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Hydrology and Water Resources Development in the Olifants River Catchment

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/ catchment areas / rain / evaporation / water resources development / dams / groundwater / irrigation / domestic water / rivers / flow / South Africa / Olifants river basin

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Summary

The Olifants River is one of the major tributaries of the Limpopo River. Approximately 3,400,000 people live in its catchment and a considerable proportion of South Africa's mining, power production and agricultural activities are concentrated there. The catchment also encompasses important tourist destinations (e.g., the Kruger National Park). Consequently, in terms of the national economy it is one of the country's most significant waterways. The catchment is one of the first in South Africa for which a Catchment Mangement Agency (CMA) is planned.

Average annual rainfall is 630 mm, but there is considerable spatial and temporal variation. Average annual open water potential evaporation exceeds 2,000 mm and, after rainfall, evaporation is by far the largest component of the catchment water budget. The average annual runoff is 38 mm, which equates to 2,040 Mm^3, and so comprises just 6 percent of the average annual rainfall. A severe drought occurs in most decades.

Since 1900, development of water resources has played a prominent role in the expansion of agriculture and industry in the catchment. Currently total storage is approximately 1,472 Mm^3 (i.e., 72% of the mean annual flow) and it is estimated that there are close to 10,000 operating boreholes in the catchment. Total human consumption is estimated to be about 1,000 Mm^3 of which 900 Mm^3 is surface water (i.e., 44% of the mean annual flow) and 100 Mm^3 is groundwater. By far the largest consumer of water is irrigation (540 Mm^3 per year) with approximately 130,000 ha irrigated (i.e., 11% of the total cultivated area in the catchment), primarily in the commercial farming sector.

There are considerable inequities in urban-domestic water consumption between different areas of the catchment. In the former homelands, where many people do not have access to piped water supplies, per capita consumption averages just 47 liters per day. This compares to 183 liters per day in areas where the majority of the white population live. Although population is not anticipated to increase greatly after 2005, the urban-domestic water consumption is expected to nearly double from approximately 118 Mm^3 to 222 Mm^3 by 2010.

No major dams have been built in the catchment for more than 10 years. However, current water resources are severely stressed and water requirements are growing rapidly. The Department of Water Affairs and Forestry (DWAF) have estimated that there will be a shortfall of 243 Mm^3 by 2025. This deficit occurs in part because current water planning requires the provision of a Reserve to meet basic human needs and safeguard aquatic ecosystems. For the Olifants, the average annual Reserve is estimated to be 460 Mm^3. To satisfy this requirement and meet other increasing demands DWAF is considering a number of measures including the possible construction of two major dams.

Lack of basic understanding constrains efforts to manage the water resources of the catchment in an integrated manner. Further research should be undertaken to provide insights into the implications of water conservation and demand management strategies and a range of factors that affect inter-sectoral water utilization.

1. Introduction

To facilitate management of water resources in South Africa the country has been divided into seven strategic planning areas, or drainage regions, each of which has approximately uniform hydrometeorlogical characteristics (Basson et al. 1997) (table 1). The Olifants River Basin is a principal sub-catchment of the Limpopo River Basin and lies within the Northern Region strategic planning area. The river rises at Trichardt, to the east of Johannesburg, in the province of Gauteng, and flows north-east, through the provinces of Mpumalanga and Limpopo, into Mozambique (figure 1). Major tributaries are the Wilge, Moses, Elands and Ga-Selati on the left bank and the Klein Olifants, Steelport and Blyde on the right bank (table 2; figure 1). In South Africa, significant mining, including coal, copper, chrome, iron, vanadium and platinum, industrial and agricultural activities, including intensive irrigation schemes, are concentrated within the catchment. Furthermore, the river is one of the principal rivers flowing through, and hence maintaining the ecology of, the Kruger National Park, which receives more than one million visitors a year. It is estimated that activities within the catchment generate about 6 percent of the GDP of South Africa.

In compliance with the National Water Act (1998) and the National Water Resources Strategy (NWRS), it is planned to establish a Catchment Management Agency to manage the water (DWAF 2002). This Agency will be responsible for managing water resources to the point where the Olifants River flows into Mozambique. At present, international cooperation with respect to the use and management of rivers in the catchment of the Limpopo River is overseen by the Limpopo Basin Permanent Technical Committee (LBTC), which comprises members from South Africa, Botswana, Zimbabwe and Mozambique. However, for the Olifants River there is no accepted international agreement specifying transboundary flow requirements. It is anticipated that a Limpopo River Basin Commission will be established in the near future and it is probable that a formal agreement specifying flow requirements will be negotiated.

The Letaba River is a major tributary (catchment area = 3,264 km^2) that rises in South Africa and joins the Olifants River in the Kruger National Park, just before the river flows into Mozambique. However, the Letaba River catchment will not be included in the Olifants River Water Management Area. For this reason, and because most previous studies have not included the Letaba River, the information presented in this technical note focuses only on the region (54,308 km^2) that will be incorporated in the Olifants Water Management Area, hereafter simply referred to as the 'Olifants catchment'.

In the Olifants catchment, the total population is estimated to be 3,402,500, approximately 7 percent of South Africa's total (DWAF 2002). The population is predominantly rural with 67 percent of the population classified as living in rural areas (DWAF 2003). However, the distribution of wealth is highly skewed between the urban and rural areas and large differences prevail in the standard of living. Similar to the national demographic trends, and mainly attributable to HIV/AIDS and increasing urbanization, little, if any, increase is expected in the rural population after 2005 (DWAF 2003).

This report comprises a review of existing data and a brief discussion of the main hydrological and water resource issues pertaining to the Olifants catchment.

Table 1. The Principal Drainage Regions of South Africa.

Drainage Region	Area (km^2)	Principal Rivers	Mean Annual Precipitation (mm)	Potential Evaporation (mm)	Mean Annual Flow (Mm^3)	(mm)
Northern	183,146	Marico, Crocodile, Mokolo, Lephala, Mogolakwena, Sand, Letaba and Olifants	565	1,783	4,747	26
Eastern Inland	62,554	Sabie/Nwanedzi, Crocodile, Komati, Usutu and Phongolo	751	1,464	7,525	120
Eastern Coastal	150,275	Mkuze, Mflozi, Mhlatuze/Matigulu, Mvoti, Mdloti, Mgeni, Mkomazi, Fatu/Mtwalume,Mzimkulu and Mtamvuma	815	1,368	18,445	123
Southern Coastal	147,184	Great Fish, Sundays, Gamtoos and Gourits	345	1,860	3,578	24
South Western	118,199	Bree, Duivenhoks, Berg and Jakkals/Verlore	293	1,738	5,077	43
Karoo	409,621	Orange	302	2,218	6,849	17
Central	196,438	Vaal, Harts and Modder/Riet	529	1,753	3,929	20
Total	1,267,417	-	450[1]	-	50,150	40[1]

Source: Basson et al. 1997
Note: [1] area-weighted average

Table 2. Summary statistics for the major tributaries of the Olifants River.

Tributary	Catchment Area (km^2)	Mean annual flow (Mm^3)
Wilge	4,356	167
Moses	1,662	39
Elands	6,148	83
Ga-Selati	2,340	80
Klein Olifants	2,391	81
Steelport	7,136	396
Blyde	2,842	436
Other	27,433	758
Total	54,308	2,040

Source: Derived from data in WSAMs database—Schultz and Watson, 2002

2. Catchment Description

For the purposes of managing water, the Olifants catchment has been divided into five regions (figure 1).Each of these regions consists a number of ‘quaternary catchments’. Quaternary catchments are the principal water management units in South Africa and were demarcated for the whole country as part of a comprehensive national water resource assessment, known as the Surface Water Resources of South Africa 1990 (WR90) study (Midgley et al. 1994). In the WR90 study, quaternary catchments were delineated to have similar runoff volumes (i.e., the greater the runoff the smaller the catchment area and vice-versa). Quaternary catchments are nested within tertiary, secondary and primary drainage areas. There are 22 Primary Drainage Regions in South Africa, of which the Olifants River Basin is one. Within the Olifants, there are 7 secondary, 13 tertiary and 114 quaternary catchments (table 3). A schematic of the quaternary catchments is presented in figure 2.

Table 3. Secondary, Tertiary and Quaternary Catchments in the Olifants River Basin (excluding the Letaba River).

Water Management Region	Secondary Catchment Identifier	Tertiary Catchment identifier	Quaternary Catchments identifier[1]	Description of Tertiary Catchment
Upper Olifants River	B1	1	A to L (11)	Olifants upstream of Loskop Dam
		2	A to E (5)	Klein Olifants
	B2	0	A to J (9)	Wilge River
Upper Middle Olifants River	B3	1	A to J (9)	Elands River
		2	A to J (9)	Olifants from Loskop Dam to confluence with Elands
Mountain Region	B4	1	A to K (10)	Steelport River
		2	A to H (8)	Spekboom River to confluence with Steelport
Lower Middle Olifants Region	B5	1	A to H (8)	Olifants from confluence with Elands to gauging station B5H002
		2	A to J (9)	Olifants and tributaries from confluence of the Elands to gauging station B5H002
Lower Olifants Region	B6	0	A to J (9)	Blyde River
	B7	1	A to J (9)	Olifants and tributaries from gauging station B5H002 to confluence with Blyde River
		2	A to K (10)	Olifants to confluence with Selati River
		3	A to H (8)	Olifants from confluence with Selati River to the Mozambique border

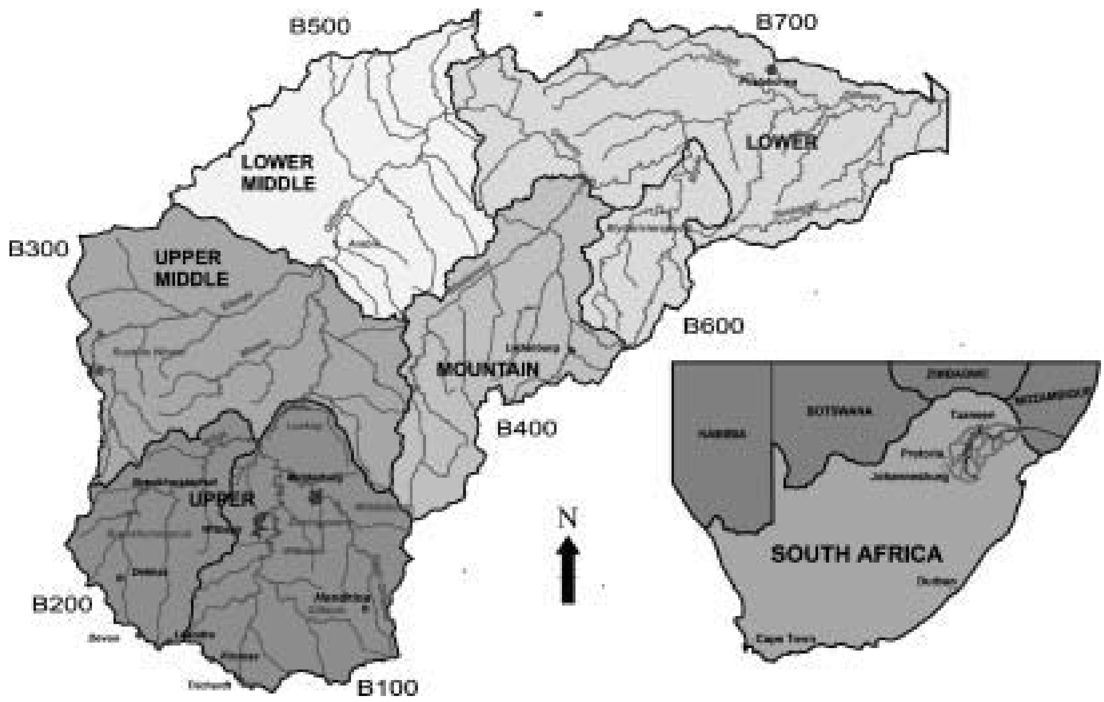
Source: Data in WSAM database
Note: The letter I, is not used as a quaternary catchment identifier

Geologically the catchment largely consists of igneous and metamorphosed rocks associated with the African and Post-African planation surfaces, which formed through uplift, approximately 100 million and 20 million years ago, respectively. These two surfaces comprise relatively low relief gently undulating plateau separated by a steep escarpment. Granite is the dominant rock type, but the area is geologically complex with the common occurrence of dolerite intrusions, in the form of dykes and sills, and silicified sedimentary formations (figure 3). A detailed description is given in DWAF (1991).

Land use in the Olifants catchment consists primarily of irrigated and dry land cultivation, improved and unimproved grazing, mining, industry, forestry and urban and rural settlements. An estimate of land cover derived from high-resolution satellite imagery published by the South African National Land Cover Project (CSIR 2003), provides a map of land-use within the catchment (figure 4a). From this map an estimate of the total cultivated area within the catchment is 1,172,389 ha (i.e., 11,172 km^2).

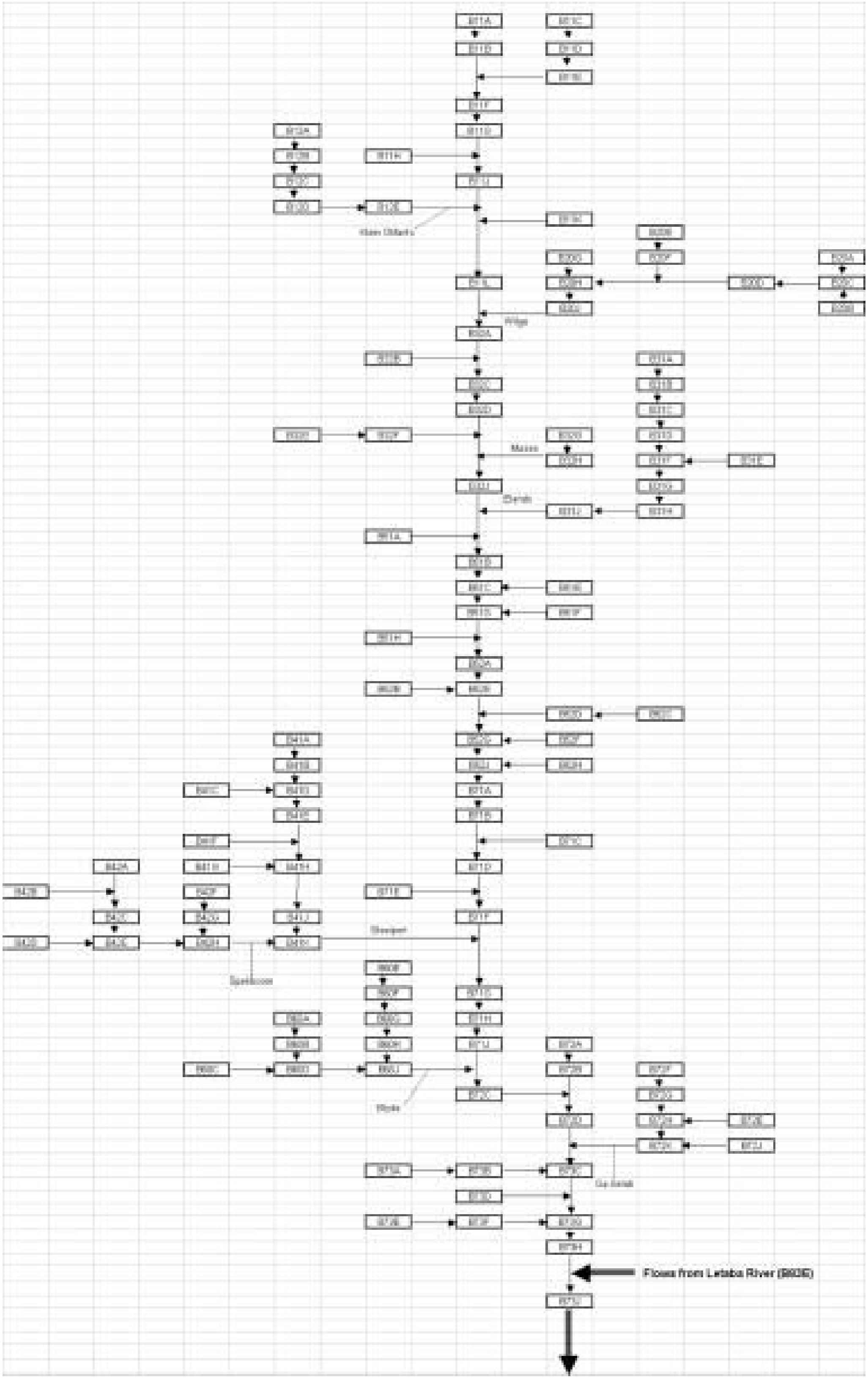
There are two major sectors in South African agriculture, the commercial and the semi-commercial/subsistence. The commercial sector comprises principally large farms, which before the end of apartheid in 1994, were primarily occupied by white farmers. In contrast, the semi-commercial/ subsistence sector comprises mainly small farms in areas that before 1994 were located within so called 'homelands'. Most of the homelands were located in marginal areas with lower rainfall and less fertile soils than is found in the commercial farming areas. Within the Olifants catchment, there are 945,948 ha of commercial and 226,441 ha of semi-commercial/subsistence cultivation. Of this, some 128,021 ha (i.e., 11% of the total cultivated area) is currently irrigated. Irrigation is almost exclusively within the commercial farming sector (figure 4b).

Figure 1. Location of the Olifants River Water Management Area and the boundaries of the five water management regions.



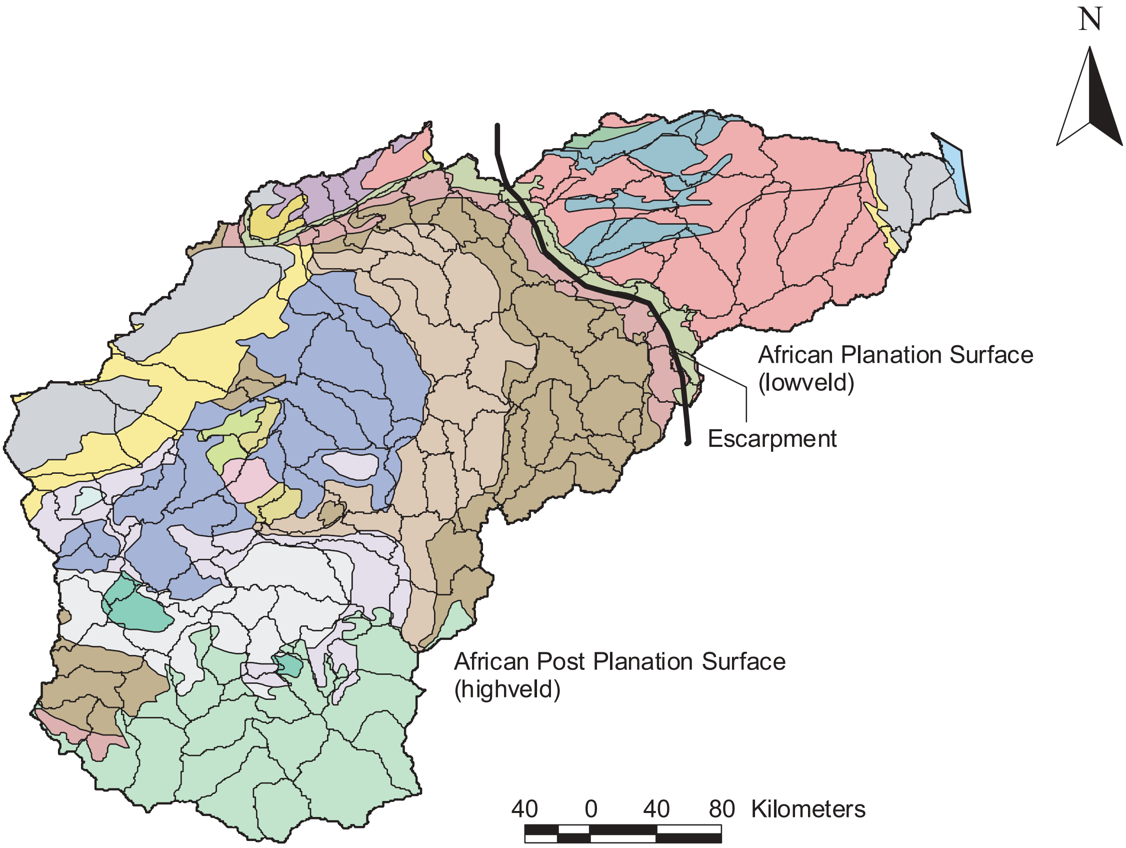
Source: DWAF 2002

Figure 2. Schematic representation of Quaternary Catchments of the Olifants River Water Management Area.



Source: Data in WSAM database

Figure 3. Geology of the Olifants catchment.



Geology of the Olifants catchment

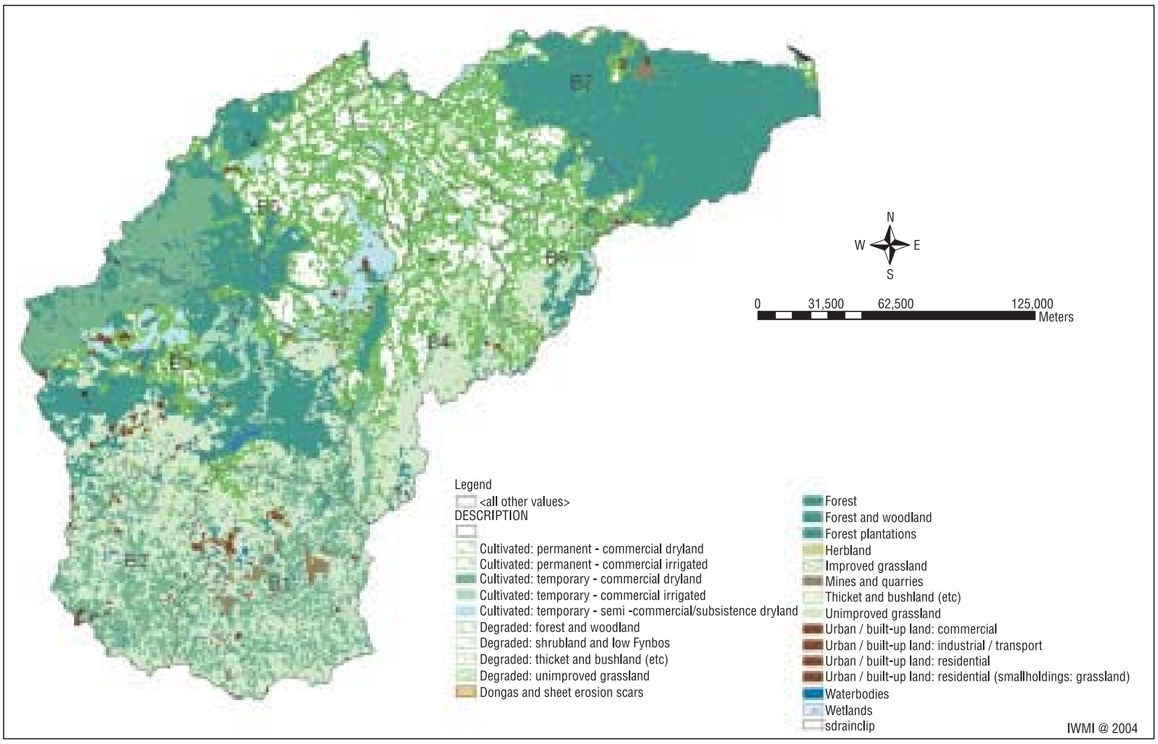
- Basalt; north-south trending dolerite dykes along Lebombo range
- Biotite-muscovite granite, gneiss, leucogranite, migmatite, potassic granite, quartz monzonite, tonalite, quartz porphyry
- Bronzitite, harzburgite, norite, pyroxenite, anorthosite, gabbro, diorite
- Diorite, gabbro
- Dolomite, chert, subordinate quartzite, conglomerate, shale; diabase and syenite dykes and sills
- Granite, biotite-muscovite granite; diabase / dolerite dykes
- Granite, granodiorite, tonalite, gneiss, migmatite
- Granophyre, hornblende and biotite granites
- Lava, tuff, quartzite, shale, conglomerate
- Lava, tuff, schist, gneiss, slate, shale, quartzite
- Potassic biotite and leucocratic granites with northeasterly trending diabase / dolerite dykes
- Pyroclastics, lava, quartzite, conglomerate, sandstone, siltstone; grit, shale, diabase sills
- Quartzite, shale, conglomerate, iron formation, breccia, diamictite, limestone, dolomite
- Quartzite, shale, dolomite
- Rhyolite, granophyre, syenite, tuff, breccia, minor sedimentary rocks
- Rhyolite, pyroclastics
- Sandstone, conglomerate, rhyolite
- Sandstone, siltstone, mudstone, shale; intruded by dolerite and includes patches of Letaba basalt
- Shale, sandstone; intruded by dolerite dykes and sheets
- Shale; intruded by dolerite dykes and sheets
- Tillite with subordinate sandstone, mudstone, shale; intruded by dolerite dykes and sheets
- Ultramafic and mafic lavas, quartzite, conglomerate, chlorite schist
- Ultramafic, mafic and acid lava, tuff, schist, conglomerate, quartzite

Source: Data in Council of Geoscience 2001

Figure 4. Land use map of the Olifants catchment a) all land classes b) cultivated areas only.

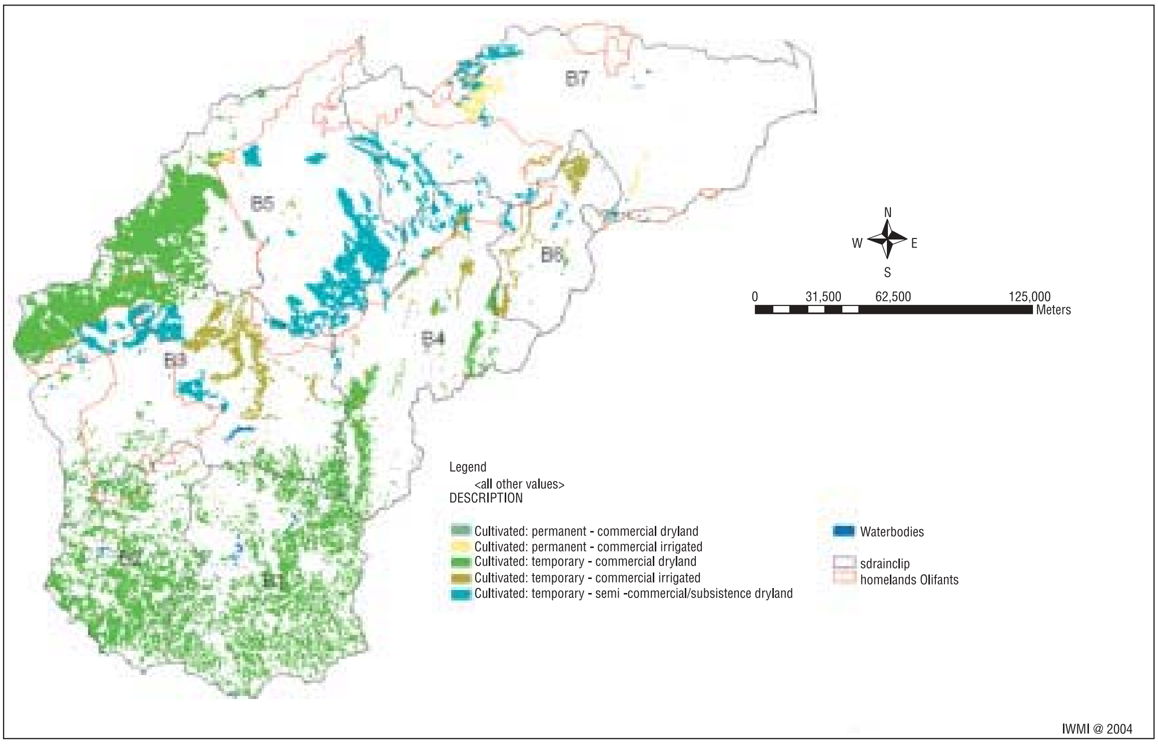
a)

Land Use/Cover in the Olifants River Basin



b)

Agricultural Areas in the Olifants River Basin



Source: Data in the South African National Land-Cover database, CSIR 2003

3. Data

In South Africa, DWAF is responsible for managing water resources. To this end, extensive data collection networks have been established throughout the country and data storage and retrieval systems as well as sophisticated software have been developed. For the International Water Management Institute (IWMI) benchmark basin study (Molle 2002) comprehensive data sets, comprising both biophysical and socioeconomic information, have been obtained from DWAF and a range of other sources. With the exception of the DWAF dam safety register, all the data used in this paper are in the public domain.

Much of the baseline information presented has been derived from an atlas of agrohydrology and climatology that has been developed for South Africa and the kingdoms of Lesotho and Swaziland (Schulze et al. 1997). This atlas comprises thematic agrohydrological and agroclimatic maps developed from specialized methods of spatial analysis. The basis for the climatic parameter mapping is a 1 minute of a degree latitude by longitude grid (raster) covering the region. Made up of 437,000 grid points, this 1 minute x 1 minute digital database serves as a basis for mapping physiographic and climatic (e.g., rainfall and potential evaporation) attributes. For climate variables, statistical goodness of fit was determined between observed and estimated values at points of measurement in order to obtain the level of confidence to which equations could be used to interpolate and extrapolate at grid points where no observations had been made. Once acceptable equations had been developed these were used to extrapolate to grid points where no observations had been made (Schulze et al. 1997). An electronic version of the atlas provides coverages for use in the ArcView GIS package (http://www.esri.com/). These coverages were interrogated to provide data specific to the Olifants catchment.

Data have also been obtained from two important water resource studies that have been conducted for the whole of South Africa. The first was the previously mentioned WR90 study, which was a 5-year project undertaken "to provide a basis for preliminary planning of water resources development" and to make available "valuable data and information for water resources planning and development" (Midgley et al. 1994). The second is a project to develop a Water Situation Assessment Model (WSAM) for rapid evaluation of the status of water resources anywhere in South Africa (Schultz and Watson 2002). The latter has built on the work undertaken in the WR90 study. Data specific to the Olifants catchment have been obtained from databases developed for both studies and provided to IWMI by DWAF.

In addition, partly as a consequence of its important role in the economy of South Africa, numerous water resources studies have been undertaken in the Olifants catchment. These reports have provided additional information. Of particular value is the Olifants River Basin Study, which collected and evaluated a lot of information necessary for addressing problems associated with human water utilization. The project comprised a comprehensive evaluation of the development potential and management of the water resources in the catchment and culminated in a main report, eight volumes of situation assessments and 28 supporting technical annexes (DWAF 1991).

As a result of the seasonality of rainfall and, hence, flow across much of South Africa (sections 4 and 6), DWAF uses a hydrological year that extends from 1 October to 30 September. For the purposes of consistency, throughout this technical note (unless stated otherwise) the hydrological year has been used when computing annual statistics. The standard convention of naming hydrological years after the year in which the month of October occurs has been adopted. Thus hydrological year 1956 (i.e., HY1956) extends from 1 October 1956 to 30 September 1957.

4. Rainfall

Mean annual precipitation characterizes the long-term quantity of water available in the catchment for agriculture and other purposes. In the Olifants catchment, precipitation data are available for 523 rainfall stations located within or very close to the catchment boundary. Of these, 47 have more than 50 years of data and 73 have more than 40 years of data. The South African Weather Bureau (SAWB) and other organizations (e.g., Department of Agriculture, South Africa Sugar Association and forestry companies) are responsible for these stations.

The climate of the Olifants catchment is largely controlled by the movement of air-masses associated with the Inter-Tropical Convergence Zone (ITCZ). During the summer, high land temperatures produce low pressures and moisture is brought to the catchment through the inflow of maritime air masses from the Indian Ocean. During the winter, the sun moves north and the land cools, causing the development of a continental high pressure system. The descending and outflowing air produces the regional dry season. For this reason, rainfall is seasonal and largely occurs during the summer months, October to April. Mean annual precipitation for the whole catchment is 630 mm, but the rainfall pattern is irregular with coefficients of variation greater than 0.25 across most of the catchment (table 4; figure 5).

Table 4. Mean annual rainfall and coefficient of variation for each of the secondary catchments.

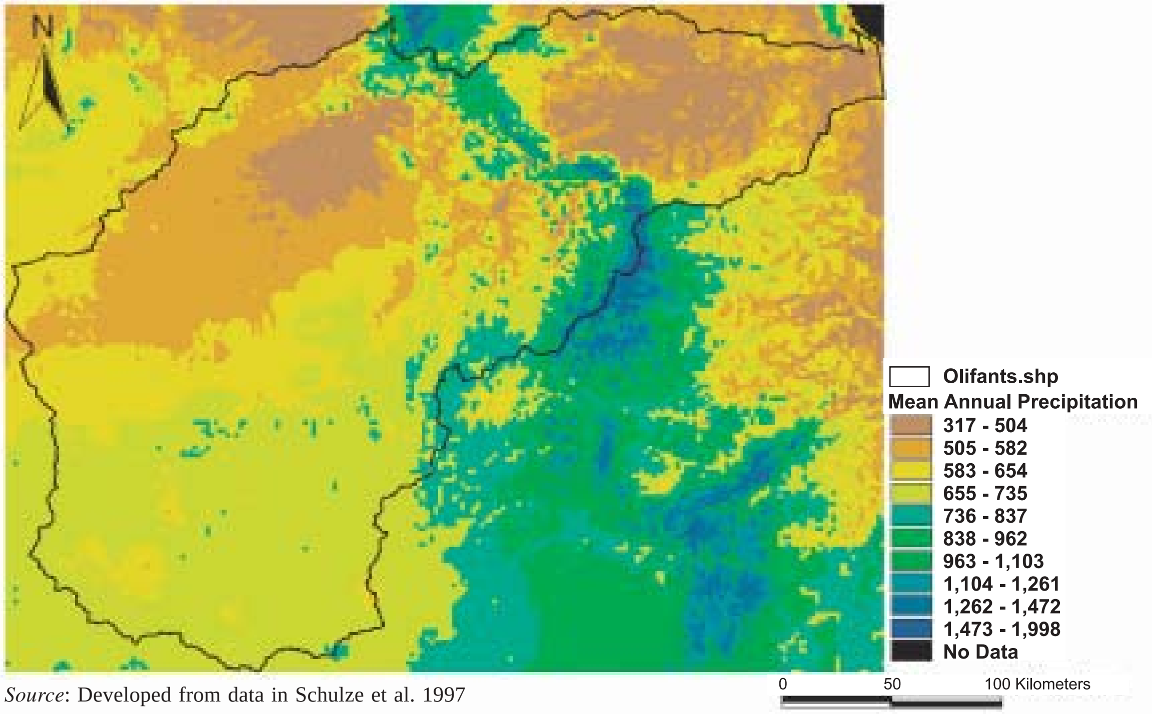
Secondary catchment	Mean altitude (masl)	Mean annual precipitation (mm)	CV	Annual precipitation exceeded with 80% frequency (mm)[1]
B1	1,588	689	0.29	557
B2	1,501	670	0.29	496
B3	1,174	617	0.24	500
B4	1,430	681	0.26	560
B5	1,097	551	0.28	441
B6	1,207	823	0.27	649
B7	603	586	0.26	442
Total Catchment[2]	1,149	630	0.27	503

Source: Computed from data in Schulze et al. 1997
Notes: [1] equivalent to the "driest year in 5"
[2] area-weighted averages

The catchment is divided into two by an escarpment, orientated approximately north-south. To the west of the escarpment the landscape is known as the highveld (i.e., altitude > 1,200 m) and to the east, it is known as the lowveld (i.e., altitude < 800 m). The highest rainfall is in the region of the escarpment. Orographic rainfall in the vicinity of the escarpment (caused when air is forced to rise over the escarpment) results in mean annual precipitation that exceeds 1,000 mm in some places. However, to both the east and the west of the escarpment, mean annual precipitation is generally 600 mm and less (figure 5). Secondary catchment B6 lies on the escarpment and as a result experiences considerably higher rainfall than the other secondary catchments in the Olifants River Basin. The lowest mean annual precipitation occurs in catchments B5 and B7 (table 4). Time series of annual rainfall and departure from the mean annual rainfall at three representative rain stations, located on the highveld, lowveld and the escarpment, illustrates (figure 6):

i. higher rainfall on the escarpment than either to east or west.
ii. considerable inter-annual variability at all locations.
iii. often several consecutive years with below average rainfall.

Figure 5. Mean annual precipitation across the Olifants catchment.



Source: Developed from data in Schulze et al. 1997

A plot of mean annual precipitation and altitude indicates that a different relationship exists between rainfall and altitude for sites in the vicinity of the escarpment than exists for locations elsewhere in the catchment, clearly illustrating the orographic influence of the escarpment (figure 7).

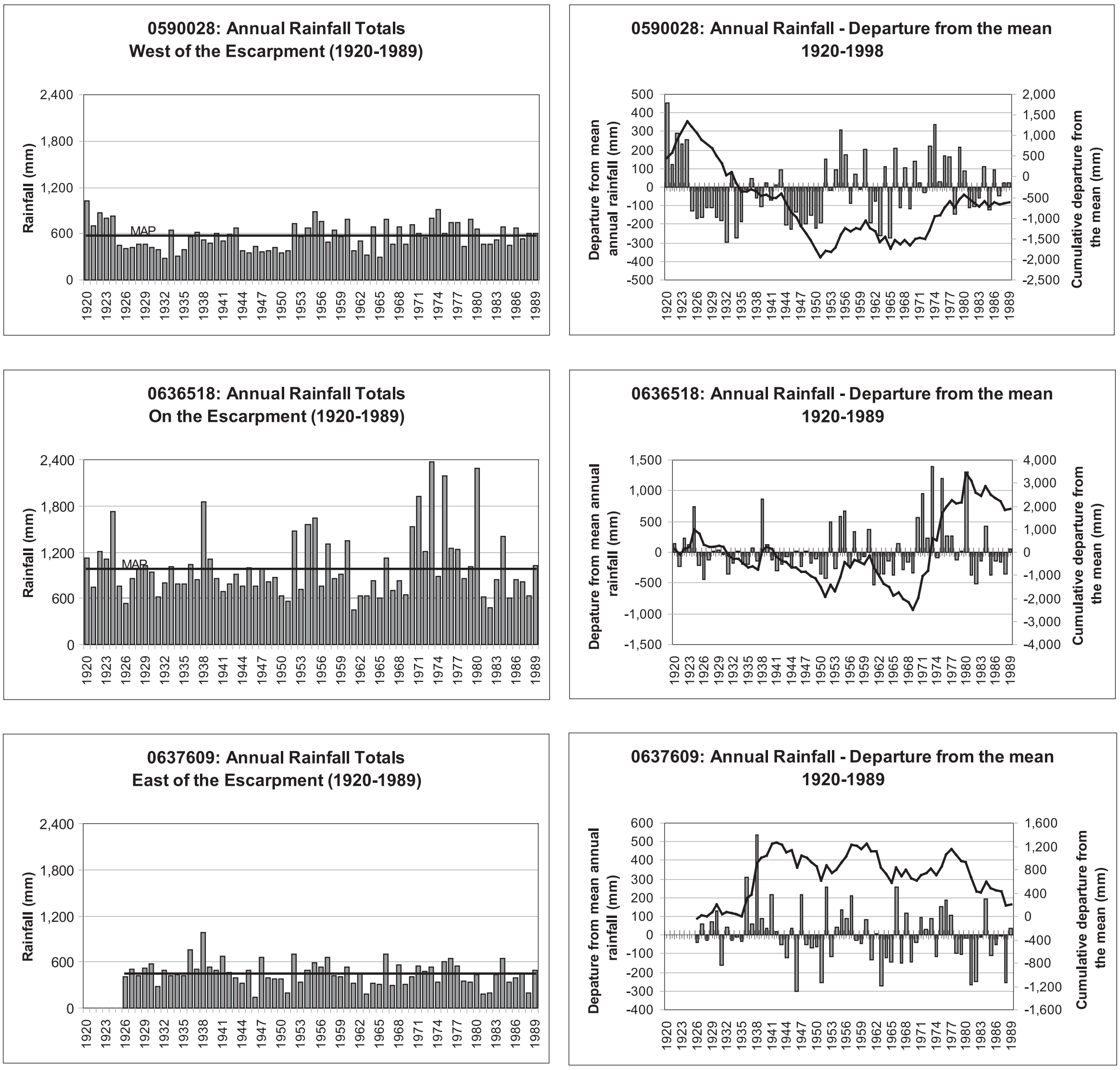
The intra-annual distribution of rainfall for each of the secondary catchments is presented in table 5, with the median rainfall for each month. A graph of mean monthly precipitation for the three representative stations used previously demonstrates the strong seasonal nature of the rainfall (figure 8).

Table 5. Median monthly precipitation for each of the secondary catchments in the Olifants catchment.

Secondary Catchment	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
B1	63.1	111.2	106.3	114.6	83.0	70.2	35.1	9.8	0.1	0.0	0.5	14.9
B2	57.2	102.9	103.6	112.9	83.0	72.4	32.7	9.2	0.1	0.0	0.1	12.7
B3	47.3	98.9	97.6	101.8	79.1	63.7	31.0	6.8	0.0	0.0	0.0	10.2
B4	52.8	107.1	110.6	110.9	85.9	70.1	37.3	8.6	0.3	0.1	0.3	13.4
B5	37.1	82.1	88.7	89.9	71.4	53.0	27.5	5.1	0.1	0.1	0.1	8.5
B6	50.4	105.7	122.0	127.3	114.8	89.1	44.5	12.4	1.8	2.4	2.5	14.8
B7	30.7	68.3	92.4	91.8	76.0	56.1	30.2	6.2	0.4	1.0	0.6	7.2
Total Catchment	45.5	92.4	99.4	102.4	80.5	63.8	32.4	7.5	0.2	0.4	0.4	10.7

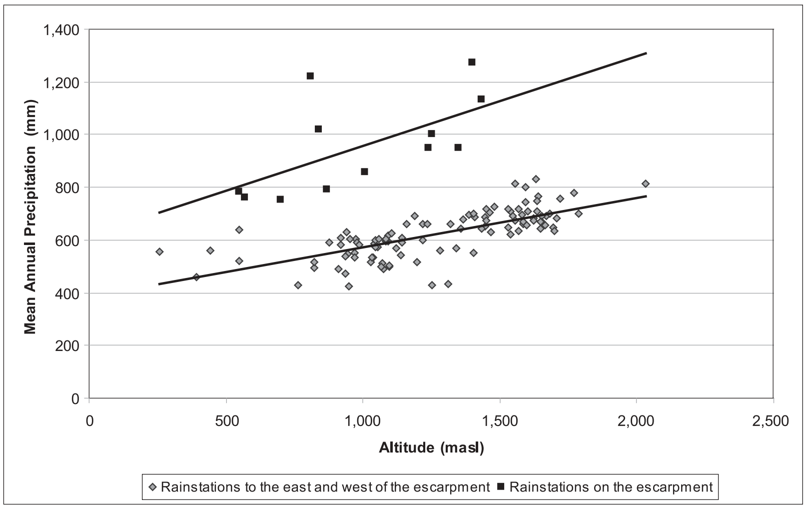
Source: Computed from data in Schulze et al. 1997

Figure 6. Rainfall at three rain stations in the Olifants catchment for the period HY1920-HY1989. Located: i) on the highveld (i.e., to the west of the escarpment), ii) on the escarpment, iii) on the lowveld (i.e., to the east of the escarpment).



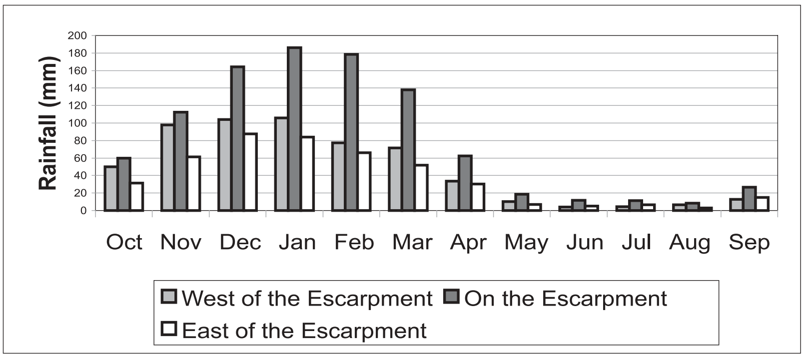
Source: Derived from data provided by DWAF

Figure 7. Relationship between mean annual precipitation (for gauges with > 30 years of data) in the vicinity of the escarpment and elsewhere in the Olifants catchment.



Source: Derived from data provided by DWAF

Figure 8. Mean monthly precipitation for the same three rain stations as figure 5.



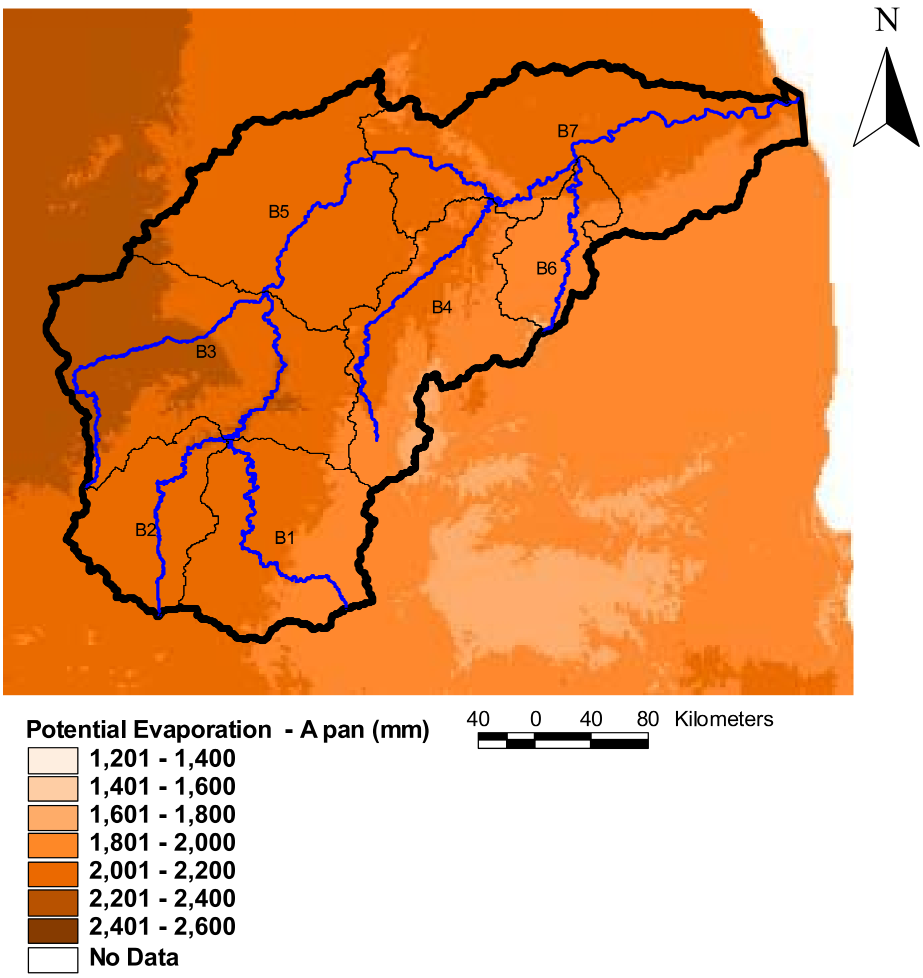
Source: Derived from data provided by DWAF

5. Evaporation

Potential evaporation, i.e., evaporation that is not constrained by moisture deficit and so fully meets atmospheric demand, can be estimated in a number of different ways. One approach is direct measurement of evaporation from the surface of an evaporation pan. In southern Africa, there is a network of over 750 US Weather Bureau Class A pans. The A-pan provides an index of open water evaporation and many crop coefficients, which relate the consumptive water use of plants at different growth stages to a reference evaporation (Doorenbos and Pruitt 1977), have been tried and tested against the A-pan (Schulze 1995). Data are available for 56 evaporation pans located in or very close to the boundary of the Olifants catchment. Of these, 19 have 40 or more years of data.

There are a number of problems with extrapolating A-pan data from its measurement at a site to other locations (Smith 1975). Consequently, for the South African Atlas of Agrohydrology and Climatology, simple climatic and physiographic variables, i.e., maximum daily temperature, extra-terrestrial radiation, altitude and median monthly rainfall, were used as surrogates to develop the grids of ‘A-pan equivalent’ potential evaporation (Schulze et al. 1997). The results for the Olifants catchment are shown in figure 9 and summarized for each of the secondary catchments in table 6.

Figure 9. Mean annual A-pan equivalent evaporation for the Olifants catchment.



Source: Derived from data in Schulze et al. 1997.

Table 6. Mean monthly and annual A-pan equivalent potential evaporation for each of the secondary catchments in the Olifants catchment.

Secondary Catchment	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Mean
B1	210.8	205.6	215.1	204.8	170.5	173.0	141.0	125.0	102.8	115.0	156.1	188.5	2,013.7
B2	226.6	220.8	228.4	217.5	179.8	180.2	145.5	129.4	106.1	118.1	160.8	198.5	2,117.0
B3	230.8	226.1	233.3	228.6	189.7	187.3	149.0	133.2	110.2	122.0	163.6	200.1	2,179.4
B4	199.9	195.0	199.9	197.4	162.9	169.1	143.6	130.6	107.4	117.5	152.8	180.8	1,962.2
B5	221.2	220.7	221.6	222.5	181.4	181.9	148.7	133.0	110.8	121.2	159.2	193.4	2,121.0
B6	194.1	192.3	195.9	194.4	165.0	167.8	144.3	130.4	107.5	117.1	149.7	174.9	1,939.5
B7	201.3	209.4	214.6	217.3	183.1	178.6	143.2	125.7	105.8	117.5	150.0	179.2	2,031.2
Total Catchment	213.7	212.6	218.1	215.2	178.7	178.6	145.4	129.6	107.5	118.8	156.5	188.8	2,068.9

Source: Computed from data in Schulze et al. 1997

An alternative recommended reference for estimating irrigation water requirements of crops is the Penman-Montieth equation (FAO 1992). This provides an estimate of potential evapotranspiration from a well-watered vegetation surface rather than an open water body (Penman 1948; and Monteith 1981). Water movement in plants is passive i.e., requires no input of biological energy, but even when the stomata of plants are fully open there is some resistance to the interchange of water between the plant and the atmosphere. Consequently, except in exceptional circumstances, evapotranspiration from a vegetated surface will always be less than that from open water. The FAO (1992) definition of potential evapotranspiration is:

> *The rate of evapotranspiration from a hypothetical crop with assumed crop height of 0.12 m, a fixed canopy resistance of 70 ms^{-1} and albedo of 0.23, which could closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water.*

For the South African Atlas of Agrohydrology and Climatology, because the gridded A-pan equivalent potential evaporation estimates had been based on readily ‘mappable’ and ‘physiographically’ related variables and because extensive verification tests had been performed on the equations used to extrapolate the data, it was decided to relate month-by-month ratios of Penman-Montieth to A-pan values (Schulze et al. 1997). The resultant estimates of Penman-Monteith potential evapotranspiration for each of the sub-catchments of the Olifants are presented in table 7.

Table 7. Mean monthly and annual potential evapotranspiration (Penman-Montieth) for each of the secondary catchments in the Olifants catchment.

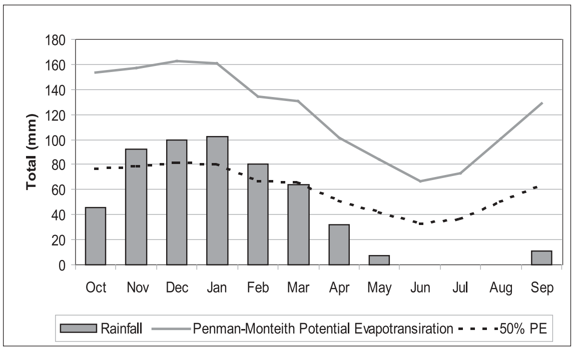
Secondary Catchment	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
B1	149.5	150.0	156.9	149.4	124.4	122.8	95.8	77.4	60.5	67.7	96.6	126.2	1,377.2
B2	160.8	161.5	167.6	160.1	132.3	129.4	99.8	81.2	63.4	70.5	100.5	133.3	1,460.4
B3	163.8	165.9	172.1	169.6	140.7	135.8	102.9	84.6	66.6	73.8	103.2	134.7	1,513.7
B4	141.8	142.5	146.2	144.5	119.3	120.6	97.9	81.3	63.6	69.6	95.0	121.2	1,343.5
B5	156.9	163.0	165.8	168.5	137.3	135.7	105.1	87.2	69.3	75.9	103.0	118.9	1,486.6
B6	139.4	141.7	144.7	143.7	122.3	121.2	99.7	82.9	65.3	71.2	95.0	131.2	1,358.3
B7	149.4	158.8	164.9	167.5	142.4	137.0	105.1	87.4	71.0	78.9	102.9	127.5	1,492.8
Total Catchment	153.2	157.1	162.3	160.9	133.9	131.1	101.8	83.9	66.5	73.5	100.5	128.7	1,453.4

Source: Computed from data in Schulze et al. 1997

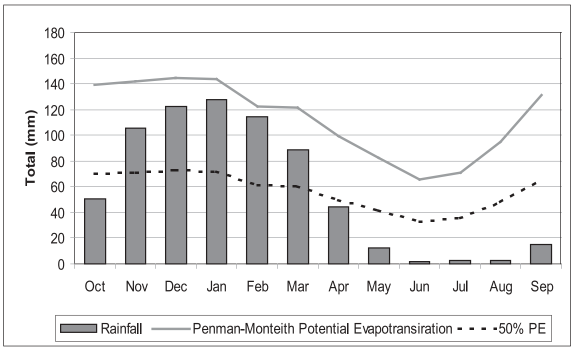
A comparison of the median monthly rainfall and the mean monthly Penman-Monteith potential evapotranspiration for the whole of the Olifants catchment shows that there are no months when rainfall exceeds potential evapotranspiration and typically it only exceeds 50 percent of potential evapotranspiration in the months November to February (figure 10a). Consequently, rainfall conditions are not ideal for the growth of crops and, irrigation is necessary to reduce the risk of water shortages. In relation to rainfall and potential evapotranspiration, the secondary catchment most suited for rain-fed agriculture is B6 (the Blyde River), in which rainfall typically exceeds the 50 percent potential evapotranspiration from November to March and is close to full potential evapotranspiration from December to February (figure 10b).

Figure 10. Median monthly rainfall and mean monthly potential evapotranspiration for a) the whole of the Olifants catchment b) the Blyde River catchment.

a)



b)



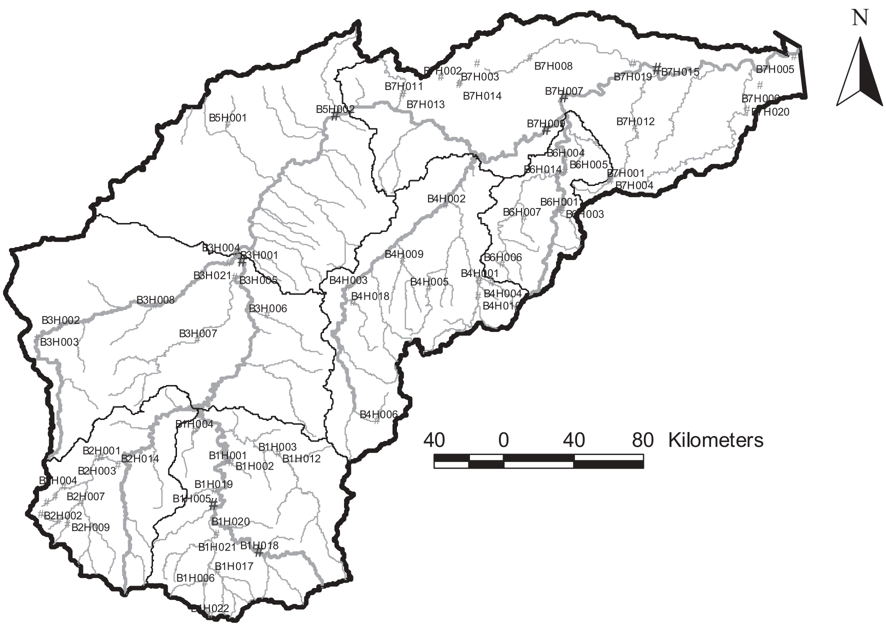
Source: Computed from data in Schulze et al. 1997

6. Flow

6.1 Measured Flow

Nearly all the 1,500 streamflow gauging stations in South Africa are maintained and the records processed by DWAF. There are 72 flow gauging stations within the Olifants catchment, with varying amounts of available data (appendix A). Flow is determined, or has been measured in the past, at seven locations on the main stem of the Olifants River (figure 11). For the current study, daily flow data provided by DWAF for all the Olifants catchment flow gauging stations have been loaded to a hydrological database (HYDATA, Renn et al. 1999) and converted to mean monthly (m^3s^{-1}) and total monthly flows (Mm^3).

Figure 11. Map showing location of flow gauging stations in the Olifants catchment.



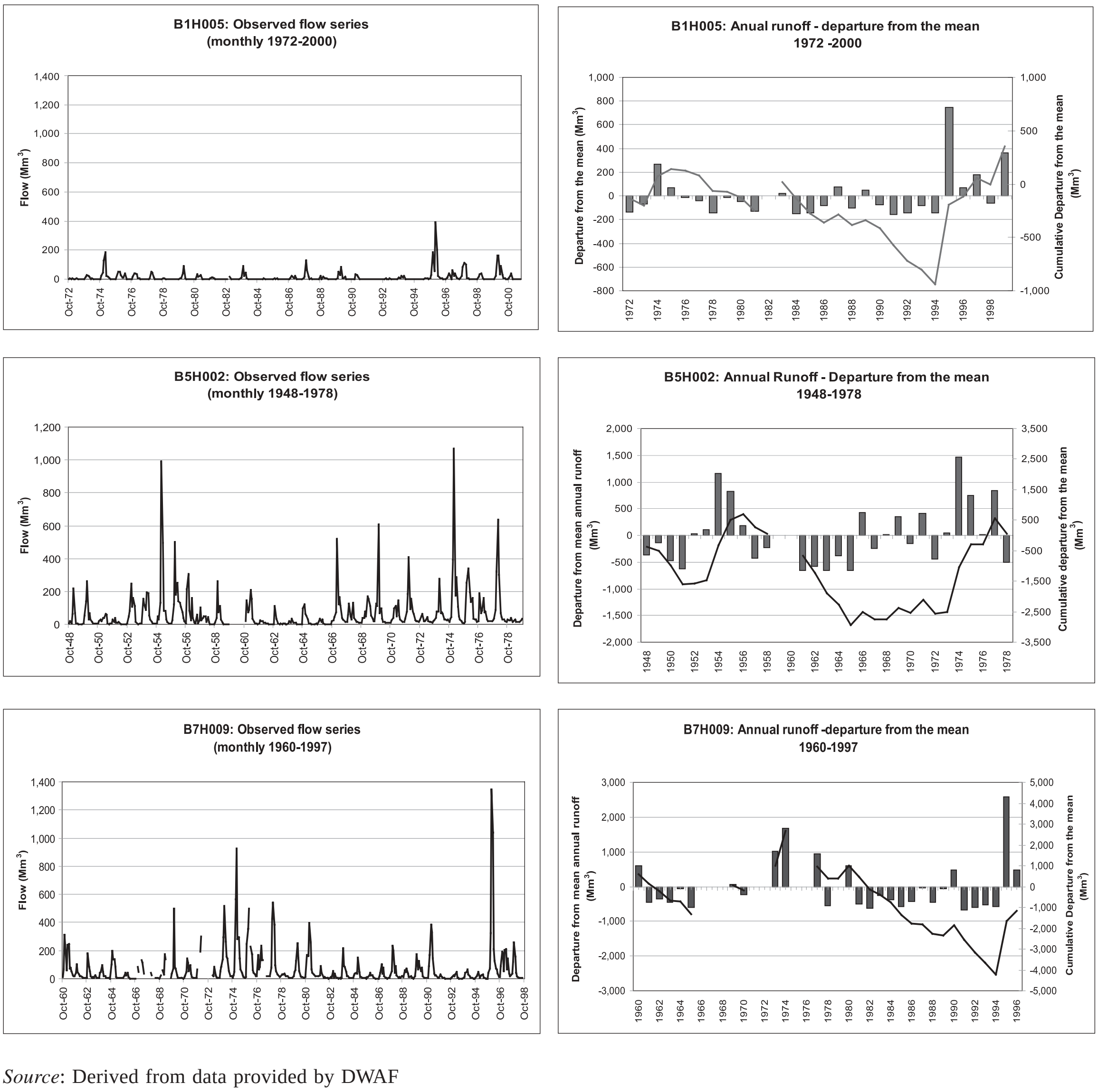
Source: Derived from data provided by DWAF

Figure 12 shows graphs of time series of flow for three of the gauging stations on the Olifants main stem —B1H005, B5H002 and B7H009, with catchment areas of 3,256 km^2, 31,416 km^2 and 42,472 km^2, respectively. Although, as a consequence of different data availability, they cover different periods of time, the graphs illustrate:

i. the general increase in flow with distance downstream.
ii. the high seasonal variation in flow.
iii. the considerable inter-annual variability at all points on the river (even allowing for the water storage within the catchment—section 7).
iv. the frequent occurrence of consecutive years in which flow is below the mean annual discharge, e.g., for much of the 1980s and 1990s.

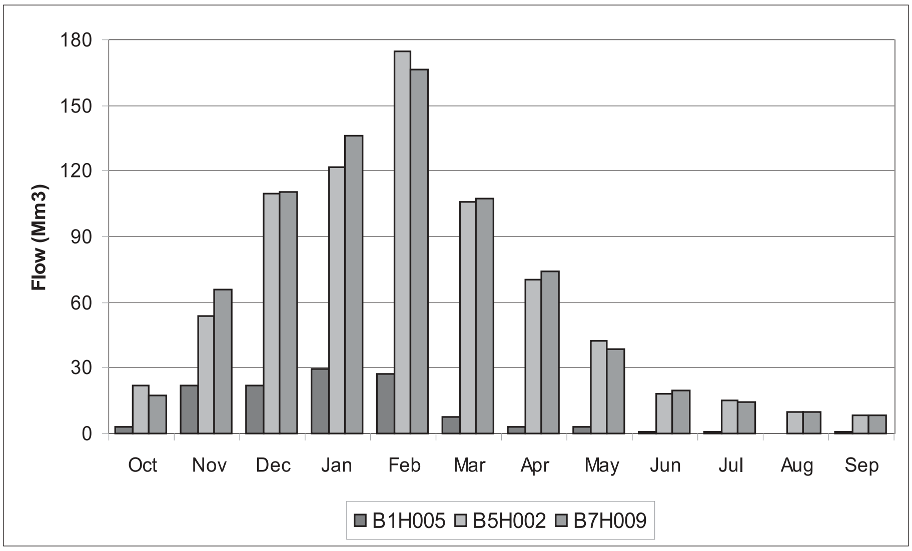
Figure 13 shows the mean monthly runoff at each of these three gauging stations.

Figure 12. Flow measured at three gauging stations on the Olifants River and departure from the mean annual runoff.



Source: Derived from data provided by DWAF

Figure 13: Mean monthly flow derived from measured flow at three gauging stations.

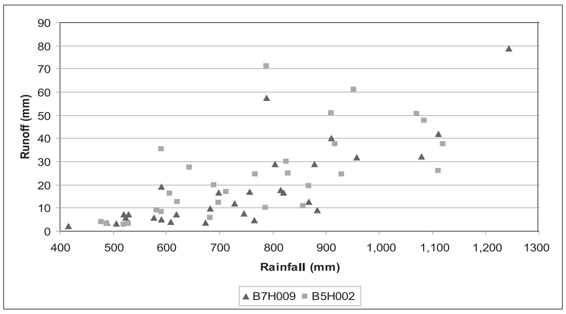


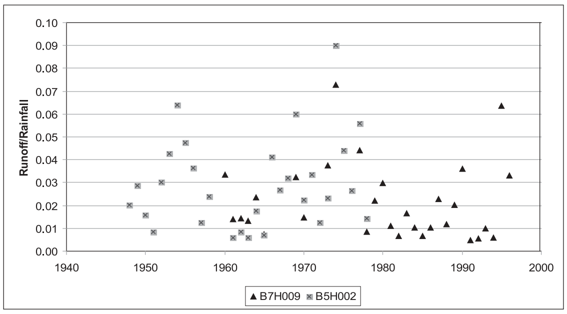
Source: Derived from data provided by DWAF

The correspondence between annual rainfall and runoff, i.e., volume of flow expressed as depth over the catchment area, is shown for two flow gauging stations (B7H009 and B5H002) in figure 14a. In this figure the rainfall is the numeric mean derived from six long-term gauges located within the Olifants catchment. Although the periods of record for the two flow gauging stations are different and B7H009 has a larger catchment area, there is no marked difference in the pattern between the two stations. As is common in arid and semi-arid environments there is only a relatively weak correlation between rainfall and runoff, reflecting the importance of the within-year temporal patterns of rainfall on runoff generating processes.

There are no flow records prior to the construction of the large Loskop Dam in 1939 (section 7.1). However, a time series of the ratio of runoff/rainfall (again combining data from B7H009 and B5H002) does not show any marked change in the runoff coefficient since 1948 (figure 14b). This would seem to indicate that the construction of dams in the catchment, particularly in the 1970s and 1980s, and the increased human consumption of water (section 7) has not had a marked impact on the total volume of flow within the catchment. However, in this analysis it is likely that trends are masked by the considerable inter-annual variability in runoff.

Figure 14. a) Rainfall/Runoff correlation—using data from two flow gauges and six rain gauges. b) Time series of coefficient of runoff derived for the same two flow gauging stations.





Source: Derived from data provided by DWAF

6.2 Naturalized Flow

For the purpose of water resource assessment, it is necessary to have an understanding of flow conditions unaffected by human-induced land cover and water use changes. In the WR90 study, considerable effort was made to calibrate and validate a deterministic model to synthesize natural flow conditions (Midgley et al. 1994). The model used, the Water Resources Simulation Model–90 (WRSM90), is a version of the Pitman Model. This is a monthly time step rainfall-runoff model developed specifically for use in South Africa (Pitman 1973). The model can be used to take into account the hydrological impacts of irrigation, the planting of non-indigenous forests, such as eucalyptus and conifer plantations, and urbanization, as well as the impact of reservoirs and water transfers into and out of a catchment. The model was applied to estimate the 'natural' hydrology at key gauging stations in the country, i.e., assuming no water resource development and 'virgin' conditions for land cover. Naturalized flow was derived for 17 of the gauging stations in the Olifants catchment, but for different periods of time. Once calibrated, model parameters were regionalized and the model was used to generate 70-year sequences (HY1920-HY1989) of naturalized flow for each quaternary catchment in the country (Midgley et al. 1994).

More recently, as part of the Water Situation and Assessment Model (WSAM) study (Schultz and Watson 2002), the naturalized quaternary catchment flows have been updated to accommodate new developments in methods for estimating the effects of afforestation and alien vegetation (Scott and Le Maitre 1994; Le Maitre 1999). However, this updating did not re-evaluate the naturalized flow at gauging stations and did not extend the naturalized flow series for the quaternary catchments beyond HY1989. A major project, funded by South Africa's Water Research Commission, is currently underway to improve and extend to HY2000 the naturalized flow series for all the quaternary catchments. However, the results of this study are not yet available and so the analyses reported here are limited to the currently available data that ceases in HY1989.

There is relatively little difference in the Mean Annual Flow (MAF) of each of the water management regions of the Olifants catchment estimated from the naturalized quaternary flows derived in the WR90 and WSAM studies (table 8). Overall, the most recent estimates provide a MAF for the whole catchment of 2,040 Mm^3 compared to 1,992 Mm^3 derived from the WR90 data. In both datasets, approximately 40 percent of the MAF is generated in the Lower Olifants region. However, the WSAM derived estimates indicate even greater variability in runoff than was the case with the WR90 estimates. This emphasizes the need for storage to meet water demands in the catchment (section 7).

Table 8.Naturalized mean annual runoff derived from the WR90 and WSAMs studies for the five water management regions of the Olifants catchment.

Water Management Region	WR90		WSAM	
	MAF (Mm^3)	Range in MAF (Mm^3)	MAF (Mm^3)	Range in MAF (Mm^3)
Upper Olifants River	466	134-1,233	424	80-1,365
Upper Middle Olifants River	200	86-538	250	42-897
Mountain Region	397	147-769	396	138-1,509
Lower Middle Olifants Region	107	23-555	121	13-636
Lower Olifants Region	822	255-2,351	849	259-4,595
Total Catchment	1,992	no data	2,040	677-8,020

Source: DWAF, 2002 and computed from data in WSAM database—Schultz and Watson, 2002.

A graph showing the contribution to mean monthly naturalized flow (derived from the WSAM study) from each of the secondary catchments (figure 15), illustrates:

i. the strongly seasonal nature of the naturalized flow regime of the river, reflecting the seasonal rainfall pattern.
ii. secondary catchments B4, B6 and B7 make the greatest contribution to the naturalized flow of the Olifants River (table 9).

The comparatively large contributions to naturalized MAF from secondary catchments B4 and B7 occur because of their relatively large areas in comparison to the other catchments. The coefficient of runoff is an index of the proportion of rainfall that is converted to runoff, i.e., the proportion of mean annual runoff (mm) to mean annual rainfall (mm). In all the secondary catchments, with the exception of B6, the coefficient of runoff is 0.08 or less (table 10). The exceptionally low value (0.02) for B5 is a consequence of both the low rainfall in this area and the underlying geology/soils, which promote infiltration and reduce runoff from the catchment (Aston 2000). In catchment B6, the coefficient of runoff is 0.19 reflecting the much higher rainfall experienced over this cachment, i.e., Blyde River, which lies along the escarpment (section 4).

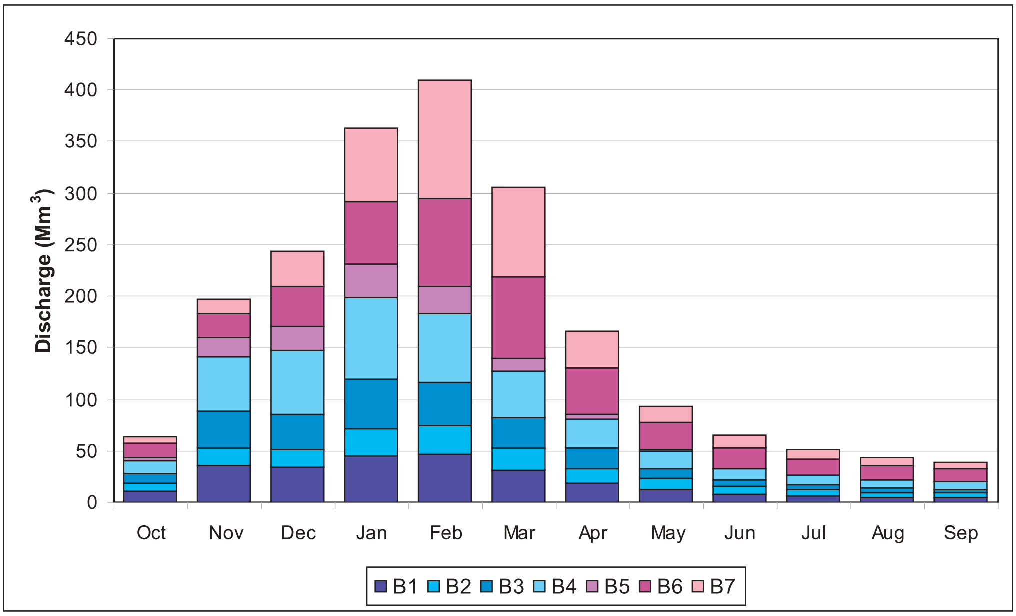
Table 9. Mean monthly naturalized river flow (Mm^3) from each secondary catchment in the Olifants River Basin.

Secondary Catchment	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
B1	10.37	35.46	34.55	44.67	46.89	31.69	18.60	11.97	7.66	5.91	4.84	4.50	257.12
B2	8.53	17.46	16.47	27.20	28.27	21.41	14.35	10.69	7.58	5.87	4.83	4.27	166.93
B3	8.68	36.03	34.69	47.57	41.44	29.38	19.04	10.66	6.81	5.56	4.63	4.15	248.64
B4	13.03	52.55	61.63	78.94	66.98	44.75	28.82	16.79	10.47	8.28	7.02	7.07	396.33
B5	2.52	18.44	23.50	33.22	25.67	13.15	3.78	0.53	0.06	0.04	0.03	0.26	121.21
B6	13.65	23.04	38.16	59.60	86.01	78.37	46.27	27.51	20.70	16.64	14.13	12.54	436.61
B7	6.62	14.35	34.11	71.55	113.78	86.76	35.91	15.32	11.27	9.03	7.59	6.53	412.82
Total Catchment	63.39	197.34	243.11	362.76	409.03	305.51	166.79	93.47	64.56	51.32	43.07	39.31	2,039.67

Source: Naturalized flow data from the WR90 study and provided by DWAF

The naturalized mean annual river flow for the whole catchment is 2,040 Mm^3 (table 9). This equates to approximately 4 percent of the total annual surface flow from South Africa, which is estimated to be 50,150 Mm^3 (Basson et al. 1997). However, given the temporal variability in the rainfall (section 4), it is not surprising that the naturalized flow series for the catchment also shows considerable inter-annual variability (figure 16). Wet years, arbitrarily defined as naturalized flow exceeding 4,000 Mm^3, were HY1922, HY1924, HY1936, HY1938 and HY1954. HY1938 was exceptionally wet with naturalized flow exceeding 8,000 Mm^3. Although not included in the naturalized flow record for the Olifants, severe floods also occurred in HY1999 (i.e., February and March 2000), when the whole of the Limpopo catchment was affected by heavy rainfall caused by 'Cyclone Leon-Eline'.

Figure 15. Contribution to naturalized mean monthly river flow from each secondary catchment.



Source: Derived from naturalized flow data from the WR90 study and provided by DWAF

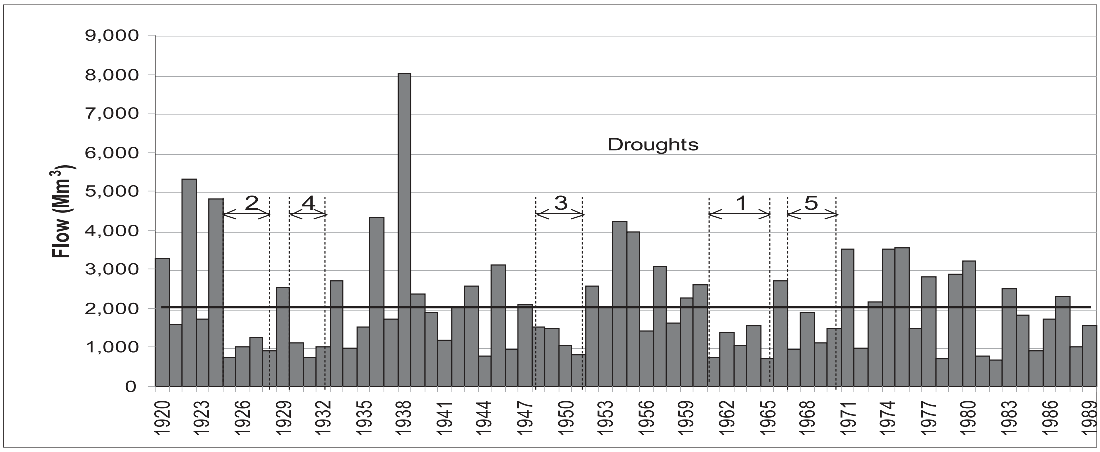
Table 10. Comparison of mean annual precipitation and mean annual runoff for each secondary catchment in the Olifants catchment.

Secondary Catchment	Area (km^2)	Mean annual precipitation (mm)	Mean annual runoff (mm)	Coefficient of runoff
B1	7,105	689	36.2	0.05
B2	4,356	670	38.3	0.06
B3	11,242	617	22.1	0.04
B4	7,136	681	55.5	0.08
B5	9,728	551	12.5	0.02
B6	2,842	823	153.6	0.19
B7	11,899	586	34.7	0.06
Total catchment	54,308	630	37.6	0.06

Source: Derived from rainfall data from Schulze et al. 1997 and naturalized flow data from the WR90 study, provided by DWAF

In addition to periods of high flow, drought is also a recurrent phenomenon. The naturalized flow record indicates the occurrence of twenty droughts, defined as periods with below average flow, between HY1920 and HY1989. Ranked in terms of severity, i.e., cumulative deficit over the period of the drought, this indicates that severe droughts occur almost every decade. The two most severe droughts occurred between HY1961 and HY1965 and between HY1925 and HY1928 (table 11). Total naturalized flow in these periods was just 53 percent and 48 percent of the long-term average, respectively. The periods of the five most severe droughts are shown in figure 16. Although not included in the naturalized flow record for the Olifants, regional analysis indicates that a severe drought was experienced across the whole of southern Africa in 1991 and 1992 and again between 1994 and 1995 (Houghton-Carr et al. 2002). Both the rainfall records (section 4) and the measured flows (section 6.1) confirm that these droughts affected the Olifants catchment. A drought also occurred in the catchment in HY2001.

Figure 16. Naturalized flow for the whole Olifants catchment (i.e., cumulative flow to quaternary catchment B73H) for HY1920 to HY1989.



Source: Computed from naturalized flow data from the WR90 study and provided by DWAF

Table 11. Droughts identified in the naturalized flow series in the period HY1920 to HY1989.

Rank	First year	Last year	Duration (i.e., number of years)	Severity (i.e., cumulative deficit) Mm^3	Percentage of average flow over the same period
1	1961	1965	5	4,755	53
2	1925	1928	4	4,216	48
3	1948	1951	4	3,260	60
4	1930	1932	3	3,245	47
5	1967	1970	4	2,699	67
6	1981	1982	2	2,638	35
7	1984	1986	3	1,651	73
8	1934	1935	2	1,605	61
9	1988	1989	2	1,503	63
10	1978	1978	1	1,331	35
11	1944	1944	1	1,253	39
12	1946	1946	1	1,109	46
13	1972	1972	1	1,067	48
14	1940	1941	2	1,011	75
15	1956	1956	1	629	69
16	1976	1976	1	539	74
17	1921	1921	1	437	79
18	1958	1958	1	431	79
19	1937	1937	1	312	85
20	1923	1923	1	301	85

Source: Computed from naturalized flow data from the WR90 study, provided by DWAF

6.3 Comparison of naturalized and measured flow

The difference between naturalized and measured flow provides an indication of water consumption within a catchment. Figure 17 compares the observed and naturalized flow at the three gauging stations (i.e., B1H005, B5H002 and B7H009) on the Olifants River. In each case the naturalized flow presented is that computed specifically for the station in the WR90 study. Although not taking into account the most recent methods for estimating the effects of afforestation and alien vegetation in computing the flow (section 6.2), these data were used in preference to those derived in the WSAM study because:

- rather than regionalized values, in each case model parameters were derived specifically for the catchment in question;
- some of the gauging stations are situated at the outlet of quaternary catchments, but this is not always the case. Consequently, using the WSAM data, it is necessary to interpolate between quaternary catchments to estimate the naturalized flow at a specific gauging station; and
- the difference between the WSAM and WR90 naturalized flow series are not large (section 6.2).

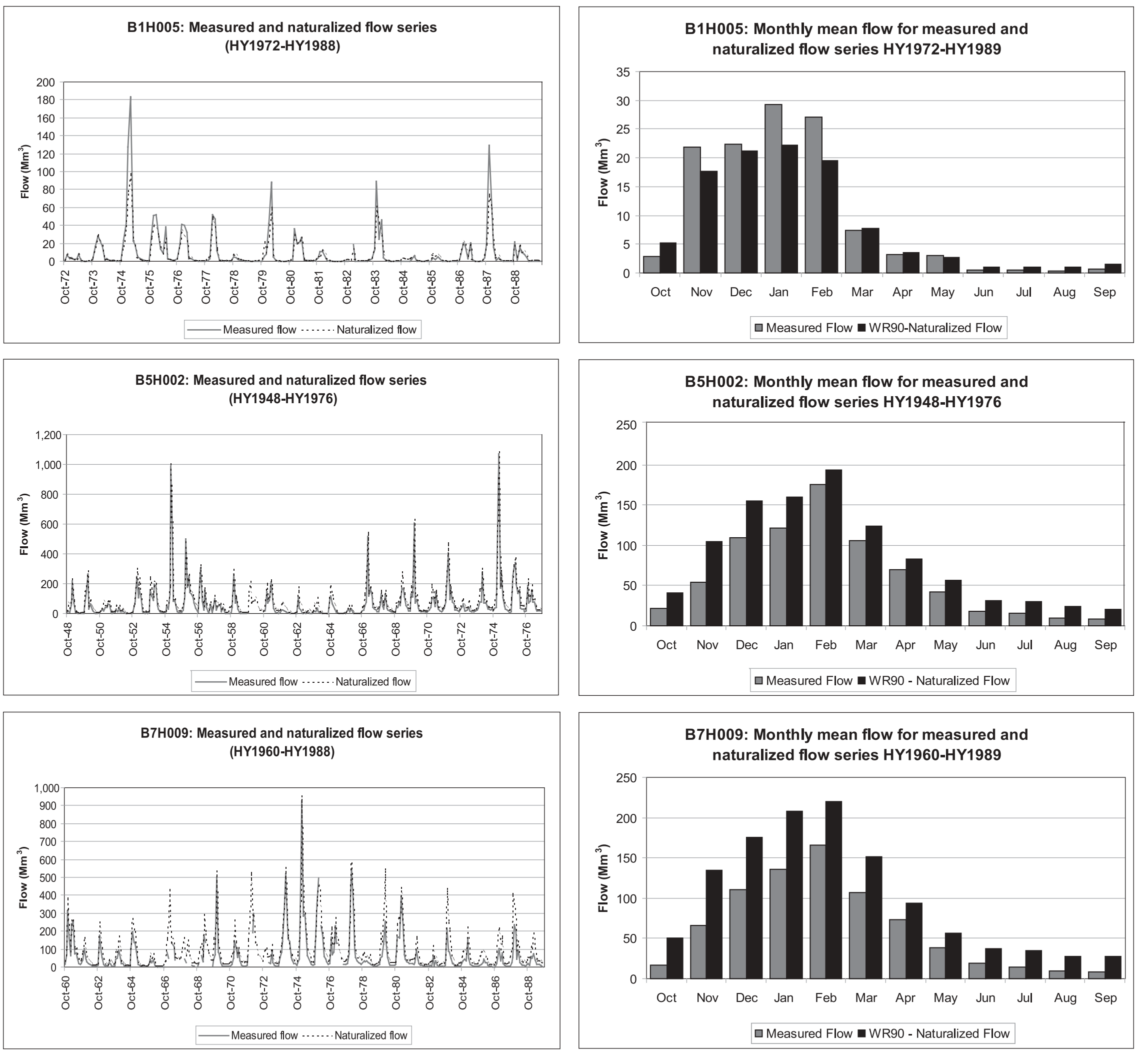
Also shown in figure 17 is the mean monthly measured and naturalized flow series for each of the gauging stations. These graphs indicate that at gauging stations B5H002 and B7H009, the measured flows are, as would be expected in a catchment in which water resources are heavily utilized, significantly less than the naturalized flows. In contrast, at gauging station B1H005, the measured flows are in many months greater than the estimated naturalized flows. It is possible that flows in this part of the catchment are enhanced by transfer of water into the basin, used as cooling water for power stations (section 7.2). However, it is also possible that the difference is due to uncertainty in both the measured and naturalized flow series. This uncertainty arises from gaps and measurement error in the observed flow series, as well as simulation errors and overestimation or underestimation of land use effects in determining the naturalized flow series. For this reason care must be taken in interpreting these data.

Within a catchment, water consumption in any particular year depends on a large number of both biophysical and socioeconomic factors. Although, as noted above, care must be taken in interpretation, the difference between measured and naturalized flow at gauging stations B5H002 and B7H009 are believed to be indicative of water consumption in the Olifants catchment. These data show considerable variation in consumption from year to year reflecting, among other things, the availability of water (figure 18). Thus, the data from B7H009 show that consumption was severely constrained in the drought years of HY1965, HY1978 and HY1981–HY1982. Conversely, water consumption was also reduced in years of high flows, such as HY1973–HY1974, presumably because irrigation requirements were reduced. For both B5H002 and B7H009, the data indicate a trend of increasing water consumption over time. Although not statistically significant, because of the considerable interannual variability, this trend is consistent with the widely perceived increase in water demand, driven by growing population and rising levels of economic activity, such as mining, within the catchment.

Comparison of mean annual measured and mean annual naturalized flow at different locations on the main stem of the Olifants River indicates increasing consumption with distance downstream (figure 19). Again, caution must be exercised in interpreting these data because they have been derived from a variety of sources and represent mean annual flows determined for a wide range of different years. Nonetheless, the data indicate that a considerable proportion of the renewable water resource is being utilized. By gauging station B7H015, the ratio of water consumption (on average 865 Mm^3) to renewable resource (1,964 Mm^3) is approximately 44 percent. If this ratio is assumed to hold to the catchment outlet, then total consumption is 898 Mm^3 (i.e., 44% of 2,040 Mm^3). Given the high variability in the natural flow regime and even allowing for the large amount of storage within the catchment (section 7), this is indicative of a catchment likely to experience periods of high water stress (Raskin et al. 1995).

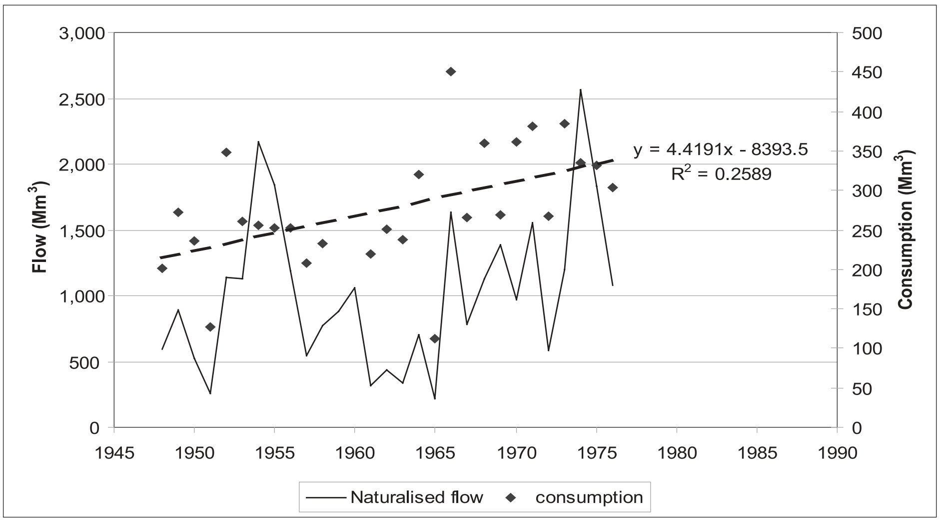
The value of consumption estimated here compares reasonably well with total 'demand' estimated by DWAF through analyses of sectoral water requirements (table 12). Since DWAF makes allowance for return flows in the estimates of demand (Havenga—*personal communication*), the 'demand' is effectively the same as 'consumption'. It is important to note that the demand for water from the power generation sector is met largely by water imported from outside the catchment (section 7.2).

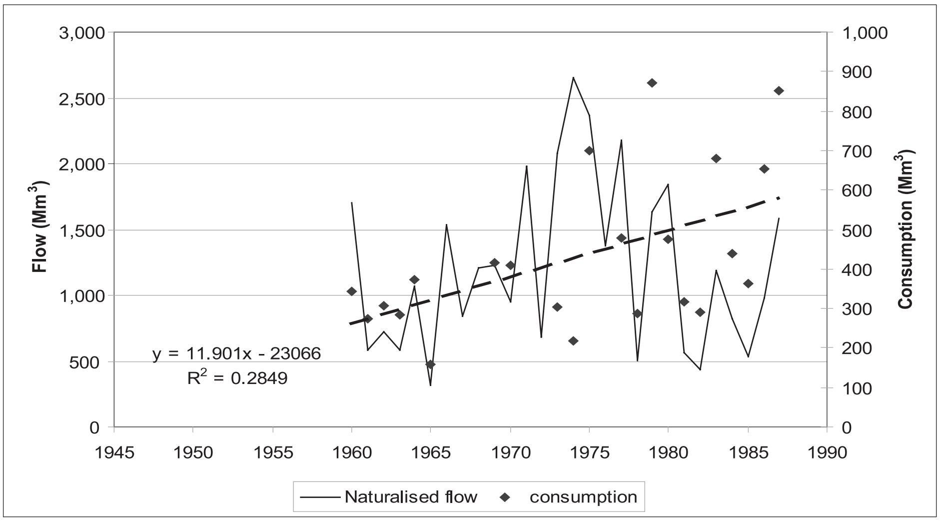
Figure 17. Comparison of measured and naturalized flow series at three locations on the main stem of the Olifants River.



Source: Derived from naturalized flow data from the WR90 study and gauged flow data, provided by DWAF

Figure 18. Annual variation in naturalized flow at gauging stations and estimated 'consumption' derived for two gauging stations on the Olifants main stem: a) B5H002 and b) B7H009.





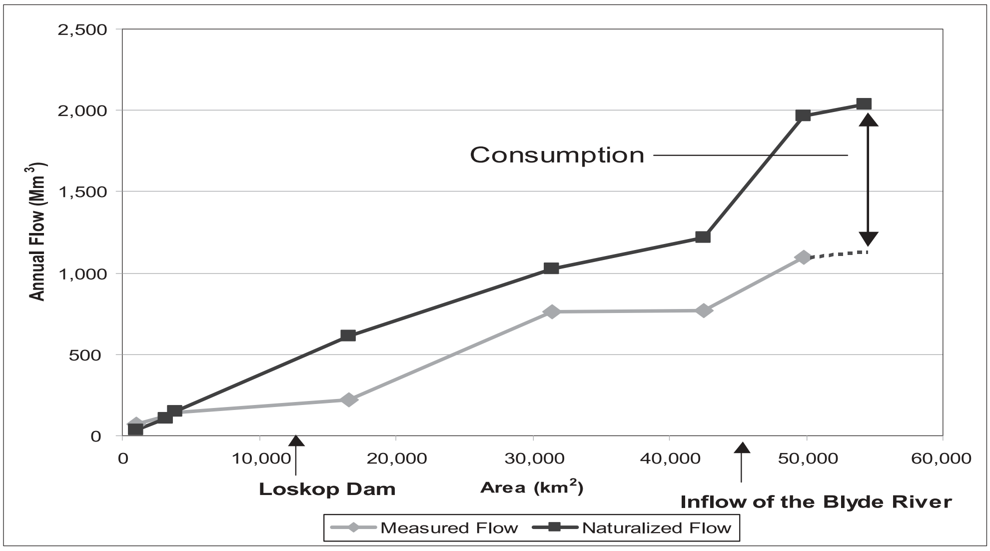
Source: Derived from naturalized flow data from the WR90 study and gauged flow data, provided by DWAF

Table 12. Total annual water demand in the Olifants catchment in 1995.

Sector	Water demand	
	Mm^3	% of total
Irrigation	540.3	54
Power Generation	160.2+	16
Urban/Domestic water supply	117.8	12
Mining/Industrial	94.3	9
Afforestation	55.4	6
Stock watering	27.8	3
Total	995.8	

Source: DWAF, 2002.
Note: + Supplied by water transfers into the Olifants Catchment (section 7.2)

Figure 19. Comparison of measured and naturalized mean annual flow with increasing distance downstream in the Olifants catchment.



Source: Naturalized flow data from the WR90 study and gauged flow data provided by DWAF

7. Water Resources Development

On average, approximately 900 Mm^3 of surface water (section 6.3) and 100 Mm^3 of groundwater (section 7.2) are consumed annually within the Olifants catchment. This equates to an average annual consumption in excess of 290,000 liters per person living in the catchment. The principal water consumers are irrigation, thermal power production (i.e., cooling water), urban water supply and mining and industrial use (table 12). Most of the water for power production is imported into the catchment (section 7.3) and because it is subsequently lost through evaporation has little impact on the overall hydrology of the catchment, although as noted in section 6.3 it may significantly modify the flow regime of the headwaters.

7.1 Dams

Water resource development has played a prominent role in the expansion of agriculture and industry in the Olifants catchment. Substantial state investment over the last century has financed the transformation of the Olifants River and its tributaries into a complex system for harvesting, storing, transporting and controlling water resources. The dams safety register, maintained by DWAF, is a national database with information on more than 4,000 dams for which there is a potential safety risk, i.e., where a breach of the dam will endanger life and/or cause significant economic loss. The register includes data on 210 dams located in the Olifants catchment (appendix B). The cumulative storage of these dams is 1,262 Mm^3.

In most cases, the dams included on the dam safety register are the largest dams in a catchment. For the Olifants catchment, 37 dams on the register are classified as 'major' dams (i.e., reservoir capacity in excess of 2 Mm^3) and 134 are classified as 'minor' dams (i.e., reservoir capacity between 0.1 and 2 Mm^3). The remainder of the dams on the register are classified as 'small' dams (i.e., reservoir capacity less than 0.1 Mm^3). However, the vast majority of small dams are deemed not to pose a safety risk and so are excluded from the register. There is considerable uncertainty about the number of minor and small dams in the Olifants catchment and over the years DWAF have published different estimates of the total number of dams and the capacity of the small and minor reservoirs (table 13). What is certain is that the number of minor dams is approximately 300 and the number of small dams is in excess of 3,000 and may exceed 4,000. On the WSAM database, the cumulative storage of nonmajor dams in the Olifants catchment is estimated to be 210 Mm^3.

Table 13. Estimates of the number of minor and small dams in the Olifants catchment and the capacity of the reservoirs they impound.

Water Management Region	DWAF, 1991[1]			DWAF, 2002[2]		
	Number of minor dams	Number of small dams	Capacity (Mm^3)	Number of minor dams	Number of small dams	Capacity (Mm^3)
Upper Olifants River	142	1,800	83.9	99	1,100	114.0
Upper Middle Olifants River	86	990	57.8	88	950	40.3
Mountain Region	35	261	16.5	42	0	15.4
Lower Middle Olifants Region	7	411	11.3	7	411	18.5
Lower Olifants Region	37	578	24.4	37	578	29.0
TOTAL	307	4,040	193.9	273	3,039	217.2

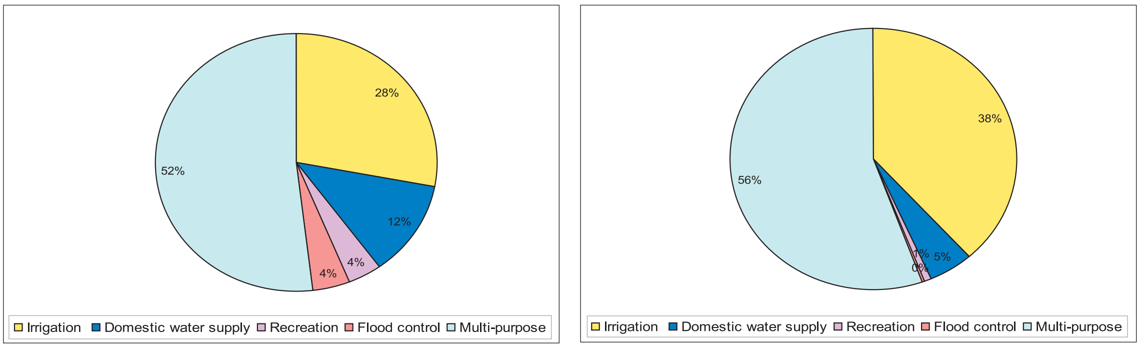
Source: [1]DWAF, 1991 and [2]DWAF, 2002

Within the Olifants catchment, the total storage, i.e., impounded by major, minor and small dams, is approximately 1,480 Mm^3. This equates to 72 percent of the average annual naturalized flow (section 6.2). Of this total 1,200 Mm^3 (85%) is impounded behind the 37 major dams (Dam safety register). These large dams were built for a variety of reasons. Information on the original reasons for construction was obtained from a variety of sources for 25 of the major dams. Using this information the following can be determined (figure 20):

- the majority of dams (52%) were constructed as multipurpose dams, i.e., they fulfil a number of functions;
- 28 percent of the dams, equating to 38 percent of the total storage, were built solely for irrigation;
- 40 percent of the multipurpose dams contribute to irrigation, so in total 52 percent of the major dams in the Olifants support irrigation;
- no dams have been built solely for industrial purposes, but 62 percent of the multipurpose dams include an industrial water supply function (including water supply to the mines); and
- 85 percent of the multipurpose dams have a domestic water supply function.

Figure 20. Function of major dams (storage > 2 Mm³) constructed in the Olifants catchment: a) number of dams; b) storage of dams (based on 25 large dams for which information on original purpose is available).

a) *b)*



Source: Various, including DWAF, 1991; Turton and Meissner, 2003

Over the last century, as the demand for water increased within the catchment, the number of dams built also increased (figure 21a). There was a rapid rise in the rate of dam construction in the 1960s and this rise continued well into the 1980s. Only in the 1990s was there a slight decline in the rate of dam construction. This pattern in the rate of dam construction lags the global trend (i.e., rapid rise following the second world war, which peaked in the 1970s and then declined) by approximately a decade (WCD, 2000). However, in terms of storage, the picture is more complex. More than 16 percent of the total storage in the catchment was constructed in the 1930s (figure 21b). This large increase was almost wholly attributable to the construction of a single dam, the Loskop Dam (capacity 178 Mm³) in 1939. Further increase in storage was limited until the 1970s and 1980s. In these two decades, more than 85 dams were built with a combined storage in excess of 800 Mm³ (i.e., 65% of the total storage in the catchment). The largest single dam built was Rhenosterkop, which impounds 206 Mm³. A large part of the increase was due to raising of the Loskop Dam in 1977 (see below).

White farmers moved into the Olifants catchment in the mid-1880s. The potential for irrigation was realized when a reconnaissance survey was undertaken between 1905 and 1907. However, it was the negative socioeconomic consequences of the severe droughts of the mid-1920s and early 1930s (section 6.2), causing great hardship to many farmers, which were a primary motivating factor in the government's decision to build dams. Moreover, many irrigation projects during the early 1930s were implemented not only to develop irrigation, but also to alleviate (white) unemployment and to stimulate the economy (Turton and Meissner 2003). The Loskop Dam is one such scheme.

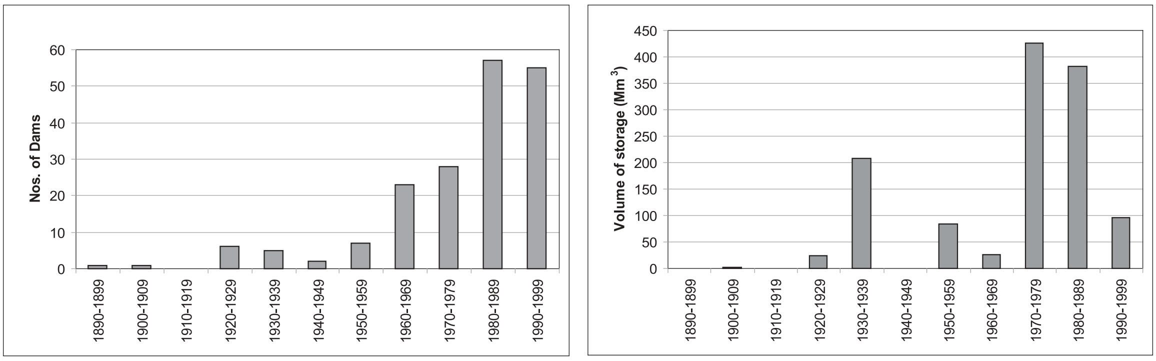
Following petitions from farmers in the area, planning for the Loskop Dam was initiated in April 1929 (i.e., in the final year of one of the worst droughts experienced in the area—section 6.2) when the Department of Irrigation recommended that the Loskop Irrigation Project on the Olifants catchment should be investigated. Work on the scheme commenced in 1934. Only white married men were employed in the construction. The work was funded by a loan from the Land Bank under the supervision of the Department of Irrigation. The reservoir filled and spilled during the high rains of December 1937 and January 1938 and the dam was completed at the end of 1938.

Following construction of the Loskop Dam, there was relatively little increase in dam storage within the Olifants catchment until the 1970s (figure 21b). By 1971, the Loskop Reservoir served a system of canals commanding an area of 25,600 ha, of which approximately 16,624 ha were irrigated. In the same year, the annual demand for water from Loskop Reservoir was estimated to be 144 Mm³. This included not only irrigation water, but also water for the municipalities of Middelburg and Groblersdal. To meet this demand and ensure supply after anticipated future development, DWAF proposed that the dam should be raised. In 1977, the dam was raised by 9.1 m to provide its present storage capacity of 374 Mm^3. This provides a firm yield of 145.2 Mm^3 a year, when operated in tandem with the upstream dams of Witbank (built 1971, capacity 104 Mm^3) and Middelburg (built 1978, capacity, 48.4 Mm^3) (DWAF 1991).

In 1973, the catchment area of the Loskop Dam was proclaimed a Government Water Control Area (GWCA) under provision of the Water Act of 1956. This prohibited the private construction of dams on the Olifants and its main tributaries upstream of the Loskop Reservoir. Off-channel reservoirs could be constructed providing that the total storage of reservoirs did not exceed 0.1 Mm^3 on any property (DWAF 1991). However, dams could be constructed if a government permit was obtained and designation of the GWCA provided farmers with direct access to loans and subsidies for the construction of dams, canals and other irrigation infrastructure (Deacon 1997, cited in Bate and Tren 2002).

Figure 21. The number of dams (a) and the capacity of storage built (b) in the Olifants catchment in each decade from 1890 to 1999.

a) *b)*

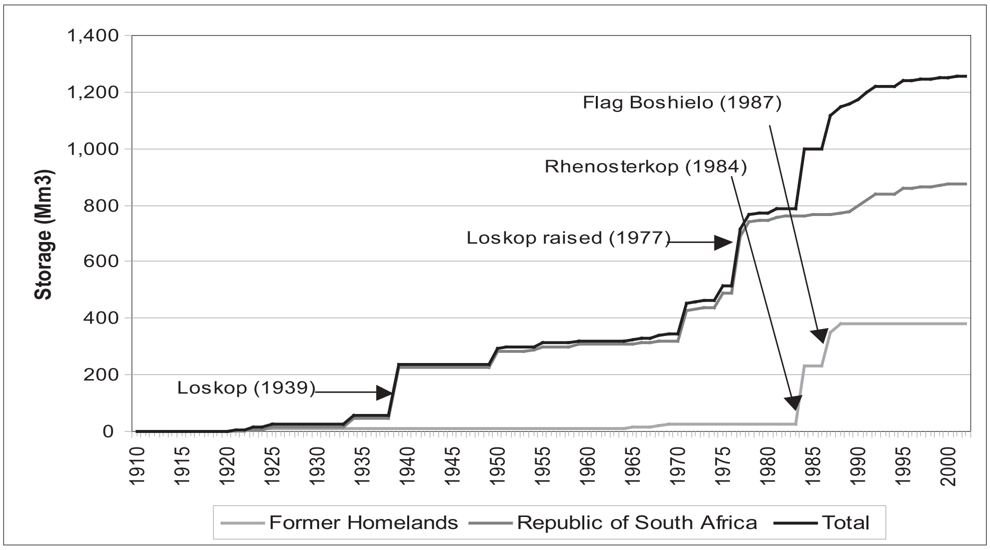


Source: DWAF dams safety register

Prior to the 1980s, during the apartheid era, a primary focus of dam construction in South Africa, was to benefit white communities. Up to the 1980s, dam construction within the so-called homelands (i.e., nominally ‘self governing’ regions, established for black communities) was significantly less than in the predominantly white regions. Within the Olifants catchment the homelands were Lebowa, Kangwane, Gazankulu and KwaNdebele. Figure 22 illustrates the difference in the historical development of storage in these homelands and what was then referred to as the Republic of South Africa (RSA). The locations of the dams built in each decade are shown on the maps presented in figure 23. Some water from dams built in the RSA was utilized in the homelands, for example, some water from the Loskop Reservoir was, and still is, used for domestic supply in KwaNdebele. However, the contrast in development is stark and it seems clear that overall the homelands benefited a lot less from water resource development than the RSA.

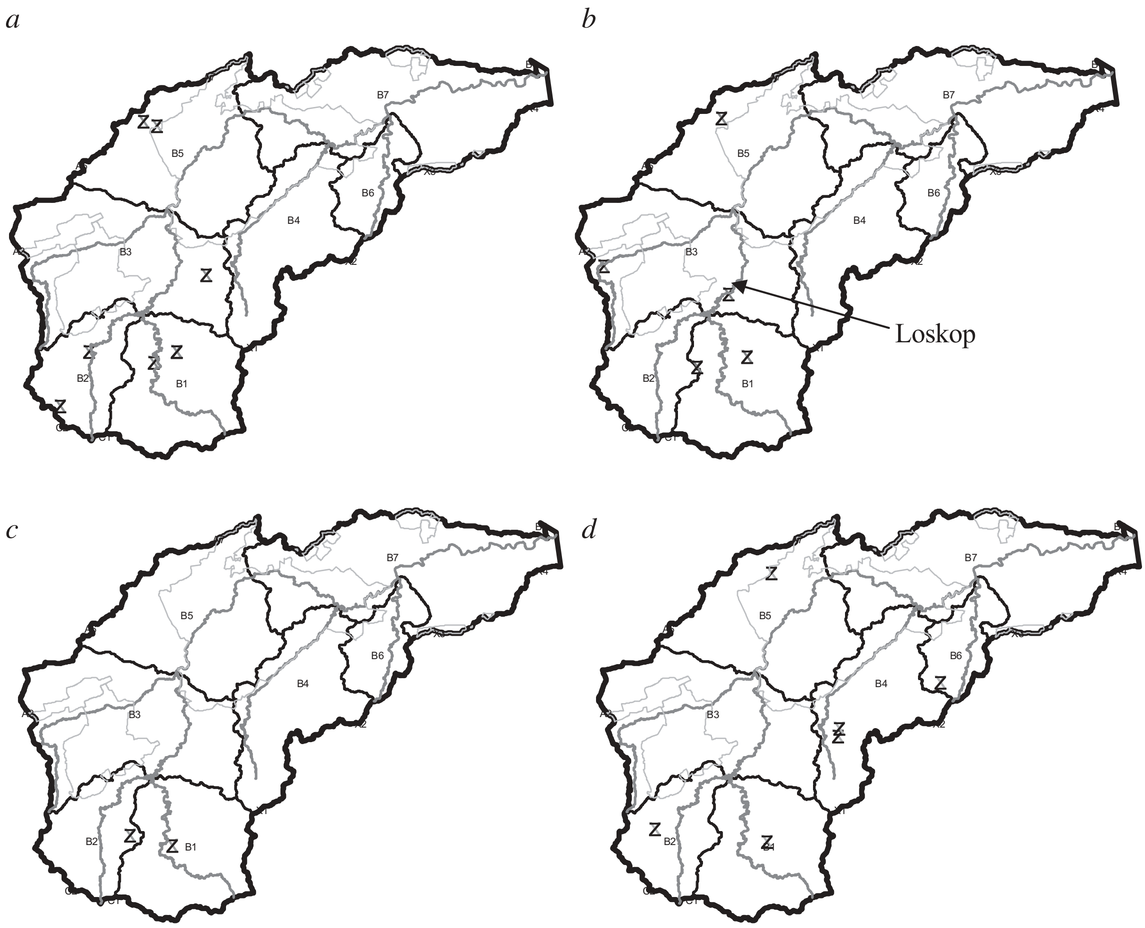
In the 1980s, two major dams were constructed in the homelands. It is possible that, at this time, the most technically attractive sites elsewhere in the catchment had already been developed. It has also been suggested that both dams were built in response to increased political pressure against the apartheid regime following the Sharpville Massacre in 1960 (Levite et al. 2003a). However, the motivation for what appears to be a change in policy is not entirely clear. Nevertheless, it is interesting that, as was the case with the 1930s construction, both dams were built following a period of severe drought (i.e., 1980 and 1981—section 6.2).

Figure 22. Development of large dam storage in the Olifants Catchment.



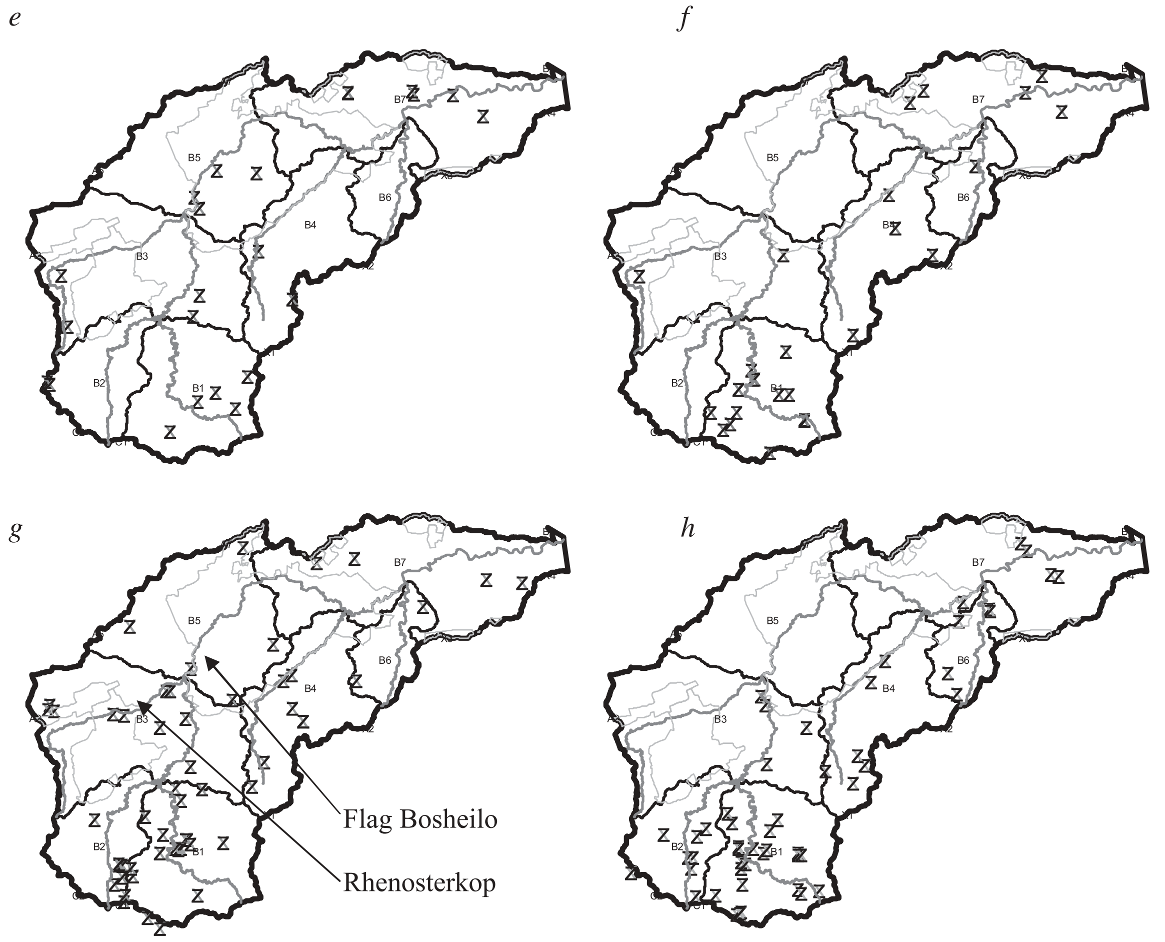
Source: Derived from DWAF dam safety register

Figure 23. Development of large dams in the Olifants catchment: a) Pre-1930; b) 1930-1939; c) 1940-1949; d) 1950-1959.



Source: Derived from DWAF dam safety register

Figure 23 (cont). *Development of large dams in the Olifants catchment: e) 1960-1969; f: 1970-1979; g) 1980-1989 and h) 1990-1999.*



Source: Derived from DWAF dam safety register

The two major dams built in the 1980s were the Rhenosterkop Dam (capacity 206 Mm^3) and the Flag Boshielo Dam (capacity 105 Mm^3 and formerly known as Arabie Dam). The Rhensoterkop Dam was built on the Elands River in what was at the time the KwaNdebele homeland. The Flag Bosheilo Dam was built on the main stem of the Olifants (downstream of the Loskop Dam) in what was then the Lebowa homeland. Both are multipurpose dams and both were financed and constructed by DWAF. The Rhenosterkop Dam was built to provide domestic and industrial water supplies in the KwaNdebele homeland. The Flag Bosheilo Dam was built to provide water for irrigation, for domestic and industrial supply and also for recreation.

The majority of small and minor dams were built to provide water for agriculture, i.e., irrigation and livestock watering. However, they are also used for a variety of other purposes including domestic supply, aquaculture and supply to the mines. The small dams will have some impact on the flows into and the yields from the major reservoirs, particularly as many do not have facilities to release water. Research in Botswana has shown that as the total capacity of small reservoirs within a catchment increases there is a decline in yield from major reservoirs. However, the decline is also affected by secondary factors such as the relative location of the small reservoirs and the way the water stored is utilized (Meigh 1995). At the present time the magnitude of the impact of small dams in the Olifants catchment is unknown, but in terms of resource planning DWAF assumes it is negligible (DWAF 1991).

Most small dams are privately financed and constructed, and most comprise simple earth embankments. It is believed that most small dams were constructed after 1960, possibly when the technology to build them easily became readily available. The most significant increase in small dams occurred between 1970 and 1980, particularly following years of low rainfall (DWAF 1991).

7.2 Groundwater

Groundwater resources in the Olifants catchment are used for partial fulfilment of urban, agricultural and mining requirements. The greatest utilization is in the northwest of the catchment in a region known as Springbok Flats (largely a former homeland area), where high yields, of the order of 30-20 ls^{-1}, are obtained from dolomite. Here, the groundwater is used extensively for irrigation and domestic supply. The mines are increasingly utilizing groundwater. However, at present, neither the magnitude of the resource nor the extent of utilization is very clear.

The variability of geology (section 2) and rainfall (section 4) mean that there is considerable spatial and temporal variation in recharge. Although difficult to determine accurately, quantifying recharge is a prerequisite for sustainable groundwater management. If abstraction exceeds recharge, then possible adverse repercussions include increased pumping costs, yield reductions, drying up of rivers and springs, and encroachment of saline water (Foster 1988).

In 1991, average annual recharge in the Olifants catchment was estimated to vary between 3 percent and 8 percent of mean annual precipitation, depending on location. Across the whole catchment, average annual recharge was estimated to be 1,825 Mm^3 (i.e., 5% of mean annual rainfall) (DWAF 1991). It is not clear which of the variety of methods available for estimating recharge was used to derive these figures. The WSAM database includes estimates of groundwater harvest potential for each quatenary catchment. Groundwater harvest potential is defined as *the maximum amount of groundwater that can be abstracted without depleting the long-term yield* and so must be equivalent to average recharge. These data suggest that average recharge is in the range 2 percent to 3.5 percent of mean annual precipitation and across the whole catchment is 900 Mm^3 (i.e., half the 1991 estimate—table 14). Again, it is not clear how these estimates were derived.

The WSAM database also includes estimates of the proportion of groundwater that is "utilizable" and the number of operational boreholes in each quaternary catchment. The proportion of groundwater that is utilizable is defined as a function of ease of extraction and water quality constraints. For the secondary catchments within the Olifants, it is estimated to range from 24 percent to 30 percent of the potential available. For the whole of the Olifants catchment, the utilizable quantity is estimated to be 251 Mm^3 (table 14). The number of operational boreholes in the catchment is based on a borehole inventory and reflects the fact that some boreholes are not used, some are only used intermittently and rates of abstraction do not necessarily coincide with borehole yields (Schultz and Watson 2002). The number of operational boreholes is estimated to be about one-third of the actual number of boreholes in a catchment. In total, there are estimated to be approximately 9,800 operational boreholes in the Olifants catchment, with nearly 50 percent in sub-catchment B3—the area containing the Springbok Flats (table 14).

Using the WSAM data, the total groundwater abstracted in the Olifants catchment is estimated to average 75 Mm^3 a year (i.e., 30% of the total accessible resource), of which 42 Mm^3 (i.e., 56% of the total) is abstracted in sub-catchments B3 and B5 (table 14). More recently the total groundwater abstracted has been estimated for the year 2000 at 99 Mm^3, of which 70 Mm^3 (i.e., 70% of the total) was abstracted from sub-catchments B3 and B5 (DWAF 2003). Best estimates, therefore, indicate that there is potential for further development of groundwater resources. However, the implications for surface water resources of utilizing more groundwater is not known at present.

Table 14. Comparison of groundwater resources in each of the secondary catchments in the Olifants River catchment.

Secondary Catchment	Area	Mean annual precipitation[1]	Groundwater harvest potential (i.e., recharge)[2]		Estimate of utilizable groundwater[2]	Estimated Nos. of operational boreholes [2]	Estimate of actual abstraction[2]
	km^2	mm	Mm^3	mm	Mm^3		Mm^3
B1	7,105	689	151	21	36	200	2
B2	4,356	670	89	20	26	161	3
B3	11,242	617	232	21	64	4,731	22
B4	7,136	681	90	13	26	757	12
B5	9,728	551	122	12	36	1,364	20
B6	2,842	823	51	18	15	196	3
B7	11,899	586	167	14	48	2,383	13
Total catchment	54,308	630	901	17	251	9,792	75

Source: [1]Computed from data in Schultz et al. 1997; [2]data in the WSAM database

Groundwater quality is generally considered acceptable although there are small areas, most notably in the Springbok Flats, with high nitrate concentrations and in areas where mining is occurring low pH (3 to 5) and high sulphate concentrations have been observed (DWAF 2002). A potential problem is foreseen with the cessation of pumping following the closure of a number of mines in about 2010. It is anticipated that when the water table ‘rebounds’, up to 171,000 m^3d^{-1} (62 Mm^3y^{-1}) of acidic mine water possibly contaminated with dissolved iron, aluminium and manganese will drain from the mines (DWAF 2003).

7.3 Inter-basin transfers

Water resources within the Olifants catchment are augmented by transfers from the Vaal, Komati, Usutu and Great Letaba Rivers (table 15). Most of the water transferred, i.e., from the Vaal, Kamati and Usutu Rivers, is utilized as cooling water in the power stations located in the headwaters of the Olifants catchment and so leaves the catchment as evaporation.

Table 15. Average annual water transfers (Mm^3) into the Olifants catchment.

Source	Power Stations	Other uses*	Total
Vaal River	21.8	5.0	26.8
Usutu River	64.0	0.0	64.0
Komati River	103.0	1.0	104.0
Great Letaba River	0.0	1.3	1.3
Total	188.8	7.3	196.1[+]

Source: DWAF, 1991
Note: * Domestic water supply, mines and fish farming

There are several schemes transferring water out of the Olifants catchment. One pumps 4.7 Mm^3 a year from a dam on the Wilge River to meet the requirements of the Premier Mine in the adjacent Crocodile River catchment (DWAF 1991). In addition, 2.6 Mm^3 a year is transferred to the Sand River for supply to the towns of Polokwane (formerly Pietersburg) and Seshego (Havenga—*personal communication*). Both the Crocodile River and the Sand River are tributaries of the Limpopo River.

DWAF estimate net transfers into the catchment in 2000 to have been 172 Mm^3 (i.e., very similar to that estimated in 1991) but provide no breakdown by source (DWAF 2003).

7.4 Irrigation

The primary consumer of water in the Olifants catchment is irrigation. From the 1950s, the area of the catchment under irrigation increased steadily from approximately 34,000 ha to approximately 130,000 ha in 1995 (table 16; figure 24). There is uncertainty about the exact extent of irrigation in 1995. The WSAMs database provides an estimate of 110,245 ha, but it is not clear how this was derived and it is possible that, although attributed to 1995, it actually reflects an average over several years. In contrast, the CSIR land-cover classification (CSIR 2003) provides an estimate of 128,021 ha. This is derived from a combination of georeferenced LANDSAT Thematic Mapper images captured in 1994 and 1995 and field observations (CSIR 1999). This is assumed to be the best estimate currently available. However, despite the high resolution of the remote sensed images, it will almost certainly have underestimated the extent of small-scale irrigation in the catchment (CSIR 1999). At present, there are no data available for the extent of irrigation in more recent years.

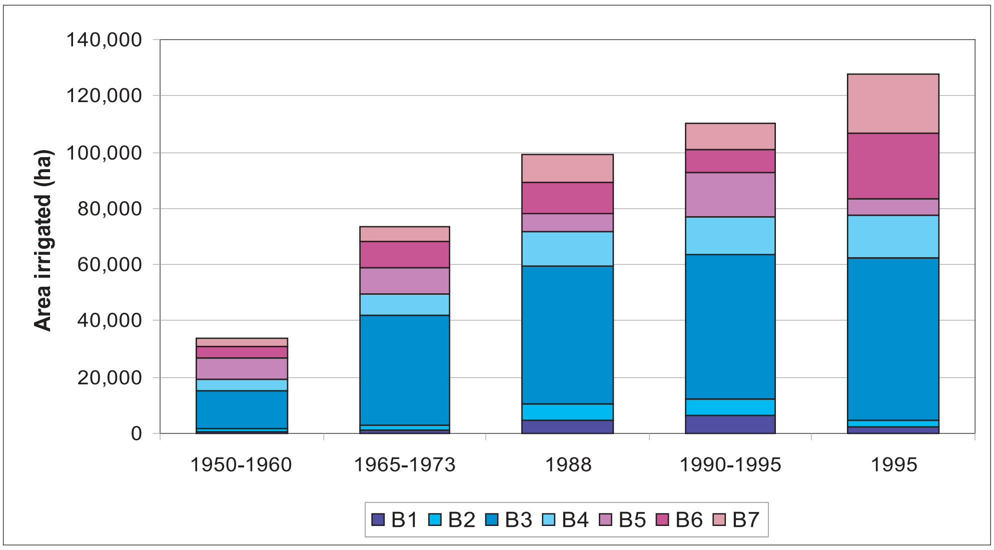
Almost all irrigation is in the commercial farming sector. The greatest proportion of the irrigation has always been in secondary catchment B3, largely in the vicinity of the Loskop Dam. However, in recent years there has been a significant increase in the area irrigated in the Lower Olifants, downstream of the Blyde Rivierspoort Dam. Figure 25, provides a comparison of the percentage area under different crops for both irrigated and dry land areas within the catchment. Wheat, maize and cotton comprise approximately 50 percent of the irrigated crops and of the rain-fed crops; maize is by far the most dominant.

Table 16. Estimated area under irrigation in the sub-catchments of the Olifants catchment.

Secondary		Area irrigated (ha)				
Catchment	Area (km^2)	1950-1960[1]	1965-1973[1]	1988[1]	1990- 1995[2]	1995[3]
B1	7,105	625	920	4,760	6,560	2,110
B2	4,356	1,280	2,040	5,580	5,589	2,435
B3	11,242	13,170	38,975	49,295	51,621	57,618
B4	7,136	4,203	7,654	12,118	13,104	15,258
B5	9,728	7,700	9,338	6,455	15,850	6,043
B6	2,842	3,875	9,400	11,297	8,291	23,521
B7	11,899	2,933	5,311	9,410	9,230	21,035
Total catchment	54,308	33,786	73,638	98,915	110,245	128,021

Source: [1]DWAF 1991, [2]WSAM 1995 and [3]CSIR 2003

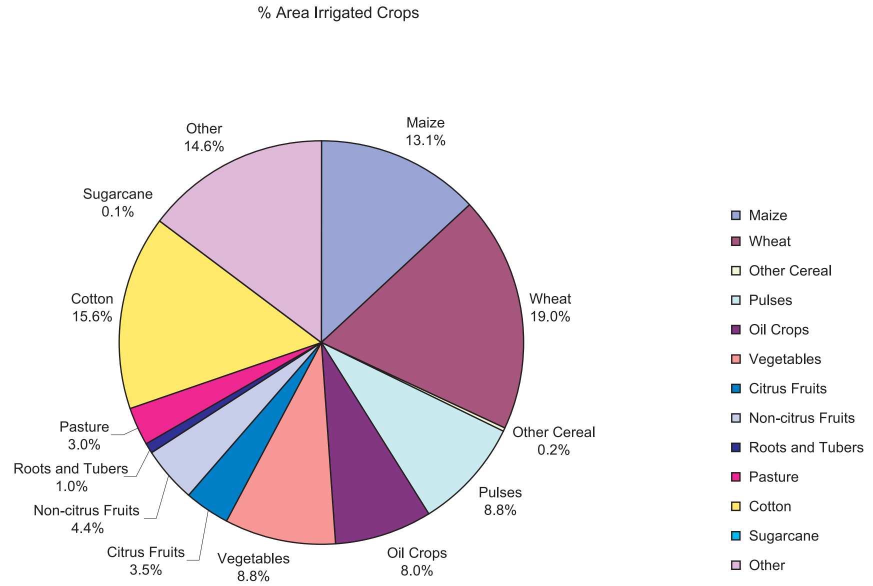
Figure 24. Estimated area under irrigation in each of the sub-catchments of the Olifants River Basin.



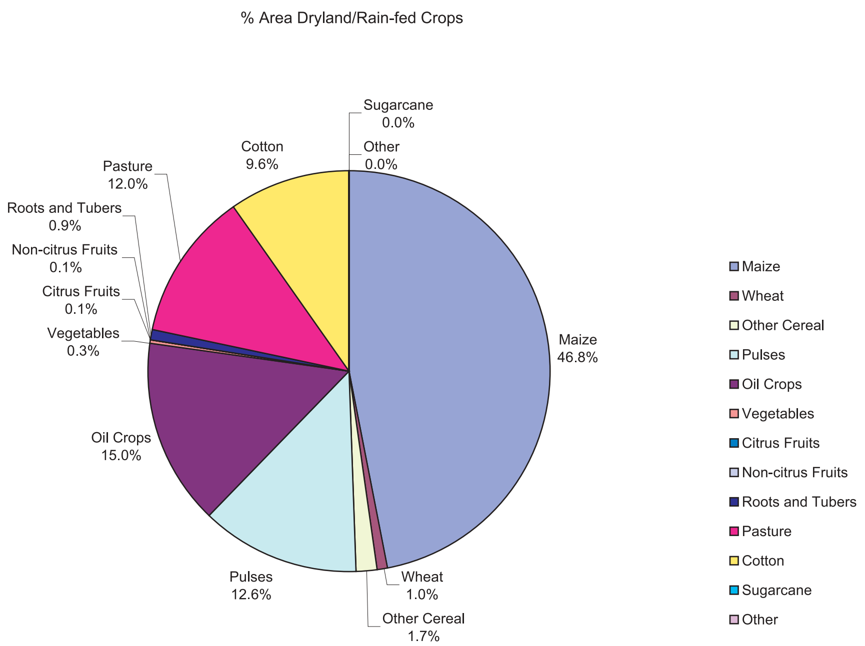
Source: Data in WSAM database, DWAF, 1991 and CSIR, 2003

Figure 25. Percentage of area in the of the Olifants catchment in 2003 under different crops a) irrigated b) dry land. Note total area of dry land cultivation is 945,948 ha and irrigated cultivation is 128,021 ha.

a)



b)



7.5 Domestic water supply

Sixty-seven percent of the population of the Olifants catchment is classified as living in rural areas. The only major urban areas are the towns of Witbank and Middelburg, both of which are located in the Upper Olifants water management region. Table 17 presents the annual urban-domestic water demand, estimated for the year 1995 and the total population for each of the water management regions in the catchment.

Table 17 illustrates clear inequities in domestic water use. Although nearly 56 percent of the population lives in the Upper and Lower Middle Olifants regions, their domestic water demand comprises just 28 percent of the total. This equates to an annual per capita demand of 17,200 liters. At the present time, many thousands of people living in the Middle Olifants region do not have access to piped water. In contrast, the 35 percent of the population in the Upper and Lower Olifants regions utilize 68 percent of the total demand, which equates to an annual per capita demand of 66,950 liters.

Table 17. Population and urban/domestic water supply in each of the water management regions of the Olifants catchment.

Water Management Region	Population		Annual Urban/Domestic Water Demand – 1995*	
	Nos.	% total	Mm^3	% total
Upper Olifants	592, 500	17.4	52.4	44.5
Upper Middle Olifants	923,120	27.1	18.7	15.9
Mountain	298,900	8.8	4.6	3.9
Lower Middle Olifants	979,594	28.8	14.1	12.0
Lower Olifants	608,328	17.9	28.0	23.8
Total	3,402,500		117.8	

Source: DWAF 2002
Note: * The demand includes smaller industrial demands, supplied by municipalities, but major industries are excluded.

The domestic water demand is expected to almost double to approximately 222 Mm^3 by 2010, in part because of the South African government's commitment to supply potable water to the entire population of South Africa (National Water Act 1998). However, the greatest increase is anticipated in the Upper Olifants River where demand is expected to increase to 125 Mm^3 by 2010 (DWAF 2002).

7.6 Future resource development

No major dams have been built in the Olifants catchment for more than 10 years. However, water requirements are growing rapidly with the development of mines and increasing power generation and domestic demand. An assessment of water requirements and availability in the Olifants catchment indicates a current annual shortfall of approximately 196 Mm^3. It is estimated that this will increase to 243 Mm^3 by 2025 (DWAF 2003). The deficit occurs in part because it is a requirement of the National Water Act (1998) that contemporary water resource planning makes provision for a Reserve. The Reserve comprises two parts: the quantity and quality of water required for basic human use and the Ecological Reserve, which is defined as the quantity and quality of water required to protect aquatic ecosystems—the base of the water resource. For the Olifants River, the volume of water required for the Reserve has been determined to be 460 Mm^3 (DWAF 2003). Flow releases from the Flag Boshielo Dam are set at 50 m^3s^{-1} to meet downstream needs and maintain the Ecological Reserve through the Kruger National Park which is set at a minimum flow of 0.54 m^3s^{-1} (DWAF 2003).

The current water 'deficit' means that water is not being supplied to users at the level of assurance DWAF would like and curtailments are necessary. The Limpopo Province Economic Development Strategy revealed that the lack of regular water supply is one of the major constraints hampering development in the region, and both the mining and the agriculture sector are producing below optimal levels because of reliance on insufficient supplies (Cambridge Resources International 2003). Furthermore, some water requirements are not being used and the water requirement of the Ecological Reserve is not being met.

To make up the deficit, DWAF is proposing to raise the Flag Bosheilo Dam and to build one or two major dams. The new dams being considered are one on the Olifants main stem (the Rooipoort Dam) and one on the Steelport River (possibly the De Hoop Dam). Raising the Flag Boshielo Dam has been approved by the government and will provide an additional assured yield of 18 Mm^3y^{-1}. The Rooipoort Dam would add an additional 134 Mm^3y^{-1} and the dam on the Steelport River would provide another 87 Mm^3y^{-1}. In addition, an extra 38 Mm^3y^{-1} has been reserved in the Vaal system for transfer to the Olifants for use in power generation (DWAF 2003). Consideration is also being given to increased exploitation of groundwater, particularly in rural areas, where it is anticipated conjunctive use schemes may be feasible.

Other strategies being developed, particularly to ease the shortfall in the near future, are:

i) improved water conservation and demand management;
ii) trading water rights between users;
iii) diminishing stream flow reduction activities (e.g., by removal of alien vegetation); and
iv) phased introduction of the Ecological Reserve.

8. Future Research Needs

Within South Africa, the establishment of the Catchment Management Agencies (CMAs) is intended to increase the opportunity for stakeholders to participate in water resource management and to optimize social and economic benefits through more effective, efficient and equitable utilization of water. The Olifants catchment will be one of the first in which a CMA will be established.

In a catchment such as the Olifants where water resources are increasingly stressed, successful management requires detailed understanding of the system hydrology as well as the integration of a range of environmental, social and economic factors. Lack of information about the hydrology and present utilization of water resources has been identified as being one of the most likely impediments to the success of the CMA (Lévite et al. 2003b). For example, the available databases, although much better than many places in the world, are presently too sparse to facilitate the detailed analysis of water use patterns, required to formulate sound management programs. There are several key areas where future hydrological research should be focused:

- Higher resolution hydrological data and system models are required to evaluate local resources, current utilization and the impacts of future use. This should include river and bulk distribution losses as well as water requirements for different sectors. In particular, there is a need for better understanding of water use for irrigation including information on abstractions, return flows and impacts on water quality. The hydrological implications of increased platinum and chrome mining activities in the Middle Olifants need to be assessed. More quantitative information is required to evaluate the impacts of the elimination of prescribed flow reduction activities (i.e., the removal of alien vegetation) within the catchment.

- Assessment needs to be made of the impact of water conservation and demand management strategies (e.g., re-use and re-cycling of water) within the catchment. Consideration needs to be given to what can realistically be achieved and the possible consequences of reduced return flows on downstream water resources, water quality and ecology. In this context, the identification of hydronomic zones (Molden et al. 2001) may assist in the development and characterization of management strategies for different areas of the catchment.

- Much more understanding is required of water quality issues within the catchment. In particular, there is need to incorporate water quality within evaluations of water productivity. In a catchment with considerable mining activities, high productivity may be achieved at the cost of much reduced water quality, which can have severe socioeconomic as well as environmental implications downstream.

- Interactions between the high value use of water (i.e., in mining and industry) and small-scale farming need to be evaluated. The socioeconomic and equity implications of re-allocating water between sectors need to be assessed.

- The consequences of water utilization and resource management within the Olifants on downstream users in Mozambique need to be considered. Of particular interest are the quantity and quality implications for the Massingir Reservoir and, in particular, the likely impact of the Ecological Reserve when this is fully implemented. Consideration also needs to be given to the implications of an international agreement on cross-border flows.

- Much more information is needed about the extent, sustainable yield and current utilization of groundwater resources as well as the link between the utilization of groundwater and the subsequent impact on surface water resources, and the implications of increased groundwater exploitation in the future. Insight will be provided by process studies such as that presently being conducted in the north-west of the catchment to evaluate groundwater-surface water interactions, with support from the University of Natal, DWAF and IWMI (Tunha 2003).

- Treatment and irrigation management options of acid mine drainage need to be evaluated, particularly in light of the mine closures anticipated in 2010. Studies such as that presently being conducted in the Upper Olifants, to assess the impact of large-scale release of low quality water through irrigation should provide a good basis for assessing the potential impact of utilization of mine effluents in this manner (Idowu 2003).

9. Concluding Remarks

The following inferences can be drawn from this review:

1) Rainfall in the Olifants catchment is influenced significantly by the escarpment, which separates the highveld from the lowveld. Mean annual rainfall in the vicinity of the escarpment is relatively high, in excess of 800 mm, but to the east and west it is much less, dropping to below 600 mm in some places. In addition to the high spatial variability, rainfall also varies considerably between years.

2) Averaged across the whole catchment, mean rainfall only exceeds 50 percent of mean potential evapotranspiration in 4 months of the year. Consequently, the catchment is not ideal for the growth of crops and in many areas irrigation is required to reduce the risks of water shortage.

3) The naturalized mean annual flow of the Olifants catchment is 2,040 Mm^3. However, the high spatial and temporal variation in rainfall is reflected in the flow. Approximately 20 percent of the total mean annual flow is generated on just 5 percent of the catchment (i.e., the Blyde River sub-catchment which lies along the escarpment). A severe drought occurs in most decades.

4) The Olifants catchment is economically very important for the economy of South Africa, supporting significant mining, agricultural and industrial activities. It is also home to 3,400,000 people. All these sectors require large amounts of water.

5) Water resource development in the catchment has been extensive. There are 37 major dams (reservoir capacity in excess of 2 Mm^3) with a combined storage capacity of 1,262 Mm^3. In addition, it is estimated that there are approximately 300 small dams (reservoir capacity 0.1 to 2 Mm^3) and between 3,000 and 4,000 minor dams (reservoir capacity < 0.1Mm^3). The combined storage of these dams is approximately 210 Mm^3. Hence, total storage within the catchment equates to approximately 72 percent of the mean annual flow.

6) Comparison of measured and naturalized flow indicates human utilization 'consumes' on average 900 Mm^3 of surface water a year, i.e., 44 percent of the total available. This estimate corresponds reasonably well with DWAF's sectoral estimates of demand. Annual estimates of consumption show considerable variation between years. It is probable that this reflects differences in both water availability and demand, between wet and dry years. Although not statistically significant, because of the high inter-annual variation, the data indicate an increasing trend from the 1950s to the mid-1980s. This is assumed to have been driven by increasing population, growing economic activity and increased water resource infrastructure.

7) Major dam construction began in the catchment in the 1930s and in terms of storage built, peaked in the 1970s and 1980s. A time line of dam construction indicates a significant discrepancy between development in what were the former homelands and the former Republic of South Africa. Prior to the 1980s, there was considerable development in the Republic but very little development in the homelands. Using the data available for this review, it is not possible to deduce the reason for this discrepancy, but it is plausible that it reflects the different development priorities given to the 'white' and 'black' areas during the former apartheid regime. Further study is required to confirm whether or not this was the case.

8) At present, there is considerable uncertainty about both the magnitude of the groundwater resource and the extent to which it is used. Best estimates are that about 250 Mm^3 are accessible of which between 75 Mm^3 and 100 Mm^3 are presently used. However, the implications of increased groundwater use for surface water resources are not known.

9) Irrigation is estimated to consume approximately 540 Mm^3y^{-1} and is the largest water use in the catchment. Almost all the irrigation water is used in the commercial sector. It is estimated that in 1995, an area of 128,021 ha were irrigated (i.e., 11% of the total cultivated area in the catchment) and hence water consumption equates to 4,220 m^3 per hectare.

10) There is a considerable difference in the urban-domestic water consumed in different areas of the catchment. In the regions that incorporate the former homeland areas and where many people still lack basic water supply, per capita consumption equates to just 17.20 m^3y^{-1} (i.e., 47 liters per capita per day). In contrast in the upper and lower catchment, where the majority of the white population live, the average per capita consumption is 66.95 m^3y^{-1} (i.e., 183 liters per capita per day).

11) At present, the water resources in the catchment are severely stressed, which is hampering development in the catchment. Plans have been proposed for the construction of new infrastructure to improve the water resource situation and safeguard the Reserve.

12) Lack of understanding is a key constraint to successful management of water resources within the catchment. Future research should, among other things, focus on gaining insight into:

   i) irrigation abstraction, return flows and impacts on water quality;
   ii) the implications of water conservation and demand management strategies;
   iii) the implications of re-allocating water between sectors;
   iv) the extent, sustainable yield and potential for increased utilization of groundwater;
   v) inter-linkages between groundwater and surface water; and
   vi) the potential for using mine water for irrigation.

Appendix A

Flow gauging stations in the Olifants catchment.

Gauge number	Start of record	End of record	River	Description	Catchment area(km^2)	Location Latitude	Longitude
B1H001	1904	1951	Olifants River	Gauging weir	3,904.4	-25.8093	29.3197
B1H002	1956	still open	Spook Spruit	Gauging weir	252.0	-25.8190	29.3378
B1H003	1957	1966	Klein-olifants River	Gauging weir	1,576.0	-25.7740	29.5428
B1H004	1959	still open	Klip Spruit	Gauging weir	376.0	-25.6740	29.1711
B1H005	1972	still open	Olifants River	Gauging weir	3,256.0	-26.0070	29.2539
B1H006	1982	still open	Trichard Spruit	Gauging weir	107.0	-26.3590	29.2167
B1H012	1978	still open	Little Olifants River	Gauging weir	1,577.0	-25.7756	29.5458
B1H017	1989	still open	Steenkool Spruit	Gauging weir	387.0	-26.3062	29.2742
B1H018	1989	still open	Olifants River	Gauging weir	985.0	-26.2173	29.4592
B1H019	1990	still open	Noupoort Spruit	Gauging weir	88.1	-25.9404	29.2575
B1H020	1990	still open	Koring Spruit	Gauging weir	133.0	-26.1065	29.3308
B1H021	1990	still open	Steenkool Spruit	Gauging weir	1,356.3	-26.1368	29.2700
B1H022	1991	still open	Trichardt Spruit	Gauging weir	-	-26.4957	29.2411
B2H001	1904	1951	Bronkhorst Spruit	Gauging weir	1,594.0	-25.7926	28.7556
B2H002	1917	1931	Rietfontein Eye	Gauging flume	-	-26.0506	28.4833
B2H003	1982	still open	Bronkhorst Spruit	Diversion weir	1,574.0	-25.7995	28.7358
B2H004	1984	still open	Os Spruit	Gauging weir	123.0	-25.9254	28.5856
B2H005	1984	still open	Os Spruit	Gauging flume	16.0	-25.9943	28.5125
B2H006	1984	still open	Os Spruit	Gauging weir	54.0	-25.9673	28.5508
B2H007	1985	still open	Koffie Spruit	Gauging weir	317.0	-25.9954	28.6628
B2H008	1985	still open	Koffie Spruit Trib	Gauging weir	100.0	-26.0795	28.5628
B2H009	1985	still open	Koffie Spruit	Gauging weir	86.0	-26.0923	28.6036
B2H013	1907	1949	Bronkhorst Spruit	Flood section	1,594.0	-25.7926	28.7556
B2H014	1990	still open	Wilge River	Gauging weir	1,086.3	-25.8273	28.8303
B3H001	1966	still open	Olifants River	Gauging weir	16,553.0	-24.9173	29.3842
B3H002	1929	1933	Elands River	Gauge plates	1,206.0	-25.2095	28.5692
B3H003	1965	still open	Elands River	Gauging weir	1,050.0	-25.2629	28.4675
B3H004	1966	still open	Elands River	Gauging weir	6,133.0	-24.8853	29.3575
B3H005	1969	still open	Moses River	Gauging weir	1,673.0	-24.9912	29.3514
B3H006	1970	1988	Diepkloof Spruit	Gauging weir	244.0	-25.1542	29.4975
B3H007	1980	still open	Moses River	Gauging weir	971.0	-25.2701	29.1847
B3H008	1979	still open	Elands River	Storage weir	4,083.0	-25.1151	28.9975
B3H021	1989	still open	Elands River	Gauging weir	6,119.0	-24.9259	29.3244
B4H001	1921	1921	Dorps River	Gauging notch	707.0	-25.0006	30.4467
B4H002	1931	1937	Steelpoort River	Gauge plates	4,411.0	-24.6659	30.2939
B4H003	1955	still open	Steelpoort River	Gauging weir	2,240.0	-25.0295	29.8567
B4H004	1960	still open	Dorps River	Diversion weir	701.0	-25.0095	30.4450
B4H005	1960	still open	Waterval River	Gauging weir	188.0	-25.0384	30.2192
B4H006	1954	1979	Lang Spruit	Gauging weir	198.0	-25.6290	29.9900

Continuation of Appendix A.

Gauge number	Start of record	End of record	River	Description	Catchment area(km^2)	Location Latitude	Longitude
B4H007	1963	still open	Klein-spekboom River	Gauging weir	151.0	-25.0087	30.4994
B4H009	1966	still open	Dwars River	Gauging weir	448.0	-24.9131	30.1033
B4H010	1979	still open	Dorps River	Gauging weir	526.0	-25.0759	30.4389
B4H018	1968	1968	Malanslaerloop	Gauging weir	-	-25.1006	29.8792
B5H001	1919	1932	Gompies River	Gauging weir	396.0	-24.3034	29.3192
B5H002	1948	1988	Olifants River	Gauge plates	31,416.0	-24.2673	29.8008
B6H001	1909	still open	Blyde River	Gauging weir	518.0	-24.6798	30.8025
B6H002	1909	1939	Treur River	Gauging weir	97.0	-24.6823	30.8147
B6H003	1959	still open	Treur River	Gauging weir	92.0	-24.6867	30.8150
B6H004	1950	still open	Blyde River	Gauging weir	2,241.0	-24.4592	30.8275
B6H005	1958	still open	Blyde River	Gauging weir	2,204.0	-24.5145	30.8289
B6H006	1963	still open	Kranskloof Spruit	Gauging weir	43.0	-24.9281	30.5461
B6H007	1971	still open	Vyehoek River	Gauging weir	86.0	-24.7248	30.6439
B6H014	1989	still open	Blyde River	Current metering	2,176.0	-24.5381	30.7958
B6H016	1910	1925	Blyde River	Flood section	518.0	-24.6798	30.8025
B7H001	1938	1950	Klaserie River	Gauge plates	137.0	-24.5506	31.0267
B7H002	1948	still open	Ngwabitsi River	Gauging flume	58.0	-24.0926	30.2753
B7H003	1948	still open	Selati River	Gauging weir	84.0	-24.1226	30.3586
B7H004	1950	still open	Klaserie River	Gauging weir	136.0	-24.5559	31.0322
B7H005	1952	1961	Bangu River	Storage weir	202.0	-24.0050	31.8500
B7H006	1952	1961	Ngotso River	Storage weir	41.0	-24.1339	31.7000
B7H007	1955	still open	Olifants River	Gauging weir – no data available	46,583.0	-24.1839	30.8222
B7H008	1956	still open	Selati River	Storage weir	832.0	-24.0098	30.6728
B7H009	1960	still open	Olifants River	Gauging weir	42,472.0	-24.3312	30.7408
B7H010	1960	still open	Ngwabitsi River	Gauging weir	318.0	-24.0356	30.4333
B7H011	1963	still open	Mohlapitse River	Gauge plates	262.0	-24.1642	30.1058
B7H012	1965	1975	Klaserie River	Gauging weir	444.0	-24.3223	31.1411
B7H013	1970	still open	Mohlapitse River	Gauging weir	263.0	-24.1731	30.1031
B7H014	1973	still open	Selati River	Gauging weir	83.0	-24.1245	30.3536
B7H015	1983	still open	Olifants River	Gauging weir	49,826.0	-24.0595	31.2372
B7H019	1961	still open	Ga-Relati River	Gauging weir	2,268.0	-24.0362	31.1289
B7H020	1988	1991	Timbavati River	Storage weir	935.5	-24.2378	31.6403
B7H023	1948	1960	Ngwabitsi River	Flood section	58.0	-24.0926	30.2753

Appendix B

Dams in the Olifants catchment that are included on the DWAF safety register.

Completion Date	Name	Long. °E	Lat. °S	River	Height (m)	Capacity (Mm^3)
1939	Loskop Dam	29.36	25.42	Olifants River/Rivier	53	374.31
1984	Rhenosterkop Dam 4	28.92	25.10	Elands River/Rivier	35	205.80
1987	Flag Boshielo Dam-was Arabie Dam (Mokgomo Matlala)	29.43	24.80	Olifants River/Rivier	36	105.00
1971	Witbank Dam	29.32	25.89	Olifants River/Rivier	42	104.02
1950	Bronkhorst Spruit Dam	28.73	25.89	Bronkhorst Spruit	32	57.91
1975	Blyderivierspoort Dam	30.80	24.54	Blyde River/Rivier	71	54.05
1978	Middelburg Dam	29.55	25.77	Lit/Kln Olifants River/Rivier	36	48.43
1988	Kennedys Vale Dam	30.10	24.84	Dwars River/Rivier	43	28.00
1934	Rust De Winter Dam	28.53	25.23	Elands River/Rivier	31	27.21
1990	Kromfontein Middle Coffer Dam	29.25	26.12	Steenkool Spruit	14	18.00
1991	Tweedraai Dam	29.22	26.43	Trichard Spruit	21	18.00
1981	Trichardtsfontein Dam	29.23	26.52	Trichardt Spruit	26	14.70
1955	Ohrigstad Dam	30.62	24.92	Ohrigstad River/Rivier	52	14.44
1995	Boschmanskop No.1 Dam	29.63	26.02	Woes-alleen Spruit	22	14.40
1992	Kromfontein Lower (Wilge) Coffer Dam	29.25	26.08	Steenkool Spruit	15	13.00
1925	Doornpoort Dam	29.30	25.87	Olifants River/Rivier	16	9.18
1923	Onder-compies Dam	29.32	24.30	Compies River/Rivier (Nkumpi)	25	9.13
1989	Der Brochen Dam	30.11	25.06	Grt. Dwars River/Rivier	31	7.30
1968	Piet Gouws Dam - Lebowa	29.61	24.57	Ngwaritsi River/Rivier	21	6.50
1992	Kromfontein Upper (Middledrift) Coffer Dam	29.25	26.12	Steenkool Spruit	20	6.00
1966	Phalaborwa Barrage	31.17	24.07	Olifants River/Rivier	21	5.65
1959	Klaserie Dam (Jan Wassenaar)	31.07	24.53	Klaserie River/Rivier	20	5.61
1987	Tours					5.50
1971	Buffelskloof Dam	30.27	24.95	Watervals River/Rivier	39	5.38
1978	Rietspruit Dam	29.22	26.17	Riet Spruit	20	4.64
1987	Molepo Dam	29.78	24.00	Mohogodima River/Rivier	20	4.52
1995	Boschmanskop No.3 Dam	29.63	26.02	Woes-alleen Spruit	20	4.50
1973	Belfast Dam (Weltevrede 386 JS)	29.99	25.66	Dorp Spruit	13	4.39
1997	Pullens Hope WPC Dam	29.65	26.03	Unnamed	9	4.10
1999	Upper Vlei Shaft Dam	29.23	25.99	Olifants River/Rivier Tr.	19	3.88
1969	Buffelsdoorn Dam – Lebowa	29.46	24.75	Makotswane River/Rivier	21	3.40
1991	Krapfontein Dam	29.24	26.42	Krapfontein Spruit	20	3.38
1951	Chuniespoort Dam	29.50	24.20	Chunies River/Rivier	15	3.37
1924	Mogoto Dam – Nuwe Dreineringsgebied	29.23	24.27	Mogoto River/Rivier	34	2.93
1988	Nkadimeng Dam - Lebowa	29.98	24.64	Pshirwari River/Rivier	19	2.80

Continuation of Appendix B

Completion Date	Name	Long. °E	Lat. °S	River	Height (m)	Capacity (Mm^3)
1972	Kromdraai Flood Diversion Dam	28.58	25.27	Elands River/Rivier Tr.	21	2.25
1921	Rooikraal Dam	29.65	25.29	Bloed River/Rivier	15	2.10
1936	Bo-compies Dam	29.31	24.25	Compies River/Rivier (Nkumpi)	15	2.09
1968	Roodepoort Dam	29.49	25.39	Selons River/Rivier	17	1.80
1984	Speculatie Dam	29.65	25.95	-	6	1.75
1909	Wilge River Dam (Premier Mine)	28.87	25.80	Wilge River/Rivier	11	1.69
	Vergelegen Dam – was Lehlagare Matlala Dam - Lebowa	29.84	24.81	Ngwantsi River/Rivier	17	1.55
1966	Lola Montes Dam – Lebowa	29.49	24.82	Motsephiri River/Rivier	21	1.40
1965	Lepellane Dam-nuwe Nr. Ou Nr. was B500-06	29.87	24.58	Sebelwane River/Rivier	28	1.30
	Dr Eiselen Dam	29.98	24.87	Shakwaneng River/Rivier	23	1.17
1964	Kromdraai Industrial Water Dam	28.58	25.27	Elands River/Rivier Tr.	16	1.14
1977	Lydenburg Town Dam	30.52	25.13	Sterk River/Rivier	27	1.10
1999	Driefontein Dam	29.33	25.99	Boesmanskrans Spruit	9	1.05
1950	Bankfontein Dam	29.47	25.98	Spook Spruit	12	1.00
1930	Pienaars Dam	29.48	25.83	Vaalbank Spruit	9	1.00
1998	Boschmanskrans Spruit Dam 1	29.42	26.00	Boschmanskrans Spruit	14	0.94
1979	Matla Power Station Terminal Reservoir Nos. 1 and 2	29.13	26.29	-	9	0.89
1979	Duvha Power Station Terminal Reservoirs Nos. 1 and 2	29.33	25.95	-	11	0.89
1980	Mahlangu Dam	29.71	25.01	Motsephiri Spruit	15	0.88
2000	Klipfontein Dam	29.53	25.94	Vaalbank Spruit Tr.	9	0.78
	Spitskop Dam	29.80	24.98	Tshweneng River/Rivier	12	0.75
	Gesluit-was Spitskop Dam-nou B401-56	29.80	24.92	Tshweneng River/Rivier	12	0.75
1996	Goedehoop Dam	29.38	24.98	Olifants River/Rivier	11.9	0.75
1966	Goosen Dam	30.48	24.06	Ga-selati River/Rivier	9	0.73
1984	Selati Dam	30.52	24.07	Ga-selati River/Rivier	8	0.72
1988	Piet Grobler Dam	31.63	24.23	Timbavati	0	0.70
1976	Kriel Terminal Reservoirs Nos. 1 and 2 (Raw Water)	29.18	26.25	-	9.2	0.68
1968	Harmonie Dam	30.48	24.05	Ga-selati River/Rivier	8	0.66
1969	Mapoch's Dam	29.88	25.10	Mapochs River/Rivier	25	0.64
1954	Tonteldoos Dam	29.94	25.28	Tonteldoos River/Rivier	17	0.63
	Rietfontein Weir/Studam	29.22	21.28	Trichard Spruit	9	0.61
1991	Syferfontein Dam	29.25	26.41	Krapfontein Spruit	12	0.60
2002	Havercroft Dam	30.18	24.30	Olifants River/Rivier	10	0.59
1982	No. 5 Pollution Control Dam	29.41	25.93	Spook Spruit Tr.	5	0.58
1985	Leeuwklip Dam	29.84	25.58	Steelpoort River/Rivier Tr.	19	0.53
	Jounie Dam	30.09	24.96	Klein Dwars Rivier/River	7	0.50

Continuation of Appendix B

Completion Date	Name	Long. °E	Lat. °S	River	Height (m)	Capacity (Mm^3)
1988	Blesbok Spruit No.1- Dam	28.99	26.34	Blesbok Spruit	7	0.50
1946	Douglas Colliery Dam	29.36	26.00	Boesmankrans Spruit Tr.	8	0.49
	Fedmis Gypsum Dam B	31.09	23.98	Selati River/Rivier Tr.	70	0.48
1989	Douglas Waters Dam	29.33	25.99	Boesmanskrans River/Rivier	6	0.46
1986	De Kafferskraal Dam H	30.18	25.15	Kafferskraal Spruit	13	0.45
1959	Vlugkraal Dam	29.95	25.23	Vlugkraal River/Rivier	26	0.44
1960	Hendrina-dorps Dam	29.73	26.15	Klein-olifants River/Rivier Tr.	7	0.43
1996	Rubicon Dam	29.41	25.04	Olifants River/Rivier	11	0.43
	Fedmis Gypsum Dam A	31.09	23.97	Selati River/Rivier Tr.	68	0.42
1986	Kendal Power Station Terminal Reservoirs Nos. 1 and 2	28.98	26.10	-	9	0.41
1890	Kruger Dam	29.45	25.80	Du Toit Spruit	7	0.41
1967	Hendrina Power Station Raw Water Terminal	29.60	26.04	-	7	0.41
1998	Tubatse Dam	30.20	24.75	Steelpoort River/Rivier Tr.	25	0.40
1999	Witbooi Dam	29.81	25.48	Steelpoort River/Rivier Tr.	15	0.40
1990	Lake Millstream	30.67	25.44	Witpoort River/Rivier Tr.	15	0.38
2002	Welverdiend Dam 2	29.40	26.03	Boesmanskrans Spruit Tr.	8	0.36
1982	No. 2 Pollution Control Dam	29.40	25.93	Spook Spruit	10	0.35
1994	Mantsibi Spruit	30.62	24.83	Mantsibi Spruit	15	0.34
1973	Bogart Dam	30.46	24.04	Ngwabitsi River/Rivier	8	0.31
1981	Weltevreden Weir	28.99	25.11	Elands River/Rivier	11	0.30
1984	Uyskraal-middel Dam	29.30	24.95	Elands River/Rivier Tr.	7	0.30
1985	Welverdiend Dam	30.97	24.39	Sand Spruit	9	0.29
1940	Clewer Dam	29.08	25.93	Groot Spruit Tr.	10	0.29
	Rhenosterfontein Dam	28.54	25.83		7	0.28
1920	Athlone Dam	29.45	25.80	Du Toit Spruit	8	0.27
1968	Victor Wilkens Dam (Peru Dam)	31.37	24.21	Nhlaralumi River/Rivier	7	0.27
1987	Sobeli Dam	31.39	24.21	Ga-sekgobela River/Rivier	7	0.26
1968	Arnot Power Station Terminal Reservoirs Nos. 1 and 2	29.81	25.94	Natural Pan	6	0.25
1976	Bramleigh Dam	30.37	24.12	Ga-selati River/Rivier	14	0.25
1983	Vlakfontein Dam	30.53	24.88	Ohrigstad River/Rivier Tr.	8	0.25
1986	Mooigelegen Dam	29.03	24.52	-	12	0.25
1994	Groblershoop Dam	29.77	26.27	Ltl/Kln Olifants River/Rivier	10	0.25
1995	Tollie Dam No. 1	29.63	26.03	Woes-alleen Spruit Tr.	10	0.25
1969	Aangewys Dam	29.30	26.30	Steenkool Spruit Tr.	7	0.24
1978	Frischgewaagd Dam	29.67	26.22	Olifants River/Rivier Tr.	7	0.24
1997	Boschmanskrans Spruit Dam 2	29.40	26.02	Boschmanskrans Spruit	7	0.24
1988	Hartbeest Spruit Dam	29.13	25.78	Klip Spruit Tr.	6	0.24
1925	Witklip Bottom Dam	28.68	26.16	Bronkhorst Spruit	4	0.23

Continuation of Appendix B

Completion Date	Name	Long. °E	Lat. °S	River	Height (m)	Capacity (Mm^3)
1983	Bombardie Farm Dam No.2	29.05	26.17	-	5	0.23
1995	California Dam – Lebowa	30.69	24.49	Phiring River/Rivier	22	0.23
1986	Kendal Power Station: Dirty Water Dam	28.96	26.10	Wilge River/Rivier Tr.	11	0.23
1988	No. 7 Allen's Dam	29.43	25.96	Spook Spruit	9	0.23
1996	Loole Dam	31.14	24.02	Ga-selati River/Rivier Tr.	8	0.23
2001	North Dam	29.64	26.03	Woest-alleen Tr.	7.7	0.23
1972	Sable Dam	31.24	23.94	Tshtshi River/Rivier	8	0.22
1978	Argyle Dam	31.37	24.18	Ga-sekgobela River/Rivier	9	0.22
1985	Kromdraai Dam	29.37	25.67	Olifants River/Rivier Tr.	5	0.22
1984	Khutala Mine: Pollution Water Dam	29.04	26.12	Klippoortjies Spruit	8	0.22
1986	Bloempoort Dam	29.23	25.19	Moses River/Rivier Tr.	13	0.21
1965	Komati-kragsentrale Rouwater Reservoirs 1, 2, 3 and 4	29.48	26.10	Koring Spruit Tr.	7	0.21
2001	Jaydee-stuwal	31.32	24.24	Nhlaralumi River/Rivier	7	0.20
1998	Navigation Dam	29.16	25.76	Schoongezicht Spruit	7	0.20
1992	Heuvelfontein Dam	28.90	26.05	Wilge River/Rivier Tr.	5	0.20
1968	Mooiplaas Dam	29.45	25.53	Mooiplaas Spruit	6	0.20
1978	Bombardie Farm Dam No.1	29.05	26.17	-	5	0.20
1985	De Kuil No.2- Dam	28.53	25.08	Elands River/Rivier Tr.	5	0.20
1986	Zondagsfontein Dam	28.98	26.18	Klippiespoortjie Spruit Tr.	8.5	0.20
1987	Kalkfontein Dam	30.05	24.88	Steelpoort River/Rivier Tr.	7	0.20
1995	Weltevreden Dam	28.95	26.31	Kromdraai Spruit	8	0.20
1966	Hope Dam No. 2	30.90	24.05	Ram Spruit	8	0.19
1993	Goedehoop North Polluted Water Dam	29.44	25.87	Spook Spruit Tr.	11	0.19
1964	Onverwacht No.1- Dam	28.62	25.60	Malan Spruit	8	0.19
1980	Uyskraal-onder Dam	29.27	24.95	-	7	0.18
1991	Vlaklaagte Dam	29.63	26.26	Bank Spruit	6	0.18
1992	Bavaria-lei Dam	30.89	24.41	Stormwatersloot	8	0.18
1997	Doornrug Dam	29.02	25.86	Saalklaps Rivier/River Tr.	7	0.17
1983	De Kafferskraal Dam D	30.18	25.15	Kafferskraal Spruit	11	0.17
1990	Cutwater Dam	30.02	25.38	Witpoort River/Rivier Tr.	8	0.17
1992	Argyle No.2- Stuwal	31.35	24.19	Nhlaralumi River/Rivier	5	0.17
1995	Fedmis Detention Dam	31.10	23.97	Ga-selati River/Rivier Tr.	5	0.17
1987	Klipbank-opgaar Dam	29.40	25.13	Olifants River/Rivier	9	0.16
	Spitskop Dam	29.90	25.62	Dor Spruit Tr.	7	0.15
1966	Closed – was Ingifell Dam	30.11	25.42	Crocodile River/Rivier	10	0.15
1984	Bucker Dam	28.80	25.80	Bronkhorst Spruit Tr.	9	0.15
2000	Nooitgedacht Nr 2 Dam	30.56	25.05	Spekboom River/Rivier	12	0.15
1991	Lakeside Dam No. 1	28.92	26.12	Wilge River/Rivier Tr.	6	0.14
1998	Kleinbub Dam	29.68	25.19	Buffelsvlei Spruit	11	0.13

Continuation of Appendix B

Completion Date	Name	Long. °E	Lat. °S	River	Height (m)	Capacity (Mm^3)
1984	120 Ml Dam	29.36	25.99	Boesmankrans Spruit Tr.	6	0.13
	Wachteenbietjieskop	28.80	25.80		15	0.13
1989	Moedverloren Dam	29.00	26.30	Blesbok Spruit Tr.	5	0.13
1977	South African Coal Estates Storage Dam	29.23	26.02	-	7	0.13
1978	Rustfontein-middel Dam	29.44	26.44	Natuurlike Loop	8	0.12
	Ons Eie Dam	30.08	25.42	Boloop Steelpoort River	10	0.12
1987	Wonderboom Dam	29.33	25.59	Olifants River/Rivier Tr.	8	0.12
1988	Loch Macdonald Dam	29.37	25.99	Boesmanskrans River/Rivier	5	0.11
1992	R.C. Dam	29.08	26.30	Riet Spruit	6	0.11
1993	Bavaria No.2- Dam	30.90	24.42	Riet Spruit Tr.	7	0.11
1993	Leeuwpoort Dam No. 2	29.19	25.82	Blesbok Spruit Tr.	7	0.11
1991	Rietkuil Dam	29.65	26.29	Bank Spruit Tr.	5	0.11
1996	Ndlopfu Stuwal	31.30	24.18	Tsiri River/Rivier	7	0.11
2002	Escom Maturation Dam	29.21	26.28		5	0.10
1979	Duvha Ash Return Water Dam	29.34	25.95	-	8	0.10
1961	Osspruit No. 2- Dam	28.48	25.97	Os Spruit Tr.	8	0.10
1976	Roodepoort No. 2- Dam	29.50	26.05	Woes-alleen Spruit	6	0.10
1982	Uyskraal-bo Dam	29.30	24.95	Elands River/Rivier Tr.	5	0.10
1985	Bala Dam	28.50	25.04	Gotwane River/Rivier Tr.	5	0.10
1985	De Kuil No.1- Dam	28.49	25.07	Gotwane River/Rivier Tr.	5	0.10
1987	Chris Boshoff Dam	28.93	26.23	Kromdraai Spruit Tr.	6	0.10
1990	Van Dyksput Dam	28.93	26.05	Wilge River/Rivier Tr.	5	0.10
1966	Hope Dam No. 1	30.91	24.07	Ram Spruit	6	0.10
1990	Junior Boerdery Dam	29.26	26.23	Steenkool Spruit Tr.	7	0.10
1986	Wasserman Dam	29.48	26.30	Jouber Spruit Tr.	5	0.09
1976	Roodepoort No. 8- Dam	29.57	26.05	Woes-alleen Spruit	5	0.09
1986	Kendal Power Station: Clean Water Dam	28.96	26.09	Wilge River/Rivier Tr.	11	0.09
1993	Paardekraal Dam No. 1	30.68	24.97	-	10	0.09
1993	Portsgate Citrus Dam A	30.72	24.36	Olifants River/Rivier Tr.	9	0.09
1989	Broderick's Dam	29.35	26.00	Boesmankrans Spruit Tr.	5	0.09
1978	Selati Tailings Return Water Dam	31.13	24.05	Selati River/Rivier	11.9	0.08
1987	South African Coal Estates Vlei Shaft Dam	29.23	26.02	-	5	0.08
1990	Kranspoort Dam	29.42	25.43	Kranspoort Spruit	10	0.08
1989	Mac's Creek Dam	29.33	25.99	Boesmankrans Spruit	11	0.08
1975	Auther Henry Pillman Dam	29.53	25.13	Diepkloof River/Rivier	15	0.08
1992	Goedehoop North Freshwater Dam	29.44	25.87	Spook Spruit Tr.	8	0.08
1998	Holfontein Leachate Storage Dam	28.52	26.15		7	0.08
	Nooitgedink Dam	28.77	25.87		8	0.08
1985	De Voetpadkloof Dam	29.43	25.45	Kranspoort Spruit Tr.	11	0.08

Continuation of Appendix B

Completion Date	Name	Long. °E	Lat. °S	River	Height (m)	Capacity (Mm^3)
1992	Vlakplaas Dam	29.99	25.56	Klein Spruit Tr.	8	0.08
1991	Tweefontein Mine Return Water Dam	30.11	24.89	Dwars River/Rivier Tr.	7	0.08
	Doornrug-Opgaar Dam	29.08	25.92	Saalklap Spruit Tr.	6	0.07
1977	South African Coal Estates Settling Dam	29.23	26.02	-	7	0.07
1986	Tweefontein	29.51	25.60	Klip River/Rivier Tr.	8	0.07
1974	Olifantspoortje Dam	30.23	24.73	Sterkfontein River/Rivier	10	0.07
1968	Osspruit No.1- Dam	28.50	25.98	Os Spruit Tr.	7	0.07
1998	A.M. Van Rooyen Dam	28.96	25.91	Saalboom Spruit Tr.	6	0.06
	Blinkwater Dam 1	29.83	25.42	Steelpoort River/Rivier Tr.	9	0.06
1979	Kafferstad Dam	29.67	26.23	Olifants River/Rivier Tr.	8	0.06
1984	Waterklip Punt C Varswater Dam	29.25	25.90	Munisipale Waternetwerk	9	0.06
1986	Cornelius Dam	29.92	25.42	Welgevonden Spruit	7	0.06
1995	Brine Storage South Dam	29.49	25.80		6	0.06
1995	Brine Storage South Dam	29.49	25.80		6	0.06
1993	Groenfontein Dam	28.74	25.90	-	7	0.06
1986	Kendal Power Station: Emergency Dam	28.96	26.09	Wilge River/Rivier Tr.	9	0.06
1930	Schoongezicht Dam	29.15	25.90	Brug Spruit and Klip Spruit Tr.	5	0.05
1976	Rustfontein-onderste Dam	29.44	26.44	Natuurlike Loop	7	0.05
	Hendrina Ash Return Water Reservoir	29.60	26.07	-	10	0.05
1985	Wildebeestfontein No. 3 Reservoir	29.15	26.45	-	14	0.05
1993	Kleinkopje-klippan Dam	29.23	25.98	Olifants River/Rivier Tr.	5	0.05
	Mabalingwe Spa Dam	29.02	25.60		7	0.03
1997	Oxbow 8 Plug Walls Dam	29.28	26.09	Olifants River/Rivier	6	0.00

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