Appendix 4

Groundwater Overview

APPENDIX 4: GROUNDWATER OVERVIEW

1. INTRODUCTION

The Olifants-Doorn Water Management Area (WMA) incorporates the E primary drainage region and marginal parts of the F and G drainage regions along the coastal plain, respectively north and south of the Olifants River estuary, covering a total area of 56 446 km^2. Its western boundary is the Atlantic Ocean, and its eastern boundary lies along the Great Escarpment divide between the Great Karoo and the Western branch of the Cape Fold Belt.

The main catchments forming the Olifants/Doorn WMA are:

- The Upper Olifants River (E10) secondary drainage region covering an area of 2 888 km^2;
- The Doring and Tankwa (E20) secondary drainage region covering an area of 21 320 km^2;
- The Lower Olifants-Hantams-Kromme (E30) secondary drainage region covering an area of 22 136 km^2;
- The Oorlogskloof (E40) secondary drainage region covering an area of 2 722 km^2;
- The Goerap (F60) tertiary drainage region covering an area of 2 790 km^2;
- The Sandveld (G30) tertiary drainage region covering an area of 4 590 km^2.

Figure 1 shows the study area and topography. **Figure 2** and **Figure 3** show the ISP sub-areas and a cross-section of the geology.

2. WATER MANAGEMENT AREA ISSUES

Groundwater resources are unevenly distributed through the Olifants/Doorn WMA, from relative abundance in the mountainous southeast to extreme scarcity in the north-western coastal desert. In that respect the Olifants/Doorn represents a microcosm of Southern Africa as a whole. In the arid western portions streams are ephemeral and flow only during episodic flood events, so that for the most part there is no alternative to groundwater, other than seawater desalination. Often the groundwater quality is brackish in these areas and requires reverse osmosis to improve water quality to potable standards.

In those parts of the WMA with better endowment of surface water, planners and engineers often overlook groundwater as a potential water source. The causative factors are feelings of unreliability and lack of trust by users, previous experience of failure in groundwater-based supply due to mismanagement (e.g., over-pumping, absence of monitoring of abstraction, spring flow and regional to local water levels, neglect of essential subsurface pump or screen maintenance), poor perception and limited understanding of groundwater (data) from a quantity, quality and/or environmental-impact perspective.

A lack of sound scientific under-standing of the mechanism of groundwater occurrence and flow, compounded by a lack of good quality information (Section 2.2 below), exacerbates this situation.

2.1 GUIDING PRINCIPLES

The New Water Act (NWA), 1998 does not distinguish between surface and groundwater. The four guiding principles of an Integrated Water Resources Management (IWRM) strategy are:

- The National Water Act gives equal weight to groundwater and surface water;
- Groundwater resources are integral to water-resource development planning, to the extent that only if groundwater is proven to be inadequate should surface water be considered as a source;
- Water demands must be optimally reconciled with all available resources;
- The optimal use of available resources is promoted through conjunctive use of surface and groundwater supply as well as storage opportunities, where feasible; and
- All water use must follow the principles of sustainability, equity and efficiency.

2.2 AVAILABILITY OF INFORMATION

Information about the volume of the available groundwater resource, the distance between a suitable source and its intended use, and its reliability (assuming proactive, appropriate aquifer management) needs to be conveniently available to planners and engineers in a readily understandable format. General background information is published in map form at 1: 2 500 000 scale on the poster sheet "Groundwater Resources of the Republic of South Africa" (Vegter, 1995), and regional information appears on the 1: 500 000 scale on the hydrogeological map of Cape Town 3218, and also Calvinia 3018. However, these graphic information sources are too generalized at too small a scale to be practically useful for aquifer exploration, development and management.

There is now a growing opinion arising from debate in the ISP workshops that hydrogeological map (graphic) information at a minimum scale of 1: 50 000 is needed, and that a geographic information systems (GIS)-based or "geoinformatics" approach to hydrogeological data management and information dissemination on the web is also required. Such an approach was pioneered within the E10 tertiary subcatchment of the Olifants/Doorn WMA during the 1998-2000 Citrusdal Artesian Groundwater Exploration (CAGE) Project.

2.3 GROUNDWATER RESOURCES

Resource assessments on regional and local scales for the southern and western parts of the Olifants/Doorn WMA are available from studies such as CAGE, the recent Olifants/Doring (sic) Water Management Area: Water Resources Situation Assessment (DWAF, 2002, Chapter 6.2, **Table 6.2.1**) undertaken to contribute to the National Water Resource Strategy (NWRS), and the current Danish International Development Agency (DANIDA) IWRM Project (2000-2004). The results of the groundwater resource evaluation are not consistent in these reports. Detailed cross-referencing and critical review of different approaches used is required, but is beyond the scope of this study.

As in other WMAs around South Africa, groundwater use can be distinguished in five general categories:

Rural Domestic: ranges from individual boreholes for primary water supply to rural landowners, villages, schools clinics, hospitals, through small scale reticulation over short distances (2 - 5 km), to larger schemes based on several boreholes that would either fall under schedule 1, general authorisation or license agreement;

Livestock/ agricultural: individual boreholes for stock watering, vegetable gardening, etc. largely falling under schedule 1 or general authorisations (GAs);

Irrigation: larger schemes requiring well developed and managed groundwater resources/wellfields requiring to be licensed or GA if the allocation (based on property size) is adequate.

Bulk water supply: wellfields in large or extensive aquifer systems consisting of several high yielding boreholes requiring to be licensed;

Industrial (incl. mining): medium to large-sized reticulation schemes based on several boreholes or a wellfield. None exists in the WMA at present as the Namakwa Sands heavy mineral mine in the F60 catchment is supplied from the Olifants River and small quarrying operations around Vredendal and Vanrhysndorp are tallied.

Table 1, extracted from the DWAF (2002) Situation Assessment, summarises the usage of groundwater in the above categories as estimated for 1995. These numbers do not take into account data or results from the CAGE Project (1998 – 2000) or the DANIDA Sandveld Study (2003).

TABLE 1: GROUNDWATER USE IN THE OLIFANTS DORING WMA (NWRS)

Use	**Annual volume (million m^3/a)**
Irrigation	42 (1)
Agriculture: rural/livestock	1.5 (2)
Rural domestic	0.5 (2)
Municipal urban (bulk water)	2
Industrial/ Industrial/ Mining	-
Total	**46**

1) About 30 million m^3/a of the irrigation use is in the Sandveld (G30A-G30H) area (Danida 2003) while 12 million m^3/a is estimated to be abstracted from the TMG aquifers in the E10 (CAGE 2000) secondary catchment. It is considered that the groundwater usage for irrigation in the DWAF (2002) is underestimated.
2) In the rural areas of the Olifants-Doorn, the distinction between these two categories is difficult, and the combined estimate of 2 million m^3/a has been arbitrarily apportioned in a 3:1 ratio.
3) These values are not readily available and the numbers presented in the NWRS do not correlate with those presented in various regional studies undertaken since 1995. Similarly the studies themselves do not agree either on resource evaluation methodology or quantity. Thus this number is excluded.

Previous and Current Work

The CAGE Project (DWAF 2000) identified obvious deficiencies in the available hydroclimatic data from the E10 area (e.g., lack of high-altitude precipitation records and temperature altitude data, poor distribution of spring and stream-flow gauging). The lack of data impacts on the reliability of water balance studies and recharge estimation. The study emphasized the need for a regional groundwater-monitoring network for the (separate) Table Mountain Group (TMG) aquifers, with adequate spatial coverage from mountain recharge domain to coastal-plain discharge zones. It developed a quantitative approach to evaluate of the resource based on aquifer storage to complement recharge estimates.

The lack of and/or inaccessibility of area- and aquifer-specific data at the scale of a quaternary catchment, or group of related quaternary catchments, constitute a major hindrance to the optimal development of groundwater resources. In the Limpopo WMA and in WMAs of the Eastern Cape, the Groundwater Resources Information Projects (GRIP) envisages 1: 50 000 scale hydrogeological maps, beginning with the most stressed and ecologically sensitive catchments, depicting the groundwater resources, groundwater quality and exploration/-development potential, based upon the needs and priorities of the end user.

Extension of the GRIP concept to the Olifants/Doorn WMA, qualified by greater emphasis on accurate physical estimates of aquifer geometry, a rigorous choice of the theoretical approach to hydraulic characterization and the Internet as a publication/dissemination medium, is recommended in the CAGE Project recommendations (DWAF, 2000).

The DANIDA/ IWRM Project is developing groundwater guidelines in support of the introduction of Catchment Management Agencies (CMAs) into three South African “pilot” WMAs for the field trial and testing of the guideline document. Early phases of this study identified resource assessment as being “inadequate for the necessary planning and licensing with respect to groundwater”. However, due to funding constraints, the scope of the DANIDA/IWRM resource assessment activities is restricted to a focus on (1) the Lamberts Bay-Elands Bay region (G30E, G30F, G30G quaternary subcatchments) and (2) the Citrusdal region (mainly E10D, E10E and E10F quaternaries, with some marginal overlaps to the south, north and west into the G drainage basin around the town of Graafwater).

An extensive groundwater resource assessment covering the northwestern part of the area, centred around the river confluence between the Olifants (E1 secondary catchment) and the Doring-Tankwa (E2 secondary catchment), forms part of the Western Cape Olifants-Doring River Irrigation Study. WODRIS is an initiative of the provincial department of agriculture (PAWC) in support of emerging new farmers from previously disadvantaged communities along the lower Olifants River, and therefore has poverty alleviation objectives (see Section 2.6 below).

The primary management objective is to have an appropriate evaluation of groundwater resource potential for different aquifers. Such evaluation must include allocable abstraction volumes at different scales for different uses. It is necessary that expected water quality, expected yields, vulnerability to contamination, use of aquifer storage as well as recharge and surface groundwater interactions are considered.

The discrepancies in the available numbers, the uneven spatial coverage in different studies and uneven emphasis and investment on surface and groundwater, differences in scientific approach as well as the gaps in information, highlight the primary management objective of the groundwater strategy.

2.4 GROUNDWATER QUALITY

Groundwater quality is one of the main factors affecting the development of available groundwater resources. The majority of serious water quality problems are related to total dissolved solids (TDS), nitrates (NO_3) and fluorides (F). In the absence of chemical analyses, TDS may be roughly estimated from electrical conductivity (EC) measurements (1 mS/m ≅ 5 mg/l).

2.4.1. NATURAL

Groundwater quality is generally controlled by aquifer lithology and geochemistry. Accordingly groundwater quality in the Olifants/Doorn WMA varies significantly between the fractured-rock (quartzitic) aquifers and the “intergranular (weathered) and fractured” or regolith aquifers that overlie generally impermeable shale- or granite-dominated pre-Cape formations. The waters in true fractured-rock aquifers such as the TMG and the Witteberg Quartzites generally have an EC of less than 70 mS/m and are moderately acidic (pH 5.5 – 6). The regolith aquifers yield neutral to alkaline groundwater with an EC greater than 300 mS/m, locally > 1000 mS/m.

Malmesbury regolith aquifers have acceptable water quality only where there is potential for groundwater leakage from higher-quality TMG aquifers. Bokkeveld groundwater is of acceptable to marginal quality. In the E10 it has a mean pH of 7.7, relatively high salinity (Na = 31%, Cl = 42%) and low alkalinity (3%). The TDS is >3000mg/l or ~600mS/m. Compared with the Bokkeveld and Karoo regolith aquifers adjacent to it, the quality of groundwater from the Dwyka Formation seems very poor (300-1000 mS/m). Groundwater of the lowest quality (>1000 mS/m) is found in primary aquifers overlying Dwyka tillite and lower Ecca shale in the Kliprand area, and from Namaqua basement aquifers of low yield and low recharge potential in the northwest. The average EC for 186 groundwater-sampling points in the Nuwerus-Stofkraal-Bitterfontein area is 709 mS/m, ranging between 463-530 mS/m near Nuwerus and 566-720 mS/m near Bitterfontein.

The groundwater in the southwestern part of the WMA is generally of ideal or very good quality (EC < 70 mS/m). It is suitable for use in small towns and rural settlements where surface water scheme supplies do not penetrate or there are no surface water allocations.

2.4.2. POLLUTION

The threat of groundwater pollution increases with population growth and development, and can result from:

- domestic use in centres of concentrated human settlement;
- agriculture;
- industrial and mining activity; and
- waste disposal.

Existing DWAF vulnerability maps appear to underestimate the potential for aquifer pollution or contamination throughout the area. "Most vulnerable" areas are shown in the primary coastal aquifer south of and around Elands Bay, and also north of Lamberts Bay, in part reflecting the potential for seawater intrusion following the agricultural exploitation of groundwater here. Some areas of "moderate" aquifer vulnerability cover fractured-rock aquifers of the TMG south of Citrusdal, and Witteberg-Bokkeveld aquifers south of Wuppertal.

An assessment of the risk of microbial contamination of surface and groundwater by human and animal wastes was obtained by intersecting aquifer vulnerability maps with maps of potential surface faecal contamination. It indicated that there is a high risk for the coastal aquifers in the south-west part of the WMA and a medium risk for groundwater in the upper reaches of the Tankwa and Olifants Rivers, and in parts of the Oorlogskloof River catchment. Elsewhere the risk to groundwater is low (DWAF, 2002).

In the larger and smaller urban centres throughout the ISP-area it is imperative the WWTWs appreciate that the aquifers are vulnerable to contamination. There is indication of IRF locally increasing the nitrate concentration in the TMG in the Clanwilliam district. The importance of spring protection, well-head protection and management of IRF should be appreciated and understood also in the rural areas.

2.5 MANAGEMENT AND MONITORING REQUIREMENTS

The protection of groundwater resources and its long-term sustainability of supply require effective monitoring and "adaptive" management.

Groundwater monitoring programmes must involve regular measurements of:

- water levels;
- water quality (macro and trace elements and biological indicators);
- abstraction volumes;
- climatic variables - rainfall, temperature, EVT and snowfall; and
- hydrologic variables – spring flow (altitude, volume, water quality, seasonal and or climate event-related variation), baseflow in rivers.

Such systematic programmes are generally implemented for particular groundwater or conjunctive-use schemes, mostly tied to production boreholes. It is seldom if ever that trace elements and full biological tests are done. There is a need to identify sites where particular trace elements (e.g. arsenic and fluoride) should be monitored routinely (dolerite and granites respectively) as they can have a long-term toxic effect, particularly for pregnant women and children. There is also an imperative need for strategically placed *observation boreholes* exclusively dedicated to groundwater monitoring in locations distant from production wellfields.

Groundwater level, as monitored at one or more observation wells (piezometers), is the most important indicator of the state of the resource. One suitably located well, preferably placed furthest from outflow boundaries to surface waters and/or away from sites that are likely to be affected significantly by surface abstraction or by local (artificial) recharge from surface irrigation, can provide substantial information about the overall state of the resource, because the dynamic variability of groundwater levels throughout an aquifer has some components that are common to all wells in that aquifer.

Dynamic behaviour as a leaky storage for natural recharge is the defining characteristic of an aquifer as a groundwater resource (Bidwell, 2003). Most of the temporal variation in piezometric levels is caused by temporal variations in land-surface recharge, together with the effects of pumped abstraction. Due to the common dynamic components related to the seasonal variability of recharge, the value of groundwater level observations increases more with length of record than with number of observation sites. The design and pattern of monitoring in the WMA can be improved as can the data availability.

The amount of groundwater stored in an aquifer at any instant in time is governed by dynamic relationships between recharge inflows, through the overlying land surface and from rivers, and outflows to surface waters and pumped abstraction. Aquifer storage acts as a buffer between highly variable, climatically driven inflow processes and the less variable outflow that supports surface water ecosystems and rivers/streams. Because abstractions of groundwater for human use, and also land-use changes of certain kinds, alter this dynamic balance between recharge and the state of surface waters, the objective of groundwater resource management is "to determine the regime of abstraction that results in acceptable environmental effects" (Bidwell, 2003, p. 7).

The strategy of "adaptive management", sometimes described as a process of "learning by doing" (Lowry and Bright, 2002), entails the development of policies as "experiments that test the responses of ecosystems to changes in people's behaviour", and is also conceived as "managing the people who interact with the ecosystem, not the management of the ecosystem itself" (Lowry and Bright, quoted in Bidwell, 2003, p. 6). An adaptive approach to groundwater management necessarily requires appropriate analytical tools or models to support it, which are (op. cit., p. 6):

- Conceptually presentable and plausible to stakeholders, and expressive of a collective understanding of participants about the:
    - physical operation of the groundwater system;
    - assessment of uncertainties;
    - prediction of the effects of various management actions;
- Capable of implementation in "real-time"mode consistent with the time scale of adaptive decision-making; and
- Suitable for use with (often sparse) available data.

2.6 POVERTY ALLEVIATION

Groundwater development impacts positively on poverty alleviation and general quality of life through:

- supply of more and/or cleaner water;
- saving of time on water collection, particularly affecting women and children, which could otherwise be given to small –scale economic activities (vegetable gardening etc.) that require ready access to water and education or economic activity that require time.

The potential of groundwater in this ISP-area to contribute to poverty alleviation and empowerment of small-scale and Resource-poor Farmers (RPFs) is significant, e.g. the recent provincial government

Western Cape Olifants-Doring River Study (WODRIS). At present there is also local government (municipality) funding of RPFs through:

- provision of use of municipal land for farming activities;
- provision of water to RPF activities at no cost; and
- provision of loans which will be repaid once the RPFs become profitable.

Even around those rural towns and villages where surface water supplies are available for RPF activities, groundwater can still be better developed and managed for conjunctive use and has the benefit of decentralisation and being away from the river stems.

3. OVERVIEW OF GROUNDWATER BY ISP SUB-AREA

As a component of the National Water Resource Strategy (NWRS), the Minister of Water Affairs and Forestry established the boundaries of the Olifants/Doring WMA, which is comprised of 88 quaternary subcatchments, and has initially been divided it into five sub-areas. However, the current Internal Strategic Perspective (ISP) exercise initially proposes eleven key sub-areas "to aid improved management" (Notes for First Workshop ISP; 1-2 October 2003).

Surface water sub-areas

These key *surface*-water sub-areas are:

- Upper Olifants, consisting of 10 quaternary sub-catchments (E10A-K);
- Sandveld, consisting of 8 quaternary sub-catchments (G30A-H);
- Koue Bokkeveld, consisting of 11 quaternary sub-catchments (E21A-L);
- Upper Doring, consisting of 7 quaternary sub-catchments (E22A-G);
- Tankwa, consisting of 10 quaternary sub-catchments (E23A-K);
- Lower Doring, consisting of 12 quaternary sub-catchments (E24A-M);
- Oorlogskloof, consisting of 4 quaternary sub-catchments (E40A-D;
- Hantams, consisting of 5 quaternary sub-catchments (E32A-E);
- Kromme, consisting of 8 quaternary sub-catchments (E31A-H);
- Lower Olifants/Sout, consisting of 8 quaternary sub-catchments (E33A-H); and
- Goerap, consisting of 5 quaternary sub-catchments (F60A-E).

Because the original sub-areas used in the Situational Assessment report(s) were more detailed they allow for more flexible cross referencing between the proposed IWRM domains sub-areas presented below from a groundwater perspective (see **Table 2** below). They also have a particular topographic and geological and hydrogeological character.

At the first workshop these areas were reduced to 6 sub-areas **(see Figure 2).** Each of the six comprise one or more of the previous eleven except for minor amendments to the boundary between the Upper and Lower Olifants sub-areas and the boundary between the Lower Olifants/Sout and the Knersvlakte.

The six sub-areas are tabled below.

- Upper Olifants, consists of quaternary sub-catchments E10A – E10H (lost the E10 J, K);
- Kouebokkeveld, consists of quaternary sub-catchments E21 A – L (unchanged);
- Doring consists of quaternary sub-catchments E22A-G, E23A – K, E24A-M, E40A – D. (i.e. the former Upper Doring, Tankwa, Lower Doring and Oorlogskloof sub-areas);
- Knersvlakte consists of quaternary sub-catchments E31A – H, E32A – E, E33A – E, F60A – E (i.e. the former Kromme, Hantams, Lower Olifants/Sout, Goerap;
- Lower Olifants consists of quaternary sub-catchments E10J, K; E33 F – H (added E10J, K); and
- Sandveld consists of quaternary sub-catchments G30A – H (unchanged).

The E10J and K have become part of the Lower Olifants sub-area but remain in the revised Olifants Sub-area. The E33A – E catchments were previously in the Lower Olifants/Sout sub-area and are in the revised Knersvlakte sub-area which also comprises the Goerap sub-sub-area together with the F60A - E.

Groundwater regions (Vegter)

From a groundwater perspective, the Olifants/Doring WMA straddles six “groundwater regions” (numbers and names below after Vegter, 2001and associated tables), namely:

- Northern part of No 57 – Swartland;
- No 48 – Northwestern Cape Ranges;
- No. 56 – Knersvlakte;
- Southern part of No. 27 – Namaqualand;
- No. 36 – Hantam; and
- No. 37 – Tanqua Karoo.

The main boundaries of these groundwater regions are primarily geological, namely (1) the base of the Karoo Sequence, which – for its greater part - separates the eastern regions No. 36 and 37 from all of those underlain by pre-Dwyka formations on its western side (Nos. 48, 56 and 27), and (2) the base of the Cape Supergroup, which separates region No. 48 from those underlain by pre-Cape formations on its southern and northern sides (i.e. No. 57 and 56, respectively).

A notable exception to this general boundary rule occurs around the triple junction between region Nos. 36, 48 and 56. A logical placing would be where the Karoo basal unconformity overlaps the Cape basal unconformity. At present the boundary between regions No. 36 and 56 extends south-westwards along the Cape unconformity until it approaches the drainage divide between the Lower Doring (E24) and Oorlogskloof (E40) catchments. The boundary between regions No. 36 and 48 is drawn along the latter topographic feature, which above the Karoo unconformity becomes the boundary between regions No. 36 and 37.

Consequently the Hantam groundwater region No. 36 incorporates in its southwestern corner a part of the Cape Supergroup, where it is restricted to a tapering wedge of the Nardouw Subgroup only. Older parts of the Table Mountain Group wedge out beneath the Nardouw within the boundary of groundwater region No. 48, and post-Nardouw formations of the Cape Supergroup are eroded away beneath the Karoo unconformity.

The essentially geological and topographic (not strictly hydrogeological) delineation of groundwater regions aimed to "obtain some degree of uniformity in respect of lithostratigraphy, physiography and climate without ending up with an unmanageable number of regions" (Vegter, 2001, p.62). It was noted that delineation of "hydro(geo)logical units requires establishment of groundwater divides and flow paths".

Integrated Water Resource Domains

A relatively simple refinement of the six groundwater regions in the Olifants-Doring WMA, linked to quaternary catchment boundaries and better reflecting patterns of groundwater storage/flow and surface-groundwater interaction, recognises two main hydrogeological provinces (Adamastor and Western Karoo, respectively), each subdivided into two subprovinces *that facilitate integrated ground- and surface water quantification objectives* (**Table 2**). These are described as Integrated Water Resource Management (IWRM) Domains.

Table 2: Relation between IWRM domains and WMA sub-areas

Province	Subprovince	Situational Assessment sub-areas
Adamastor	Cederberg	Sandveld (G30 A – H) Upper Olifants (E10 A – K) W Kouebokkeveld (E21G, H, J, K) W Lower Doring (E24A, J, L, M, lower part of E24K) Lower Oorlogskloof (E40D)
	Knersvlakte	Lower Olifants/Sout, Goerap
Western Karoo	Tankwa Karoo	Upper Doring E Kouebokkeveld (E21A-F, L) Tankwa E Lower Doring (E24B-H, upper part of E24K)
	Hantam	Upper Oorlogskloof (E40A-C) Hantams Kromme

The distribution of the TMG Peninsula Aquifer is the main determinant of the eastern boundary between the Cederberg and Tankwa subprovinces, which is here made to coincide approximately with the TMG-Bokkeveld contact while respecting quaternary boundaries (except in the E24K instance). This proposed modification of the "groundwater regions" concept represents a development towards a hierarchy of aquifer-related spatial domains relevant and useful to Integrated Water Resources Management (IWRM) purposes (see **Figure 4**).

The success in the exploration and development of groundwater in this WMA and elsewhere will depend upon an appropriate exploration and management strategy. It can be confidently stated that IWRM is not possible if aquifer specific information is not available. If quaternary averaged MAP is used rather than isohyets and if realistic groundwater usage figures are not available and regularly updated, regulation of groundwater usage will not be successful.

Approach to Evaluating Groundwater Potential

A simple and robust approach to evaluating the unused groundwater potential has been adopted in this study. An aquifer specific GIS based evaluation of recharge using three different approaches (Riemann, Mlisa, Hay, in preparation) was undertaken in-house using the MAP data from the WR90 study.

Recharge

The average of three different GIS based in-house models (fixed recharge based on amount of rain and weighted as a function of lithology as per DWAF (2002); fixed recharge rates and recharge rate as per Turc (1954) is used to evaluate vertical recharge *on an aquifer specific basis*, normalized per quaternary, provides values that reasonably coincide with those documented by Vegter (1995).

The model appears to overestimate recharge to the primary and regolith aquifers, as it is weighted by the outcrop extent of the aquifer rather than the storage capacity. Using a low (<5%) fixed recharge rate based on the average rainfall appears to overestimate in the flood hydrology/sheet flooding and regolith aquifers dominated eastern and northern areas of the WMA. The regolith and primary aquifers are generally thinly developed (less than 50m). These areas have high temperatures and less than 200mm/a rainfall. In general recharge is unlikely to occur in years wherein less than 200mm of rain is received and the aquifers are usually only recharged in the extreme event.

In contrast, the storage in the TMG aquifers is significant and the recharge figures for the Peninsula and Nardouw Aquifers are considered to be very conservative. They do not reflect the impact of snowfall on recharge and it is known that the rainfall in the high lying areas exceeds the 2100 mm/a maximum given in the WRC 90 database.

The Sandveld, the Knersvlakte and the Lower Olifants sub-areas are dominated by primary aquifer outcrop, relatively low rainfall (300 – 500mm/a) and high temperatures. The relatively high factor (1.5) for weighting based on lithology used in the DWAF model (DWAF, 2000) as well as the fixed recharge model for the primary aquifers positively skews the results.

Baseflow

The baseflow estimates vary widely between Hughes, Pitman and Schulze. More recently Van Tonder has weighted the above estimates to derive an “average” value. In many instances, if the Hughes values are used the baseflow exceeds the recharge estimated at a quaternary level and a sub-area scale particularly in the TMG dominated terrain. In other instances the values derived by Schulze appear to be inconsistent with known spring distribution and flow rates. Rather than use a weighted average of previous numbers (van Tonder and Hughes) that is more complex to evaluate the local application of, the Pitman values have been used in this study.

Usage

The NWRS or Baron and Seward (2000) usage numbers are subtracted to establish the unexploited groundwater potential unless more recent usage figures based on local studies are available (e.g. Upper Olifants and Sandveld sub-areas). An in-house model was developed to establish groundwater usage. Comment is made as regards any difference in the usage values. The existing Hydrogeological map series (1: 500 000 DWAF Hydrogeological map series) cannot be used to determine usage. It is based on the average yields for different areas and the NGDB database for documented boreholes. The NWRS usage figures are used unless local studies with ground truth data are available (e.g. Sandveld and Upper Olifants sub-areas).

Groundwater available for abstraction

The Pitman values for baseflow given per quaternary are subtracted from the recharge and 50% of the result is assumed to be available for abstraction in the Upper Olifants, Lower Olifants, Kouebokkeveld and Sandveld sub-areas and 20% thereof in the Doring and Knersvlakte areas. Current usage is substracted in order to establish the amount of groundwater *currently* available.

Using 50% or 20% of recharge less baseflow is a simple and robust, but not definitive, estimate to take into account the impact of abstraction, storage and accessibility limitations, the current and potential impacts of abstraction as well as the variation in rainfall over a number of years including drought years without discriminating between these influences. While a 50% factor could be considered conservative for primary aquifers that are generally more efficient than fractured rock aquifers, this is offset by the recharge factors noted above in the Sandveld and Lower Olifants sub-areas. Upper and lower limits have been described in the Sandveld and Lower Olifants sub-area.

In areas that are dominated by flood hydrology, low rainfall (<200mm/a), low aquifer storage, extensive fractured rock outcrop and limited to no baseflow component, the model (Recharge – Baseflow)/2 is inappropriate. It is considered that 20% rather than 50% of Recharge – Baseflow is a more accurate reflection of the processes and this has been used in the Doring and the Knersvlakte sub-areas to calculate Groundwater Potential.

It may be that with more detailed and aquifer specific study in certain sub-areas only 10% is available or that up to 80% could be available. More detailed aquifer specific studies in different IWRM domains would improve the confidence in these estimates.

Discussion

Comparisons are made with the Harvest Potential and the Exploitation Potential[8] maps for purposes of comparing the numbers generated in this study with the only other available regional scale estimates of groundwater usage and potential. The differences in the methodologies are clearly understood and acknowledged. It is beyond the scope and not the purpose of this study to debate or to defend the differences merely to note them.

There will always be differences of opinion on the safe yield of a wellfield or an aquifer. The only way in which any values presented can be refined is to use the groundwater and have a well designed monitoring network that is appropriately monitored and the data correctly interpreted to update and revise estimates for groundwater abstraction as well as management thereof. This is adaptive management and is a critical component of risk management. It is possible that the Groundwater Resource Assessment Phase 2 study currently underway will address the differences in methodology used to date and address the scientific issues raised in this study.

In general the values realized in this approach are <u>*less*</u> than those documented in the Exploitation Potential (WSM 2000). The Exploitation Potential maps (DWAF 2000) indicate a total of 914 million m^3/a groundwater available for this WMA. The Exploitation Potential considers economic (accessibility) and environmental (impact, water quality) factors. Average borehole yield was considered as a proxy for transmissivity as the primary measure of exploitability. A value between 0 – 1 was assigned based on yields >3 l/s (0.7) or less 0.3 l/s (0.3) with other values ranging between and using transmissivity as the main consideration for area for this sub-area. A drought factor was applied. The impact of this factor is evident in the areas dominated by flood hydrology.

The Harvest Potential (Seward and Seymour 1996) is defined as the maximum volume of groundwater that may be abstracted per area without depleting the aquifers. It is based on the annual recharge and storage as estimated by Vegter (1995) combined with a rainfall reliability factor (20^{th} percentile precipitation divided by the median precipitation) as a measure of drought length. They appear to be more realistic in the Karoo dominated areas.

The ISP numbers are comparable with the NWRS but are higher in the TMG dominated areas. They are considered suitable for planning purposes and can be improved upon, once additional information becomes available in the Olifants and Kouebokkeveld areas.

The results and comparisons with available numbers are shown in the tables attached.

3.1 UPPER OLIFANTS (E10A – G)

This sub-area is a narrow N/S-trending valley bounded on the west by the Olifantsberge range, on the south by the Great Winterhoek range, and on the east by the Kouebokkeveld and Cederberg ranges. It

[8] Haupt's "Exploitation Potential" is the exploitation potential multiplied by a factor which is determined by borehole yields. Harvest Potential is an attempt to provide a maximum figure for groundwater available whereas Exploitation Potential is an attempt to estimate how much is practically abstractable.

consists of a major downfold (Olifants River Syncline) in the Table Mountain Group (TMG), containing two local outliers of Bokkeveld Group along the fold axis. Numerous major faults and fracture zones crosscut the structure, particularly along a NNW/SSE direction. Younger alluvial deposits occur around the river flood plain.

The E10 sub-area falls within the Cederberg Municipality, incorporating the town of Citrusdal (E10E). Citrusdal has experienced summer periods of failure in surface water supply from the Olifants River, and now obtains a groundwater supply from high-yielding boreholes (>20 l/s) in the Boschkloof wellfield. Citrus and other irrigated fruit farming activity is the economic mainstay in the valley. Groundwater is being increasingly seen as a solution to the summer shortfalls in irrigation water from the river in the portion upstream of the Clanwilliam Dam (E10D-F).

Groundwater quality varies significantly between the fractured-rock (quartzitic) aquifers and the “intergranular (weathered) and fractured” aquifers that overlie generally impermeable Bokkeveld shale formations. The TMG fractured-rock aquifers generally have an EC (TDS proxy) of less than 70 mS/m, whereas the regolith aquifers locally yield groundwater with EC greater than 300 mS/m.

Hot (>40°C) spring occurrences at The Baths and Warmwaterkloof (E10D), and various thermal artesian boreholes along the western side of the valley, indicate an active deep flow system from high (>1500 m) mountain recharge areas in the Kouebokkeveld and Great Winterhoek.

Groundwater from both shallow and deeper parts of the TMG fractured-rock aquifers provides the important base flow contribution to surface water drainage. Isotopic data from groundwater with a distinct TMG character abstracted along the coastal plain carry a high mountain signature and spring flow on the coast indicate lateral recharge in excess of local potential. Thus it has been postulated that groundwater that is recharged in the high lying area of the E10 also discharges in the coastal plain either as springs or subsurface into the primary aquifer in the Sandveld sub-area as well as directly at surface and sub surface along the coast. This hypothesis needs to be tested by drilling monitoring boreholes across the Peninsula, Piekenierskloof, Graafwater transition where it is cut by faults.

The groundwater yield (groundwater in use) is estimated at 4 million m^3/a in the NWRS documentation, probably representative only of the resource in alluvial and regolith aquifers in the axial part of the valley. Based on the CAGE hydrocensus data the abstraction as at 1999 was primarily from the Nardouw Aquifers (12 million m^3/a and 8 million m^3/a from remaining aquifers, totaling 20 million m^3/a.

The in-house usage model estimated that a maximum of 13 million m^3/a and 9 million m^3/a are abstracted from the Peninsula and the Nardouw aquifers respectively. The total usage is estimated at a maximum of 27 million m^3/a. Whilst the spatial pattern of usage is puzzling the total accords reasonably with the1999 CAGE data of ~12 from the TMG aquifers and ~20 million m^3/a abstraction in total. A usage of 12 million m^3/a was accepted at the second workshop for abstraction from the TMG.

For this study a value of 20 million m^3/a of groundwater usage is used.

The Pitman value for baseflow is 7.5 million m^3/a. The Hughes value for baseflow is 125 million m^3/a and would result in a groundwater deficit of 22million m^3/a.

The sum of estimated average recharge to all aquifers in this sub-area is 120 million m^3/a, of which the bulk is recharged to both the Peninsula and the Nardouw Aquifer.

In the E10C-G portion, a recharge-based approach indiscriminate of aquifer type or characteristics estimated allocable groundwater at ~25 million m^3/a (Conrad et al., 2003). A previous storage-based approach to *only* the confined Peninsula Aquifer in the CAGE study area (Hay and Hartnady 2000) estimated the deeper resource at ~45 million m^3/a. Haupt (1996) using the Water Situation Assessment Model (WSAM) estimated the Exploitable Potential in the E10C-G to be ~162 million m^3/a.

Of the 120 million m^3/a recharge estimated in this study, 73 million m^3 annually recharges the exposed portions of the Peninsula fractured-rock aquifer, 39 million m^3 recharges the Nardouw aquifer and 2.2 million m^3 recharges the shallow intergranular-and fractured system. About 2,5 million m^3 enters fractured aquifers other than TMG. 4 million m^3 recharges the primary aquifers, largely river alluvium.

Using the approach outlined in section 3 above *the available unexploited groundwater in this sub-area is* ***very conservatively*** *estimated to be 36 million* m^3*/a.*

It is supported by the CAGE study and the WRYM results in which the potential in the Peninsula aquifer in a conjunctive use scenario was evaluated to be 30 million m^3/a and in a storage based evaluation to be 45 million m^3/a.

The numbers are considered conservative with respect to earlier estimates in the range 457 million m^3. (Seymour 1996). The Harvest Potential and Exploitation Potential (WSM, 2000) are respectively estimated as 457 and 308 million m^3/a for this sub-area. It is not possible to understand or evaluate the discrepancies in the numbers at present because of the scale differences in the data available and insufficient published information on the assumptions governing the numbers at the quaternary catchment and aquifer specific scale.

The recharge estimates for the Peninsula and the Nardouw Aquifers which occupy the greatest outcrop area are ~ 112 million m^3/a. These aquifers have significant storage and even if the recharge to these aquifers were doubled (which is not wholly unreasonable in the case of the Peninsula Aquifer) the numbers remain disparate. It is necessary to evaluate using more detailed spatial and other input data than is available from published information how the Harvest Potential numbers were derived and to calibrate the recharge models using isotopic and other data (Hay, in preparation).

The estimates of unused groundwater potential in this sub-area and the rural nature of the population suggest that groundwater could contribute to widespread provision of the basic human need, as well as an allocation for irrigation via a conjunctive use scheme with or without the raising of the Clanwilliam Dam.

Issues

- The disparity in groundwater resource evaluation and quantification of sustainable pump rates is of concern and requires rationalization. It is necessary to prioritise detailed resource evaluation with respect to existing use, catchment/aquifer stress and dependency, particularly above the length of the Olifants River above the Clanwilliam Dam and as far as Klawer;
- There is concern over deep-drilling abstractions taking place in the Citrusdal area. The consequences of groundwater abstraction may or may not transect quaternary and tertiary catchment boundaries;
- It is uncertain to what extent groundwater abstraction in the E10 secondary catchment may impact on groundwater availability in the Sandveld and *vice versa*. It is necessary to establish the transmissivity of the Piekenierskloof Formation and the Graafwater Formation as well as potential for hydraulic connection with the Peninsula Aquifer arising from structural discontinuities to objectively evaluate this concern;
- Registration of farmer's boreholes requires attention;
- Exploration and management of the confined artesian basin requires consideration as *ad hoc* development and management of the aquifer could lead to significant degradation of the resource. Artesian groundwater needs to be controlled, perhaps through proclamation of a Groundwater Control Area;
- (Groundwater quantity) There are differences of professional opinion as to what the safe yield is of a wellfield or an aquifer in this area. ACTION: Prepare a best international practise standard for fractured rock aquifer resource and wellfield evaluation using quantitative methodologies applicable to fractured rock ACTION: Evaluate the level of certainty needed with regard to the local and regional scale use and level of stress in the aquifer or SW/GW/ECO system, taking into account local priorities and political sentiment;
- Groundwater management: Groundwater allocations particularly where aquifer storage capacity can be considered over more than one season must take into account the worth of the use of water, the period needed for this use and the time needed for aquifer levels to recover from possible temporary over abstraction. This is a resource management issue and shall require cooperative governance;
- Licensing/Groundwater: There is lack of clarity on RDM as regards the evaluation process for issuing of licenses, hence license applications are taking up to five years or more to be processed, possibly due to is a lack of capacity (competence confidence and legal context know how) to deal with the license applications. *Actions:* Institute formal training for staff in how to deal constructively with license applications and what would be appropriate conditions with reasonable compliance with the law. Review and revise DWAF procedures and chain of communication/command with regard to processing of licensing applications. RO Geohydrology recommends that profession-specific input is identified and the co-ordination for finalisation of license applications is centralized;
- Licensing/Groundwater: It is possible that in the Reserve determination process that access to groundwater will be lost or reduced in some areas. ACTION: Prepare plan on how to manage this process and determine constructive intervention;

- The feasibility/desirability of allocating groundwater to resource-poor farmers, possibly away from river stems as opposed to increasing allocations to established farmers who primarily occupy riparian land.

3.2 SANDVELD (G30)

This sub-area bounded on the west by the Atlantic coastline, on the east by the Olifantsberge range, and on the south by the Piketberg range. It is underlain on the eastern side by a major upfold (Porterville Antcline) in the pre-Cape basement (Malmesbury Group) and overlying Table Mountain Group (TMG), which in this area consists mainly of the lower section (Piekenierskloof, Graafwater and Peninsula Formations). On the western side, localized synclinal downfolds plunge in a northwesterly direction from the Piketberg divide, subparallel to a major fault that crosses the coastline near Elands Bay. Numerous other major faults and fracture zones crosscut the fold structures, particularly along a NNW/SSE direction, extending across the Olifantsberge divide with the adjacent E10 sub-area.

Along the coastal plain, young wind-deposited sands cover older marine deposits related to former high stands of sea level, and also more localized fluvial deposits in buried palaeochannels related to former low stands of sea level during times of much less arid palaeoclimate. In certain central areas of the Sandveld it is postulated that these deeper-lying, fluvial, intergranular aquifers are mainly recharged, not from the overlying land surface, but from lateral inflows of far-traveled (E10 source area and local highlands e.g. Piketberg) groundwater from fracture systems in the underlying TMG units. Isotopic and hydrochemical (macro and trace) data from relevant Sandveld and TMG boreholes support this hypothesis (Cage Study, DWAF 2000).

The G30 sub-area is divided between the Cederberg Municipality, here incorporating the towns of Elands Bay (G30E), Lamberts Bay and Graafwater (G30G), and the Matzikama Municipality, here incorporating the coastal settlements of Strandfontein and Doring Bay (G30H). Apart from fishing and eco-tourism around the coastal resort towns, potato farming, using center-pivot irrigation technology, is the economic mainstay on parts of the G30 coastal plain. All of these activities are entirely dependent on groundwater, except in a restricted northern part of the G30H, where a canal from the Olifants River Government Scheme, reaches Strandfontein and Doring Bay, and along the Verlorevlei drainage (G30B-E), supplied by perennial stream flows from the Olifantsberge and northern Piketberg.

Groundwater quality varies significantly between the fractured-rock (quartzitic TMG) aquifers discharge, the primary aquifer of marine origin, the primary aquifer of alluvial origin and the fractured dolerite dyke aquifer (of limited extent). The TMG underlies the primary sediments except in the extreme south of the sub-area which is underlain by Malmesbury bedrock. TMG fractured-rock aquifers generally have an EC (TDS proxy) of less than 70 mS/m, whereas the primary aquifers have a EC varying between <80 and up to 800 mS/m depending upon whether the sample was taken from palaeochannels which receive TMG discharge or the primary aquifers of marine origin and whether saline intrusion is evident or not. The pH varies from 5.4 to >7.8.

The usage of 30 million m^3/a (DANIDA 2003) is used since it is the only value based on ground studies and is recent.

Groundwater usage is variably estimated. It has been estimated to be 30 million m^3/a in the G30 A – H (Danida 2003) but does not consider abstraction from the Peninsula aquifer. Baron and Seward (2000) estimate usage to be 30 million m^3/a, the number used in the NWRS. An in-house model estimates 76 million m^3/a and includes abstraction from all aquifers including the fractured rock aquifers on the western limb of the Olifants Doring River syncline. If the DANIDA groundwater usage figures are correct then there is considerably more groundwater available than previously thought.

Using the in-house ISP model total groundwater recharge is estimated to be 135 million m^3/a. This comprises of 56 million m^3/a into the Primary Aquifer, 40 million m^3/a recharges the Peninsula Aquifer, 14 million m^3/a the intergranular and fractured aquifer and 24 million m^3/a recharges the fractured aquifers other than the Peninsula or Nardouw.

The recharge to the primary aquifer, which occupies 44% of the sub-area surface, could be overestimated in this study. Generally if the rainfall is less than 200 mm/a, no vertical recharge is considered. In this sub-area it varies between ~300 – 500mm/a and a fixed recharge rate of 4% was assigned in one model. This yielded the lowest in the recharge range of 31 – 71 million m^3/a to the primary aquifer calculated using different methods. The DWAF model allocates a factor of 1.5 to recharge to primary aquifers accounting for the high-end value.

The extent to which there is hydraulic connection between the Peninsula Aquifer and thus lateral recharge to the coastal plain is a function of the hydraulic connectivity across the Piekenierskloof and Graafwater Formations with the latter being of a less transmissive nature (see section 3.1 above). No lateral recharge has been taken into account.

For consistency the Pitman value of 1 million m^3/a for baseflow is used.
Pitman estimates the baseflow to be 0.75 million m^3/a. Discharge from the Peninsula Aquifer to the primary aquifer based on spring hydrocensus data collected for the CAGE project was estimated to be 0.7 – 2 million m^3/a and considered to be underestimated. Hughes estimates the baseflow to be 10 million m^3/a.

The unexploited groundwater potential is 37 million m^3/a.
It is noted that use of 50% in this study estimation of *Groundwater Available for Abstraction/Potential* is conservative for intergranular aquifers, but considered appropriate given the uncertainty as regards the recharge and baseflow numbers. Groundwater Potential could be as low as 12 million m^3/a. (using lowest model recharge value for primary aquifers, highest baseflow (Hughes) but lowest usage (Danida, 2003)). The worst-case scenario (lowest recharge value, highest abstraction (Umvoto model) and highest baseflow (Hughes)) results in a groundwater deficit of 14 million m^3/a, with the G30F-H being stressed at present abstraction rates.

The Harvest Potential (Seward and Seymour 1996) and the Exploitation Potential (WSM 2000) for this sub-area as per the DWAF Hydrogeological series are given as 224 and 136 million m^3/a respectively. The former is significantly higher than the estimated total recharge of 132 million m^3/a obtained in this study.

The G30F is reported in the Danida study to be stressed. Outside of these catchments it would be expected that any declining water levels, seawater intrusion would be a result of inappropriate aquifer management rather than groundwater shortage or over abstraction

Issues:

- Stressed areas/future requirements: Elands Bay (G30F), Lamberts Bay, Graafwater, Nuwedorp and Leipoldtville are dependent on groundwater and there are concerns because there are no backup supplies to these towns;
- Between Elands Bay and Lamberts Bay, the G30F is considered to be a stressed aquifer (Danida 2003). Results of this study suggest that the G30 G and H and Strandfontein area should be monitored for early warning signs of stress and seawater intrusion. ACTION: Prepare monitoring plans and once the resource has been reliably quantified and seasonal and spatial patterns of recharge are understood, management plans can be established and tested in practice;
- The Wadrif Wetland is considered to be particularly vulnerable to groundwater mismanagement.
- There is concern that Sandveld groundwater availability may be influenced by the water abstraction from the Upper Olifants sub-area and *vice versa*. It is necessary to establish the transmissivity of the Piekenierskloof Formation and the Graafwater Formation as well as potential for hydraulic connection with the Peninsula Aquifer, arising from structural discontinuities to objectively evaluate this concern;
- Potato farmers in the Sandveld are polluting the groundwater with their effluent and are abstracting groundwater without proper licence arrangements. Pollution from vineyards also has a seasonal effect, and to a lesser degree also lucerne and barley wheat. ACTION: Groundwater should be protected from pollution by establishing recharge zone protection and wellhead protection standards, and monitoring agricultural practise and effluent discharge;
- There is a need to evaluate the potential for utilization of poor quality groundwater and to blend it with surface water or treat it using reverse osmosis;
- Evaluation of the groundwater Reserve of coastal vleis and estuaries and the dependence of these ecosystems on perennial spring discharge is important;
- WWTWs and the use of septic tanks will have an impact on groundwater quality (e.g. Redelinghuys) and should be monitored;
- Cumulative impacts of individual or small-scale groundwater developments are insufficiently documented;
- There is no Working-for-Water programme in the Sandveld, but the impact of clearing alien vegetation on groundwater discharge and recharge should be monitored, in order to inform prioritisation of alien clearing as a component of groundwater catchment management;
- The Sandveld Forum has been experiencing poor support and cohesion, perhaps due to the fact that as a groundwater dependent area, there is no history of user cooperation as practiced elsewhere with irrigation boards;
- There is a need to educate people on utilising and monitoring groundwater particularly at municipalities;
- In order to adequately monitor and protect groundwater resources from contamination by irrigation return flow and/or seawater intrusion, the monitoring data that is required is of a background, diffuse and a point source nature. At present the relevant data from the RO Water

Quality sub-directorate is not being integrated into the groundwater database in a routine manner and neither does the capacity currently exist within the hydrogeological division to evaluate the data itself;

- Groundwater monitoring sites are considered adequate by RO, but the frequency of monitoring requires attention. The groundwater needs to be monitored more regularly, with particular emphasis on the piezometric levels and electrical conductivity (as a WQ proxy measure). Biological monitoring is required. The monitoring network design requires careful evaluation as regards bedrock discharge and lateral recharge to the primary aquifers.

3.3 KOUE BOKKEVELD (E21)

This sub-area of the Riet and Leeu river drainages lies between the Kouebokkeveld and southern Cederberg ranges on the west (E10 boundary), and the Swartruggens range on the east (E22 boundary. It is underlain by formations of the Table Mountain Group (TMG), Bokkeveld Group and Witteberg Group, affected by several N/S-trending open fold axes. Major faults and fracture zones crosscut these structures, particularly along a NNW/SSE direction crossing the adjacent E10 boundary divided within TMG fractured-rock aquifers. Younger alluvial deposits occur in restricted areas around the river flood plains.

There are no towns in this area, hence no municipal supply schemes, but there is intensive agricultural (over-)development, mainly deciduous fruit and vegetables, on lands underlain by Bokkeveld shales on the western side of the area (E21D, E21G) and numerous boreholes have been drilled around the TMG-Bokkeveld contact here.

According to current NWRS (under-)estimates the available groundwater resource is 5 million m^3/a, and the total demand exceeds the available surface water resource by about 7 million m^3/a, mainly met by groundwater and return flow. Unless significant water conservation and demand management can be implemented, any further agricultural development would depend on the discovery of an additional groundwater resource, which could possibly be realised by deep exploration of the TMG Peninsula Aquifer in confined artesian settings.

The most important aquifers are the Peninsula, the Nardouw and the Witteberg quartzites. These aquifers are thicker than 100 – 200 metres thus having significant storage potential. The groundwater quality is acidic to neutral with the Witteberg becoming alkaline in places. The EC varies but is generally less than 75 mS/m varying between <10 and 75 with discreet outliers above 100 and 200 mS/m. These outliers are associated with the contact zone with the regolith aquifers.

To date the Peninsula aquifer and the Witteberg Series are under-exploited. This is true for both aquifers throughout the Western and the Eastern Cape, but more particularly the Witteberg which is as yet also seldom considered or given strategic priority in local and regional studies. The Witpoort Formation is the preferred target in the Witteberg Series and the regolith aquifer.

The regolith aquifer comprises all pre-Cape rocks (Malmesbury and Namakwa/Gariep and Nama sediments), the Karoo sequence and the Bokkeveld group. In general the groundwater quality in the regolith (weathered and fractured rock) is poor although the recharge estimate (see **Appendix B**) indicates 14 million m^3/a. The boreholes are generally drilled to depths below 100 m and yields are low (<5/s. The water is alkaline and the EC is largely above 100 mS/m. The exception are the Bokkeveld Sandstone Formations which have a lower EC (<75 mS/m and often yield between 5 and 20 l/s. The groundwater yield in the Bokkeveld sandstones is dependent upon local discharge from the TMG.

The NWRS usage figure of 5 million m^3/a is used in this study

Haupt (2000) estimated the groundwater use at 18.5 million m^3/a. The in-house model estimates usage at 14 million m^3/a.

The recharge is estimated at 110 million m^3/a

The Peninsula receives an estimated average of 26 million m^3/a, the Nardouw 32 and the Witteberg quartzites 34 million m^3/a. The regolith and primary aquifers receive an estimated 14 and 3 million m^3/a respectively.

The baseflow is 7.3 million m^3/a. (Pitman)

Hughes has estimated the baseflow to be 86 million m^3/a. If this were correct there would be a groundwater deficit of 2 million m^3/a in this sub-area.

The unexploited groundwater potential is very conservatively estimated to be 37.5 million m^3/a.

The Harvest Potential and the Exploitation Potential are given as 284 and 178 million m^3/a respectively for this sub-area. Both these numbers are significantly higher than the estimated recharge of 109 million m^3/a for the area. It is possible that the recharge to the TMG aquifers and the Witteberg that dominate the area has been under-estimated as it is known that the high mountain rainfall is very conservative and that snowfall would play an important role in groundwater recharge in this area. It is considered that recharge would reach as much as 45% of precipitation in the high lying areas whereas a maximum of 21% has been used in the in-house models in this study.

This difference would still not account for the discrepancy. It warrants more detailed study.

Issues:

- No groundwater issues were recorded. It is critical however to improve the groundwater resource evaluation in this water short sub-area.

3.4 DORING (E22, E23, E24, E40)

This large, geologically heterogeneous ISP sub-area has four main divisions, i.e., the Upper Doring, Tankwa, Lower Doring and Oorlogskloof areas, each separately described in the following subsections.

3.4.1 Upper Doring (E22)

This sub-area lies between the Swartruggens range on the west (E21 boundary), the Witteberg range on the south (J drainage boundary), and a ridge extending from the escarpment range (E24 boundary). It is underlain by formations of the Witteberg Group, Dwyka Formation, Ecca Group, and lower Beaufort Group. These strata generally dip at shallow angles eastward, but in the south-east (E22A-D) they are affected by several ENE/WSW-trending open fold axes related to the folding in the Witteberg range. The E22E subcatchment lies at the SE termination of a NW/SE fault system that is related to the major TMG faults and fracture zones in the southern Cederberg. Younger alluvial deposits occur in restricted areas around the river flood plains.

The Witteberg and the regolith are the largest primary aquifers in the sub-area. The regolith aquifers comprise the Dwyka and the Ecca Formations which generally yield non-potable water and very little of it. The groundwater in the Witteberg has an EC <75 mS/m and a pH varying between 5 and 8.5 but generally being <7.

Due to the flood hydrology it is generally the infrequent events that recharge the aquifers in this area. The recharge estimate for the Witteberg is estimated to be 26 million m^3/a and to the regolith aquifer 29 million m^3/a. There is a small exposure of the Nardouw in this area that can be discounted. Recharge to the alluvial aquifers is estimated to be 2 million m^3/a. The water quality in the alluvial aquifer will vary depending upon the runoff provenance.

The total usage in the sub-area is estimated in this study to be ~ 2 million m^3/a. The Harvest Potential and Exploitation Potential for this sub-area is given as 55 million m^3/a and 29,5 million m^3/a respectively. The recharge estimates (57 million m^3/a) obtained in this study and the Groundwater Harvest Potential are in reasonable accord.

Much of the unexploited groundwater is of very poor water quality and given relatively low yields would be capital intensive and not suited for any large-scale supply. Emphasis must be given to the Witteberg Aquifer and the alluvium for storage potential and contributions to base flow.

3.4.2 Tankwa (E23)

The Tankwa Karoo is bounded on the east by the escarpment range and its southern promontory ridge (J Drainage boundary), which form a triangular amphitheatre leading down to a confluence with the main stem of the Doring. It is underlain by generally gentle-dipping strata of the Dwyka Formation, Ecca Group, and lower Beaufort Group, affected by mild folding in the south. Younger alluvial deposits occur in restricted areas around the Tankwa river stem.

The largest aquifer is regolith comprising the Karoo sequence (Dwyka and Ecca). While the recharge is estimated to be 63 million m^3/a the water quality is very poor and the yields are very low. There is ~4.5 million m^3/a recharge estimated to the alluvial aquifers and water quality will be controlled by runoff provenance and therefore likely to be of poor quality. The groundwater Harvest Potential is estimated at 51 million m^3/a and the Exploitation Potential at 28 million m^3/a. The total groundwater usage is estimated at <1 million m^3/a. The best available sources would be in the fractured dolerite dykes and the alluvium. Recharge in to these aquifers is estimated to be 1 million m^3/a and 4 million m^3/a respectively. Storage potential is unknown.

Given the groundwater quality and low yields the rainfall harvesting and use of the storage in the alluvium is recommended rather than conventional groundwater exploration.

3.4.3 Lower Doring (E24)

This heterogeneous area is bounded on the east by the escarpment range, which has promontories and subcatchments (E24C, D, E, F, K) leading to confluences on the right bank of the Doring; on the west by the northern Cederberg range (E10 boundary), runoff from which feeds tributary subcatchments (E24A, B, L) on the left bank. Between these areas lie central subcatchments (E24H, J, M) along the main river stem. A small area of pre-Cape Gariep Group occurs along the Klawer Fault in the E24M area around the Olifants-Doring river confluence. The western and central stem subcatchments are underlain by gently folded formations of the Table Mountain Group, Bokkeveld Group, and Witteberg Group. The eastern subcatchments are underlain by gently east-dipping strata of the (upper) TMG, Bokkeveld Group, Dwyka Formation, Ecca Group, and lower Beaufort Group. Karoo dolerite intrusives (dykes and sills) are abundant in strata above the Dwyka Formation. Younger alluvial deposits occur in restricted areas around the river courses.

The total recharge estimate for this area is 122 million m^3/a of which ~ 55 million m^3/a is to the TMG aquifers, 10 million m^3/a to the primary aquifers on the coastal plain, 7 million m^3/a to the Witteberg and 6 million m^3/a to the dolerite dykes. The balance is to the regolith aquifers that dominate the eastern sub catchments. The total usage is estimated to be 19 million m^3/a, with the greatest volume being abstracted from the Nardouw (7 million m^3/a) and the regolith aquifers (10 million m^3/a).

The Harvest Potential and the Exploitation Potential is given as 174 million m^3/a and 105 million m^3/a respectively. The recharge estimates have not been reconciled with those prepared for the WODRIS study in which more detailed geological and rainfall data was used. The estimates in this study are conservative. It is considered that at least 63 million m^3/a would be available primarily in the fractured rock aquifers.

3.4.4 Oorlogskloof (E40)

This sub-area extends in a relatively narrow belt from the escarpment range (Lower Orange WMA boundary) in the east, curving south along a canyoned stretch in the Nardouwberge range on the west (E33 boundary), to its confluence with the Doring River. A small area of pre-Cape Nama Group occurs near the southwards bend in the E40C subcatchment and in small inliers father south (E40D). The western subcatchments (E40C, part of E40 D) are underlain by sub-horizontal formations of the Cedarberg Formation and Nardouw Subgroup (Table Mountain Group), and a narrow wedge of the Bokkeveld Group. The eastern part of E40C and the remaining subcatchments (E40A, B) strata of the Dwyka Formation, Ecca Group, and lower Beaufort Group and Karoo dolerite intrusives (dykes and sills) are abundant in strata above the Dwyka Formation.

The estimated total recharge is 44 million m^3/a. Most of the usage is from the regolith aquifers with minor amounts from the dolerite dykes. The Harvest Potential and the Exploitation potential are given as 57 million m^3/a and 32 million m^3/a, respectively.

The groundwater in the Oorlogskloof sub-area will be of a poor quality requiring reverse osmosis unless it is abstracted from the dolerite aquifer. Yields are low and it would be suitable only for stock watering. It is not possible in this study to reconcile the numbers without detailed examination of local scale studies. This is beyond the scope of this study.

3.4.5 Sub-area summary

For the entire Doring ISP sub-area, *the NMWRS usage figure of 3.3 million m^3/a is used.*
Haupt (2000) estimated the groundwater use at 4.6 million m^3/a. The in-house model estimates usage at 40 million m^3/a.

The recharge is estimated at 294 million m^3/a
The Peninsula Aquifer receives an estimated average of 11 million m^3/a, the Nardouw 60 million m^3/a and the Witteberg quartzites 32 million m^3/a. The regolith and primary aquifers receive an estimated 162 million m^3/a and 17 million m^3/a respectively. Fractured dolerite dykes and sills receive an estimated 12 million m^3/a.

The baseflow is 0.5 million m^3/a. (Pitman)
Hughes has estimated the baseflow to be 17,5 million m^3/a.

The unexploited groundwater potential is very conservatively estimated to be 58,4 million m^3/a. using 20% of (Recharge – baseflow)
If a 50% factor is used the Groundwater Potential is 107 million m^3/a

The Harvest Potential and the Exploitation Potential are given as 338 million m^3/a and 194 million m^3/a, respectively, for this sub-area. Both these numbers are higher than the estimated recharge and the unexploited groundwater determined in this study. The recharge values are dominated by the large outcrop of regolith aquifers and the use is also primarily in this aquifer. There groundwater quality is poor and the aquifer is inefficient. It is possible that the higher potential (107 – 198 million m^3/a) could not be realized in practical terms. However to evaluate this will require more detailed study, in particular quantifying the long term recharge average in a flood hydrology dominated environment as well as the possible discharge of groundwater from the TMG aquifers into the Doring River catchment.

Issues:

- Monitoring systems should be put in place in the upper, more mountainous reaches of the rivers, mainly in the form of weather stations so that the inter-relationship between the presence of snow and the low flows experienced during the summer months can be closely studied;
- Potato farmers are abstracting groundwater without proper licence agreements.
- Calvinia (small dam and three boreholes) and Nieuwoudtville (one borehole) are reliant on groundwater and are stressed urban supply areas;
- There is a need to evaluate the potential for utilization of poor quality groundwater and to blend it with surface water or treat it using reverse osmosis.

3.5 KNERSVLAKTE (E31A-H, E32, E33A-F, F60)

This ISP sub-area comprises the Hantam, the Kromme, the Lower Olifants and the Goerap areas.

3.5.1 Hantams (E32)

This area extends from the escarpment range (Lower Orange WMA boundary) in the east to a confluence with the Krom River in the west, before the latter joins the Sout River. The western, terminal subcatchment (E32E) is underlain by gently dipping formations of the Nama Group, a northward thinning wedge of Nardouw Subgroup (Table Mountain Group) in the south, covered by Dwyka Formation tillite along its eastern border. The eastern subcatchments (E32D-A) expose strata of the Dwyka Formation and Ecca Group, overlying upper Nama beds (in the western part of E32D). Karoo dolerite intrusives (dykes and sills) are abundant in strata above the Dwyka Formation.

The recharge is estimated to be 47 mm^3/a. The primary usage is from the regolith aquifers (12 million m^3/a) and the dolerite dykes (3 million m^3/a). Given the low volume high dependency pattern of usage it is assumed that it would be economic for stock watering and domestic use.

The Harvest potential and the Exploitation potential are given as 41 million m^3/a and 22 million m^3/a, respectively. The numbers are in reasonable accord with the results of this study.

3.5.2 Kromme (E31)

The northern boundary of this sub-area extends across a topographically subdued portion of the Great Escarpment divide (Lower Orange WMA boundary) around a region of endoreic drainage (E31A subcatchment), which is postulated to have been connected several tens of millions of year ago to an extensive palaeo-drainage system in the southern part of the Lower Orange WMA. During the climatically much wetter conditions at that time, the present Olifants-Doring River was a relatively minor southern tributary of this major Bushmanland-Karoo river system.

The western, terminal subcatchment (E31H) is underlain by gently dipping formations of the Nama Group overlying basement graniotids of the Namaqualand Metamorphic Complex (NMC). NMC basement underlies Dwyka Formation tillite and Ecca Group shale in the western part of the sub-area (E31A, D, E, G, H). The eastern subcatchments (E31B-C) expose strata of the Dwyka Formation and lower Ecca Group, overlying NMC basement (in the western part of E31C). Karoo dolerite intrusives (dykes and sills) are abundant in strata above the Dwyka Formation. Extensive alluvial cover sediments occur above Dwyka bedrock near Kliprand (eastern part of E31A) and above NMC bedrock lower down in the E31D and E31 H subcatchments. These younger cover deposits may be related to the former floodplain of the Bushmanland-Karoo palaeo-drainage.

The groundwater quality is poor.

There is a large difference between the recharge estimates obtained in this study, and the groundwater Harvest Potential and Exploitation values given in the DWAF Hydrogeological series. These are 70 million m^3/a, 16 million m^3/a and 8 million m^3/a respectively. The most conservative value has been selected to be used in this study.

It is most likely that the recharge models used over estimate recharge in this arid flood hydrology environment where the MAP is under 200 mm per annum and for practical purposes, it is common practise to assume that zero recharge is recorded since aquifers are only recharged in extreme events. In this situation the storage of the aquifer is critical to evaluating the potential and this, although not explicitly documented for this area or these aquifers, was taken into account in the *Harvest Potential* calculations by WSM (2000).

For strategic planning purposes it is considered that there would be limited groundwater potential in this sub-area. Reports of declining water levels in the small town supplies support this.

3.5.3 Lower Olifants/Sout (E33A – E)

The eastern boundary of this sub-area extends northwards along the crest of the Nardouw escarpment around Van Rhyns Pass and across the north-eastern section of the Knersvlakte plain around the area of the Kromme, Hantams and Sout river confluences, part of the ancient flood plain of the now decapitated Bushmanland-Karoo river system.

Except for a thin fringe of TMG formations around its south-eastern and south-western margins, this sub-area is underlain mainly by Nama Group overlying basement granitoids of the Namaqualand Metamorphic Complex (NMC) in its northeastern part, and by Gariep Group strata overlying reworked NMC basement in its south-western part. Karoo intrusives (dykes and subvolcanic complexes occur in some part of the area. Extensive alluvial cover sediments occur above NMC and Nama bedrock in the Knersvlakte parts of the E33A, E33B and E33D subcatchments. These particular cover deposits may be related to the former floodplain of the Bushmanland-Karoo palaeodrainage.

The sub-area is dominated by the primary and regolith aquifers with a small exposure of the Peninsula and the Nardouw aquifers.

The recharge and usage values obtained, using the models in this study, are estimated to be 95 mm^3/a and 52 million m^3/a respectively. These are not considered to be reliable and further work would be required. The Harvest potential and the Exploitation Potential are calculated to be 33 million m^3/a and 20 million m^3/a respectively. As in the Hantam sub-area the rainfall to the primary aquifers is below 200 mm/a and recharge is expected to be infrequent and related to extreme events. Thus the average obtained from the three recharge models used in this study would not be appropriate as it is skewed.

The lowest recharge value obtained for the Primary aquifer in this sub-area is 40 million m^3/a. The lowest recharge value obtained for the regolith aquifers is 22 million m^3/a i.e. a lower estimate of 62 million m^3/a, still considered somewhat high. It is not specified how the Harvest Potential recharge and storage estimates were made at the aquifer specific nor quaternary scale and the numbers cannot be reconciled.

It is sufficient for strategic planning purposes to record that the groundwater potential is limited by aquifer storage that is at this stage unknown. The recharge processes and patterns with respect to the historical rainfall record are also unknown. Given this the predictions must be conservative. However it is critical that correct groundwater usage figures are established.

3.5.4 Goerap (F60)

The eastern boundary of this sub-area extends northwards along the crest of the Nardouw escarpment around Van Rhyns Pass and across the north-eastern section of the Knersvlakte plain around the area of the Kromme, Hantams and Sout river confluences, part of the ancient flood plain of the now decapitated Bushmanland-Karoo river system.

Except for a thin fringe of Nama formations along faulted contacts near its north-eastern boundary, this sub-area is underlain mainly by reworked NMC basement, overlain by Gariep Group formations and small outliers of TMG in its south-western part. Karoo intrusives (dykes and subvolcanic complexes occur in some part of the area. Aeolian, shallow-marine and alluvial terrace deposits occur in a belt along the coastal plain.

The young wind-deposited sands cover older marine deposits related to former high stands of sea level, and also more localized fluvial deposits in buried palaeochannels related to former low stands of sea level during times of much less arid palaeoclimate. The F60E area is of particular interest with regard to possible former fluvial and estuarine deposits related to a more northerly mouth of the palaeo-Olifants system.

The area is dominated by the regolith and the primary aquifers and experiences a rainfall of close to or less than 200 mm/a. The average groundwater recharge in this study in the Goerap sub-area is estimated to be 25.5 million m^3/a and the lowest estimate would be 18 million m^3/a. The usage is estimated to be ~ 3 million m^3/a, the Harvest Potential is recorded as 15 million m^3/a and the Exploitation potential as 7 million m^3/a.

It is recommended that the most conservative value for *Unexploited Groundwater Potential* is 7 million m^3/a. DWAF figures are used for strategic planning purposes.

3.5.5 Sub-area summary

The NWRS value for groundwater usage is 3 million m^3/a.
The groundwater usage is primarily in the regolith aquifer with some use of the primary aquifer. The actual groundwater usage figures are unknown. The in-house model indicates very high groundwater usage of 34 million m^3/a, which is most likely an indication of a high number of dry or abandoned boreholes since a success rate was not applied.

The Pitman value for baseflow is zero million m^3/a.
The Hughes model gives baseflow as 0 million m^3/a.

Recharge in this sub-area is 207 million m^3/a.

The unexploited groundwater Potential is 38 million m3/a.

The NWRS indicates 19 million m^3/a unexploited groundwater potential. **We recommend that the lower figure be used for planning purposes, until updated usage and recharge figures are available.** The area in general receives less than 200 mm/a rainfall, and is dominated by large outcrop areas of regolith aquifer and thus limited aquifer storage. Recharge would only happen in the extreme event.

The Harvest Potential and Exploitation Potential are given as 82 million m^3/a and 42 million m^3/a, respectively. It is most important that the correct usage values are obtained and the impact of recharge in extreme events only is better understood in order to refine the unexploited groundwater potential. The results of the robust method used in this study and the Groundwater Exploitation Potential are otherwise in reasonable accord.

Issues:

- Water has a high salinity, generally not of a potable standard (TDS of 1000 mg/l at best);
- Loeriesfontein (six boreholes) is reliant on groundwater and is a stressed urban supply area;
- Monitoring/paucity of data: The groundwater situation in the E31 sub-area needs to be studied;
- Groundwater management: Groundwater allocations particularly where aquifer storage capacity can be considered over more than one season must take into account the worth of the use of water, the period needed for this use and the time needed for aquifer levels to recover from possible temporary over abstraction. This is a resource management issue and shall require cooperative governance;
- Bitterfontein (seven boreholes), Nuwerus, Rietpoort and Mulsvlei urban supply areas are reliant on groundwater and are stressed;
- Bitterfontein has a desalination plant, which for the local municipality is too costly to run, although running costs have been reduced considerably over time;
- There is a need to evaluate the potential for utilization of poor quality groundwater and to blend it with surface water or treat it using reverse-osmosis.

3.6 LOWER OLIFANTS (E33F – H, E10J-K)

This sub-area covers the lower main stem of the Olifants River below Klawer (E33G-H), the Troe-Troe (E33F) tributary in the Vanrhynsdorp area, and the main stem of the Olifants below Clanwilliam Dam and around the Doring confluence (E10J-K). The E33F-H catchments area is underlain mainly by low-grade metamorphic schists, limestone and marbles of the Nama and Gariep Groups, locally overlain by aeolian, shallow-marine and alluvial terrace deposits. The E10J-K catchments are underlain by gently folded and faulted Table Mountain Group (TMG) units, with localized outcrop of lower Bokkeveld Group around Clanwilliam (E10J).

The Baron and Seward (2000) value for groundwater usage of 1 million m^3/a is used
The groundwater usage is primarily in the primary aquifer along the coast and in the regolith aquifer with some use of the TMG aquifers. The actual groundwater usage figures are unknown. The in-house model indicates very high groundwater usage of 52 million m^3/a which could be an indication of a high number of dry or abandoned boreholes. Haupt (2000) estimated 0.28 million m^3/a.

The Pitman value for baseflow is 0.77 million m^3/a.
The Hughes model gives baseflow as 9 million m^3/a.

Recharge in this sub-area is 60 million m^3/a.
A total of 21 million m^3/a is to the primary aquifer, 17 million m^3/a and 14 million m^3/a to the Peninsula and Nardouw Aquifers respectively, and a nominal 7 million m^3/a to the regolith aquifers.

The Unexploited Groundwater Potential is 29 million m^3/a.
This is largely a function of what the current groundwater usage is. If it is as low as indicated by Haupt (2000), there is 24 million m^3/a available. If the modeled usage and Pitman baseflow is used, there is a 22 million m^3/a groundwater deficit. The groundwater exploitation figure given (Haupt 2000) is 55 million m^3/a.

It is necessary to establish confident groundwater usage and baseflow numbers in this water short area where there is significant recharge to the fractured TMG aquifers as well as the primary aquifer.

Issues:

- There is a need to integrate the results of the WODRIS study into groundwater resource planning and evaluation in this area;
- Licensing/Groundwater: It is possible that in the Reserve determination process that access to groundwater will be lost or reduced in some area (e.g. the E33F is considered as a stressed catchment ACTION: Prepare plan on how to manage this process and determine constructive intervention;
- Groundwater quantity and quality: The groundwater table is being lowered and the groundwater quality is deteriorating in the E33F subcatchment (Troe-Troe River) due to agricultural use and irrigation return flows;
- There is a need to evaluate the potential for utilization of poor quality groundwater and to blend it with surface water or treat it using reverse osmosis.

GROUNDWATER/SURFACE WATER LINKAGE

There is little to no quantitative knowledge of surface groundwater interaction in this WMA. Studies funded by the RDM office of DWAF and research is underway but study domains are restricted and not necessarily defined by an IWRM concept or domain for planning purposes.

A current WRC funded study on ecological impacts of groundwater abstraction from the TMG is focusing on establishing the groundwater dependency of wetlands and seep zones in high lying mountainous areas of the Breede WMA. Preliminary results show that the surface groundwater interaction is situated at lithological and or structural defined regions as was postulated in the CAGE project.

There is ongoing work undertaken on the vleis of the Sandveld in order to establish the groundwater contribution to the ecosystems. Concerns have been raised about the impact of abstraction on the ecosystems. It has been pointed out however that the study area is defined by lateral discharge along palaeochannels into the vlei as well as a wellfield situated within the vlei.

Baseflow is low to zero in the regolith dominated sub-areas of the Doring and Knersvlakte sub-areas, indicating a very low, negligible groundwater contribution to surface water bodies.

In the TMG dominated areas of the WMA, elevation and depth of boreholes is a more critical factor to consider than distance from a river in regulating groundwater abstraction with regards to impact on baseflow. In general the upper 50 m of the TMG aquifers are annealed in the transmissive zones. Most of the baseflow in rivers is originated from perennial springs and seep zones. Interaction between surface and groundwater from the TMG within the river course is limited to a few areas, where the Bokkeveld Formation is eroded. Impact on springs can be managed by supplementing the decrease in spring flow from managed wellfields.

Springs were documented during the CAGE study and V-notches established at selected sites. To date the monitoring data obtained has not been interpreted. The Peninsula Aquifer daylights as perennial springs on the contact with the Cederberg Shale Formation, along palaeochannels on the coastal plain and as high lying seasonal seep zones primarily on the eastern limb of the syncline. The Nardouw Aquifer contributes to baseflow as seep zones at the Bokkeveld contact within the valley and more directly in the upper reaches of the Olifants River and some 15 km north of Citrusdal, where the Bokkeveld is not present.

Most of the streams and rivers in the upper regions and the relatively dry areas of the WMA are considered detached (piezometric level at all times below streambed and no discharge to surface water), intermittent (piezometric level slopes towards the stream and recharge occurs at intervals or occasionally) or famished (piezometric level slopes towards the stream, but groundwater does not reach due to evapo-transpiration (definitions by Vegter and Pitman, 1996). Relevant surface groundwater interaction is therefore limited to perennial springs (see above) and rivers embedded in alluvial aquifers.

The bigger effluent rivers with riparian zones, constituting the alluvial aquifers, are located in climatic regions of low rainfall and high evaporation. These aquifers are not considered relevant for water resource development. Rivers do normally not act as source for groundwater recharge. However, in the event of floods the river becomes influent and recharges the groundwater, if the storage capacity is sufficient. It is suggested that it would be appropriate strategy to consider rainfall harvesting or water banking using the alluvial aquifers in these circumstances.

A similar strategy can be adopted in the management of the TMG storage, viz., drawdown of the groundwater table in summer in order to enhance recharge in the winter and optimize the evaporation free storage. This is another approach to water banking, because winter floods can be stored in an aquifer. This opportunity is borne out by isotopic results that indicate that up to 90% of floods comprise of rejected groundwater recharge in these areas.

SUMMARY OF TABLES

Table 1: Recharge and baseflow in million m^3/a

Sub-area	Recharge (Umvoto model)	Recharge (Vegter)	Baseflow (Pitman)	Baseflow (Hughes)
Upper Olifants	120	98	7.5	125
Sandveld	135	122	0.8	10.3
Doring	294	193	0.5	17.5
Kouebokkeveld	110	125	7.3	87
Knersvlakte	207	73	0	0
Lower Olifants	60	46	0.8	9.1
Total	**926**	**657**	**17**	**246**

Note: The Baseflow given by Hughes exceeds recharge and or is close to 80% of recharge. Given the high storage and rate of recharge in TMG dominating these sub-areas this is not considered realistic. Increasing use and monitoring of the aquifer(s) will result in increasing certainty as regards the quantification of surface groundwater interaction and the impacts of abstraction.

Table 2: Groundwater Usage in million m^3/a

Sub-area	Usage (NWRS)	Usage (Baron and Seward 2000)	Usage based on NGDB and WRC Yield map (1)	Usage (ISP)	Comment
Upper Olifants	4	26	19	20	Cage Study results
Sandveld	30	55	77	30	Danida Sandveld Study results
Doring	3	5	40	3	NWRS selected
Kouebokkeveld	5	18	14	5	NWRS selected
Knersvlakte	3	3	34	3	NWRS selected
Lower Olifants		<1	51	1	Included in Upper Olifants in NWRS
Total	**45**	**108**	**235**	**62**	

1) The method used to estimate usage would significantly over estimate in the Karoo-dominated sub-areas due to high % of dry boreholes and assumed pumping regime in model.

Table 3: ISP Groundwater Available for Development in million m^3/a

Sub-area	Recharge (Umvoto)	Baseflow (Pitman)	Usage (ISP)	%	Groundwater Available for Development
Upper Olifants	120	7.5	20	50	36
Sandveld	135	0.8	30	50	37
Doring	294	0.5	3	20	55.5
Kouebokkeveld	110	7.3	5	50	46
Knersvlakte	207	0	3	20	38
Lower Olifants	60	0.8	1	50	28
Total	926	16.9	**62**		**240.5**

1) 20% or 50% of (Recharge – Baseflow) less usage = Groundwater Available for Development. It could be as low as 10% or as much as 80% if additional information is obtained.

Table 4: Comparison of available Groundwater Available for Development Values in million m^3/a

Sub-area	Harvest Potential	Exploitation Potential (WSM 2000)	NWRS	ISP	Comment
Upper Olifants	457	308	50	36	
Sandveld	224	136	42	37	
Doring	338	194	62	55.5	
Kouebokkeveld	285	179	26	46	
Knersvlakte	82	42	19	38	Select NWRS value
Lower Olifants	89	55		28	Lower Olifants included in Upper Olifants number in NWRS
Total	**1475**	**913**	**199**	**240.5**	

1) The Groundwater Potential estimated in this study for the Olifants (Upper and Lower) and the Kouebokkeveld is considered to be very conservative for reasons discussed in text.

2) The NWRS value for the Knersvlakte is recommended to be used for planning purposes until ground-truthed updated figures of usage and recharge become available. <u>We recommend that the NWRS numbers be revised accordingly (see table 2 below).</u> The total Groundwater Potential for development would be 240 million m^3/a

SUMMARY TABLE OF POTENTIAL AND CURRENT SUPPLY

ITEM	Groundwater Available for Exploitation/ Development	Groundwater Supply
Unit	Million m^3/a	Million m^3/a
Ref	ISP	NWRS, DANIDA, CAGE
Formula	Recharge – baseflow/2 or 5 less Supply	
Kouebokkeveld	46	5.0
Sandveld	37	30
Olifants	28 (Lower) + 36 (Upper)	21
Knersvlakte	19	3.0
Doring	55.5	3.3
Total	**221.5**	**62.3**

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