study (Midgley *et al.*, 1994a and b). Using these methods, 32.4 million m<sup>3</sup>/a recharge was calculated for Resource Unit 1 (see **Table 3-1**).

Relatively recent estimates of groundwater recharge from the Groundwater Resource Assessment Phase II (GRA II) project (DWAF, 2006a) indicate a mean annual recharge of 60.5 million m<sup>3</sup>/a for Resource Unit 1 in the study domain (see **Table 3-1** and **Figure 3-3**). This is not considered a realistic estimate.

In the Breede River Basin Study (BRBS; DWAF, 2002) DWAF introduced a method for preliminary recharge estimation, which takes MAP per quaternary catchment into account. Since rock types differ in their capacity to absorb infiltration, this method is combined with an aquifer specific factor, varying between 0.5 for low permeability aquifers and 1.5 for primary aquifers, making the method aquifer specific. Applying the recharge factors to a gridded version of the MAP distribution and the outcrop area for the unconfined Peninsula Formation, the recharge for Resource Unit 1 is estimated to be 36.2 million m<sup>3</sup>/a (see **Table 3-1** and **Figure 3-4**).

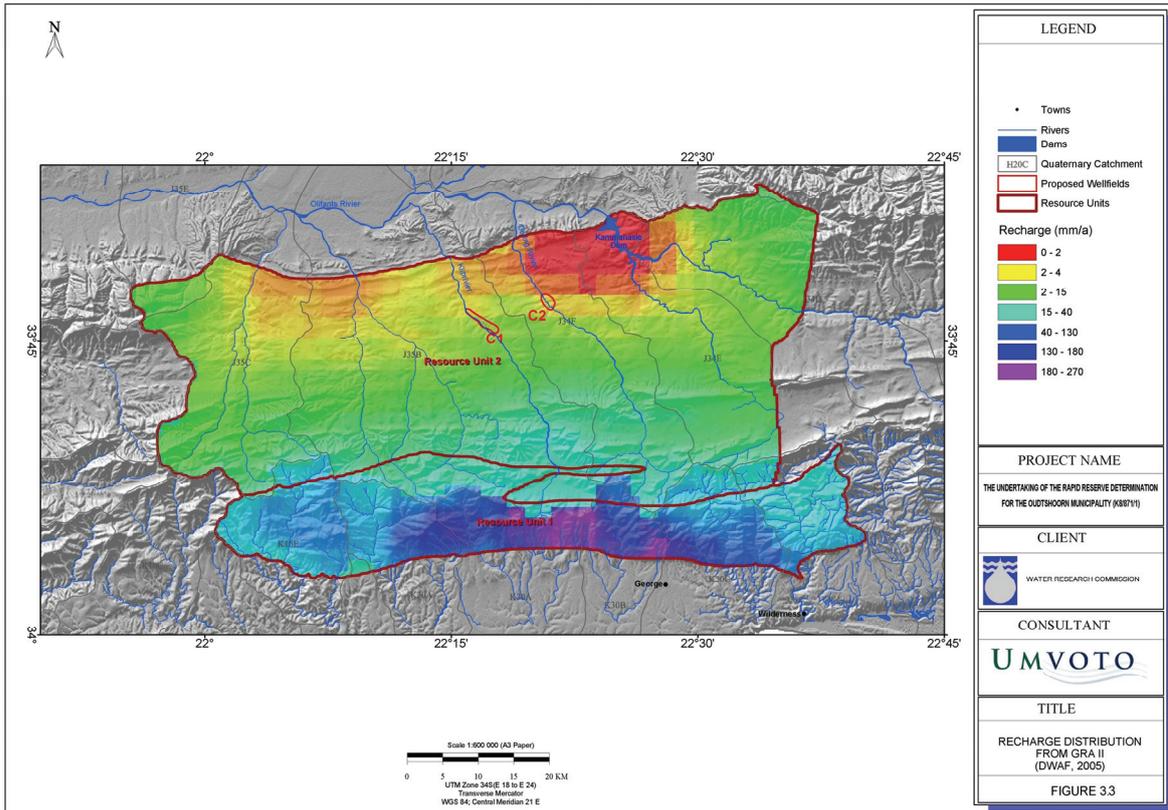
Seasonal groundwater level fluctuations can be used to calculate the recharge to the aquifer. However, the standard methods (i.e. Saturated Volume Fluctuation, SVF) only apply to unconfined aquifers and require an estimate of the groundwater outflow or discharge. An alternative method was developed for the confined Peninsula Aquifer, which is based on fluctuations in hydraulic head, measured in boreholes that are not influenced by pumping, and the storage coefficient. Based on field water level measurement data, average annual water level fluctuations of 0.3 m and 0.5 m were assigned to the confined portions of the Peninsula Formation aquifer, and an average recharge of 30 million m<sup>3</sup>/a to Resource Unit 1 was estimated. Due to the high uncertainty of input parameters, this estimate is not considered further.

The final averaged recharge for **Resource Unit 1** is calculated to be **34.3 million m<sup>3</sup>/a**, based on the recharge estimation from Phase D and the BRBS method.

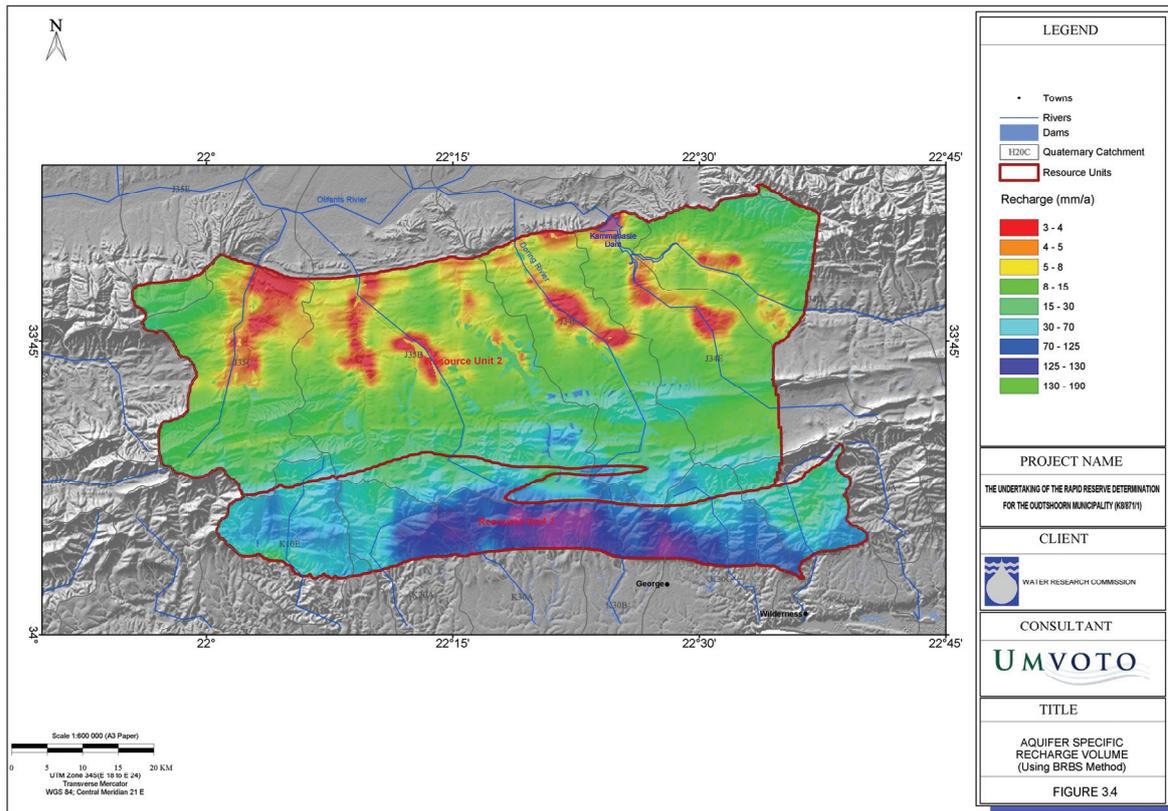
**Table 3-1 Comparison of recharge estimations.**

Aquifer type	Recharge [million m <sup>3</sup> /a]				
	Phase D	GRA II	BRBS	SVF	Average *
Resource Unit 1	32.4	60.5	36.2	30.0	34.3

\* Average of recharge estimations from Phase D and BRBS method; GRA II and SVF considered outliers and not reliable.



**Figure 3-3 Recharge distribution, using GRA II method.**



**Figure 3-4 Aquifer specific recharge volume, using the BRBS method.**

### 3.3.2 Groundwater contribution to surface water bodies

The second important parameter in the Reserve determination process is the amount of groundwater that flows from the regional aquifer into the rivers and contributes to the baseflow or low flow. A minimum flow needs to be maintained in the river to sustain the ecological function of the surface water body. The groundwater contribution is an important factor to maintain the ecological flow requirements.

The groundwater contribution to baseflow is considered to be the portion of groundwater that contributes to the low flow of streams originating from the regional groundwater body. To calculate the baseflow contribution from the unconfined Peninsula Formation aquifer in the study area, three approaches are considered:

- assignment of all baseflow values acquired from the GRDM software to the unconfined Peninsula Formation aquifer in catchments with that specific aquifer outcrop;
- spatial disaggregation of baseflow data proportionally to outcrop area, and
- spatial disaggregation of baseflow data proportionally to recharge. The aquifer-specific discharge estimation and groundwater contribution to baseflow is then disaggregated according to average recharge.

The default GRDM software baseflow estimates, however, usually include interflow and far exceed the low-flow requirements. Also, the estimates are not aquifer specific. It is therefore required to disaggregate the above baseflow estimates into aquifer units, proportionally to aquifer recharge, on the assumption that the aquifers discharge in the same catchment within which they are recharged. The aquifer specific baseflow is then calculated as a function of total baseflow in the catchment and recharge distribution, using the following equations:

$$Bf_{OPE} = Bf_{study} / Re_{study} \times Re_{OPE} \quad (1)$$

With

$$Bf_{study} = Bf_{total} / A_{total} \times A_{study} \quad (2)$$

Where

$A_{total}$  = Catchment area, total

$A_{study}$  = Catchment area, within study area

$Re_{study}$  = Catchment recharge, within study area

$Re_{OPE}$  = Peninsula recharge, within catchment

$Bf_{total}$  = Catchment baseflow, total

$Bf_{study}$  = Catchment baseflow, within study area

$Bf_{OPE}$  = Peninsula baseflow, within catchment

The method and results are illustrated with particular reference to the J35B catchment in **Table 3-2**.

**Table 3-2 Disaggregation of baseflow estimates to Peninsula Aquifer for J35B catchment**

J35B	Whole catchment	Part in study area	Peninsula outcrop
Area	651 km <sup>2</sup>	651 km <sup>2</sup>	64 km <sup>2</sup>
Recharge		14.45 million m <sup>3</sup> /a	2.39 million m <sup>3</sup> /a
Baseflow	2.65 million m <sup>3</sup> /a	2.65 million m <sup>3</sup> /a <sup>1)</sup>	0.44 million m <sup>3</sup> /a <sup>2)</sup>

1) Estimated with equation (1)

2) Estimated with equation (2): 2.65 / 14.45 x 2.39 = 0.44

Using this approach, the averaged baseflow value calculated for **Resource Unit 1** is **14.1 million m<sup>3</sup>/a**, of which 13.6 million m<sup>3</sup>/a discharge into the southwards flowing rivers and the remaining 0.5 million m<sup>3</sup>/a discharge into the rivers flowing northwards into the Klein Karoo.

The degree of groundwater – surface water interaction is defined in the GRDM method in terms of the percentage of baseflow to recharge. Grouping the results in classes of (1) negligible, (2) less than 25 %, (3) less than 50 % and (4) more than 50 % gives an indication of the significance of groundwater – surface water interaction and of the vulnerability of the surface water system to reduction in baseflow. The percentage of baseflow to recharge in Resource Unit 1 (i.e. 41%), falling within category (3), indicates that a high degree of surface water – groundwater interaction can be expected within Resource Unit 1. This occurs mainly on the southern boundary of Resource Unit 1, where groundwater continuously discharges into the southward-flowing streams.

The northward-flowing rivers receive less groundwater from the Resource Unit 1. The flow

gauging stations on these rivers indicate ephemeral flow conditions (see Section 2.5). It appears from groundwater level data at the northern boundary of Resource Unit 1 that the groundwater discharge to these rivers has a high seasonal variation. In addition, it can be expected that the rivers are intermittent further downstream (within Resource Unit 2); i.e. losing during high flow conditions and gaining during low flow conditions.

### 3.3.3 Groundwater use

Relatively recent estimates of the groundwater use from the Groundwater Resource Assessment Phase II (GRA II) project (DWAF, 2004), the Water Use Registration and Licensing (WARMS) database and the National Groundwater Database (NGDB) were used in determining the groundwater abstraction within the study area.

Since these estimations are not aquifer specific, it was decided to recalculate the groundwater use per aquifer per catchment, using two different approaches:

- disaggregating the GRA II values with respect to the outcrop area of the different aquifers, assuming an equal and *pro rata* spatial distribution of boreholes and abstraction points over the catchments, as well as that the boreholes only penetrate the surface geology;
- assigning the registered groundwater abstraction in the WARMS database to aquifers by linking WARMS registered use with boreholes in the NGDB and assigning volumes *pro rata* to the number of boreholes in the different aquifers and then recorded for the unconfined Peninsula Formation aquifer.

The disaggregating of the GRA II data is purely based on the outcrop area of the Peninsula Formation aquifer and therefore not physically correct. It is also not necessarily realistic since certain aquifers are much more developed than others. It can be expected that the groundwater use from the primary aquifers as well as the 'intergranular-fractured' aquifers in certain areas is underestimated with this approach, as aspects such as accessibility and yield are not taken into account. A groundwater abstraction figure of **0.36 million m<sup>3</sup>/a** was calculated from the GRA II database for **Resource Unit 1**. However, some of the estimates and allocations to different water use sectors in the GRA II database seem to mismatch with the registered use in WARMS.

Hence, it was decided to use the WARMS database and link the entries with borehole information from the NGDB to increase the confidence in groundwater use per aquifer. The cadastral data on farm and properties, as received from Department for Land Affairs, Chief Directorate: Surveys and Mapping (CDSM), was used to link the registered groundwater use on the WARMS database to a farm or property.

The boreholes registered on the NGDB were also linked to the properties from the cadastral database and to the aquifers, based on the surface geology as described in earlier phases of DAGEOS. Since on most farms a number of boreholes exist, often in different aquifers, the registered use from the WARMS was assigned proportionally to the aquifers with the most boreholes. In cases where more than 90 % of the boreholes were situated in a particular aquifer, the use volume was assigned to this aquifer only.

The combination of WARMS and NGDB databases are used for calculations on a regional scale, as they are more conservative and considered more realistic in terms of the aquifer-specific allocation. A groundwater abstraction figure of **0.45 million m<sup>3</sup>/a** was calculated from the WARMS and NGDB database for **Resource Unit 1**, which is considered the existing lawful use.

It is noted that groundwater abstraction from Resource Unit 1 appears to have increased significantly during the last few years and actual abstraction might be larger.

### 3.4 Resource Unit 2 hydrogeology

#### 3.4.1 Recharge

Due to Resource Unit 2 being comprised of deeply confined Peninsula Formation that is not recharged by direct rainfall, only lateral inflow from Resource Unit 1 is considered. The inflow into Resource Unit 2 is dependent on recharge, baseflow and abstraction from Resource Unit 1, and is estimated as:

$$RU2 \text{ inflow} = RU1 \text{ recharge (34.3 Mm}^3) - RU1 \text{ baseflow (14.1 Mm}^3) - RU1 \text{ BHN (0.02 Mm}^3) - RU1 \text{ groundwater use (0.45 Mm}^3).$$

The current inflow to **Resource Unit 2** is therefore **19.7 million m<sup>3</sup>/a**.

#### 3.4.2 Groundwater contribution to surface water bodies

To balance inflow along its southern boundary it is assumed that equivalent discharge from the deep artesian basin occurs via hot springs (e.g. Calitzdorp Spa) and possible diffuse discharge along faults at and beyond the northern boundary of Resource Unit 2.

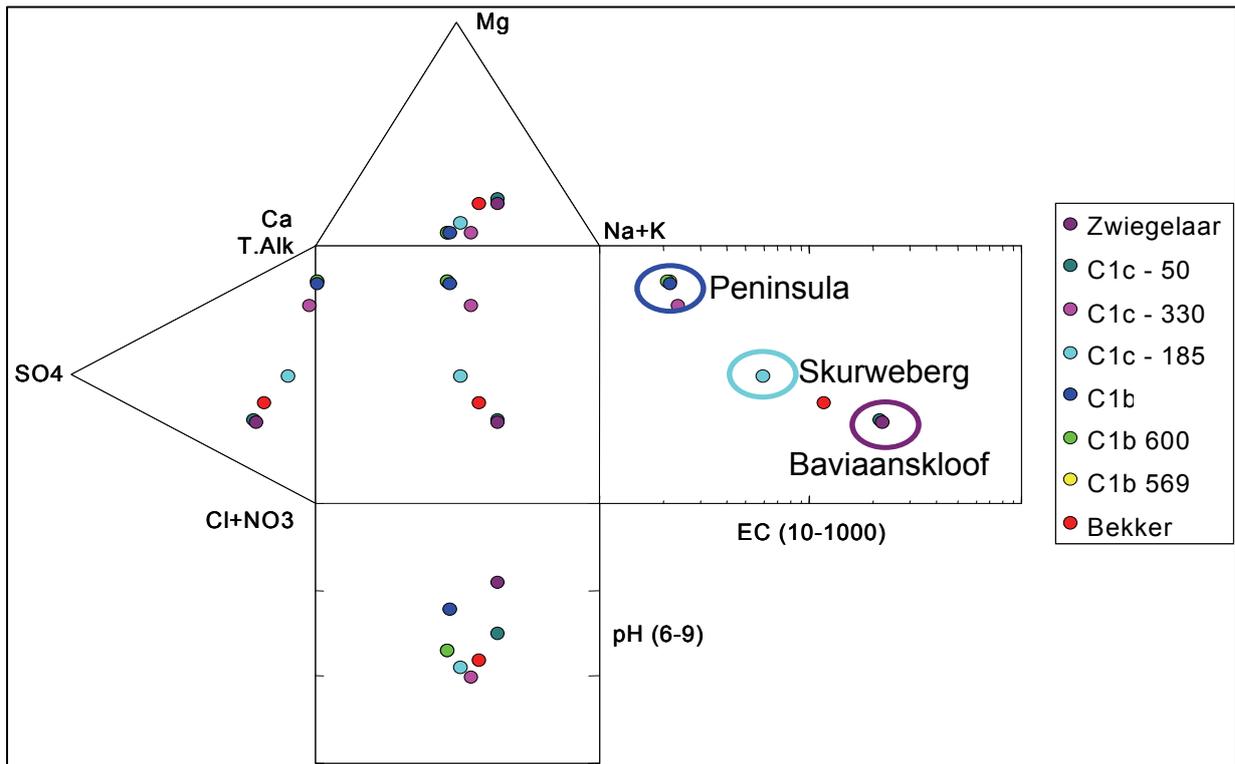
However, being a confined aquifer unit at great depth, **Resource Unit 2** does not discharge directly into surface water systems, and hence baseflow is considered to be **0 million m<sup>3</sup>/a**. This is also shown in the ephemeral character of the rivers in the Klein Karoo Basin.

#### 3.4.3 Groundwater use

Since no abstraction and no known boreholes do or are planned to intersect Resource Unit 2, other than the proposed C1/C2 Wellfields, groundwater abstraction from **Resource Unit 2** is **0 million m<sup>3</sup>/a**.

### 3.5 Groundwater quality

The groundwater quality analysis of the confined Peninsula Formation aquifer is based on results from the two deep boreholes drilled at Blossoms (C1b and C1c). These are compared in **Figure 3-5** to analysis from shallower sections in the boreholes and farmers' boreholes in the area (Zwiegelaar and Bekker boreholes). Sampling at the two Blossoms boreholes were taken at different depths during drilling, as indicated in the legend. The EC is very low (around 20 mS/m) for all Peninsula Formation samples, while the water from the Skurweberg Formation aquifer has an EC of 60-100 mS/m. The pH ranges between 7 and 8. The chemistry of the Peninsula Formation aquifer in this area is atypical in that it has a very high content of alkalinity and high calcium. The data does not indicate that the hydrochemistry in the Peninsula Formation aquifer is a limiting factor. It suggests that locally shale dominated lithologies can result in a moderate variation in the chemistry. There is no evidence of groundwater contamination in the confined Peninsula Formation aquifer, and the groundwater quality is generally very good (i.e. Class 0 to Class 1; see DWAF, 1996).



**Figure 3-5 DUROV diagram for groundwater from the Peninsula Formation aquifer at Blossoms, compared to shallower aquifers at the same location.**

### 3.6 Future groundwater use

Target Zone C south of Oudtshoorn within Resource Unit 2 is the highest priority target area because the Outeniqua compartments of the Table Mountain Group aquifers are most extensive in the subsurface around this zone, and have the best potential for sustainable recharge from the higher rainfall areas along the Outeniqua Mountain range (Resource Unit 1). During the exploration phase Target Area C, with sub areas C1 and C2, were defined with generalised circular boundaries (see **Figure 3-6**). Within C1 three Target Sites (C1a, C1b, C1c) were identified for the drilling of exploratory and monitoring boreholes (see **Figure 3-6**). Now that a successful initial (“wildcat”) artesian groundwater discovery has been realized at C1b, further drilling to delineate the full extent of the C1 and C2 Wellfield developments is possible. C2 is situated along the same Witkliprug Anticline as C1, hence allowing for the Peninsula Formation aquifer to be accessed at depth in this area.

In **Figure 3-6**, the full extent of the C1 and C2 Wellfield is indicated (red and blue boundary lines respectively), to enclose areas within which all likely production well sites, observation boreholes, access roads, pipelines and any other associated extraction infrastructure will be contained. In C1, this area includes the present C1a, C1b and C1c sites, and now extends northwestwards to a new C1d exploration/observation site (all target sites delineated by green boundary lines in **Figure 3-6**). Between C1b and C1c, two further exploration/observation sites, C1e and C1f, are approximately indicated. In the longer term, it is probable that production wells will be developed at the new C1d, C1e, and C1f sites, within the areas approximately indicated. Further production well development may also prove possible at C1b and C1c. In C2 two exploration and observation sites have been identified, namely C2a and C2b, and these will be developed in the future after the C1 Wellfield has been completed.



## 4 RDM ASSESSMENT

This phase includes:

- The classification or categorisation of each resource unit
- The determination of the groundwater Reserve
- Setting Resource Quality Objectives (RQOs)

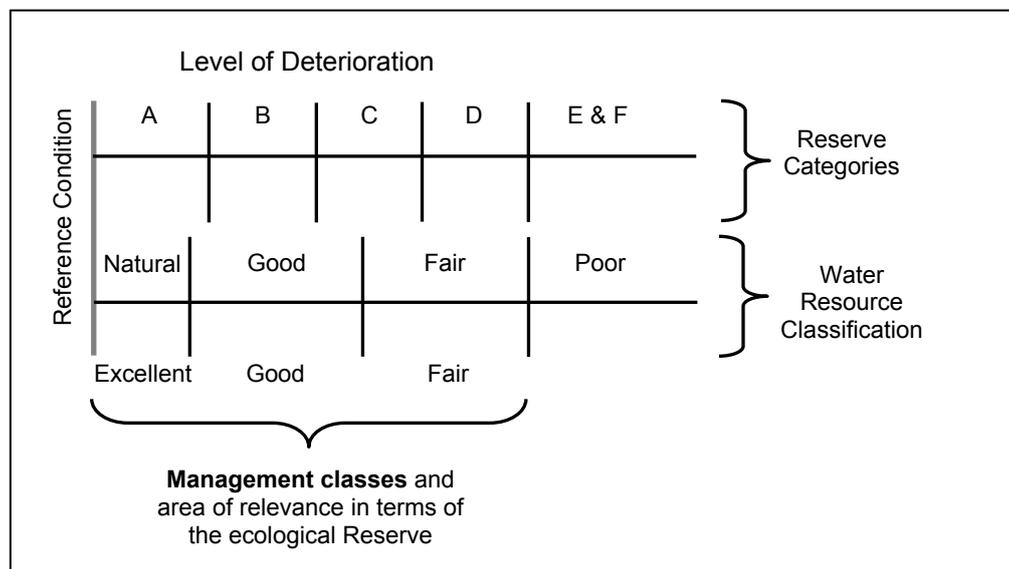
### 4.1 Classification

#### 4.1.1 Methodology

Classification of resource units includes reviewing reference conditions, current status and future management. Water quantity and water quality aspects are taken into account. Classification is based on methods designed by Xu *et al.* (2003); however other methodologies as suggested by Colvin *et al.* (2004) are also taken into account.

In this process both the Reserve Categories (i.e. A to F; see **Figure 4-1**) and the Water Resource Classification (i.e. natural, good, fair and poor; see **Figure 4-1**), as proposed by DWAF, will be used to describe the present ecological status (PES) of the groundwater in the different Resource Units.

According to Parsons and Wentzel (2007) the words ‘class’ and ‘classification’ are used to describe the management class of a water resource, as set through the public process. The word ‘category’ is used for all sorting or grouping prior to the public process. In other words, categorisation is based only on technical input by experts in a particular field. Classification implies both technical and public input into the classification process.



**Figure 4-1 Relationship between various classification systems (after Parsons and Wentzel, 2007).**

**4.1.2 Water Quantity**

The recent status of a groundwater resource unit can be assessed in terms of sustainable use, observed ecological impacts or water stress. Since no information about ecological impacts of groundwater abstraction is available, the concept of water stress was applied for the classification process.

The concept of stressed water resources is addressed by the National Water Act, but is not defined. Part 8 of the Act gives some guidance by providing the following qualitative examples of ‘water stress’:

- Where demands for water are approaching or exceed the available supply;
- Where water quality problems are imminent or already exist; or
- Where water resource quality is under threat.

To provide a quantitative means of defining stress, a groundwater stress index was developed by dividing the volume of groundwater abstracted from a groundwater unit by the estimated recharge to that unit (Parsons and Wentzel, 2007). However, this concept does not take cognizance of the impact of other land use practices on groundwater and surface water resources. It is therefore proposed to modify the stress index by taking the groundwater contribution to baseflow into account. The modified stress index reads then:

$$\text{Stress Index} = \frac{\text{Groundwater Abstraction}}{\text{Recharge} - \text{Baseflow}}$$

The present status category was then assigned according to the stress-index and classes described in **Table 4-1**.

**Table 4-1 Guide for determining the level of stress of a groundwater resource unit, based on abstraction, baseflow and recharge (modified after Parsons and Wentzel, 2007).**

PRESENT STATUS CATEGORY	DESCRIPTION	STRESS INDEX (groundwater abstraction / recharge – baseflow)
A	Unstressed or low levels of stress	< 0.05
B		0.05-0.20
C	Moderate levels of stress	0.20-0.50
D		0.50-0.75
E	Stressed	0.75-0.95
F	Critically stressed	> 0.95

Recharge, baseflow and groundwater abstraction are estimated per resource unit as described in **Section 3**. Applying this modified concept, the present status categories in terms of water quantity are estimated and the results per resource unit are listed in **Table 4-2** below.

**Table 4-2 Present Status Category for Resource Units, based on Stress Index.**

Resource Unit	Water Quantity				
	Recharge	Baseflow	GW-Use	Stress Index	
	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a		Class
1 – Unconfined Ope	34.3	14.1	0.45	0.02	A
2 – Confined Ope	19.7	0.00	0.00	0.00	A
Total	34.3	14.1	0.45	0.02	A

**4.1.3 Water Quality**

The categorization of groundwater quality is based on:

- the level of observed contamination and
- the expected contamination due to land use and vulnerability, see **Table 4-3**.

Resource Unit 1 is generally comprised of high mountain ranges, which are protected nature reserves. However, part of the area is extensively used for agricultural purposes. Hence, low to moderate impact can be expected, but is not observed yet. Being unconfined however means that if any contamination had to occur, it would move directly into the confined portion of the aquifer via infiltration, indicating medium vulnerability.

Resource Unit 2 is confined and hence vulnerability to contamination is very low. The land use is mainly agriculture with ostrich and game farming and limited dryland agriculture, resulting in low impact.

**Table 4-3 Present Status Category, based on vulnerability and expected land use impact (after Parsons and Wentzel, 2007).**

	VULNERABILITY			
		Low	Medium	High
EXPECTED LAND USE IMPACT	Low Impact	A	B	B
	Moderate Impact	B	C	D
	High Impact	C	D	E

The analysis of the water quality shows no indication for groundwater contamination in the TMG aquifers.

Contamination is defined as concentrations of chemical parameters in groundwater above the natural background concentration that could render the water unfit for human consumption (i.e. domestic use), cattle (i.e. stock watering) or irrigation (i.e. agriculture).

The assigned PES for water quality is based on the observed data, where sufficiently available, rather than the expected contamination (see **Table 4-4**).

**Table 4-4 Present Ecological Status for water quality in the Resource Units, based on observed contamination, expected land use impact and vulnerability.**

Resource Unit	Contamination	Impact / Vulnerability			Final
	PES	Expected Impact	Vulnerability	PES	PES
1 – Unconfined Ope	A	Low	Medium	B	A
2 – Confined Ope	A	Low	Low	A	A

**4.1.4 Combined Classification**

When taking both the water quantity and the water quality into account, the Present Status Category can be defined for each Resource Unit (see **Table 4-5**). To describe the combined status of the water resource, the worst of both aspects is considered.

The proposed principles for assigning the desired ecological status for the resource units are:

- the present ecological status in terms of water quality should be maintained or improved on, deterioration of water quality needs to be avoided;
- protected areas, such as Nature Reserves, require a B class in water quality to ensure sustainability of protected ecology;
- Resource units containing the headwaters of the main rivers and aquifers require a B class in water quality to protect water resources further downstream;
- Resource units with mainly commercial agriculture and forestry require a C class in water quality to ensure sufficient water quality for irrigation;
- however, a D class can be accepted for water quantity, provided that this does not have a negative impact on the assigned DES class in downstream resource units;
- Resource units that mainly comprise rural villages and small towns, that are partly or fully dependent on groundwater for stockwatering, small hold agriculture and domestic use, require at least a C class in both water quantity and water quality to protect the livelihood of the rural population;
- a D class for water quantity is acceptable even in protected areas, as long as a comprehensive monitoring network is in place to detect impacts at an early stage.

The proposed Desired Ecological Status for both Resource Units is given in **Table 4-5**, based on the above principles. These are proposed and require verification during the Water Resource Classification process.

**Table 4-5 Present Ecological Status and proposed Desired Ecological Status of the Resource Units.**

Resource Unit	Present Ecological Status			Desired Status	
	Quantity	Quality	Combined	Quantity	Quality
1 – Unconfined Ope	A	B	B	C	B
2 – Confined Ope	A	A	A	D	B

## 4.2 Reserve Determination

The groundwater component of the Reserve is the part of the groundwater resource that sustains basic human needs and aquatic ecosystems. To be able to quantify the groundwater component of the Reserve, it is required to estimate the volume of groundwater needed to satisfy Basic Human Needs (BHN) and groundwater discharged to surface water bodies to maintain the ecological integrity of the surface water bodies.

The groundwater Reserve is set per resource unit with an associated confidence level. The following factors were taken into account:

- Aquifer classification,
- Aquifer heterogeneities,
- Water quality issues,
- Upstream / downstream users,
- Population growth,
- Potential for increased groundwater use,
- Ecological flow requirements,
- Protected areas, such as Nature Reserves,
- Riparian ecosystems as they play a large role in the groundwater balance

The aquifer classification and water quality issues are addressed in **Sections 3** and **4.1** above.

The Basic Human Need component of the Reserve is calculated based on current population numbers and the minimum requirement per Water Services Act (Act No. 108 of 1997) of 25 litres/person/day. To calculate the BHN per resource unit, the population figures per quaternary catchment were portioned to the Peninsula Formation aquifer according to the outcrop area. A population of approximately 1 620 was calculated for **Resource Unit 1** using data from the DWAF Water Services communities database, which equates to a BHN of **0.015 million m<sup>3</sup>/a** for the unit. Due to Resource Unit 2 being deeply confined and inaccessible to the general population within the unit, as well as that same population presently making use of groundwater from other shallower aquifers, **Resource Unit 2** has a BHN of **0 million m<sup>3</sup>/a**.

The Ecological Reserve is assumed to be equal to the groundwater contribution to baseflow, as the required maintenance low flow is not determined yet and the approved EWR for these catchments is higher than the normal groundwater contribution to baseflow. This amount is considered very conservative, as the minimum requirement to sustain the ecological integrity during low flow conditions is usually less than the groundwater contribution to baseflow. As discussed in **Section 3**, the baseflow values per quaternary catchment are disaggregated according to the recharge per aquifer within each catchment. The Ecological Reserve for **Resource Unit 1** is then calculated as **14.1 million m<sup>3</sup>/a**. The groundwater from the deep confined Peninsula Aquifer in **Resource Unit 2** does not contribute to baseflow, hence the Ecological Reserve is set zero (see Section 3.4.2).

The total Reserve for Resource Unit 1 is then determined as **14.1 million m<sup>3</sup>/a**. The results of the Reserve assessment for both resource units are documented in **Table 4-6**. The total is shown for information, as the Reserve of Resource Unit 2 depends upon the groundwater use and allocation in Resource Unit 1.

Based on the difference between recharge and Reserve, the total allocable groundwater in the study domain amounts to **19.7 million m<sup>3</sup>/a**. This value does not take into account the groundwater use from Schedule 1 and General Authorisation, as well as accessibility, possible impacts on other users and water quality. Considering the proposed Desired Ecological Status (Class D), about **14.8 million m<sup>3</sup>/a** are available from Resource Unit 2. Since the inflow into Resource Unit 2 depends upon the groundwater use in Resource Unit 1, this figure is the amount allocable from Resource Unit 2, if no further groundwater abstraction is allowed in Resource Unit 1.

The groundwater allocation should be accommodated by concise licensing conditions that comply with the RQOs as set out in the following section.

**Table 4-6 RDM Assessment for delineated Resource Units.**

Resource Unit	Classification				Resource Evaluation			Reserve Components		Allocable Groundwater	
	Present		Proposed		Recharge	Baseflow	GW-Use	BHN	EWR	Reserve	Class
	Quant.	Qual.	Quant.	Qual.	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a	Mm <sup>3</sup> /a
1	A	B	C	B	34.3	14.1	0.45	0.02	14.1	19.7	9.9
2	A	A	D	B	19.7	0.0	0.00	0.00	0.0	19.7	14.8
Total	A	A	D	B	34.3	14.1	0.45	0.02	14.1	19.7	14.8

### 4.3 Resource Quality Objectives

#### 4.3.1 General RQOs for Study Domain

Resource quality objectives are measurable indicators (e.g. gradients, water levels, quality ranges) set to ensure the sustainable functioning of the groundwater system. **Table 4-7** gives a summary of RQOs and indicators that are applicable in the study area. The RQOs relevant to the confined Peninsula Aquifer (Resource Unit 2) are listed in **Table 4-8**.

**Table 4-7 Resource Quality Objectives and indicators, relevant to the unconfined Peninsula Formation aquifer in Resource Unit 1.**

Resource	Resource Quality Objective	Indicator – Measurement
Perennial River	Maintain water level or groundwater gradient	Distance of borehole to river Water level in monitoring borehole Groundwater gradient
	Maintain water quality	Concentration of selected parameters in groundwater
Riparian Zone	Maintain water level or groundwater gradient	Distance of borehole to river Water level in monitoring borehole Groundwater gradient
River Pools	Maintain water level or groundwater gradient	Distance of borehole to river Water level in monitoring borehole Groundwater gradient
Cold Spring	Maintain water level or groundwater gradient	No boreholes within capture zone
Basic Human Needs	Maintain water level or groundwater gradient	No boreholes within protection radius Drawdown in abstraction borehole
	Maintain water quality	Concentration of selected parameters in groundwater
Protected Area	Maintain water level or groundwater gradient	No boreholes within protection radius

**Table 4-8 Resource Quality Objectives and indicators, relevant to the confined Peninsula Formation aquifer in Resource Unit 2.**

Resource	Resource Quality Objective	Indicator – Measurement
Skurweberg Aquifer	Maintain water level or groundwater gradient	Water level in monitoring borehole Groundwater gradient
Basic Human Needs	Maintain water quality	Concentration of selected parameters in groundwater

#### 4.3.2 RQOs and licence conditions for the DAGEOS C1/C2 Wellfields

To ensure that the groundwater abstraction from the confined Peninsula Aquifer at the wellfields C1 and C2 does not impact negatively on the Reserve, the environment and existing users, the following license conditions are considered necessary:

- Development of a numerical aquifer and wellfield model, which can simulate different scenarios and forms the basis for wellfield operation procedures. This needs to be based on a sound conceptual model and the data collected to date.
- Implementation of the Monitoring Programme, as approved by the Monitoring Committee, and any subsequent amendments prior to commencing full-scale abstraction from the wellfields.
- Automation of the monitoring during operation with installation of a telemetry system, to avoid unnecessary data gaps and unreliable data.
- Agreement on threshold values for several monitored parameters (e.g. water level, flow rate) by the Monitoring Committee prior to commencement of bulk abstraction to ensure the sustainability of the operation (see below).

As explained above, abstraction of groundwater from the deep artesian basin in Resource Unit 2 would only impact on the Reserve in Resource Unit 1, if the perimeter of the drawdown cone propagates beyond the southern boundary of Resource Unit 2; i.e. from the confined to the unconfined portion of the Peninsula Aquifer. Due to the significant storage volume available in the aquifer in Resource Unit 2, the aquifer storage can be managed over a period of at least a decade.

Hence, the following RQOs are specified for Resource Unit 2 only:

1. The pumping capacity of the abstraction works in both wellfields C1 and C2 will be designed to allow for managing the aquifer over a 1:200 year drought. Abstraction rates would be assigned accordingly to allow bridging long-term drought periods without significantly impacting on the environment, existing lawful use and ecological integrity of the streams fed by groundwater.
2. The drawdown of piezometric level due to abstraction at the C1 and C2 wellfields in monitoring boreholes situated in the confined Peninsula Aquifer close to or along the southern boundary of Resource Unit 2 will be limited to a maximum threshold that is yet to be determined<sup>1</sup> from an analysis of monitoring data since 2005. This threshold will be subject to the quantification and exclusion of localized drawdown related to abstraction from boreholes in the unconfined Peninsula Aquifer of Resource Unit 1 (e.g. the Waboomskraal agricultural area), and chosen to ensure that the cone of depression centred on the C1/C2 wellfields does not propagate into Resource Unit 1 under normal abstraction scenarios. In the exceptional circumstances of 2005-2008 (see footnote 1 below), the approximate range of

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<sup>1</sup> From current (2005-2009) water-level monitoring within Resource Unit 1 on the northern side of the Outeniqua range, it is clear that the recent period has been characterized by above-average rainfall, including severe precipitation and flood episodes in August 2006 and November-December 2007. Consequently the general level of the water table in the unconfined Peninsula has risen between 2005 and end-2008, and the range of water-table fluctuation during recharge events was probably exceptional. It would therefore be imprudent to use this limited record as the evidence on which to base a satisfactory determination of the drawdown-impact threshold for future C1/C2 abstraction. As the 2009-2010 hydrological year appears to be characterized by exceptionally low rainfall, amounting in some areas to a disastrous drought, it would be preferable to accumulate a longer record, covering a major drought episode, before the impact-threshold decision is finalized. The general principle to be applied is that C1/C2-induced impacts should not exceed the drawdown level reached during natural drought periods at a given (e.g. 1:200-year) recurrence interval.

natural fluctuation due to rainfall-recharge episodes was ~3 m (see borehole DB7 in fig. 4-21 in Umvoto, 2009).

3. Subject to the quantification and exclusion of drawdown related to abstraction from other (non-DAGEOS) boreholes in the Skurweberg Aquifer of Resource Unit 2, and in order to reduce the impact on existing lawful use in the vicinity of the wellfield under normal climatic conditions and abstraction scenarios, the potential (albeit highly unlikely) DAGEOS-induced drawdown in monitoring boreholes within the Skurweberg and or Bokkeveld aquifers due to abstraction at the C1 and C2 wellfields will be limited to a maximum that is yet to be defined according to the general principles outlined in item 2 and attached footnote 1 above. Under 2005-2008 conditions, the approximate range of observed seasonal (natural and artificial) fluctuation in the Skurweberg Aquifer was ~ 5 m (see fig. 4-16 in Umvoto, 2009)
4. Records will be kept, as specified in the Monitoring Programme, of:
  - (a) Water levels in the abstraction boreholes at not less than hourly interval;
  - (b) Pumping rates, pumping times and daily volumes abstracted;
  - (c) Water levels in specified monitoring boreholes at not less than hourly interval;
  - (d) Water levels in further monitoring boreholes at various, not necessarily fixed intervals;
  - (e) Chemical analysis of water samples from abstraction and monitoring boreholes, as specified in the Monitoring Programme;
  - (f) Weather data from automated weather stations in the vicinity of the wellfield.
5. These records, the data analysis and reporting will be made available to the Responsible Authority and other relevant organisations as specified below:
  - (a) During operation a monitoring report will be prepared every six months and submitted to the Monitoring Committee or its legal successor;
  - (b) A copy of the report will be submitted to the Responsible Authority in terms of the National Water Act;
  - (c) Should the monitoring data indicate the need to cease or adjust the pumping regime, a separate report will be issued and submitted to both the Monitoring Committee and the Responsible Authority for decision;
  - (d) Copies of the field sheets and digital data will be available on request.
6. Pumping will be adjusted, if impacts on the environment or other existing users, as defined by the agreed threshold values in clauses 2 and 3 above, are encountered during monitoring.

## 5 RECOMMENDATIONS

### 5.1 Recommended Methodology for Artesian Basins

The revised methodology for the GRDM assessment in artesian basins that was applied in this study is described in Section 3.1.

Based on the results of this study, the following considerations for the Reserve determination in artesian basins need to be taken into account:

- Basic Human Needs can be neglected for the artesian aquifer as this need is usually provided from shallower unconfined aquifers.
- Rejected recharge and overspill in the aquifer outcrop area (i.e. unconfined portion) contributes to river flow, which might be impacted by abstraction if the zone of influence reaches the unconfined portion of the aquifer.
- Discharge zones from the deep artesian basin are limited to hot springs (where flow paths can be mapped) along with possible diffuse discharge along fault-bounded boundaries of the artesian basin.
- The storage capacity for the confined aquifer is sufficient for managing the aquifer over a longer time period than 1 or 2 years, as usual for unconfined aquifers and dams, without impacting on the environment.

The following steps are considered necessary:

- Conceptual flow model identifying recharge areas, possible flow paths, discharge areas and specific discharge points (i.e. springs).
- Delineation of study domain to include recharge areas, artesian basin and discharge zones
- Delineation of Resource Units based on aquifer characteristics (i.e. unconfined and confined) and discharge regime (i.e. cold springs vs. hot springs).
- Water balance model for estimation of recharge, storage and discharge volumes; for each Resource Unit.
- Possible water surplus in unconfined Resource Unit is set equal to inflow for confined Resource Unit.
- Basic Human Need is set zero for the confined Resource Unit.
- Numerical model for quantifying flow rates and time lags (required for comprehensive Reserve Determination).
- Numerical model for scenario testing and impact testing (required for comprehensive Reserve Determination).
- Operational procedures to develop RQOs (required for comprehensive Reserve Determination).

### 5.2 Outcome of this Reserve Determination

Based on this intermediate Reserve determination it is recommended

- to issue a Reserve determination for the Peninsula Aquifer within the quaternary catchments J34E, J34F, J35B, J35C, K10E, K20A, K30A, K30B, K30C and K30D, and
- to approve the licence application by the Oudtshoorn Municipality for groundwater abstraction from the C1 and C2 wellfields.

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