Orange-Senqu River Basin

Orange-Senqu River Commission Secretariat
Governments of Botswana, Lesotho, Namibia and South Africa

UNDP-GEF
Orange-Senqu Strategic Action Programme
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Surface and Groundwater Resources

Contribution to the Final Transboundary Diagnostic Analysis and Built Structures Database for the Orange-Senqu Basin

Technical Report 20
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UNDP-GEF
Orange-Senqu Strategic Action Programme

Surface and Groundwater Resources

This report has been submitted by
Allan Bailey (allanb@ssi.co.za), utilising previous research on the subject, including previous work of ORASECOM and its ICP supported projects.

This detailed report is a background document to the Transboundray Diagnostic Analysis Report.

This report has been issued and amended as follows:

Revision	Description	Date	Signed
0	Final standalone (detailed) report	07 Dec 2011	AB

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UNOPS

Surface and Groundwater Resources Contribution to Final Transboundary Diagnostic Analysis and Built Structures Database for the Orange-Senqu Basin

FINAL STANDALONE (DETAILED) REPORT



December 2011

Submitted by: SSI Engineers and Environmental Consultants

Executive Summary

The Orange-Senqu Basin (hereafter referred to as the Basin) covers a large part of South Africa, the whole of Lesotho and parts of Namibia and Botswana. It is the most important basin in South Africa and Lesotho. The rivers in the Basin are a source of water for agriculture, domestic use in towns and settlements, industry, mining, energy, recreation and tourism. In South Africa the Basin includes the Vaal and Orange rivers which form a major part of the water resources and water infrastructure in the country. The Lesotho-Highlands transfer from Lesotho to South Africa is one of the most important sources of water for South Africa but there are also a number of other important transfers. There is an increasing need for water in the Basin which is generally classified as semi-arid and has erratic and low rainfall on average. This increasing competition for water among the various water users, finite available water resources and environmental considerations require an integrated, detailed water resources analysis of the Basin of which this study forms a part.

This Transboundary Diagnostic Analysis (TDA) report of the Orange-Senqu Basin forms a part of the set of deliverables for this study. The other deliverables are as follows:

Built structures fact sheets of physical information, photographs, locality diagrams and other pertinent information on the following:

- dams;
- streamflow gauges;
- transfer schemes;
- water purification works and
- wastewater treatment works.

These fact sheets are accessible electronically via the Orange-Senqu Water Information System (WIS) and link to scanned DWA information sheets for some of the dams and transfer schemes. They are also available in hardcopy. Schematic diagrams have been compiled for the overall catchment with links to more detailed sub-catchments/countries showing the built structures, dams and river systems.

A number of hydrological issues were investigated such as climate, catchment delineation and areas, available water resources, water requirements and resulting water balance. The Water Resources Simulation Model (WRSM2000, also known as the Pitman model) has been used for analyzing the entire Basin except for Namibia where another model called NAMRON was used. The groundwater-surface water interaction mode was used in the model. Issues pertaining to the models such as calibration have been described. Water resources information has been obtained from a number of sources including the Water Resources of South Africa, 2005 (WR2005) Study. The volume of water reaching the mouth of the Orange River averages 5 500 million m^3/a but can vary considerably from year to year. It is about half of the natural flow due to abstraction of water from the Vaal River which is mainly domestic and industrial and abstraction from the Orange River which is mainly for irrigation purposes. Water availability and water requirements have been described which culminates in the water balance. The growth or decline in water requirements has been dealt with by analyzing water requirements for the 2000 year of development as well as more recently for 2010.

A number of water resource issues were investigated that have direct and indirect effects on each other, namely: drought and flood management, water and food security, climate change and water and energy.

The groundwater analysis was based on five sub-catchments, namely: Vaal, Upper Orange, Lower Orange, Northern Ephemeral rivers and Orange River Mouth Basins. Groundwater and surface water bodies can be closely linked and may be interactive especially during surface water and groundwater recharge periods. The influence of land use such as large scale irrigation, mining, industrialization, urbanization and livestock farming in the Basin on aquifers has been described. Geology of these five sub-catchments was dealt with as well as the occurrence of groundwater. Mechanisms for groundwater recharge and groundwater movement were described. Groundwater use for the sub-catchments is of major importance and is the only source of water available for large portions of the Basin. Trans-boundary implications of groundwater use do not appear to be that significant. Due to low regional rainfall, recharge is limited and generally only small quantities can be abstracted on a sustainable basis. With surface water fully utilized in many parts, further development will have to make use of groundwater resources. Further exploitation of groundwater may have effects on surface water which is an obvious concern.

The fluvial morphology was assessed, particularly sediment loads and mass balance considering historical data and to predict future trends. The impacts of river and reservoir sedimentation are twofold. Firstly, water quality in both rivers and reservoirs is greatly affected by suspended sediment concentration resulting from massive land degradation. Secondly loss in storage due to sedimentation reduces the ability of reservoirs to supply water for domestic, industrial, irrigation, hydropower and for flood control. The fluvial morphology was described in terms of channel geometry. Sediment loads were tabulated for various locations and dams and the pictorial representation shows the accumulation towards the Orange River estuary. The extent of reservoir sedimentation was shown for the major reservoirs and the influence on fluvial morphology was described. The efficient and effective management of the Basin will require shared understanding and concerted effort between the four countries with respect to critical sediment sources and the corresponding crucial sedimentation areas. More resources and data are required to deal with problematic sediment sources and the monitoring of mitigation measures.

Conclusions and recommendations have been given for updating and improving the assessment in the future.

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List of Acronyms and Abbreviations

B	Width
D	Depth
DRC	Democratic Republic of Congo
DWA	Department of Water Affairs
EWR	Ecological Water Requirement
GIS	Geographic Information System
ICOLD	International Congress for Large Dams
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
MAE	Mean Annual Evaporation
MAR	Mean Annual Runoff
MAP	Mean Annual Precipitation
NAMRON	Namibia rainfall-runoff model
SA	South Africa
TDA	Transboundary Diagnostic Analysis
The Basin	Orange Senqu River Basin
UCT	University of Cape Town
WRSM2000	Water Resources Simulation Model 2000
WIS	Water Information System
WMA	Water Management Area
WR2005	Water Resources of South Africa (WR2005)
WRYM	Water Resources Yield Model
WRC	Water Research Commission

Groundwater notation

Confined aquifer — a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

Dispersion — the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown — the distance between the static water level and the surface of the cone of depression.

Karstic topography — a type of topography that is formed on limestone, gypsum, and other rocks by dissolution, an is characterised by sinkholes, caves and underground drainage.

Permeability — related to hydraulic conductivity, but is independent of the fluid density and viscosity and has the dimensions L^2. Hydraulic conductivity is therefore used in all the calculations.

Porosity — the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Recharge — the addition of water to the zone of saturation; also, the amount of water added.

Sandstone — a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale — a fine-grained sedimentary rock formed by the consolidation of clay, silt or mud. It is characterised by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Static water level — the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity — the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total dissolved solids — a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity — the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

Unconfined, water table or phreatic aquifer — different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the water table, which is in contact with the atmosphere so that the system is open.

Vadose zone	the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.
Water table	the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

1. INTRODUCTION AND OBJECTIVE

1.1 INTRODUCTION

The Orange-Senqu Basin (hereafter referred to as the Basin) is shown in Figure 1.1. The Basin) includes parts of four countries, namely: South Africa, Lesotho, Botswana and Namibia. In South Africa the Basin includes the Upper Vaal Water Management Area (WMA), Middle Vaal WMA, Lower Vaal WMA, Upper Orange WMA and almost all of the Lower Orange WMA, covering about 59% of the of the Basin. The whole of Lesotho and the southerly parts of Namibia and Botswana are included. Water supply is required for agriculture, domestic needs, industry, mining, energy, conservation and tourism.

The Vaal River Basin comprises the Upper Vaal WMA, Middle Vaal WMA and Lower Vaal WMA. It is also of huge importance and flows through the largest and most important economic region of South Africa before joining the Orange River. The Vaal River and its tributaries, namely: Wilge, Suikerbosrand, Klip, Mooi, Schoonspruit, Renoster, Vet and Harts have numerous dams with the most important being the Vaal Dam and Bloemhof Dam.

Due to the high demand for water, there are many transfer schemes in both the Vaal and the Orange River systems with the most important being the international system of Lesotho Highlands supplying water from Katse Dam to a tributary of the Wilge River and the Thukela-Vaal pumped storage transfer scheme involving Sterkfontein Dam to ultimately supplement Vaal Dam.

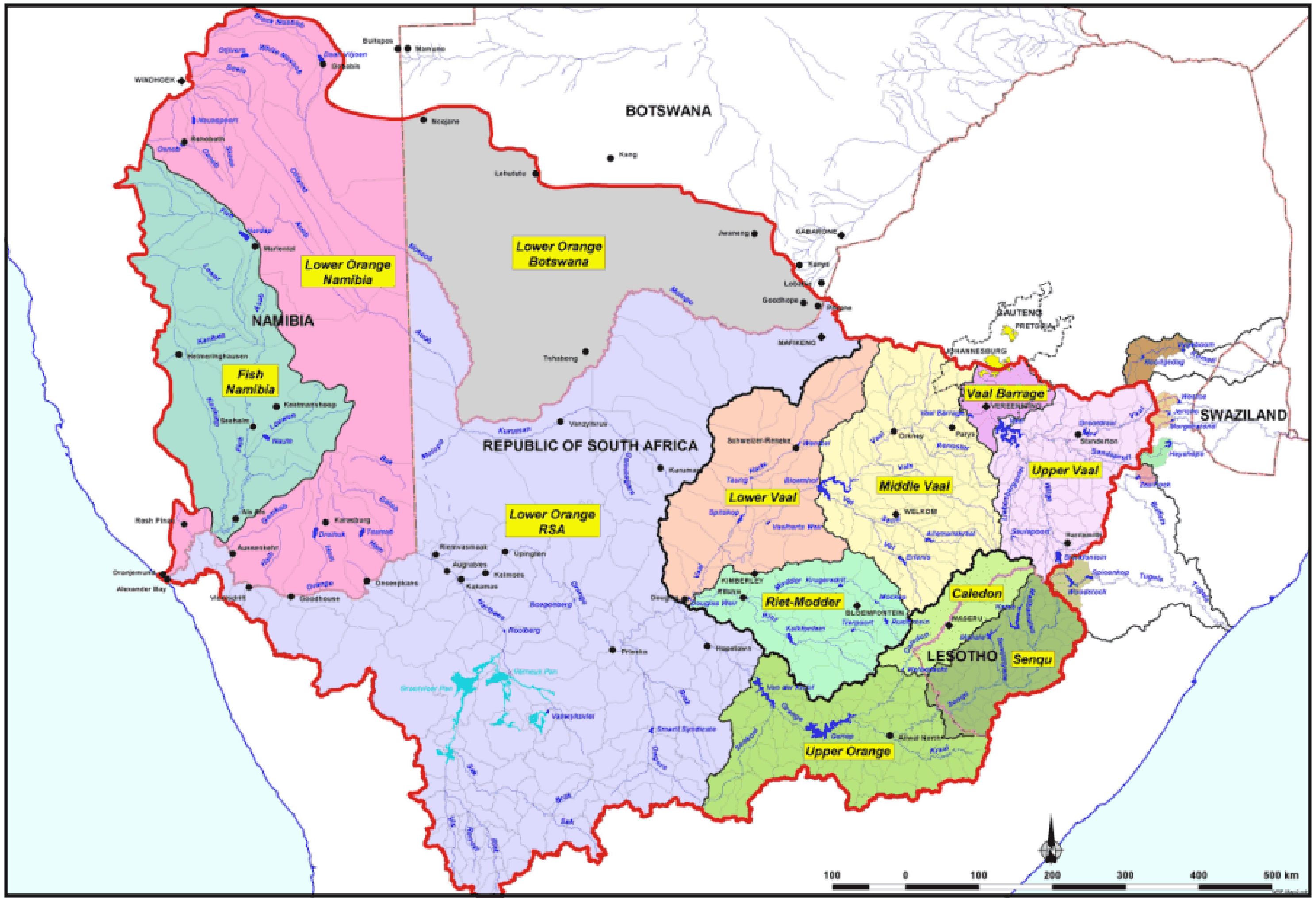

Figure 1.1: Orange-Senqu Basin *(Source: Orasecom 001/2007)*

In South Africa, the Vaal River serves the Reef Complex and the Vaalharts Irrigation Scheme. The major share goes to the Rand Water Board for distribution. Water is not only imported from the Usutu and Thukela WMAs, as well as from Lesotho, but also exported out of the catchment to major domestic centres and to Eskom power stations. Due to the many return flows and developed nature of the Vaal River and its tributaries, water quality is deteriorating and is becoming an increasing concern.

The Orange River Basin is the largest river basin in the catchment and has its source, known as the Senqu River, in Lesotho and the Orange from where it emanates from Lesotho flowing westwards right across South Africa to the Atlantic Ocean. The Senqu River and its tributaries, namely: Makhaleng, Mohkare, Phuthiatsana, Senqunyane drain most of Lesotho Highlands which is very mountainous and has a relatively high mean annual precipitation (MAP). The most important dams are Katse Dam and Mohale Dam. Phase 1 of the Lesotho Highlands Scheme was implemented fully in 2005 to generate electricity for Lesotho and to transfer water to the Vaal River. A second phase has been planned for the future. Katse Dam in Lesotho is also of huge significance as is the third largest dam - Sterkfontein Dam, which is situated on a tributary of the Vaal River. The Figure 1.2 below shows the Lesotho Highlands where the Senqu River originates.

Figure 1.2: Lesotho Highlands (Source:©iStockphoto/Coenders)

The Figure 1.3 below shows the confluence of the Vaal and the Orange Rivers.

Figure 1.3: Confluence of the Vaal and the Orange Rivers (Source: R McKenzie)

Gariep and Vanderkloof dams are the two largest dams in South Africa and provide hydro power generation, water supply for irrigation and urban requirements and also for flood control. There are also a number of transfers via the Orange-Fish tunnel from Gariep Dam for urban and irrigation demands and Vanderkloof Dam and the Orange River at Marksdrift for irrigation demands. The Caledon River forms the border between Lesotho and South Africa for most of its length and supplies Bloemfontein and other towns via a series of dams and pipelines.

Figure 1.4 shows Katse Dam in Lesotho.

Figure 1.4: Katse Dam (Source: en.wikipedia.org)

The lower part of the Orange is joined by the tributaries Kraai (draining from the north-eastern Cape) before traversing through a very arid region, with the main tributaries being the Ongers and Sak rivers (draining from the northern Karoo), the Kuruman and Molopo (draining from the Northern Cape and southern parts of Botswana) and the Fish River (draining from southern Namibia).

The Molopo River flows along the South Africa-Botswana border and joins the Nossob as it flows in a south-westerly direction. The Kuruman River has its source in South Africa and flows to the west until it meets the Molopo River draining a large area. There are no dams or weirs in the Molopo and Nossob rivers in Botswana and flow from the Molopo is blocked from reaching the Orange River by sand dunes. There is, however, a dam – Disaneng Dam on the Molopo River in South Africa near Mafikeng.

The Fish River is the largest river in Namibia. It rises to the south of Windhoek and flows in a mostly southerly direction over a distance of about 636 kilometres before it joins the Orange River about 100 km upstream of the river mouth. Flow in this river varies considerably. There are a number of dams in Namibia that supply domestic and irrigation requirements with Hardap and Naute dams being the largest. Other important rivers in Namibia are the Nossob and the Auob.

Figure 1.5 shows a schematic of the Basin with major infrastructure included.

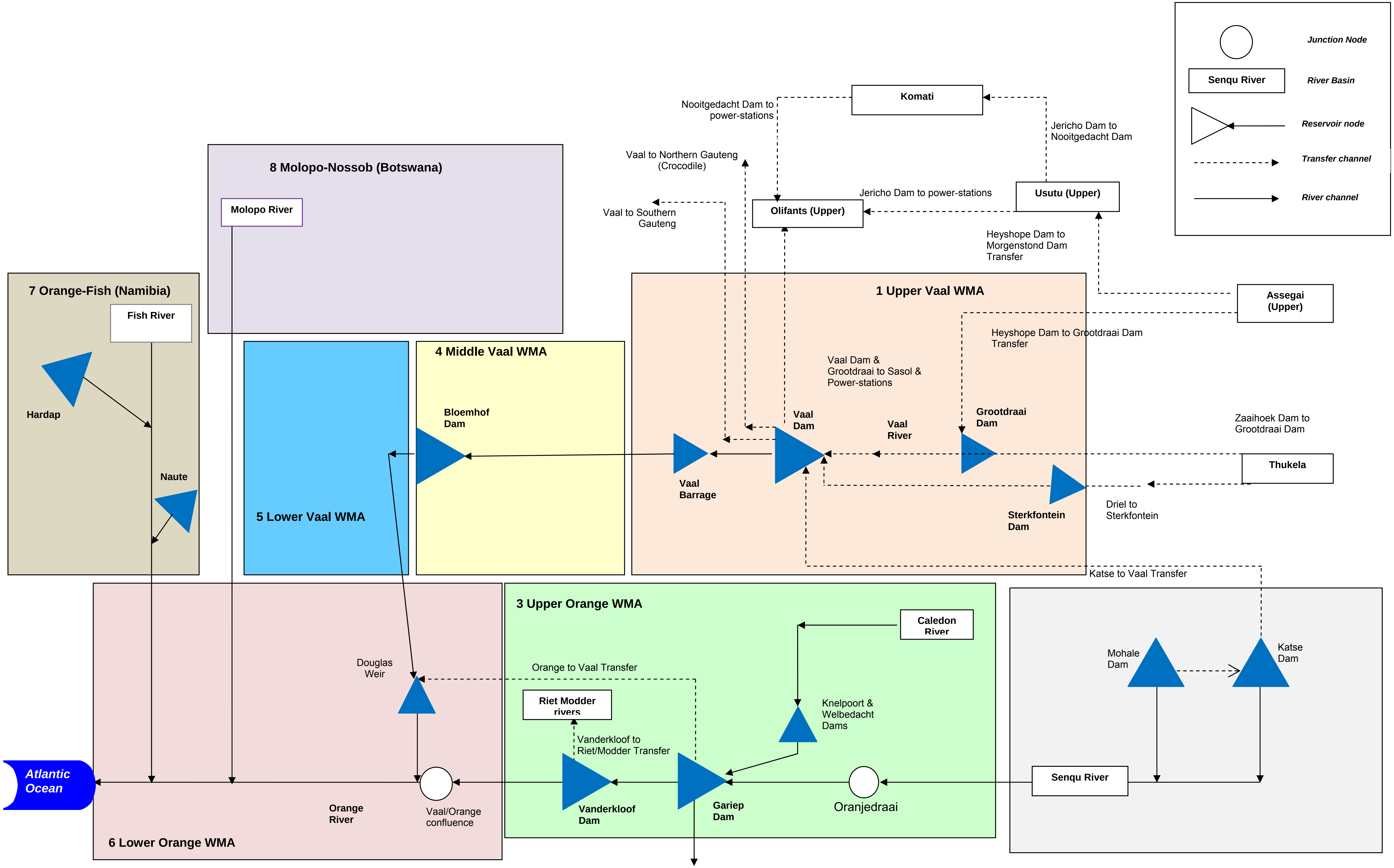

Figure 1.5: Schematic – broad overview of the Basin

1.2 OBJECTIVE

The objective of this study is as follows and the purpose is to provide technical information to water authorities in the four countries:

- to establish a built structures database and report of task sheets on the following structures in the Orange-Senqu :
  - dams;
  - streamflow gauges;
  - transfer schemes;
  - water purification works and
  - wastewater treatment works.
- The task sheets provide physical data, photographs and locality sketches for the dams and links to scanned (DWA) documents (where available). Major infrastructure is also on the GIS map that is accessible by the Water Information System (WIS) on the Internet. The user has the option of accessing the task sheets via a list of infrastructure or from the GIS map in the WIS system;
- This database contains important physical information on the built structures and has spatial and thematic search functions linking it to information in the fact sheets;
- a Transboundary Diagnostic Analysis (TDA) report covering surface water, groundwater and river morphology and sedimentation issues (detailed standalone version);
- a Transboundary Diagnostic Analysis (TDA) report covering surface water, groundwater and river morphology and sedimentation issues (summarised version for the integrated report) and
- a “coffee table” / executive summary report.

2. SURFACE WATER AND WATER BALANCES

2.1 CLIMATE

2.1.1 Temperature

As the Orange-Senqu covers almost the full width of South Africa, temperature, rainfall and evaporation has been dealt with per WMA as well as the Fish and Molopo catchments. Temperatures are given in Table 2.1 as follows:

Table 2.1: Temperature

Catchment	January (summer) average temperature (°C)	January (summer) average range (°C)	July (winter) average temperature (°C)	July (winter) average range (°C)
Upper Orange WMA	22	7-25	8.5	0-10
Lower Orange WMA	24	16-32	10	2-18
Upper Vaal WMA	20	18-22	8	6-10
Middle Vaal WMA	22	20-24	10	7-11
Lower Vaal WMA	24	16-32	10	6-12
Fish *	30		20	
Molopo and Nossob &	32		6	

Notes: Source: DWA P08000/00/0101, DWA P09000/0*0/0101 and DWA P09000/00/0101*
* average, & average minimum and maximum

2.1.2 Rainfall

Rainfall is strongly seasonal over most of the Basin with the most rainfall in summer generally over October to April usually occurring as convective thunderstorms sometimes accompanied by hail. Lesotho has significantly higher rainfall than the South African part of the catchment. Moving westwards through the Lower Orange WMA, the rainfall decreases and at the coast is the lowest with a typical winter rainfall with the peak month in March. The mean annual precipitations of each catchment (MAP) are given in Table 2.2 below:

Table 2.2: Rainfall

Catchment	Average MAP (mm)	MAP Range (mm)
Upper Orange WMA (Lesotho part)	850	500-1200
Upper Orange WMA (South Africa part)	500	300-800
Lower Orange WMA	200	20-300
Upper Vaal WMA	700	500-1000
Middle Vaal WMA	550	300-700
Lower Vaal WMA	350	200-500
Fish *		0-200

Catchment	Average MAP (mm)	MAP Range (mm)
Molopo and Nossob &		400-600 in the headwaters of the Molopo , 200-400 in the middle areas of the catchment and 0-200 in the most westerly parts

Note: Source: DWA P08000/00/0101, DWA P09000/00/0101 and DWA P09000/00/0101
* and & Source : Global Environmental Facility, April 2008.

2.1.3 Evaporation

Both S-pan and A-pan evaporation is shown in Table 2.3 below. S-pan relates to evaporation from open water while A-pan relates to evapotranspiration, i.e. the evaporation from leaves and stems of crops.

Table 2.3: Evaporation

Catchment	MAE Symons-pan Average (mm)	MAE Range A-pan (mm)
Upper Orange WMA (Lesotho part)	1 410	1 000 - 2 100
Upper Orange WMA (South Africa part)	1 700	1 200 - 2 680
Lower Orange WMA	2 260	2 420 - 3 280
Upper Vaal WMA	1 510	1 600 - 2 200
Middle Vaal WMA	1 620	1 800 - 2 600
Lower Vaal WMA	2 240	2 646 - 2 690
Fish *		2 950 - 3 800
Molopo and Nossob &		1 250 - 1 650

Note: Source: DWA P08000/00/0101, DWA P09000/00/0101 and, DWA P09000/00/0101
* Source: DWA PB D000/00/4303
& Source: Global Environmental Facility, 2008 (appears to be underestimated).

2.2 HYDROLOGICAL ANALYSIS

Detailed analyses have been carried out using a rainfall-runoff model called the Water Resources Simulation Model (WRSM2000) on a monthly time step on all catchments in the Basin in South Africa, Lesotho and Botswana. The analyses for South Africa and Lesotho have been documented in the recently completed “Water Resources of South Africa, 2005 Study” (WR2005) which was undertaken for the Water Research Commission. In the Namibian part of the Basin, a model called NAMRON was used to do a similar analysis. The analysis on the Orange River tributaries in Namibia were, however, done by Dr Bill Pitman using WRSM2000. The WRSM2000 analysis is based on setting out a network of modules consisting of runoff, reservoir, irrigation, channel reach and mining modules connected by routes which define the flow of water. Abstractions, return flows and transfers are included at the channel reach modules. All data pertaining to the water balance is entered into these modules. The most important input is that of rainfall: individual stations are combined and averaged to form a catchment rainfall file and are included together with evaporation (Symons Pan for open water and A-pan for irrigation) and other related factors into all the modules. The runoff module includes calibration parameters which are manipulated to get the best possible convergence between observed and simulated streamflow, by means of graphs and statistics. Details for major reservoirs as well as smaller farm dams, some of which are lumped together are included in the reservoir model. All data pertaining to crops and irrigated areas are included in the irrigation block module. Channel reach modules account for wetlands and all inflows and outflows. Mining modules are used only for major mines having an influence on the water balance. Some routes include time series streamflow datafiles of observed streamflow. Once a successful calibration has been achieved, the streamflow is naturalized by removing man made influences such as dams, irrigation schemes, urbanization, etc. for use in the Water Resources Yield Model (WRYM) in order to determine the yields of dams in a complex system of competing water users.

2.2.1 Catchment Areas

The following Table 2.4 describes the catchments comprising the Basin and their associated catchment areas.

Table 2.4: Tertiary Catchment Areas and Associated Quaternary Catchments

Major Catchment	Sub-Catchment	Quaternary Catchments	Gross Sub-catchment Area (km^2)(1)	Gross Major Catchment Area (km^2)
Vaal	Upper Vaal	C11A-M, C12A-L, C13A-H, C81A-M, C82A-H, C83A-M	38 638	196 438
	Vaal Barrage	C21A-G, C22A-K	8 651	
	Middle Vaal	C23A-L, C24A-J, C25A-F, C41A-J, C42A-L, C43A-D, C60A-J, C70A-K	60 836	
	Lower Vaal	C31A-F, C32A-D, C33A-C, C91A-E, C92A-C	55 019	
	Riet-Modder	C51A-M, C52A-L	33 294	
Upper Orange	Caledon	D21A-L, D22A-L, D23A-J, D24A-L	21 884	99 277
	Senqu	D11A-K, D12A-F, D15A-H, D16A-M, D17A-M, D18A-L	27 647	
	Upper Orange	D13A-M, D14A-K, D31A-E, D32A-K, D33A-K, D34-AG, D35A-K	49 746	
Lower Orange	Brak/Ongers	D61A-M, D62A-J	33 733	243 313
	Sak/Harts	D51A-C, D52A-F, D53A-J, D54A-G, D55A-M, D56A-J, D57A-D, D58A-C	93 041	
	Middle Orange	D71A-D, D72A-C, D73A-F	40 100	
	Lower Orange	D81A-K, D82A-P	76 439	
Molopo/Nossob	Kuruman	D42A-G	41 195	356 788
	Upper Molopo	D41A-J	148 167	
	Lower Molopo	D45A-D	30 078	
	Nossob	D43A-C	71 650	
	Auob	D44A-D	57 698	
Namibian Fish	Fish	D46A-J	81 630	81 630
Total Catchment Area				977 446

Note: The areas reported are as given in the WRC TT380/08 for quaternaries inside the South African borders and Lesotho, and as given by ORASECOM 006/2011 for the Namibian and Botswana quaternaries

2.2.2 Reservoirs

Gariep and Vanderkloof dams in the Upper Orange WMA are the largest dams in the Basin and both have major hydroelectric power stations and also supply water to users in the Upper Orange WMA particularly to support agriculture. The Vaal Dam is the fourth largest (slightly smaller than Sterkfontein Dam) and managed by the Rand Water Board, supplies water to the Upper Vaal WMA. There are numerous other dams in the Basin as shown in Table 2.5.

Table 2.5: Reservoirs in the Basin

Dam	Gross Storage (10^6 m^3) #	Live Storage (10^6 m^3) &	Dead Storage (10^6 m^3)
Sengu			
Katse	& 1 950.0	1 518.6	431.4
Mohale	& 946.9	857.1	89.8
Muela	6		
Orange			
Gariep	5 342.9	4 710.0	632.9
Vanderkloof	3 187.1	2 173.2	1 013.9
Bethulie	2.0		
Welbedacht	11.7 $		
Knellpoort	136.2	130.3	5.9
Armenia	13.8	13.2	0.6
Egmont	9.3	9.3	0
Kalkfontein	258.3	318.9	0
Tierpoort	33.0	34.0	0
Krugersdrif	73.2	73.2	0
Rustfontein	71.2	71.2	0
Groothoek	13.2	11.9	1.3
Mockes	6.0	3.3	2.7
Boegoeberg	19.9	20.7	0
Modderpoort	10.0	10.0	0
Ratelfontein		6.9	
Rooiberg	3.7	3.7	0
Smartt Syndicate	101.1	101.1	0
Van Wyksvlei	143.1	143.1	0
Victoria West	3.7	3.7	0
Vaal			
Saulspoort	15.7	16.9	0
Klipdrift	13.6	13.6	0
Boskop	20.7	21.0	0
Klerkskraal	8.0	7.9	0.1
Driekloof	32.1	32.2	0
Sterkfontein	2 617.0	2 482.3	134.7
Grootdraai	356.0	318.0	38.0
Vaal	2 606.8	2 442.5	164.3
Erfenis	212.2	207.5	4.7
Allemanskraal	179.3	174.2	5.1
Koppies	41.1	41.8	0
Rietspruit	7.3	7.2	0.1
Johan Neser	5.7	5.7	0
Bloemhof	1 218.1	1 239.5	0
Lakeside		2.0	
Douglas	16.7	16.1	0.6
Vaalharts	48.7	48.7	0
Spitskop	57.9	57.8	0.1
Taung		66.0	
Wentzel	6.6	6.7	0
Namibia			

Dam	Gross Storage (10^6 m^3) #	Live Storage (10^6 m^3) &	Dead Storage (10^6 m^3)
Oanob	35.0		
Naute	84.0		
Otjivero	17.6		
Nauaspoort	5.0		
Hardap	294		
Daan Vijoen	0.3		
Tilda Viljoen	0.5		
Dreihuk	16.0		
Tsamab	Unknown		

Notes: # Source: SANCOLD 2009
& Source: Orasecom 001/2007
$ Welbedacht Dam's live storage has been considerably reduced by siltation

Farm dams are generally lumped together in a suitable manner in the quaternary catchments and entered into the WRSM2000 model as single reservoirs.

2.2.3 Alien Vegetation

This streamflow reduction is included in the WRSM2000 model. It has been dealt with in a separate report.

2.2.4 Water Requirements

The Upper Vaal WMA is the most developed, industrialised and densely populated part of the Basin. Large quantities of water are transferred into this WMA from the Usutu to Umhlatuze and Thukela WMAs, as well as the Katse Dam in Lesotho ultimately to the Vaal Dam. The Lesotho Highlands Water Project involves Katse and Mohale dams, the Matsoku diversion weir, tunnels and a hydro power station. Water gravitates from Katse Dam through tunnels into the Liebenbergsvlei River, then into the Wilge River and finally into the Vaal Dam (referred to as Phase 1). Figures 2.1 and 2.2 show the Thukela-Vaal and Katse transfers. Phase 2 is under way and involves the Polihali Dam. Figure 2.3 shows the location of this proposed dam.

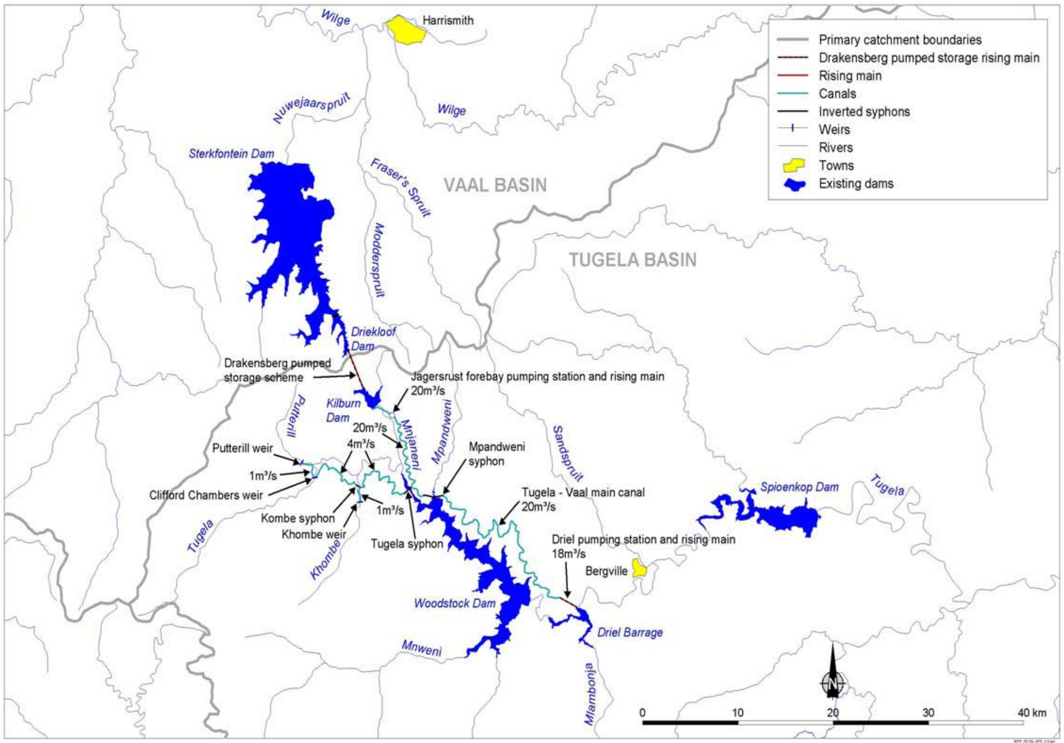

Figure 2.1: **Thukela-Vaal Transfer Scheme** **(ORASECOM 001/2007)**

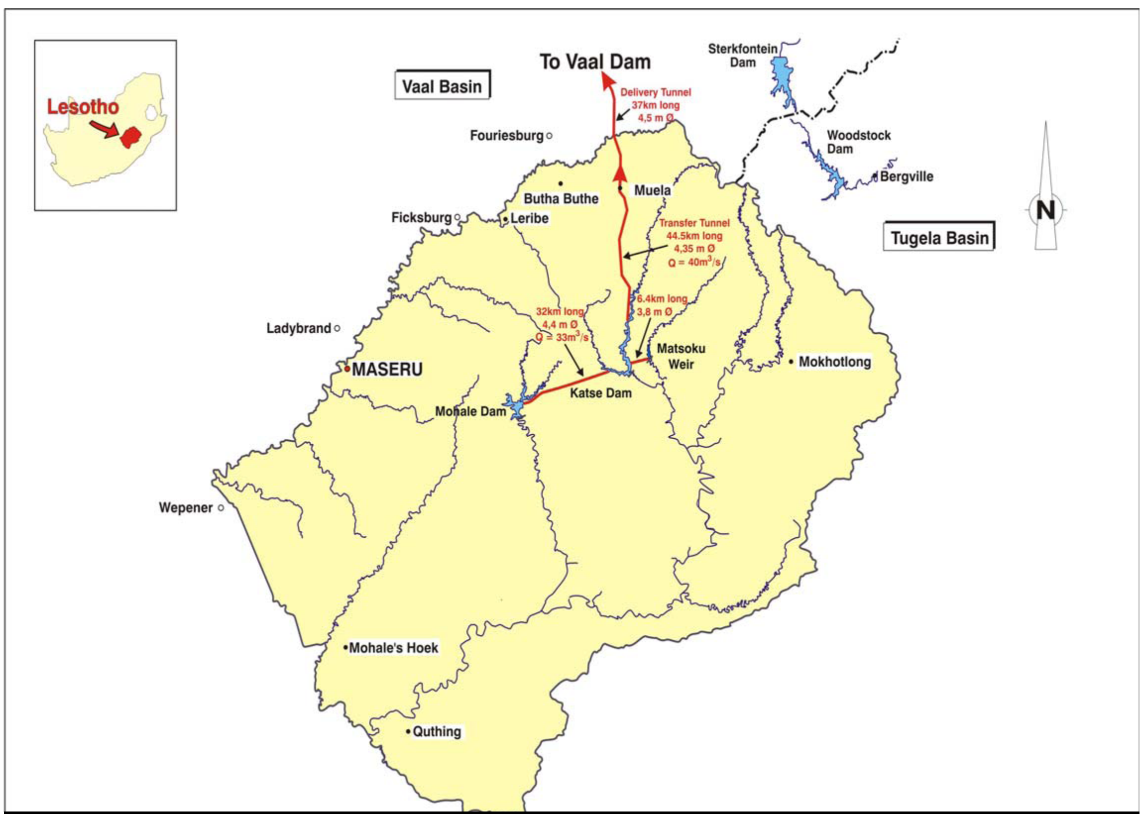

Figure 2.2: **Katse transfer to Vaal Dam** **(ORASECOM 001/2007)**

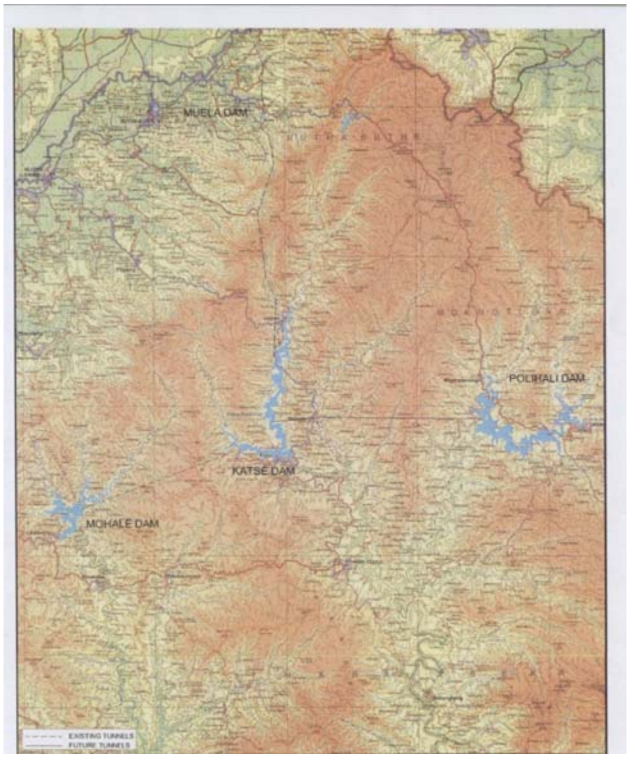

Figure 2.3 : Lesotho Highlands Phase 1 layout and proposed Phase 2 **(source : vke.co.za)**

Large quantities of water are also released along the Vaal River to support users in the Middle Vaal and Lower Vaal WMAs and are also transferred to the Crocodile West and Marico and Olifants WMAs to supply large urban and industrial demand centres and Eskom power stations. The Upper Vaal schematic layout is given in Appendix A1 and it shows infrastructure, demand centres and transfers. Rand Water is the major water suppliers and their supply has been simplified into five areas of supply from the Vaal River at Zuikerbosch and Vereeniging as shown in Appendix A1 and Figure 2.4 . The Mooi River Government Water Scheme and Klipdrift Irrigation Schemes provide water for irrigation from Klerkskraal Dam and a system of canals. There is also return flow from wastewater treatment works which goes back to the Vaal River.

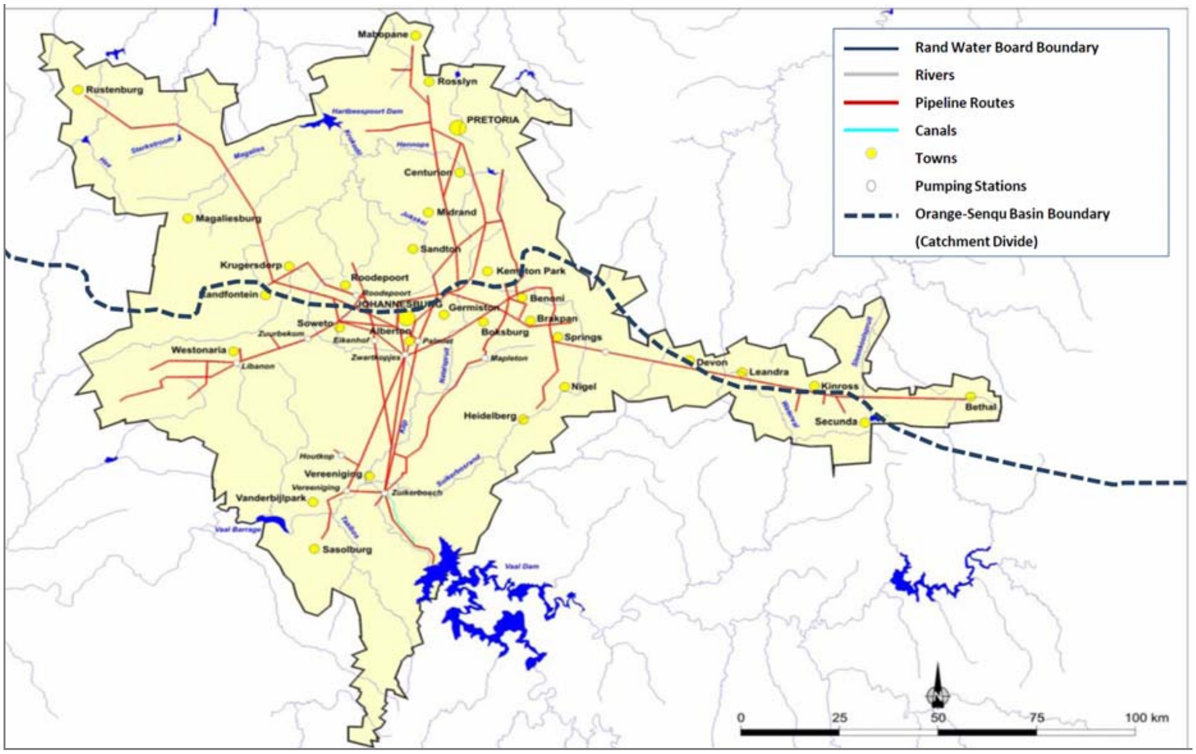

Figure 2.4: Rand Water supply area **(ORASECOM, 001/2007 with catchment divide added)**

The Middle Vaal WMA is dependant on water releases from the Upper Vaal WMA to supply the bulk of the water required by the urban, mining and industrial sectors. Sedibeng Water Board and Midvaal Water Company are responsible for water supply to the users in this WMA. Sedibeng Water abstract water at Balkfontein, upstream of Bloemhof Dam and also from Allemanskraal Dam. Midvaal Water Company abstract from the Vaal River in the Klerksdorp-Orkney area for domestic water supply and gold mining. The Sand-Vet scheme supplies water for irrigation of about 6 800 ha and involves the release of water from Erfenis and Allemanskraal dams into canals and pipelines to supply the Sand-Vet Government Water Scheme. Other water supply systems in the Middle Vaal WMA are the Vals River system supplying domestic water, the Koppies Dam system supplying both domestic and irrigation water, the Schoonspruit Irrigation Scheme supplying domestic and irrigation water from the Schoonspruit Eye and various dams and the Klerksdorp Irrigation Scheme supplying irrigation water.

Over 90% of the water used in the Lower Vaal WMA is supplied from releases from the Upper Vaal WMA, and from Bloemhof Dam. About 80% of the water used in this WMA is for irrigation, mainly the Vaalharts irrigation scheme which is the largest irrigation scheme in South Africa. Water is released from Bloemhof Dam to the Vaalharts Weir and is then diverted into a canal system. There is also some domestic supply from the Vaalharts scheme to Taung and Naledi. Wentzel and Spitskop dams also supply irrigation water. There are also significant return flows from this irrigation scheme. Kimberley receives water from the Vaal River at Riverton. The Vaal-Gamagara Regional Water Supply Scheme supplies mines and domestic water in the Gamagara Valley from Delpoortshoop on the Vaal River. Appendix A2 shows the infrastructure, demand centres and transfers in these WMAs.

Approximately 60% of the water associated with the Upper Orange WMA, originates from the Senqu River in Lesotho. There are a number of small water supply schemes in Lesotho to supply irrigation and domestic water. The two largest storage reservoirs in South Africa

(Gariep and Vanderkloof dams), are located in this WMA. Both dams are used for hydro-electricity generation. The Gariep Dam supplies the Fish and Sundays rivers and ultimately Port Elizabeth in the Fish to Tsitsikama WMA via the Orange-Fish tunnel. Bloem Water also provides various towns via a pipeline network from Gariep Dam. Bloemfontein is located in the Modder River catchment, which has insufficient water resources to meet its growing requirements. The water supply to Bloemfontein is therefore augmented from the adjacent Caledon River. Welbedacht Dam on the Caledon River was constructed as the main storage element of the Caledon-Modder Transfer Scheme which is run by Bloem Water. Water is abstracted from this dam for transfer to Bloemfontein and various smaller users along the way. Water is transferred via the Caledon-Bloemfontein pipeline. Mazelpoort Weir also supplies water to Bloemfontein. The Welbedacht Dam is heavily silted and the off-channel dam Knellpoort is used to support. The supply from Knellpoort Dam to urban centres is referred to as the Novo scheme. Figure 2.5 shows the Novo scheme.

Vanderkloof Dam downstream of Gariep Dam, provides water for irrigation and domestic water via the Orange-Riet Canal to the Riet River Settlement, Scholtzburg Irrigation Board, Ritchie Irrigation Board and Lower Riet Irrigation Board. Vanderkloof Dam also provides downstream irrigation water requirements via the Ramah canal. The water is primarily used for irrigation but also supplies urban requirements. Water is also abstracted from the Orange River at Marksdrift Weir to be transferred to Douglas Weir in the Vaal River, known as the Orange-Vaal transfer scheme. The water is used mainly for various irrigation schemes and to improve the water quality. There are also various abstractions along the Orange River between Gariep Dam and Vanderkloof Dam for irrigation and between Vanderkloof Dam and Marksdrift for domestic water for various towns. The Modder River Government Water Scheme, downstream of Krugersdrift Dam, supports irrigation in this area. There are also the Tierpoort and Riet River Schemes in this area supported by Tierpoort Dam and Kalkfontein Dam respectively. Figure 2.6 shows the Vanderkloof transfer and Modder-Riet catchment. Appendices A3 and A2 show the infrastructure, demand centres and transfers in this WMA and Lesotho respectively.

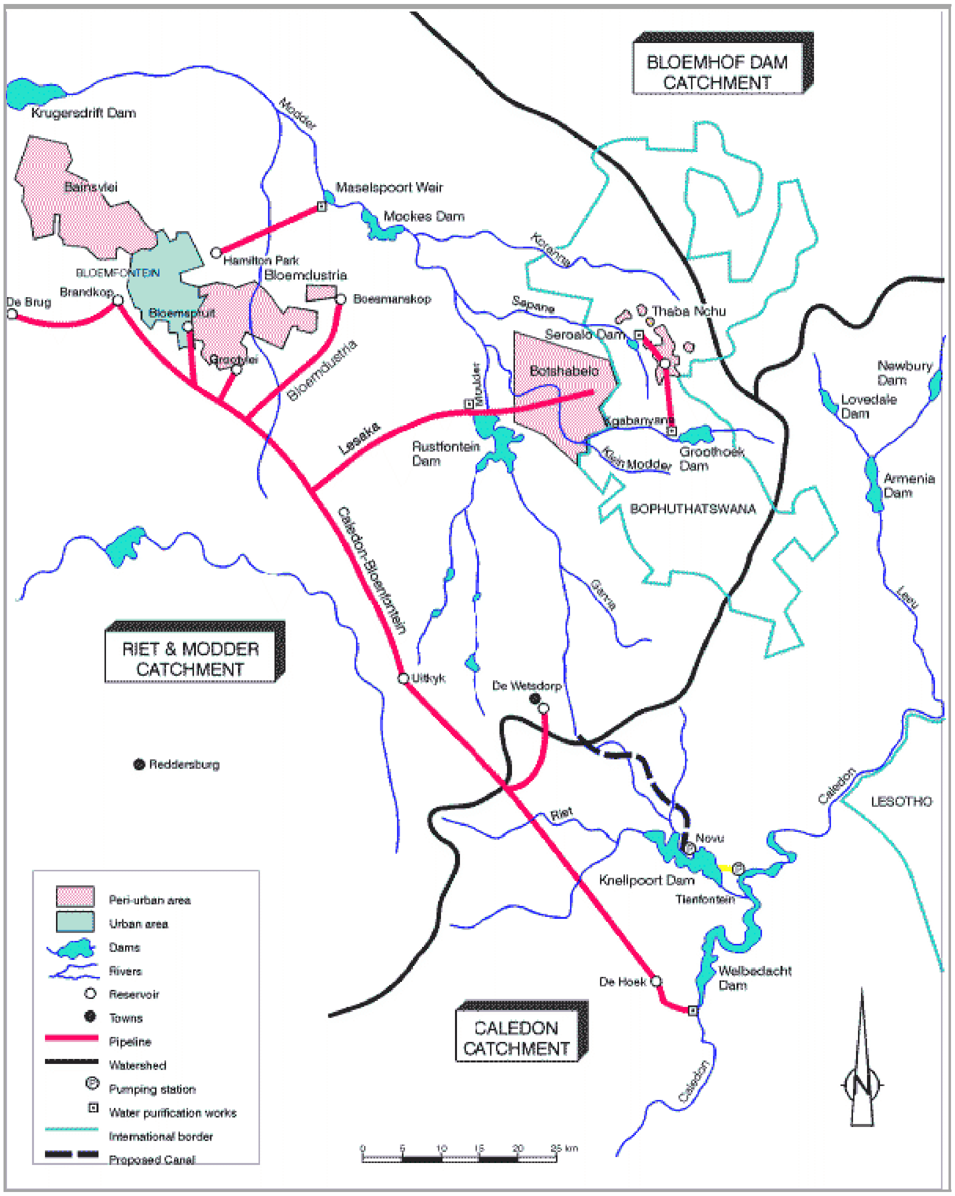

Figure 2.5: The Novo scheme and supply to Bloemfontein **(ORASECOM 001/2007)**

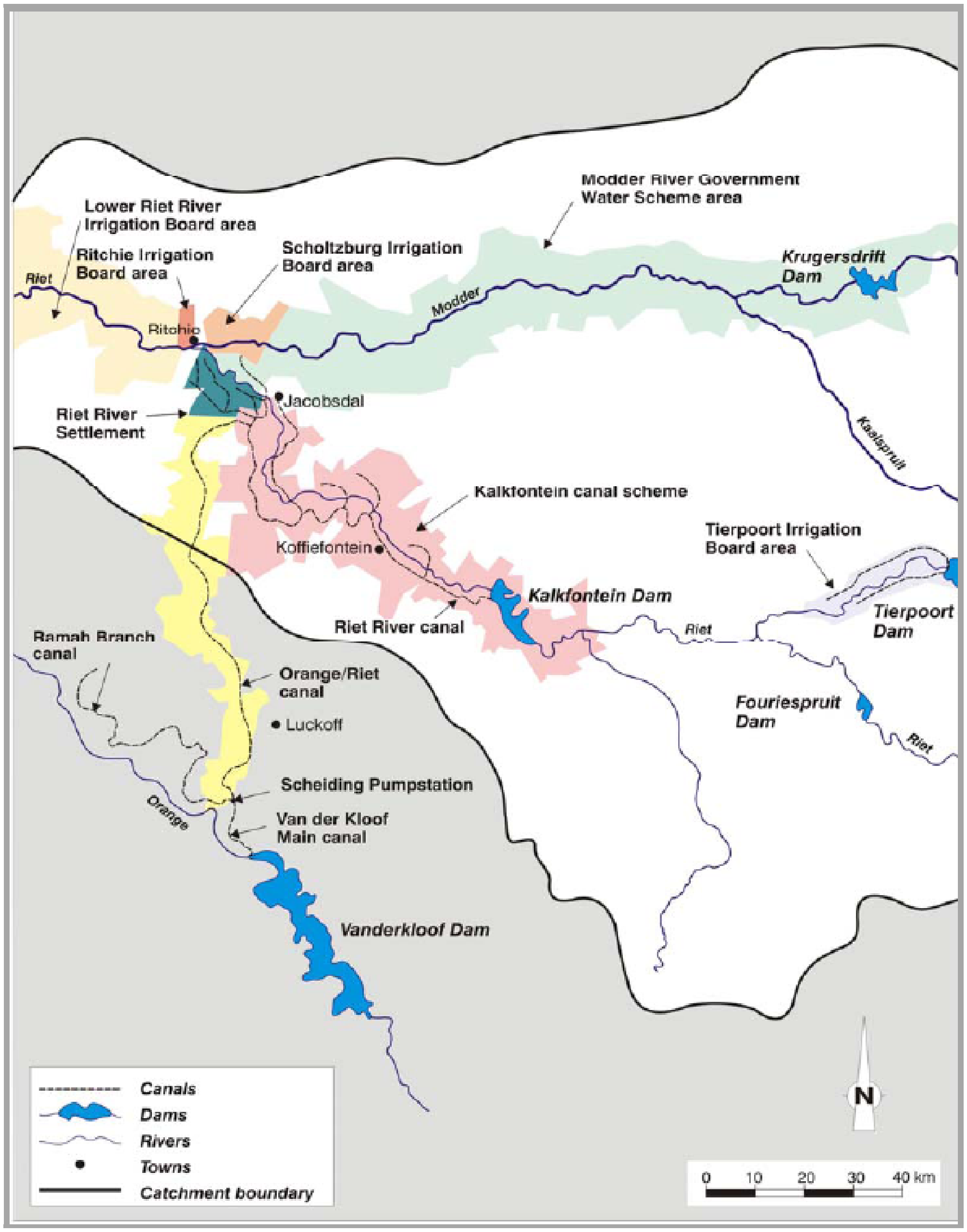

Figure 2.6: Modder-Riet catchment and Vanderkloof transfer (ORASECOM 001/2007)

There is very little development in the Lower Orange WMA, however, water is used for irrigation, mines and domestic requirements. There are the Kalahari-West, Pelladrift and Springbok water supply schemes that supply water for a number of towns and mines. Irrigation is via a number of weirs and canals on the Orange River to a number of irrigation schemes. Figure 2.7 shows water demands in the Lower Orange WMA. The Molopo River (Botswana) and Fish River (Namibia) join the Orange River. Appendices A6 shows infrastructure and demand centres in this WMA.

In Namibia, water is taken from the Orange River via a canal system for Noordoewer and Aussenkehr Irrigation Areas. There are also some domestic and mining requirements provided by the Orange River. Appendix A7 shows the development in Namibia. There is no development in the Botswana part of the Basin.

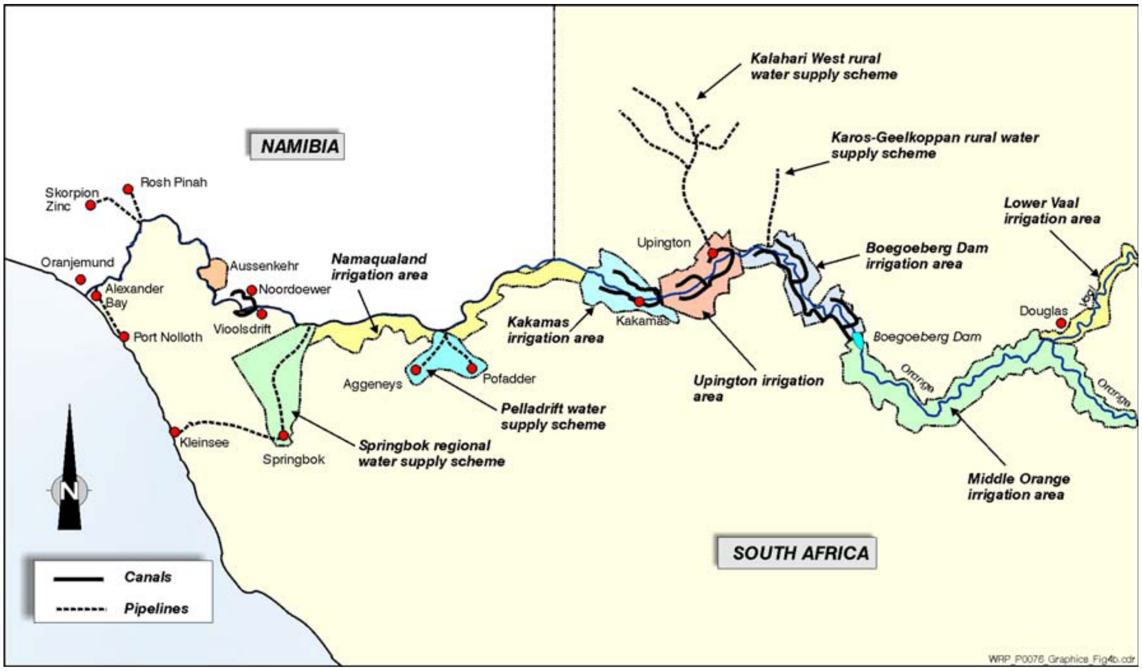

Figure 2.7: The Lower Orange: Water demands (ORASECOM 001/2007)

Transfers in the Basin have been shown in Figure 2.8 below.

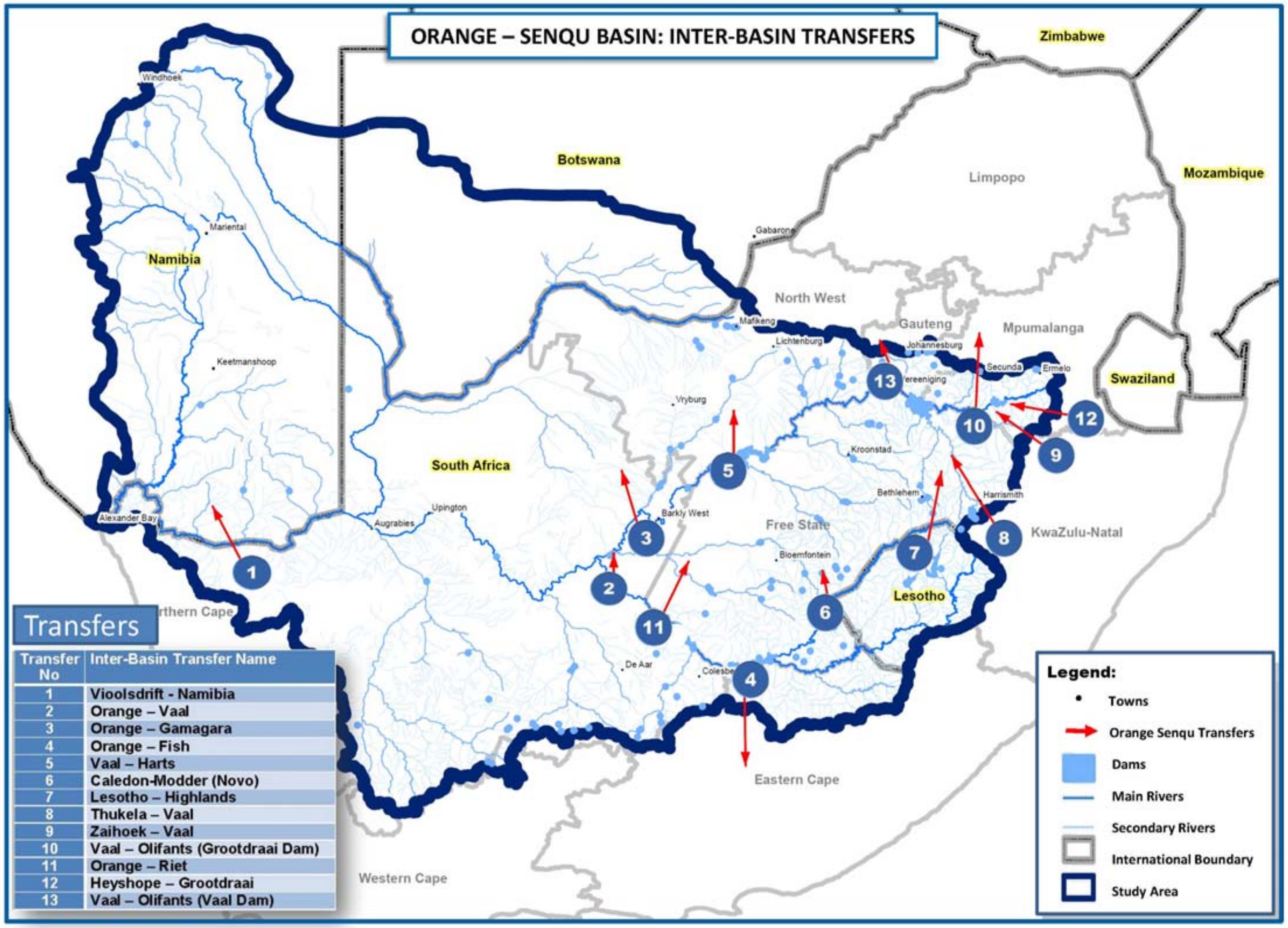

Figure 2.8 : Transfers in the Basin

Water requirements have been analysed for two development levels to give an indication of growth. Table 2.6 shows the water requirements based on development levels at 2000. Table 2.7 shows the water requirements collated into similar catchments for 2010. Some difficulty was experienced with the data for Table 2.7 in that these demands were given from a modeling perspective. The Orange-Fish tunnel transfer was removed and irrigation requirements in the point demands section were moved over to the irrigation section. The remaining point demands included urban, industrial, mining, losses, yield and environmental and the statement was given in the report that yields may not necessarily equate to demand. It is also not clear whether losses and environmental demands were part of the 2000 figures or to what extent they were. For these reasons, it was difficult to compare water requirements from two different sources for 2000 and 2010. Inspection of Tables 2.6 and 2.7 reveals that water requirements appear to have grown from the order of 4 366 (if one chooses the 2010 figure for Botswana as no information was available in 2000) to 5 787 million m^3/a, an increase of about 30%, however, the increase is probably less than this for the reasons given above. Figure 2.9 gives a pictorial representation of the water requirements for 2000 with the various user groups breakdown (2000 was chosen as it gave a clear indication of the breakdown into user groups).

2.2.5 Return flows

The return flows from industry, mining and urban are relatively high upstream of the Vaal Barrage while in the Lower Vaal WMA, most of the return flows are from irrigation.

Table 2.6: Water requirements at 2000 development levels (all figures in 10^6 m^3/a)

Catchment	Net Point Demands &	Point return flows	Irrigation Average Net Demands	Streamflow Reductions	Total
Upper Vaal WMA					
Wilge	42	0	18	0	60
Upstream of Vaal Dam	187	0	29	0	216
Downstream of Vaal Dam	702	0	67	0	769
Total UV	931	0	114	0	1 045
Middle Vaal WMA					
Rhenoster-Vals	28	0	26	0	54
Middle Vaal	96	0	33	0	129
Sand - Vet	87	0	100	0	187
Total MV	211	0	159	0	370
Lower Vaal WMA					
Harts	42	0	452	0	494
Vaal downstream of Bloemhof	40	0	73	0	113
Molopo	36	0	0	0	36
Total LV	118	0	525	0	643
Upper Orange WMA					
Senqu Lesotho	15	0	8	0	23
Caledon Lesotho	28	0	12	0	40
Caledon SA	17	0	88	0	105
Kraai	19	0	84	0	103
Riet/Modder	99	0	252	0	349
Vanderkloof	10	0	336	0	346
Total UO	188	0	780	0	968
Lower Orange WMA					
Orange	28	0	961	0	989
Orange Tributaries	15	0	16	0	41
Total LO	43	0	977	0	1 020
Total South Africa	1 489	0	2 555	0	4 044
Molopo (Botswana)	Unknown	Unknown	Unknown	Unknown	Unknown
Fish (Namibia)	8	Unknown	42	Unknown	50
Total Orange-Senqu $	1 632		2 598	0	4 230

Note: All figures except Namibia were taken from the DWA P WMA 08/000/00/0203, DWA P WMA 09/000/00/0203, DWA P WMA 10/000/00/0203, DWA P WMA 13/000/00/0203 and DWA P WMA 14/000/00/0203. For Namibia the source was DWA PB D000/00/4303

& Net point demands are gross point demands with return flows subtracted

$ Using 2010 figures for Molopo which are relatively small

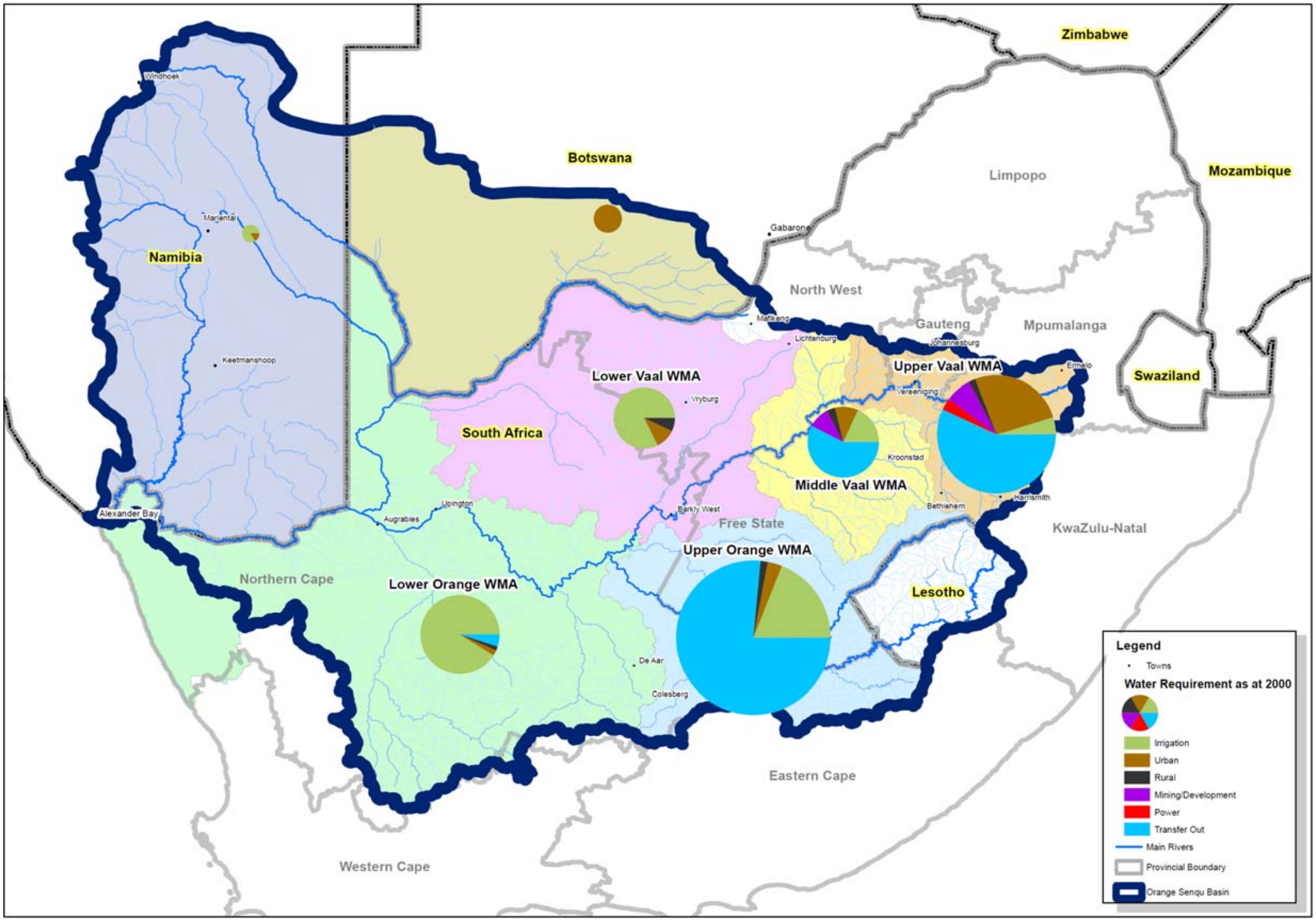

Figure 2.9: Water requirements for 2000

Table 2.7: Water requirements at 2010 development levels (all figures in 10^6 m^3/a)

Catchment	Gross Point Demands	Point return flows	Net Point Demands	Irrigation Average Net Demands	Streamflow Reductions	Total
Upper Vaal WMA						
Wilge	48	0	48	72	0	120
Upstream of Vaal Dam	1 328	36	1 292	89	3	1 384
Downstream of Vaal Dam	99	568 $	-469 $	96	1	-372 $
Total UV	1 475	604	871	257	4	1 132
Middle Vaal WMA						
Rhenoster-Vals	19	6	13	28	0	41
Middle Vaal	267	34	233	70	0	303
Sand - Vet	48	14	34	45	4	83
Total MV	334	54	280	143	4	427
Lower Vaal WMA						
Harts	178	0	178	469	0	647
Vaal downstream of Bloemhof	&	&		&	&	&
Molopo	0	0	0	0	0	0
Total LV	178	0	178	469	0	647
Upper Orange WMA						
Senqu Lesotho	27	0	27	2	0	29
Caledon Lesotho	62	0	62	71	0	133
Caledon SA	%	%		%	%	%
Kraai	#	#		#	#	#
Riet/Modder	78	0	78	500	0	578
Vanderkloof	18 ^	0	18	766 $	61	845
Total UO	185	0	185	1 339	61	1 585
Lower Orange WMA						
Orange	84	0	84	1 558	0	1 642
Orange Tributaries	0	0	0	0	0	0
Total LO	84	0	84	1 558	0	1 642
Total South Africa	2 256	658	1 598	3 766	69	5 433
Molopo (Botswana)	150	15	135	1	0	136
Fish (Namibia)	172	0	172	46	0	218
Total Orange-Senqu	2 578	673	1 905	3 813	69	5 787

Note: Source: ORASECOM 001/2011. With adjustments for irrigation and removal of the Orange-Fish transfer.
& Included in Harts
% Included in Caledon SA
# Included in Vanderkloof
@ Included in Orange
$ Return flows exceed point demands
^, $ ORASECOM 001/2011 shows this as 1 440.54 but it includes the Orange-Fish transfer.

2.2.6 Calibration

The WRSM2000 model makes use of statistics and graphs to aid the user to calibrate the simulated streamflow (i.e. produced by the model) against the observed streamflow. An example is shown for the Vaal Dam below in Figure 2.10 . One advantage of this is the generation of streamflow where observed flows do not exist.

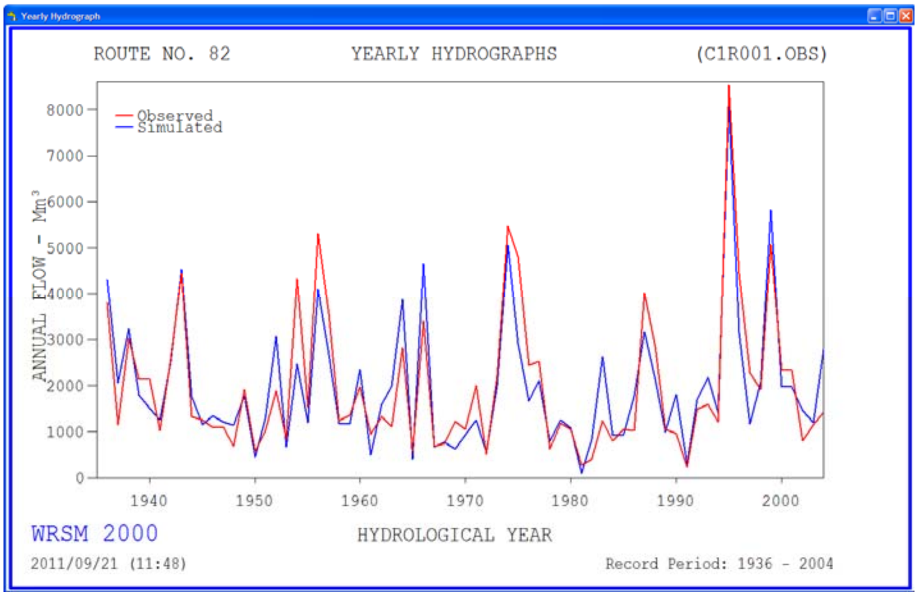

Figure 2.10: Annual hydrograph for the inflows to Vaal Dam

Key gauges were selected for each catchment. Table 2.8 gives the observed and simulated streamflows at these key locations.

Table 2.8: Calibration details for key gauges

Major Catchment	Sub-Catchment	Streamflow Gauge	River/Dam	Record Period	Observed MAR (10^6 m^3/a)	Simulated MAR (10^6 m^3/a)
Vaal	Upper Vaal	C1R002	Grootdraai Dam	1978-2004	464	447
		C1R001	Vaal Dam	1936-2004	1 882	2 008
		C8H027	Wilge River	1985-2004	885	803
		C8H022	Liebenberg's Vlei	1961-2002	920	943
	Middle Vaal	C9R002	Bloemhof Dam	1968-2004	2101	2 158
		C4R002	Erfenis Dam	1958-2004	123	124
		C4R001	Allemanskraal Dam	1958-2004	78	80
		C7H006	Rhenoster River	1977-2004	109	110
	Lower Vaal					
		C9R001	Vaalharts Weir	1947-2004	1 861	2 116
		C9R003	Vaal River (Douglas Weir)	1958-1985	1 517	1923
Orange	Upper Orange					
	D16	LESG03	Senqu River (Lesotho)	1971-1987	3 882	2742

Major Catchment	Sub-Catchment	Streamflow Gauge	River/Dam	Record Period	Observed MAR (10^6 m^3/a)	Simulated MAR (10^6 m^3/a)
	D12	D1H003	Orange River	1920-2004	4 478	4 037
	D15	D1H009	Kornet River	1960-1995	3 939	3 347
	D35	D3R002	Gariep Dam	1971-2004	6 421	6 500
	D31	D3R003	VanderKloof Dam	1977-2004	4 745	5 296
	C51	C5H016	Riet River	1952-1998	217	202
	C52	C5R004	Modder River	1970-2004	121	116
	D13	D1H011	Kraai River	1965-2004	596	670
	Lower Orange					
	D73, D53 and D54	D7H008	Orange River	1971-2004	7 008	7 887
	D81, D82, F	D8H003	Orange River	1935-1982	9 382	7 588
Molopo/ Nossob (Botswana)		No gauges				
Fish (Namibia)		3124M02 (Stampriet)	Auob River	1977-2007	3.6	
		3124M01 (Gochas)	Auob River	1973-2007	4.9	
		3126M01 (De Duine)	Olifants	1976-1997	0.0	
		3111R01 (Daan Viljoen Dam)	Black Nossob	1969-2005	0.8	
		3111M02 (Mentz)	Black Nossob	1973-2006	0.7	
		3122R02 (Nauaspoort Dam)	Usib River	1987-2006	13.6	
		Hardap Dam &	Fish River	1962-1990	182.1	
		Tsamab weir %	Ham River	1969-2004	8.45	9.39

Note: Source: WRC TT380/08 and TT381/08 was used together with supplementary analysis by Dr Bill Pitman for WRP Consulting Engineers to give the data in the above table
Source: & DWA PB D000/00/4303.
Source: % Dr Bill Pitman, 2011

2.2.7 Naturalised flows

The determination of naturalized stream flow, i.e. streamflow that would have been experienced if there were no man-made influences such as dams, irrigation schemes, towns, industry, mines, etc. are important for a number of reasons. One of the most important is their use in the WRYM where we normally use present day levels of development for land users competing for water to determine yields of dams.

Naturalised flows have been taken from the WR2005 project for key locations as given in Table 2.9 below.

Table 2.9: Naturalised flows

Water Management Area/Country	Catchment name	Tertiary/Quaternary Catchments	Naturalised MAR 1920 – 2004 (10^6 m^3/a)
Upper Vaal	Upper Vaal	C10	1 100
	Vaal Barrage	C21-C23	404
	Wilge	C80	948
	Total		2 452
Middle Vaal	Middle Vaal	C24-C25	181
	Vet	C40	406
	Vals	C60	178
	Renoster	C70	147
	Total		912
Lower Vaal	Harts	C30	121
	Lower Vaal	C90	45
	Molopo	D41B-D41M	22
	Molopo	D42C	8
	Orange in D73C	D73A and D73C	5
	Total		201
Upper Orange	Riet	C50	366
	Upper Orange	D10	4 827
	Caledon	D20	1 370
	Middle Orange	D3	193
	Total		6 756
Lower Orange	Auob, Molopo	D42A,B,D,E	7
	Hartebeest	D50	106
	Brak	D60	57
	Orange	D71, D72, D73	74
	Orange tributaries	D80	11
	Total		255
Botswana	Molopo/Nossob		44 *
Namibia	Fish		651 &
Total			11 271

Note: Source: WRC TT380/08 and TT381/08
* Source: ORASECOM 006/2011 (Appendices).
& Source: DWA Namibia, October 2011 (1920 – 1999)

2.2.8 Water Balance

The water balance for the Orange-Senqu Basin for the period 1920 to 2004 has been taken from the WRP report (WRP, 2011). A summary table has been given in Table 2.10 and the full details have been given in Tables 2.11 and 2.12. Catchments and rivers have been added to the tables shown in Table 2.11 and 2.12. Transmission losses in the Lower Orange have been included in demands. “System inflows” describe inflows from one system to another whereas “Other Inflows” describe local inflows, for example eye inflows on the Molopo River, mine water runoff in the Barrage, etc. Some irrigation demands have been included in demands where no “irrigation block modules” were used in the WRYM.

Table 2.10: Water Balance Summary 1920 - 2004

Details	Volume (10^6 m^3/a) Surplus (+)/ Deficit (-)
Natural hydrology Vaal	3 609 (+)
Natural hydrology Orange	8 220 (+)
Thukela transfer inflow	478 (+)
Net demands Vaal	2 205 (-)
Net demands Orange	4 022 (-)
Evaporation and dam storage	1 724 (-)
Spills to sea	4 182 (-)
Surplus yield	175

Note: Source: ORASECOM 006/2011

Table 2.11: Water Balance of the Vaal River System for the period 1920 – 2004
(all figures in 10^6 m^3/a)

Sub-Catchment name	Sub-Catchments	Main River	Natural Hydrology Inflows (+)	Inflows to system (+)	Other inflows (+)	Streamflow Reductions (-)	Demands (-)	Irrigation Block Demands (-)	Net Evaporation	Storage	Outflows from system (-)	Balance
Vaal												
Grootdraai Dam	C11A - L	Vaal	460	0	6	0	107	16	48	-1	295	0
Thukela	#	Wilge	694	0	0	0	8	0	6	-4	684	0
Wilge River	C81, C82, C83	Wilge	771	477	0	0	48	72	64	0	1 064	0
Grootdraai Dam to Vaal Dam	C11M,C12, C13	Vaal	823	1 359	29	3	11	73	213	-18	1 929	0
Suikerbos River	C21	Suikerbos River	100	0	105	0	22	14	8	0	161	0
Klip River and Vaal River to Vaal Barrage	C22	Klip and Vaal	173	881	390	0	10	51	8	0	161	0
Kromdraai	C23A - C	Vaal River	42	1 375	0	0	15	5	1	0	1 396	0
Mooi River	C23D – H and L	Mooi River	87	14	68	0	44	26	11	0	87	1
Klipdrift River	C23J - K	Klipdrift River	21	0	5	0	6	1	5	0	14	0
Schoonspruit River	C24A – J	Schoonspruit River	62	48	14	0	25	24	9	0	65	1
Renoster River	C70	Renoster River	132	0	0	0	10	13	21	0	88	0
Vals	C60	Vals River	153	0	6	0	9	15	9	-1	126	1
Sand-Vet	C41, C42, C43	Sand and Vet Rivers	417	0	14	4	48	45	78	-3	259	0
Bloemhof Dam	C25	Vaal	131	2 021	20	0	242	46	215	-14	1 681	1
Lower Vaal	C31, C32, C33, C91	Vaal and harts Rivers	189	1 681	0	0	313	333	84	0	1 141	0
Total Vaal			4 255	& 48	658	7	918	734	780	-41	& 2 557	4

Note: Source: ORASECOM 006/2011
& This does not equal the total as inflows and outflows include within and outside of the Basin
# Outside the Basin but transfers water into the Basin via Driekloof and Sterkfontein dams

Table 2.12: Water Balance of the Orange River System for the period 1920 – 2004
(all figures in 10^6 m^3/a)

Orange											
Sub-Catchment name	**Sub-Catchments**	**Main River**	**Natural Hydrology Inflows – Streamflow Reductions(+)**	**Inflows to system (+)**	**Other inflows (+)**	**Demands (-)**	**Irrigation Demands (-)**	**Net Evaporat -ion**	**Storage**	**Outflows from system (-)**	**Balance**
Senqu River	D11, D15, D16, D17, D18A - L	Senqu River	4 105	0	0	29	0	9	8	4 060	0
Caledon River	D21, D22, D23, D24	Caledon River	1 219	0	0	133	0	31	-1	1 056	0
Upper Orange	D12, D13, D14, D18K	Orange River	1 378	4 287	0	1 441	-10	720	12	3 501	0
Vaal (Modder-Riet)	C51 and C52	Modder and Riet Rivers	375	1 590	0	162	416	118	-4	1 273	0
Lower Main	D31 - D35, D71,D72, D73	Orange River	135	15	0	150	0	10	0	2 983	0
Lower Tributary	D61, D62, D51 - D57	Ongers River, Sak River, Hartebeest River	162	4 500	0	0	20	23	-3	124	-1
Molopo	D41 – D45	Molopo River	135 @	0	15	150	1	0	-1	0	0
Fish	D46	Fish River	695 @	0	0	218	0	66	-4	416	0
Total Orange			8 204	& 1 141	15	3 775	427	977	7	& 4 177	-1

Note: Source: ORASECOM 001/2011
& This does not equal the total as inflows and outflows include within and outside of the Orange-Senqu Basin
@ These numbers conflict with Table 2.9 which has 44 and 651 respectively.

2.2.9 Flood and Drought Management

As the Orange-Senqu catchment is heavily utilized there are several major dams, particularly along the Orange and on its main tributary, the Vaal. These dams, although designed primarily for water supply, play an important role in flood and drought management.

The possible impacts of climate change should not be ignored here. The various models predict increasing rainfall in the east and decreasing rainfall in the west, but are not in accordance concerning the actual decrease/increase. If rainfall were to increase in the east, which is the region of highest rainfall and hence the source of the majority of runoff in the Basin, one can expect greater floods and less severe droughts (but they could become more severe, depending on the variability of rainfall from season to season). A reduction in rainfall in the already arid western regions would have little impact on flood and drought management.

2.2.9.1 Flood management

There are no dams specifically built for flood control but, as a general rule, the larger the capacity in relation to inflow, the greater the attenuation of floods. Dams with gated spillways have the greatest capacity for flood control, provided they are operated correctly by, for example, releasing water before the flood peak arrives. Grootdraai, Vaal and Bloemhof dams – all on the Vaal – have gated spillways but there are none on the Orange and its tributaries; however, Gariep and Vanderkloof have significant outlet works and hydro-power stations in addition to large capacities.

Flood waves move down the Orange and Vaal Rivers at an average velocity of about 3 m/s, which translates to approximately 250 km per day. As the total length of the Orange-Senqu is 2 200 km (1 400 km from Vanderkloof Dam to the mouth) one has a lead time of several days to warn people on the Lower Orange and Vaal of an impending flood. Flood forecasting capabilities for Lesotho and Botswana are confined to short and long-term rainfall, whereas Namibia and South Africa include water level monitoring. Problems associated with forecasting include lack of rainfall and streamflow stations, vandalism, communication problems during floods, lack of manpower and limited flood-line information for hazard determination.

The primary concern for dam operation during floods is the safety of the dam. The second priority is to minimize the loss of life and other impacts due to inundation. Of particular concern in the Basin is the timing of flood peaks downstream of the Orange-Vaal confluence: every effort is made by DWA to avoid coincident peaks from the Orange and Vaal occurring at the confluence at Douglas whenever possible. An analysis of major floods in the Orange-Senqu over the last 25 years is summarized in Table 2.13 . For this analysis, the two major dams on the Vaal and Orange were selected, namely Vaal and Bloemhof (Vaal) and Gariep and Vanderkloof (Orange).

Table 2.13 : Attenuation of floods by major dams in Vaal and Orange Rivers

Flood Event	Inflow Peak (m^3/s)	Date	Outflow Peak (m^3/s)	Date	Peak Reduction (m^3/s)	Attenuation (%)
C1R001 – Vaal Dam						
Mar-1988	1972	14th	1013	18th	959	49
Feb-1996*	3930	17th	2371	21st	1559	40
Feb-2000*	1954	15th	1522	16th	432	22
Jan-2011	2611	6th	2442	7th	169	6
C9R002 – Bloemhof Dam						
Mar-1988	5199	15th	4463	15th	736	14
Feb-1996*	3248	21st	2637	26th	611	19
Feb-2000*	2173	16th	1755	16th	418	19
Jan-2011	No data	-	2793	8th	-	-
D3R002 – Gariep Dam						
Mar-1988	6767	14th	4453	14th	2314	34
Jan-2011	No data	-	2380	29th	-	-
D3R003 – Vanderkloof Dam						
Mar-1988	4443	15th	4128	16th	315	7
Jan-2011	No data	-	2446	30th	-	-

Note * These floods affected the Vaal river only.

Attenuation of nearly 50% has been achieved at Vaal Dam but was less than 10% for the most recent flood (January 2011), whereas Bloemhof Dam has effected a fairly consistent but modest attenuation. For the one major flood in the Orange, attenuation at Gariep Dam was more pronounced than at Vanderkloof Dam, owing to its much larger storage capacity.

The largest flood analyzed is that of March 1988, which affected both the Vaal and the Orange Rivers. Inflow and outflow hydrographs at the four major dams are shown in Figures 2.11 (Vaal) and 2.12 (Orange). The beneficial effect of Vaal Dam is quite apparent (Figure 2.11), where delay and attenuation of the peak saw it arrive at Bloemhof three days after maximum inflow, thus reducing the impact on the Lower Vaal to a considerable degree. Figure 2.12 shows clearly the significant attenuation exerted by Gariep Dam, followed by the lesser impact of Vanderkloof Dam.

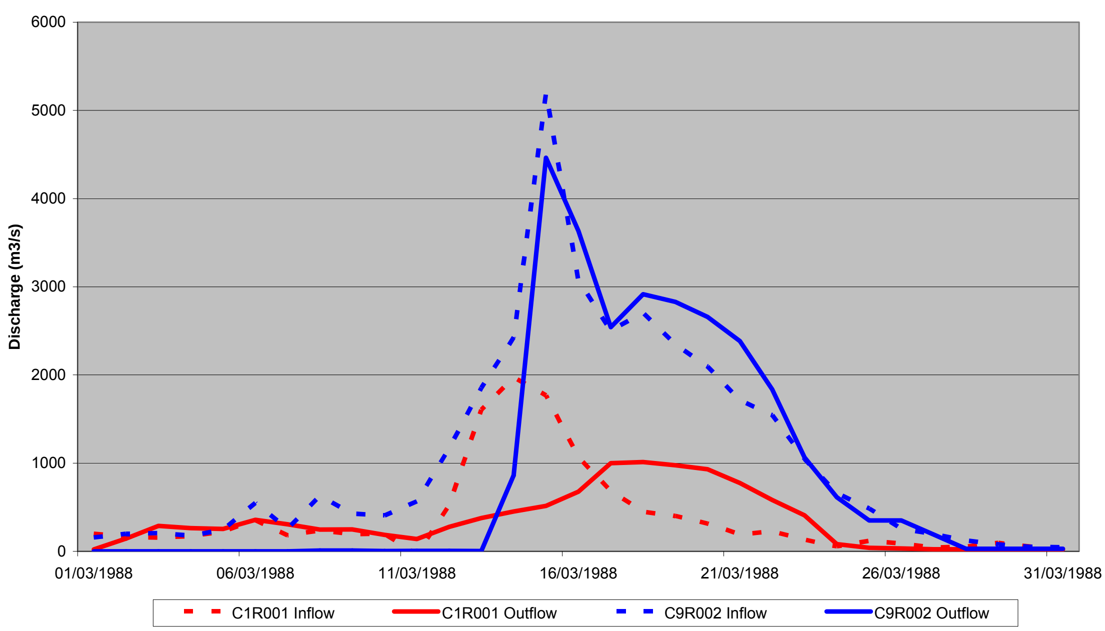

Figure 2.11: Vaal River – March 1988 Flood

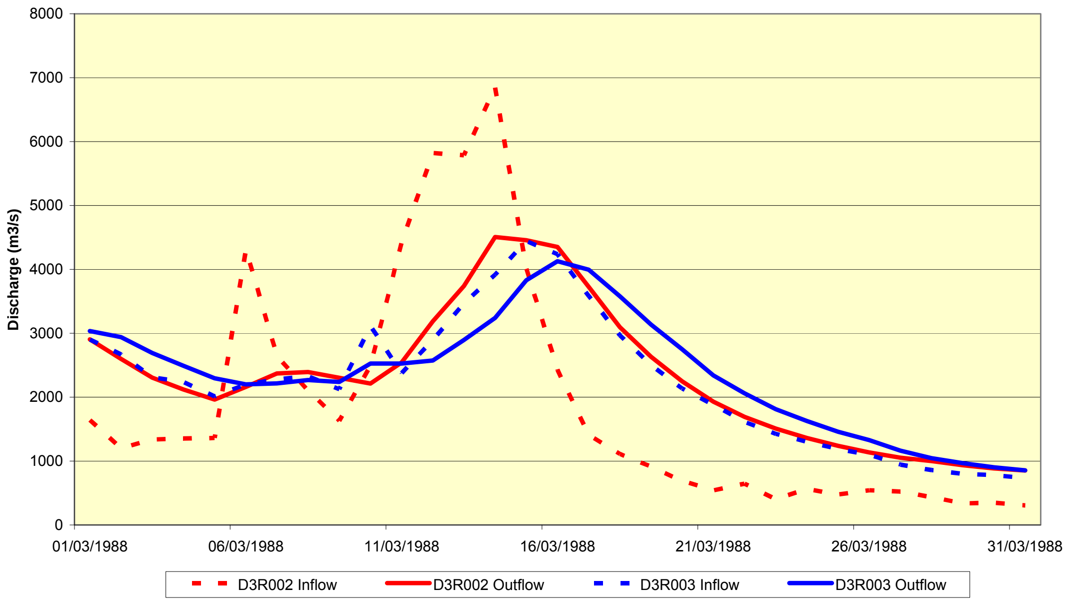

Figure 2.12: Orange River – March 1988 Flood

The data analyzed show the significant role in flood management played by the major dams in the Vaal and Orange rivers. There are, however, certain issues that need to be addressed in order to improve the situation. While all four countries have Disaster Management Plans, it is felt that these should be more detailed and that a more integrated approach should be pursued. Floodlines for a range of floods should be prepared for all areas susceptible to flooding and Emergency Preparedness Plans should be compiled for all major dams. Various problems associated with flood forecasting should be investigated and an integrated solution proposed to stakeholders.

2.2.9.2 Drought Management

All dams in the Basin are built for the purpose of water supply which, in its broadest sense, can be construed as drought management. However, all dams have an impact on the flow regime of rivers on which they are built. Water from many dams is transferred to consumers remote from the river and, in some cases, to adjacent river basins. The Orange-Fish Scheme is a prime example of such an inter-basin transfer. Some dams release water for hydro-power or for consumers situated some distance downstream of the dam, thereby often improving the flow regime during drought periods. As an example of the impact of major dams on drought flows, the same four dams as referred to regarding flood management have been selected. The most severe droughts over the last 30 years occurred in the early 1980s and early 1990s. These two events have been chosen to illustrate their impact and the results are summarized in Table 2.14.

Table 2.14: Mitigation of drought flows by major dams in Vaal and Orange Rivers

Drought Year	Inflow volume (10^6 m^3)	Volume released (10^6 m^3)	Increase (+)/ decrease (-) (10^6 m^3)	Comments
C1R001 – Vaal Dam				
1981/82 1982/83	263 304	481 570	+218 +266	
1991/92 1992/93	207 1482	497 1388	+290 -94	Inflow augmented by releases from Sterkfontein Dam
C9R002 – Bloemhof Dam				
1981/82 1982/83	331 174	654 549	+323 +375	
1991/92 1992/93	299 821	729 784	+430 -37	Inflow augmented by releases from Sterkfontein Dam
D3R002 – Gariep Dam				
1981/82 1982/83	3551 2669	3789 1778	+238 -891	
1991/92 1992/93	3537 No data	3700 No data	+163	
D3R003 – Vanderkloof Dam				
1981/82 1982/83	3641 1572+	4108 1699+	+467 +127	1 month missing data
1991/92 1992/93	3858 1999	4813 1906	+955 -93	

For three of the four years analyzed, Vaal Dam increased flows downstream owing to demands in the Middle Vaal. The small decrease in 1992/93 is a result of transfers to Vaal Dam from Sterkfontein Dam; however this transfer made possible the release of water far in excess of the natural flow. For all four years the inflow to Bloemhof Dam is much lower than the Vaal Dam releases as a result of abstractions in the reach between the dams. Releases total at least double the inflows for the first three years (due mainly to demands by the Vaal-Hartz Irrigation Scheme) and the small decrease in 1992/93 is again due to Sterkfontein Dam.

Gariep Dam shows an increase in two years but a significant decrease in 1982/83, owing to the need to transfer large volumes of water via the Orange Fish Tunnel. Inflows to Vanderkloof Dam are similar to Gariep Dam releases, as there is very little usage and natural inflow between the two dams. Apart from 1992/93 the outflow exceeds inflow, as water is released for hydro-power and to supply irrigation in the Upington-Keimos-Kakamas area in the Lower Orange River. The decrease for 1992/93 results from closing down the hydro-power station at the height of the drought.

Apart from the dams constructed as part of the Lesotho Highlands Water Project (LHWP), all major dams in the Orange-Senqu were built before an Ecological Water Requirement (EWR) became a required release from a reservoir. EWRs are designed to maintain the environmental integrity of rivers downstream of dams, but in all cases the EWR flows do not exceed the natural flow in the river.

2.2.10 Water and Food Security

While the Basin has adequate agricultural production to feed its population, many people suffer from malnutrition due to insufficient food security. In 2001, for the South African provinces the percentage of 'food poor' households was estimated respectively for the Northern Cape at 61.5%, for the Free State at 55.1% and for the North West at 52.1%. This means that including those who grow their own food at home, are given food and those buying food, a high percentage had insufficient food for their basic needs. In Botswana, the malnutrition rate for children under five was 9.2% in 2001, 15% in Lesotho (2000), 20.3% in Namibia (2000) and 11.5% for South Africa (1999) (WDID 2009 as quoted in Orange Senqu River Awareness Kit). In particular during large scale droughts, food security concerns are very high. In the regionally dry year of 2002, some 650 000 people in Lesotho required emergency food assistance (Lesotho National Vulnerability Assessment Committee, 2002). While water security is important in influencing food security, it is but one of the many factors in increased agricultural production and/or sufficient income possibilities to purchase food.

Large scale agricultural production in the Basin is mainly maize production in the North West and Free State provinces, irrigation along the lower Orange River and cattle ranching in other parts of the catchment. While maize and cattle ranching are mainly rain fed, the irrigation in the lower Orange River depends very much on reservoir operation in the Basin. Additionally, the water transfers from the Basin to surrounding basins increase agricultural production in these basins. However, this agricultural production does not directly benefit the vulnerable communities. The critical role of water for food security in rural communities can be improved through improving on-farm management of water, improving the performance of irrigation services, augmenting water supply and rainwater harvesting (FAO, 2003).

In South Africa, increasing water security and therewith food security for subsistence and small scale farmers is intended through support for the development of small scale irrigation (Department of Agriculture, 2002). Government policy is to support emerging farmers with reallocation of land and water rights, for example through the Orange River Emerging Farmer Settlement and Development Program (www.agrinc.gov.za, Nov. 2011). Rainwater harvesting and groundwater use is being advocated and researched. The suitability of in-field rainwater harvesting is shown in Figure 2.13 . The adoption rate of special programs has so far been very low (Mwenge Kahinda et al, 2008).

In Lesotho, intentions to increase food security through water security have been geared to education for farmers on tillage methods that conserve soil moisture, choosing drought and frost resistant crops and encouragement of the reduction of livestock herd-sizes, as well as the development of irrigation water infrastructure (Mphale, M.M and E. G. Rwambali, undated). Research has shown that certain seasonal climate forecasts, tailor made for small scale farmers, can also help to improve food security (Ziervogel and Calder, 2003).

For Namibia, most food security reports focus on the flood and drought risks in the northern areas, where most of the crop production takes place. For the part of Namibia in the Basin, water security for livestock and new opportunities for irrigation development are the main issues. The national food security program (Government of Namibia, 2007) has four pillars, namely: food availability (1), food access (2), food utilisation and nutritional requirements (3) and stability in equitable food provision (4). In relation to water, pillar (1) will address sustainable utilisation of water resources, develop irrigation and increase aquaculture, pillar (2) will address access to water resources and pillar (4) will improve disaster management, climate change adaptation and combating desertification.

Botswana has maintained a relatively stable food security situation, but is reliant on imports. Also, the seven year drought of 1981-1987, brought serious problems. Some of the past policies aimed at achieving household food security, such as the Financial Assistance Policy and the drought subsidies for livestock led to environmental degradation of some communal lands (Moepeng, undated). The National policy on Agriculture is currently under review (www.moa.gov.bw, Nov 2011).

With climate variability increasing, the vulnerability in terms of food security may increase. However, as De Wit (2010) argues, addressing the underlying, systemic causes of food insecurity in Southern Africa will go a long way towards absorbing shocks brought about by expected increases in climate variability and longer-term climate changes.

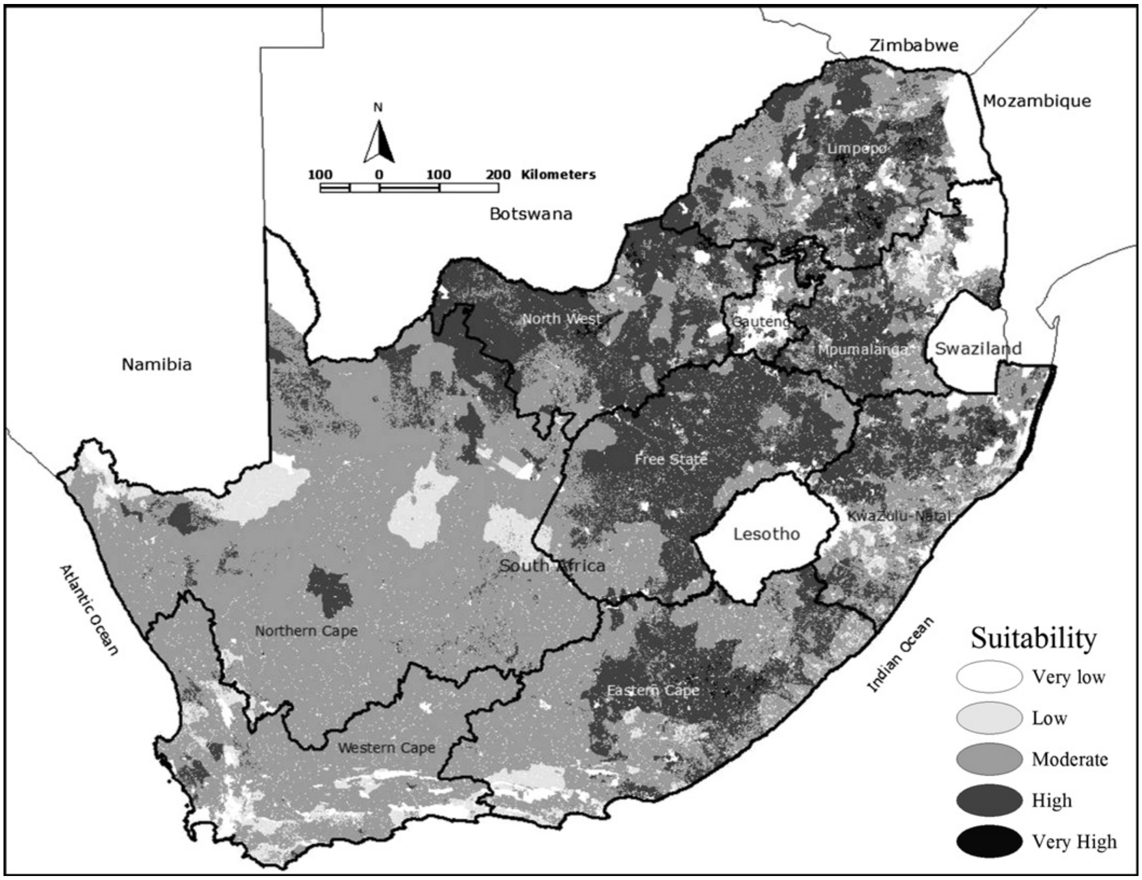

Figure 2.13: In-field rainwater harvesting suitability map for South Africa, based on both physical and socio-economic factors, (Mwenge Kahinda at al., 2008).

2.2.11 Climate Change implications on water cycle, yield and demand development

For an impression of what climate change may mean for the Basin, the following points are emphasized:

- Climate change forecasts cannot be based on a few models only, as there are large differences between model assumptions and predictions;
- The naturally high inter-annual and intra-annual variability of both precipitation and runoff in the Basin make it very difficult to observe climate change trends. Such

trends can easily be masked by the natural variability. It can also happen the other way around; what is perceived as climate change could be natural variability;

- The projected temperature increases are unevenly distributed across the seasons. In the study by Crerar et al. (2011) the largest increases predicted in the Basin are up to 3°C for the summer months around the Kalahari Desert in 2100. During the initial summer period, the increase in temperature over the Lesotho Highlands is also at its highest. For the autumn and winter season, an increase in temperature is still predicted, albeit not as extreme. In autumn and winter, the temperature increases are predicted at between 1°C and 2°C in 2100, fairly evenly distributed over the basin;

- In any climate change forecast there is a high degree of uncertainty related to the predicted changes in precipitation. According to Knoesen et al. (2009) the differences in results between different Global Circulation Models (GCMs) are higher for smaller periods (average 7 day rainfall uncertainty higher than for average annual rainfall) and more consistent for longer return periods (1:50 year rainfall more consistent than 1:2 year rainfall). Some of the downscaling models which the University of Cape Town uses, give similar monthly rainfall change. However, consistency between models depends on where and when changes are being assessed (verbal communication 2011, Mark Tadross, UCT);

- The uncertainty for temperature changes is less that that for precipitation. The changes in temperature and rainfall (cloud cover) translate into evaporation changes and

- Climate change trends can impact on land cover, which will impact on hydrology indirectly. The climate change scenarios are consistent in that in general a higher variability in water resources is predicted (often more floods and more droughts).

Climate change has been a feature of earth's climate for aeons. Accordingly, climate change is regarded by different scientists with different perceptions.

In the International Panel on Climate Change, twenty-one different GCMs are used, each with their own merits and weaknesses. Each of these models can be fed with different scenarios of greenhouse gas emissions. The GCMs make computations over grid cells of about 50,000 km^2 (250 x 250 km). Therefore local geographical details such as mountains and lakes are smoothed in the computations. Downscaling methods are therefore used to translate these model results to a smaller spatial scale. Thus, apart from different GCMs and different greenhouse gas scenarios, there are different scenarios for climate change due to different downscaling methods.

The University of Cape Town is leading the research in the region and uses nine models for further downscaling. They choose to use percentile curves to analyse the variation in outcomes between different models. Such curves give an indication of the percentage of model outputs which are predicting a certain outcome. The whole 'envelope' of different model outputs is studied.

Some scientists within Southern Africa (i.e. Alexander et al., 2007) are confident that long time cycles in climate, possibly related to sunspots and variations in the sun's and earth's orbits, explain the monitored trends that appear to be climate change.

Institutes outside of Southern Africa also model climate change in this region, each with their own preferences for models. Crerar et al. (2011, for ORASECOM) used different downscaling methods (dynamic downscaling model CCLM and statistical downscaling model STAR II). The greenhouse gas emission scenario ‘A1B’ was used, which assumes a globalised world emphasising economic growth, with relatively high greenhouse gas emissions. It is unclear which GCMs were used, but a distinction is made between a wet, dry and moderate scenario, using the statistical model STAR II for downscaling. The predicted seasonal precipitation changes are presented for 2051-2060 in Figure 2.14 .

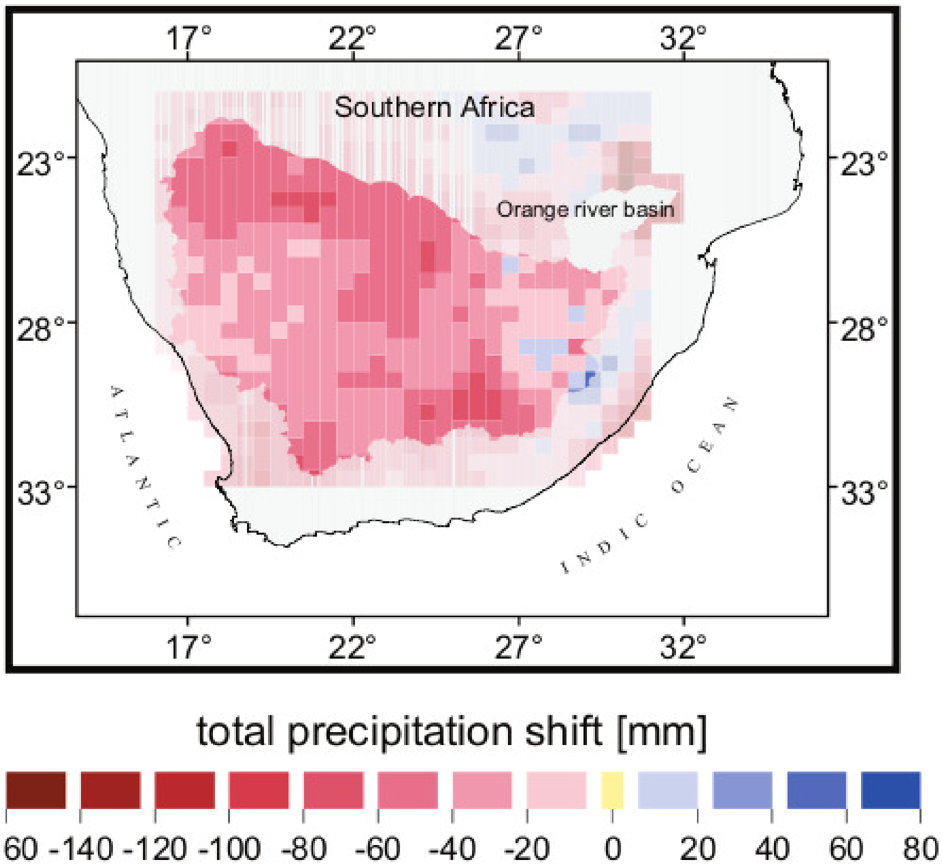

Figure 2.14: Precipitation Shift under Median Realizations **(2051 – 2060, ORASECOM, 009/2011)**

The main conclusions of the study of Crerar et al. (2011) are:

- Temperature increases are expected throughout the basin, varying from around a 1 °C increase at the coast (river mouth), to a maximum of around 3 °C in the Kalahari Desert. The increase in the upper river basin is between 1.5 and 2 °C;
- The impacts on runoff are different for different areas. The Lesotho highlands and source of the Caledon River in South Africa may experience an increase in precipitation. A relatively small increase in precipitation in these key runoff producing areas could result in a significant increase in runoff, perhaps enough to offset the reduced runoff in the lower runoff producing areas to the west. Runoff in the Fish River is likely to be adversely affected by the significantly reduced precipitation in that sub-basin, although this may be partially offset by more extreme rainfall events. (It is noted that the discussion on runoff in Crerar et al. shows that only the impact of precipitation changes on runoff changes is referred to. The considerable increases in

predicted temperature would result in increasing potential evaporation and will therewith decrease the proportion of rainfall that becomes runoff;

- In the Upper-Middle catchment area, a significant temperature increase, coupled with a significant reduction in precipitation, will make rain-fed farming increasingly difficult;
- In the Lower Orange Corridor and irrigation areas in Namibia, a significant increase in temperature over all of the areas concerned is to be expected. The decrease in precipitation is likely to be less than for the middle part of the basin but will have some impact in crop requirements for irrigation and
- For the stock-farming in the Lower Orange, Namibia and Botswana, a significant increase in temperature will increase heat stress during summer and reduce the risks of very cold nights during winter. Cattle watering requirements will increase. Changes in vegetation are likely to occur due to reduced precipitation, but may be counteracted by the carbon dioxide fertilisation effect on grazing lands.

It is noted that these conclusions were based on very few different scenarios and models.

The University of Kwazulu Natal uses rainfall and evaporation scenarios generated by UCT for further hydrological modelling. Their study on the Basin (2009) presented the results of one model (ECHAM5), but the scenarios of 5 models were used for analysis (GCM 3.1, CNR-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4). The results of this research are very different to those of Crerar et al. (2011). Temperature changes are higher, between 2.0 and 3.5 degrees Celsius for 2046-2065 and 4 to > 7 degrees Celsius for the longer term (2081-2100). The research findings expect an overall increase in rainfall over the Basin, not just in the Highlands. These basic differences in scenarios create a completely different scenario for the impact on hydrology than was the case in Crerar et al. (2011).

The above differences in insights on climate change, as well as the possibility of a higher frequency of floods and droughts show that planning of water resources needs to prepare for the unexpected and therefore should include robust or flexible solutions.

2.2.12 Water and Energy

Energy production in the Basin is confined to South Africa and Lesotho. The bulk of South Africa's energy production, i.e. coal-fired thermal power, is situated outside the Basin. Only the Lethabo, Tutuka, Camden and Grootvlei and Thermal Power Stations are situated in the Basin. The latter three stations have recently been demothballed. Other sources of energy such as nuclear, solar, wind, bio fuels, etc. have potential but at present, it is clear that water is the main natural source of energy that can be produced within the confines of the Basin. However, the water demand and management for South Africa suggests that using this basin is very challenging.

Lethabo Power Station (3 708 MW) was fully commissioned by 1990 and together with Tutuka Power Station, are modern stations whereas Camden and Grootvlei are relatively old. Lethabo Power Station's wet cooled plant performance is amongst the best in the world. They both operate desalination plants, treating mine water. Lethabo also uses water from the Vaal River and treated sewage water. Tutuka Power Station (3 654 MW), fully commissioned by 1990, is a wet cooled station.

Typical water usage of thermal power stations is (www.eskom.co.za):

- Wet Cooled: 50 million m^3/a and
- Dry Cooled: 3.5 million m^3/a

Camden Power Station (1 600 MW) was commissioned in 1967, mothballed between 1990 and 2006. During the severe drought in 1982 only one unit out of eight was running, as there was no water available to run the station. The water supply is primarily obtained from the Jericho Dam on the Mpama River 43 km away and additional supplies, when required, from dams on the Ngwempisi and Usutu rivers. Recent efforts by Eskom have reduced this consumption by about 20%. Grootvlei Power Station (1 200 MW) has a mix of wet and dry cooled systems. Groootvlei was extended by adding two dry cooled units which were the largest in the world at that time. Three of Grootvlei's six units were mothballed in 1989 and the rest in 1990. By 2008, two units were demothballed and it currently has four units running. Table 2.15 shows the raw water consumption for the four thermal power stations.

Table 2.15 : Thermal Power Station Raw Water Consumption

Power Station	Present Raw Water Consumption (m^3/s)
Lethabo	1.32 (to be upgraded to 0.95)
Tutuka	1.49 (to be upgraded to 1.28)
Camden	1.26 (to be upgraded to 1.03)
Grootvlei	0.87 to 0.92

A direct relationship exists between energy produced and water consumed, expressed as litres per kilowatt-hour (l/kWh). This relationship is called 'specific water consumption' and is calculated by dividing water consumption by energy sent out. This measure is used to assess the performance of power stations. Eskom have reduced the specific water consumption (for all generation technologies) from 2.85 l/kWh in 1980 to 1.29 l/kWh in 2003. Eskom's future strategy is to only construct dry cooled power plants.

There are two large hydropower plants (conventional hydropower) in South Africa, both of these are located on the Orange River. Gariep (360 MW) and Vanderkloof (240 MW) which is 130 km downstream of Gariep, are the two largest hydropower plants in South Africa. Both of these plants are supported through a combined reservoir capacity of 8 906 million m³ (the two largest dams in South Africa). The influence of such reservoir capacity to the river system cannot be underestimated. During energy production the stored water is passed through the turbines with consequences for the settlements on the downstream side of the river. Irrigation as well as flood control are key considerations during the energy production cycle. During times when turbines are shut, evaporation of the stored water reduces the critical water resource.

Due to the multi-purpose nature of the Orange River Scheme as a whole, a balance has to be maintained with regard to water resources for irrigation, urban, etc. and water available for power generating purposes. Wet and dry cycles of river flow influence the availability of the power plant. In practice, a sophisticated operating model has been developed by ESKOM and DWA for optimum management of this precious water resource for both power generation and water supply purposes. Control curves maximise generation of electricity without violating the rights of downstream users. The hydro stations are predominantly used as peaking power stations due to limited water resources and as such do have the ability to provide a swift response to the needs of the South African energy market. The units are able to come on line within three minutes and can be operated by remote-control from Eskom's national control centre.

Outstanding operating and maintenance processes have resulted in decades of excellent plant performance. The proactive development of technical plans for current maintenance, future refurbishment and capacity upgrades, as well as the focus on long term plant health, will ensure that these environmentally friendly hydro plants continue to deliver electricity for decades to come. The stations produce base load energy during times of flood risk to try and maintain some buffer storage and to take advantage of an opportunity for low cost energy production. The innovation of running a Gariep unit for one hour every three hours allows water release for downstream users while deriving energy that would otherwise have been wasted. The electricity produced by the Orange River Hydro stations is relatively cheap with the average cost of production at almost 5 times less than coal-fired power stations.

The feasibility of upgrading Gariep has been investigated. This upgrade would be to make available an additional 80 MW of peak and emergency generation to the national grid. This can be extremely important to the grid at this stage in our supply crisis and given the fact that this is considered to be renewable energy makes it more environmentally friendly as well. But there are some risks as follows:

- Utilisation Factor **-** One of the major risks to the feasibility of upgrading Gariep is that of the availability of water in the Orange River system. This currently has a significant impact on the load factor of both hydro stations on the Orange River with the average load factor for the preceding 7 years at Gariep Dam being only 18.8% and

- Level of the Gariep Dam **-** The full increase in capacity will only be available when the level of Gariep Dam is above a certain level. This level is at 74.6% of full supply level. Below this dam level the total increase drops proportionately to the dam level. Gariep Dam has been above this level 69.1% of the time over the past 7 years, which is positive, however, the Load Factor for the additional capacity is likely to be in the region of 5% only thus putting further pressure on the financial justification of the upgrade.

Hydropower in the Basin is augmented with pump storage schemes. Pump storage incorporates a conventional hydropower generation when converting water's potential energy into electrical energy. However, during times when energy is not produced, the power plant is used as a pumping scheme where water in the lower reservoir is pumped and directed elsewhere in the river system. This mechanism of creating energy during peak demand periods and drawing energy from the electrical network (pumping) during low demand periods, is very useful for river control. It is even more useful if water can be transferred between rivers. Because it is necessary to pump the water back after use, pumped storage power stations can only provide energy for limited periods of time. In addition they are more expensive to operate than conventional hydroelectric power stations because of their pumping costs. These disadvantages are offset by their quick re-action to changes in electricity demand which play a major part in maintaining the stability of the Eskom national grid in South Africa. Eskom has a pump storage power plant at

Drakensberg (1000 MW). The Drakensberg plant is used as a pump station in the Thukela – Vaal Water transfer scheme. Water is transferred from the Thukela WMA to the Upper Vaal WMA and also facilitates the generation of hydroelectricity. It involves Woodstock Dam, Driel Barrage, Kilburn Dam, Driekloof Dam, Sterkfontein Dam and a number of pump stations, pipelines, canals and tunnels. . There is an additional 1 330 MW planned (under construction) at another plant called Ingula, also located within the Basin.

Other hydropower plants within the Basin belong to the Lesotho Highlands Scheme located in Lesotho and developed in partnership between the governments of Lesotho and South Africa. It comprises a system of several large dams, with Katse Dam being the most important and tunnels throughout Lesotho and South Africa. In Lesotho, it involves the rivers Malibamatso, Matsoku, Senqunyane and Senqu. In South Africa, it involves the Vaal River. It is Africa's largest water transfer scheme. The purpose of the project is to provide Lesotho with a source of income in exchange for the provision of water to the central Gauteng province where the majority of industrial and mining activity occurs in South Africa, as well as to generate hydroelectric power for Lesotho (currently almost 100% of Lesotho's requirements). There are three phases of which Phase 1A and 1B have been completed. Phase 2 is currently under way which involves the construction of Polihali Dam which will augment the Vaal River system to ensure the water security of Gauteng which is the economic hub of South Africa which is expected to increase its water requirements by 30% within the next 20 years. At present the Muela hydropower plant (72 MW) and a planned pump storage scheme in Lesotho have minimal influence on the broader Basin. However, it is mooted that the planned pump storage (LHDA) may be as large as a 1000 MW. Such capacity will have a significant impact in the Basin.

The contrast between energy needs and water conservation and service delivery can be shown in Table 2.16 below.

Table 2.16: Energy needs and water supply management

ENERGY	WATER SUPPLY AND MANAGEMENT
Energy conversion requirements. (Potential Energy – kinetic – power). Baseload Power Demand (Energy in excess of 12 hours of integration). Peak Demand Management (Energy demand for ± 3 hours at a time).	Consumption of the water resource hence availability and sufficiency. River water levels, irrigation system control, flood control. Reservoir evaporation threats and insufficient delivery.

The contrasting needs of energy production and water delivery (Table 2.16) are intertwined. It is often the compromise that is sought to come to some guidelines on how hydropower plants are operated.

In the South African context the energy demand curve contains two clear peaks (morning and evening). Each of these peaks lasts for about three hours. The speed of development of both peaks is relatively quick. Superimposed, on this peak is a baseload which progresses throughout the day. The compromise that is sought with the hydropower plants is that they are the first to be started to chase the peaks. Starting these plants is relatively quick, and in the space of less than five minutes, the peak demand can be tracked and serviced. Care has to be taken not to discharge the river through the turbines to the extent of flooding downstream settlements. It is also quite attractive that hydropower plants can be started and operated entirely remotely. Hydropower plants are also quite cheap to run.

They do not ‘consume’ the water resource save only for the storage and conversion from potential energy through kinetic energy (turbine) to electric power.

At the moment, baseload power is still predominantly supplied through burning of coal. The clean emissions drive, and global climate change mitigation are slowly becoming a vice for burning coal. It may be that the case for balancing baseload support from hydropower (and other renewables) and water supply constraints will be revisited in the near future.

3. FLUVIAL MORPHOLOGY AND SEDIMENT BALANCE

3.1 INTRODUCTION

3.1.1 Background on Historical Sediment Transport Data in the Basin

In order to optimise the benefits from the Basin, an understanding of the fluvial morphology is essential. Currently, sedimentation has a significant effect on the fluvial morphology and sediment balance of the Orange-Senqu River system including the reservoirs within its Basin. Appropriate solutions to deal with sedimentation problems are essential in order to achieve economic and environmental sustainability, which are key to sustainable development and management of infrastructure projects such as dams in the Basin.

This review is aimed at providing an insight into the fluvial morphology of the Basin, particularly sediment loads and mass balance considering historical data and to predict future trends. Sediment loads were determined from river sediment sampling and reservoir sediment deposit data surveys. In addition, the sediment loads were also predicted using analytical methods for those catchments that had no observed data.

The analytical methods for sediment yield prediction are based mainly on the recently revised Sediment Yield Prediction for Southern Africa Report – 2010 Edition, of the SA Water Research Commission (WRC, 2010). This report has been used to provide a quantitative analysis of sediment transport data and mass balance in the Basin, particularly in the part of the Basin that is situated in South Africa and Lesotho. The historical sediment transport data and the current sedimentation trends for Namibia and Botswana were acquired using the available records and reports from the respective countries.

3.1.2 Impacts of River and Reservoir Sedimentation

The impacts of river and reservoir sedimentation cannot be ignored in the Basin. Special attention to river and reservoir sedimentation trends within the Basin is needed considering that the largest and second largest reservoirs in South Africa are located in this Basin. Already, the water quality in rivers and reservoirs has been greatly affected by an increase in suspended sediment concentration resulting from massive land degradation within the Basin. Some reservoirs have lost significant volumes of their original storage capacity due to sedimentation. This loss in storage reduces the ability for the reservoirs to meet human needs such as domestic and industrial water demand and irrigation requirements. Considering the beneficial advantages of reservoirs in the storage of water for drinking, irrigation, recreation, hydropower production and flood control, sedimentation could result in serious socio-economic losses, and environmental and aesthetic problems. Food production from irrigated agriculture can be affected by reduced water volumes in reservoirs.

3.2 DESCRIPTION OF THE FLUVIAL MORPHOLOGY OF THE RIVER SYSTEM

3.2.1 Introduction

A river's regime with respect to its width, depth, slope and channel pattern is affected by the following factors; water discharge, sediment load and bed and bank materials. However, the water discharge and sediment discharge variables are the most dominant. It therefore follows that floods have an influence on the fluvial morphology of a river system. The floods and sediment loads, which are the morphological processes that affect a river's regime, are time dependent.

River flow patterns and structural components such as main channel width, B, and depth, D, can also be affected by the construction of dams upstream and river bank activities. Using satellite images and targeted observations, it can be concluded that some of the river's structural components (morphology) have changed from the more "natural" condition prior to the construction of dams in the Basin. Storage of sediment by dams upstream has contributed to downstream river bed degradation depending on the interaction of erosion and deposition processes. Flood attenuation on the other hand caused by dams often leads to a decreased sediment transport capacity locally downstream of dams and riverbed aggradation.

3.2.2 Channel Width Changes

An analysis of periodical satellite images for the river shows the extent of the temporal and spatial changes in the river channel widths and meandering patterns. The changes are related to the complex nature of interactions between the effects of overland and channel erosion, mass movement of soil, deposition, the rate of discharge at the relevant locations during a given period of time and the stability of river bank material.

The effect of changing variables on the main channel width, B, can be summarised as follows. An increase in the discharge results in an increase in the channel width and vice versa. The change in the particle size, d, is directly proportional to the change in the main channel width, B. The decrease in the channel slope, S, results in an increase in the channel width and an increase in the channel slope, S, results in a decrease in the channel width, B. According to Beck and Basson (2003), this can be described by the following equation:

$$B = 4.03Q^{0.369}S^{-0.228}d^{0.053} \qquad (1)$$

Table 3.1 shows some of the observed river width changes (Beck and Basson, 2003) after dam construction within the Basin. Table 3.1 illustrates the effect of dams on the regime of some of the rivers in the Basin.

Table 3.1: Observed river width change

Dam	River	Width before dam construction (m)	Width following dam construction (m)	% change
Bloemhof	Vaal	92	82	-11
Noordoewer	Orange	222	208	-6
Gariep	Orange	269	255	-5

The regime depth equation for rivers in South Africa is given as:

$$D = 0.0071Q^{0.374}S^{-0.154}d^{-0.02} \qquad (2)$$

Where D = flow depth

Q = 10 year flood

S = local river energy slope

d = median sediment diameter

Note that equations 1 and 2 are not applicable immediately downstream of a dam.

3.2.3 Sediment Characteristics

The sediment characteristics vary greatly within the Basin. This is due to the varying climatic conditions, land use types and geological characteristics within the Basin. The river has an alluvial sand bed with some reaches with bedrock. The washload (silt and clay) fraction is high during floods (70 to 80 %), especially on the Caledon River where the clay fraction is high. The median bed sediment diameter is in the range of 0.2 to 0.5 mm.

3.2.4 The Role of Floods

Floods play an important role in the transport of sediment. Floods are dependent on the intensity of rainfall, runoff transporting capacity of tributaries and soil draining capabilities. In general, there is spatial and temporal variability in flood exceedance intervals within the Basin which is composed of many river sub-catchments. The notable flood regions within the Basin include the Vaal, Harts, Riet, Caledon, Upper Orange (Senqu), Ongers, Molopo, Nossob, Fish and Hartbees river sub-catchments. These sub-catchments have varying mean annual precipitation which ranges from around 850mm in the Senqu (Upper Orange) to 140mm in the arid region of the lower Orange River.

When considering sediment load over a long period of time, an effective discharge passing through a point along a river or a reservoir would best be represented by a recurrence interval flood. Most sediment is transported during floods larger than the average runoff from the catchment. Therefore, the greater the variability in runoff; the larger the percentage of sediment carried by infrequent floods. This means that the dominant discharge is bound to have a longer recurrence interval than 1 - 2 years. The role of floods in sediment transport can be explained by the following observations within the Basin.

The relatively arid region of the Molopo River is characterised by sands and dolomites, but the sediment load is limited by the little or no perennial flows and occasional seasonal floods. Even though more sediment could be available in this sub catchment or river, the extent of floods limits the actual sediment loads to be observed at the outlet.

The runoff from the Lesotho Highlands contributes almost half of the flow in the Orange River (Sene et al., 1997). The maximum instantaneous flow recorded in Lesotho is more than 6000m^3/s. However, due to the number of dams that have been constructed within the Lesotho highlands, the effect of the floods on sediment load downstream is dependent on the extent of floods, availability of sediment and the trap efficiency of the dams. The availability of sediment is related to the erosion hazard potential of the catchment.

For example, the average sediment yield at the Koma-Koma flow gauging station on the Senqu River which covers a catchment area of 7950km^2 was calculated as 78t/km^2.a. This is taken as the average sediment yield because of the high variability in the annual sediment yield along the Senqu River which was observed to be ranging from 30t/km^2.a to 250t/km^2.a during drought and wetter years respectively. The relatively lower simulated average sediment yield could be as a result of the dry period during specific years which are characterised by low observed flows while higher sediment yields could be associated with periods of high floods.

3.2.5 River Longitudinal Profiles

The characteristic river properties such as discharge, slope, average grain diameter and channel width vary in relation to the longitudinal profile of a river course. In normal circumstances, there is an increase in discharge along the course of the river as one goes in the downstream direction. The increase in flow is contributed by the tributaries that join the river.

The natural flow along the course of the Basin has been affected by the presence of dams that have been constructed. These dams trap sediment along the river course and control the amount of water that reaches the estuary. In the end, the fluvial morphology with regard to sediment load and mass balance is also affected along the various sections of the main river course and its associated tributaries. In addition, the fluvial morphology is affected by the variability in annual precipitation and the frequency of high intensity floods from various tributaries.

The main river component in the longitudinal profile is the slope, S. As discharge decreases the slope becomes steeper. This occurs because the transport capacity of the river channel decreases as the discharge is reduced and the increase in channel slope is a measure that is aimed at increasing the transport capacity again. The change in the particle size, d, on the other hand is directly proportional to the change in the channel slope, S. Figures 3.1 to 3.5 show the slopes along the longitudinal profiles of selected tributaries of the Basin. Table 3.2 shows the Q_{100} floods, slopes and widths for selected points on the longitudinal profiles.

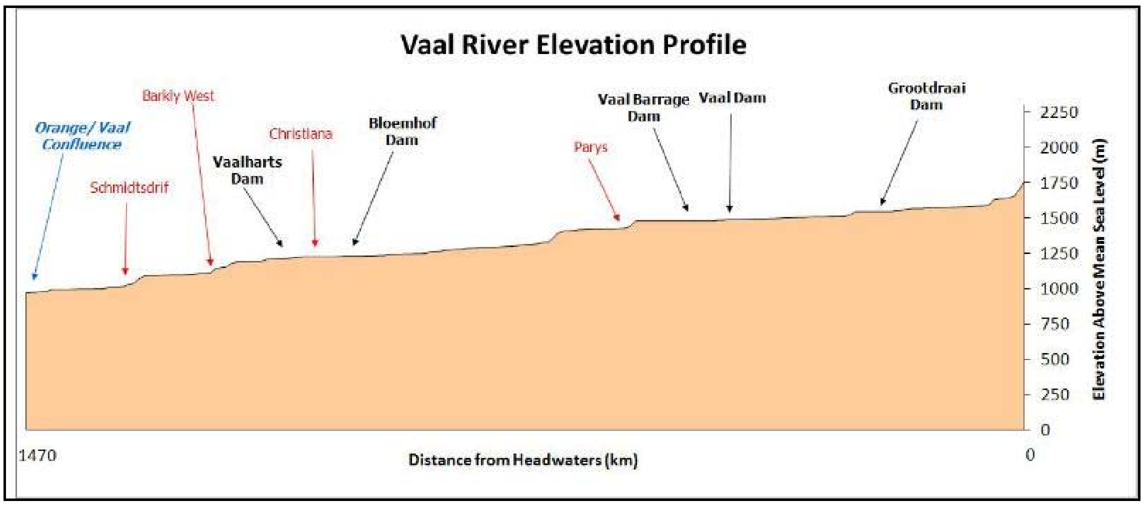

Figure 3.1: Vaal River Elevation Profile *(Source:* www.orangesenqurak.org*)*

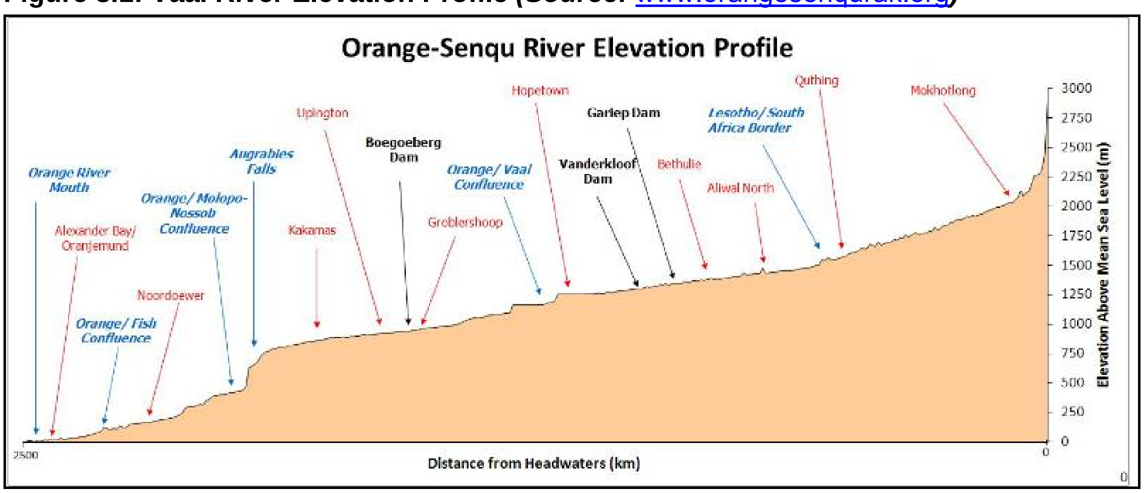

Figure 3.2: Orange Senqu River Elevation Profile *(Source:* www.orangesenqurak.org*)*

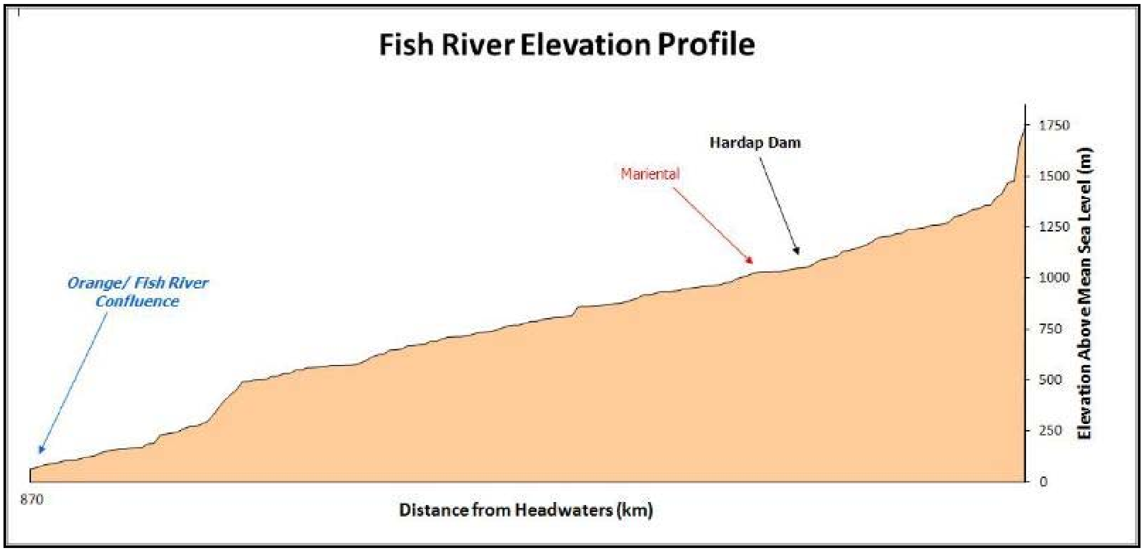

Figure 3.3: Fish River Elevation Profile *(Source:* www.orangesenqurak.org*)*

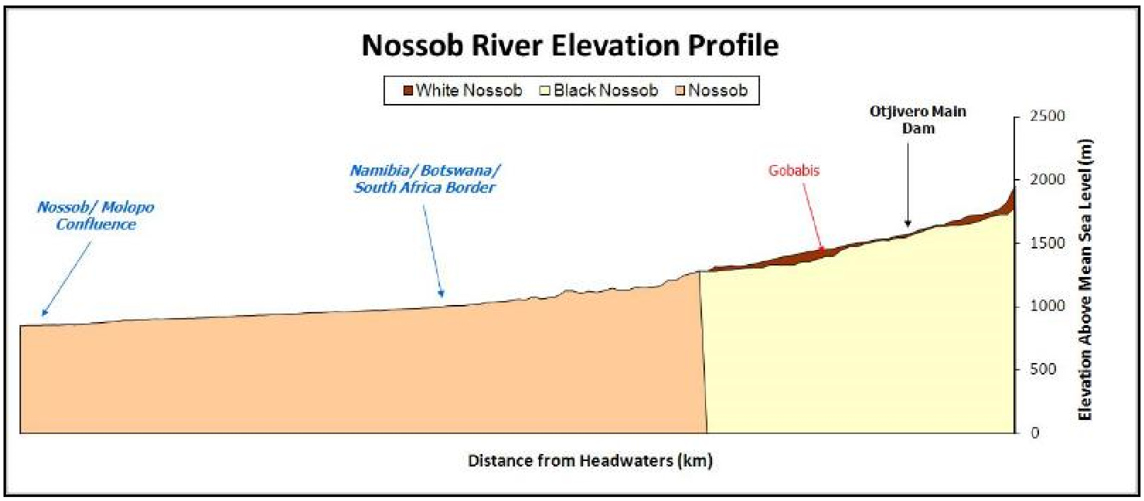

Figure 3.4: Nossob River Elevation Profile *(Source:* www.orangesenqurak.org*)*

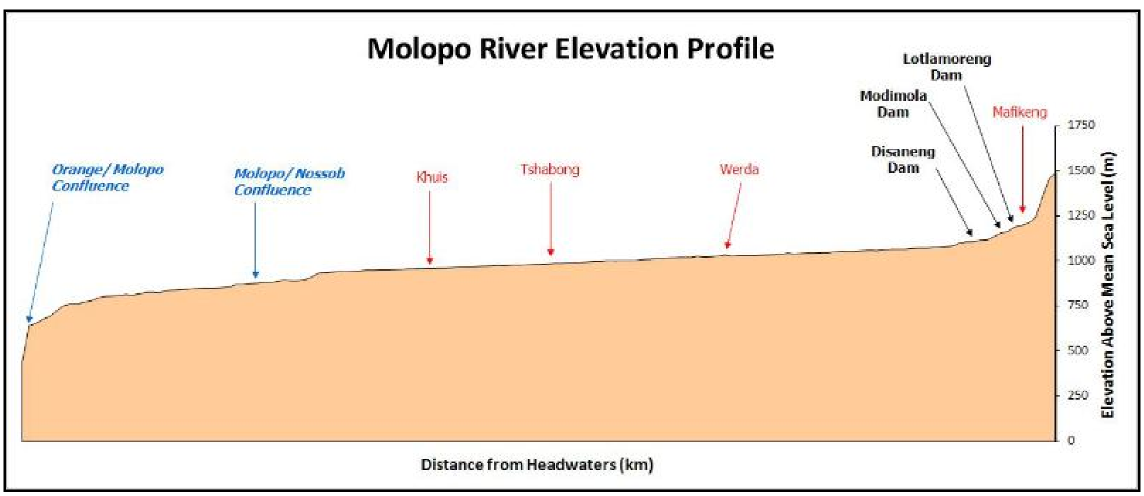

Figure 3.5: Molopo River Elevation Profile (Source: www.orangesenqurak.org)

Table 3.2: The average river slope, main channel width and Q_{100} floods at selected longitudinal profile locations in the Basin

No	Station Name	River Name	DWA Gauge Number	Q_{100} (m^3/s) +	Slope (%) ++	Width (B)+++
1	Allemanskraal Dam	Sand	C4R001	160	1.55	120
2	Bloemhof Dam	Vaal	C9R002	5510	1.00	200
3	Boskop Dam	Mooi	C2R001	110	1.16	14
4	Disaneng Dam	Molopo	D4R003	442	1.02	10
5	Egmont Dam	Wit Spruit	D2R001	330		15
6	Erfenis Dam	Groot-Vet	C4R002	2870	1.39	40
7	Gariep Dam	Orange	D3R003	10920	7.59	190
8	Gerrands Dam	Jordan	C8R006			14
9	Grootdraai Dam	Vaal	C1R002	2100	1.83	75
10	Kalkfontein Dam	Riet	C5R002	3160	1.08	35
11	Klerkskraal Dam	Mooi	C2R008	210	1.00	
12	Klipdrif Dam	Loop	C2R004	885	1.34	15
13	Loch Athlone Dam	Jordan	C8R005		3.09	15
14	Rietspruit Dam	Riet	C2R007	275		30
15	Rustfontein Dam	Modder	C5R003	890	1.18	40
16	Saulspoort Dam	Nuwejaar	C8R004	710	3.22	20
17	Spitskop Dam		C3R001	1480	0.90	55
18	Tierpoort Dam	Harts	C5R001	750	1.14	270
19	Vaal Dam	Vaal	C1R001	4700	2.01	270
20	Vanderkloof Dam	Orange	D3R003	4250	1.73	225
21	Upington	Orange			1.09	220
22	Mohale Dam	Senqu				95
23	Katse Dam	Malimabatso				80
24	Hardap Dam	Fish				60
25	Naute Dam	Loewen				115

Notes:

+ Source: DWA (SA)
++ Average river slope upstream of the dam
+++ Upstream of a reservoir (in case of a dam)

3.2.6 The Impacts of Contaminants or Pollutants on the Sediment Quality

Contaminants can be embedded in sediment. The understanding of the impacts of contaminants on sediment quality is significant in the management of chemicals that are associated with specific sediment. The fact that sediment is transported from one point to the other, polluted sediment can transport unwanted contaminants from polluted areas to unpolluted areas along the river. Therefore, apart from the sediment themselves affecting the fluvial morphology of the river, the contaminated sediment can cause detrimental effects to the river system's fauna and flora. It is important to be able to identify situations where either the contaminants associated with sediments or the sediments themselves may represent a likely risk to ecosystem health and integrity (Gordon and Muller, 2010).

Contamination of fluvial systems by chemical compounds or minerals has been reported in some catchments within the Basin. For example, Uranium contamination was studied in the Koekemoerspruit, a tributary of the Vaal River. This is a typical example of a river whose fluvial morphology is contaminated by mining contaminants (Winde, 2002). The contaminants are transported as solutes within water sediment systems. The higher immobilization rate in the flowing water systems is due to co-precipitation of Uranium along with Calcium Carbonate and Iron Manganese (Winde, 2002). In this particular case, the unlined slimes dams of the Buffelsfontein Gold mines were identified as the most important sources of Uranium contamination within the catchment.

In a related case, an investigation of the levels of five heavy metals in water and sediment in some sub-catchments within the Vaal River catchment found that sediment had higher levels of heavy metals than in water, ranging from 10 times higher for Aluminum to 350 times higher for Uranium (Dzoma et al., 2010). This scenario points out to the role of sediment in contaminant transport. The transport of sediment in river channels could constitute the transfer of heavy metals. Effective management of sediment transport in these particular cases is necessary in order to limit the transport of contaminants such as heavy metals from one point to another via sediment re-entrainment.

3.3 THE AVERAGE LONG TERM SEDIMENT YIELDS, LOADS AND MASS BALANCE

3.3.1 Background

The average long-term sediment yields, loads and mass balance in Lesotho and South Africa were based mainly on the (WRC, 2010) study on sediment yield prediction which included Lesotho and South African catchments of the Basin. Namibia data on reservoir sedimentation was obtained, but no data is available in Botswana.

3.3.2 Sediment Yields and Loads

The total average sediment outflow from sub catchments areas within the Basin were computed at selected river gauging stations or dam locations as shown in Table 3.3. Figure 3.6 shows the schematic representation of the annual sediment load for selected stations in Table 3.3.

The historical sediment transport data of the Basin dates back from a continuous record (daily) from 1929 to 1969 for the gauging stations at Prieska and Upington on the lower Orange River (Rooseboom, 1992). The cumulative sediment discharge and the ten year moving averaged values from 1929 to 1969 are given in Figures 3.7 and 3.8 respectively. Subsequent to this period, additional sediment yield data was obtained from reservoir sediment deposit data and stream sampling records at specific locations in the Basin. An analysis of the sediment transport data from this period to date is explained in the catchment specific paragraphs.

Table 3.3: Average long term sediment yields and loads at selected stations

ID	Station Name	River Name	Quaternary Catchment	Total Catchment area (km^2)	Mean Sediment Yield ($t/km^2.a$)	Sediment Load (t/a) *
1	Mokhotlong	Senqu	D16J	1 660	38	78 242
2	Koma-Koma	Senqu	D16M	7 950	73	213 458
3	Lesotho	Malibamatso	D11C	806	9	7 254
4	Senqu @ Lesotho	Senqu	D11G	2 180	9	12 692
5	Katse Dam	Malibamatso	D11F	1 869	175	327 075
6	Mohale Dam	Senqu	D17B	938	145	136 010
7	Paray	Malibamatso	D11J	3 240	175	152 517
8	Whitehill	Senqu	D17M	10 900	145	839 361
9	Marakabei	Senqu	D17F	3 504	145	513 300
10	Jammersdrift	Caledon	D22L	13 220	621	3 850 200
11	Slabbertswag	Caledon	D21L	3 563	832	2 964 416
12	Gariep Dam	Orange	D35K	70 667	392	28 593 406
13	Vanderkloof	Orange	D31E	84 019	136	2 927 382
14	Grootdraai Dam	Vaal	C11L	7 995	63	488 574
15	Saulspoort Dam	Nuwejaar	C83A	746	109	78 875
16	Loch Athlone &	Jordan	C83B	746	95	23 130

ID	Station Name	River Name	Quaternary Catchment	Total Catchment area (km^2)	Mean Sediment Yield ($t/km^2.a$)	Sediment Load (t/a) *
	Gerrands Dams					
17	Vaal Dam	Vaal	C12L	36 638	163	4 850 563
18	Klerkskraal Dam	Mooi	C23F	1 324	18	22 402
19	Klipdrif	Loop	C23J	890	6	5 180
20	Boskop Dam	Mooi	C23K	3 297	10	8 742
21	Allemanskraal Dam	Sand	C42E	3 628	410	1 442 856
22	Erfenis Dam	Groot-vet	C41E	4 724	148	678 177
23	Bloemhof Dam	Vaal	C43D	108 125	38	2 207 724
24	Tierpoort Dam		C51D	922	160	143 094
25	Kalkfontein Dam	Riet	C51J	10 264	67	745 938
26	Rustfontein Dam	Modder	C52A	937	123	111 793
27	Ongers Mouth on Orange	Ongers	D62J	33 732	205	6 915 265
28	Upington	Orange	D73F	400 000	205	32 022 745
29	Nossob-Molopo Mouth on Orange	Confluence	D42E	367 201	4	1 468 804
30	Hardap Dam	Middle Fish	D46B	13 600	36	489 600
31	Naute Dam	Loewen	D46G	8 630	48	414 240
32	Fish Mouth on Orange	Fish	D82K	95 680	48	3 525 600
33	Hartebees Mouth on Orange	Hartebees	D53J	88 243	19	1 505 256
34	River Mouth	Orange	D82L	830 000	19	44 322 405

Note: * Sediment trapping in major reservoirs has been considered

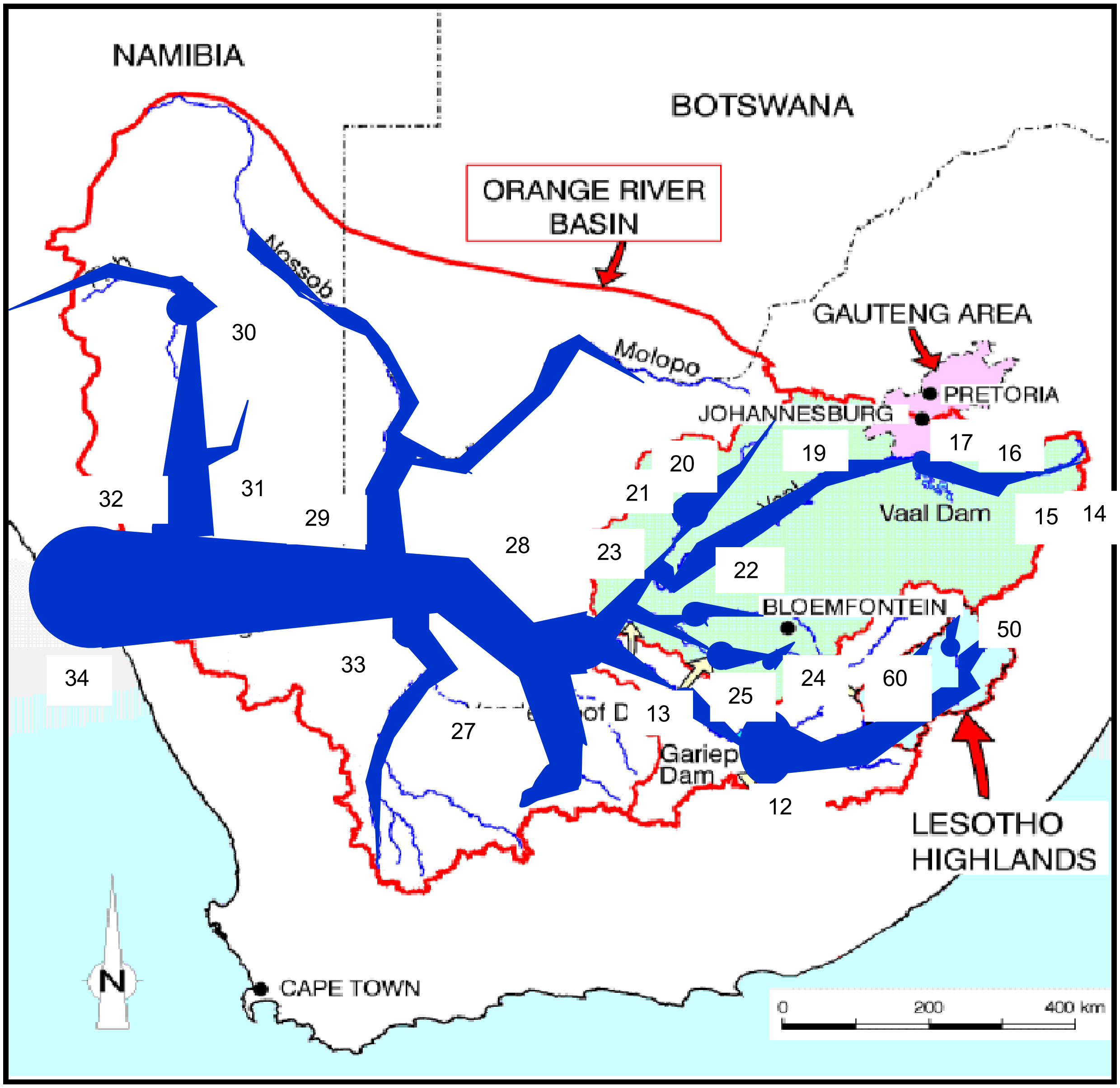

Figure 3.6: Schematic representation of sediment loads of the Orange-Senqu River (Numbers refer to Table 3.3)

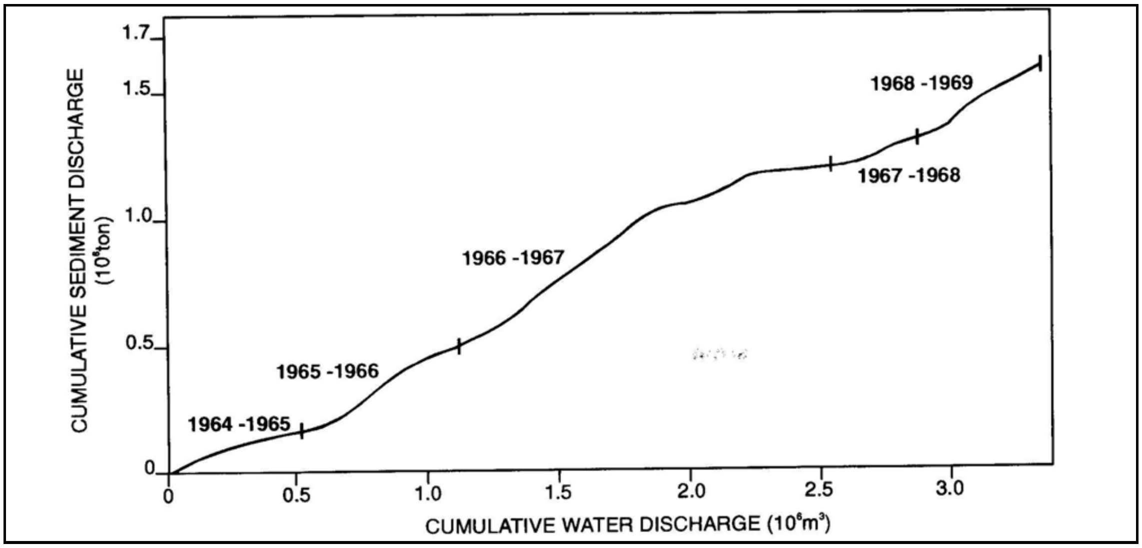

Figure 3.7: Cumulative sediment load versus discharge relationship on the Orange River, South Africa (Rooseboom, 1992)

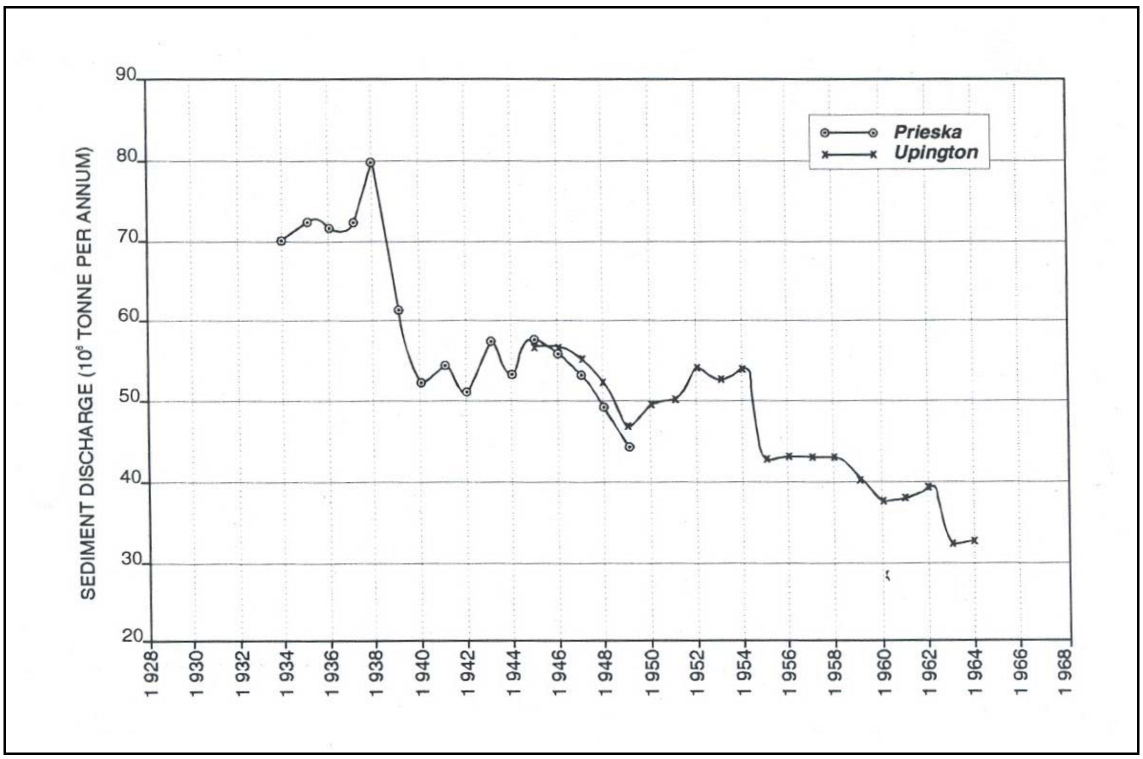

Figure 3.8: Observed sediment loads plotted for Lower Orange River, South Africa (Rooseboom, 1992)

3.3.3 Lesotho Sub Catchments

The basin of the Senqu (Upper Orange) River has a drainage area of more than 20 000 km^2 within Lesotho. The soils are thin and fragile. The vegetal cover is mainly grasses and scattered shrubs, reflecting the results of overstocking and hence overgrazing (Makhoalibe, 1984). The sub catchment consists mainly of the basaltic regions of Lesotho situated along the upper Orange River (Senqu). Due to the fact that the basaltic regions have low sediment yields, the regional average yield is notably low.

The available data for Lesotho is based on Makhoalibe (1984). Makhoalibe (1984) analysed suspended sediment data collected in Lesotho during the period 1976-1982. The drainage areas of the measuring sites varied between 200 and 20 000 km^2. The results showed that annual suspended sediment yields ranged from less than 10 $t/km^2.a$ in the igneous region to more than 2000 $t/km^2.a$ in the sedimentary region. The sediment yield in the basaltic region is limited by the extent of land use with regard to agricultural activities and the extent of the cultivated land. According to Makhoalibe (1984), it was found that within the Basin, the Caledon sub catchment exhibited the highest average sediment yields followed by the Vaal and the Senqu (Upper Orange) sub catchments.

3.3.4 South African Sub-Catchments

The South African sub-catchments are partly situated along the lower reaches of the Orange River, which is characterised by arid conditions, the Vaal catchment and part of the Caledon sub-catchment.

The central Karoo is geologically one of the more homogeneous regions in the sub-catchment. Sheep farming is the dominant land use. Though the region is geographically huge, the average sediment load data was limited. Six out of the seven catchments have sediment yield values of less than 50 $t/km^2.a$. The low sediment yields are due to the prevailing arid conditions whereby the sediment yields are limited by the transporting capacity rather than the availability of sediment.

Figure 3.8 shows the long term variations in sediment loads of the lower Orange River based on a combined record for the gauging stations at Prieska and Upington. The decrease in the observed sediment loads as plotted in Figure 3.8 was attributed mainly to a decrease in the availability of erodible soils within the effective catchment (Rooseboom and Harmse, 1979 as cited in Rooseboom, 1992).

Table 3.3 gives the currently recalculated sediment load at Upington taking into consideration the sediment loads from the major tributaries upstream of Upington, namely Vaal, Orange-Senqu, Ongers and Molopo-Nossob. As shown in Table 3.3, the average sediment load at Upington (Station 28) remains relatively constant with respect to the observed value during the year 1964 in Figure 3.8. This can be attributed to the fact that some of the dams constructed after 1964 are bound to trap the majority of the sediment upstream. In this case, any possible increase in the availability of erodible soils within the catchment would have little effect on the sediment load in the subsequent years.

The other sub catchment in South Africa is the upper Orange and Caledon basin down to the Gariep Dam including the south eastern part of Lesotho. The Caledon drains the lowlands of Lesotho and the eastern part of the Orange Free State province of the Republic of South Africa. The drainage area within Lesotho is 6 700 km^2 and is underlain by a sedimentary formation (Cave Sandstone). The sandstone is more easily eroded than the basalts of the mountain region. The soils of this basin, and in particular the duplex soils, are highly erodible. The population is mostly concentrated in this basin which forms only one third of Lesotho. Overgrazing is more pronounced than in the mountain region (Makhoalibe, 1984). Some of the highest sediment yield areas in the Basin are situated in this Caledon River catchment. Measured sediment yield values range from 392 $t/km^2.a$ to 1141 $t/km^2.a$.

3.3.5 Botswana and Namibian Catchments

The rivers that are located in the northern part of the Basin in Botswana and Namibian catchments are ephemeral rivers. These include the: Molopo, Kuruman, Nossob, Auob and Fish rivers. As ephemeral rivers, the runoff is characterized by sporadic and short periodic flows mostly after a heavy rain. Water may flow for hours or even days, but rarely longer. Consequently, measurable discharge could occur for less than 10% of the year (Jacobson, 1997: as cited by UNESCO, 2002). This occurrence is influenced by geological, environmental and climatic conditions. Such a scenario has implications on the sampling and prediction of sediment load and mass balance. The actual sediment loads are limited by the transporting capacity even though the sediment is available for transport within the sub-catchment.

The major dams in the Fish River sub-catchment are the Hardap and Naute dams. Flow in this river is sporadic and varies between almost zero to as high as 5 300 million m³/a (ORASECOM, 2007 as cited in www.orangesenquak.org). The sediment load in Table 3.3 for Hardap Dam has been calculated based on reservoir sediment deposit data obtained from a report from DWA (2005). The report details sediment surveys carried out at Hardap Dam in 1980 and 1992. There is no sediment data for Naute Dam on the Loewen River. Therefore, the sediment load for Naute Dam could not be calculated based on either sediment sampling data or reservoir sediment surveys. The sediment load indicated in Table 3.3 has been predicted based on a comparative analysis of erosion hazard classes of the adjacent catchment located in South Africa. This was achieved by assuming the worst case erosion hazard scenario with respect to the maximum known erosion hazard class in its close proximity's catchment. The sediment yield value compares relatively well with the observed data at Hardap Dam. A similar prediction methodology has been applied to compute the sediment load at the confluence between the Fish River and the Orange River which has been given in Table 3.3.

The major dams in the Molopo-Nossob sub-catchment are Oanob Dam on the Oanob River, Dreihuk Dam on the Hom River, Otjivero Dam on the White Nossob, Otjivero Silt Trap on the White Nossob, Nauaspoort Dam on the Usib River, Tilda Viljoen on the Black Nossob and Daan Viljoen on the Black Nossob. There is no data on sediment sampling because of the nature of discharge in these ephemeral rivers. Similarly, there is no data on reservoir sediment surveys. The Nauspoort and Oanob Dams which are located in the upper reaches of the Oanob River cannot significantly affect the sediment load at the Molopo-Nossob confluence with the Orange due to the fact that it is now blocked by the Kalahari Desert dunes downstream of its confluence with the Nossob River and never reaches the Orange River as surface flow.

Both the Molopo and Nossob Rivers receive extremely low and erratic rainfall. There are no significant dams in the Molopo-Nossob sub-catchment within Botswana. The sediment load at the Molopo-Nossob confluence with the Orange has been predicted using a similar prediction methodology as explained for Naute Dam. However, an average known erosion hazard class in the close proximity of the catchment has been applied. Even though, the rivers are ephemeral, it can be assumed that the predicted average annual sediment load is possible during occasional heavy rains and the resultant floods over a period of time.

3.4 RESERVOIR SEDIMENTATION

3.4.1 Introduction

Most of the dams in South Africa were constructed in the 1960s and 1970s. Reservoir surveys to determine reservoir sedimentation and sediment yields are carried out typically every 10 to 15 years at most of the DWA reservoirs in South Africa. Some critical reservoirs are however surveyed more frequently. This data was used to determine the current state of reservoir sedimentation within the Basin if say at least 20 years of data is available and relatively large floods have been experienced between the surveys.

3.4.2 Current State of Reservoir Sedimentation

In general, the analysis of the reservoir sediment deposit data for South African dams in the Basin, showed only 4 % of the dams have lost 40 to 50 % of their storage capacity, and that 42 % has lost 5 to 10 %.

3.4.3 Rate of Sedimentation in Comparison with International Trends

Table 3.4 shows the results of the assessment of the state of reservoir sedimentation based on reservoir sediment deposit data obtained from the DWAs' dam list (DWA, 2006).

Table 3.4: State of reservoir sedimentation in South Africa (storage lost as a percentage of the original capacity)

Storage lost (%)	Percentage of selected dams (SA)	Cumulative percentage of dams (SA)	Percentage of dams (Basin)	Cumulative percentage of dams (Basin)
0 – 5	28	28	24	24
5 – 10	18	46	40	64
10 – 20	20	66	20	84
20 – 30	6	72	8	92
30 – 40	5	77	4	96
40 – 50	7	84	4	100
50 – 60	8	92	0	100
≥60	8	100	0	100

Figure 3.9 shows storage loss as a percentage of the original capacity of the reservoirs within the Basin.

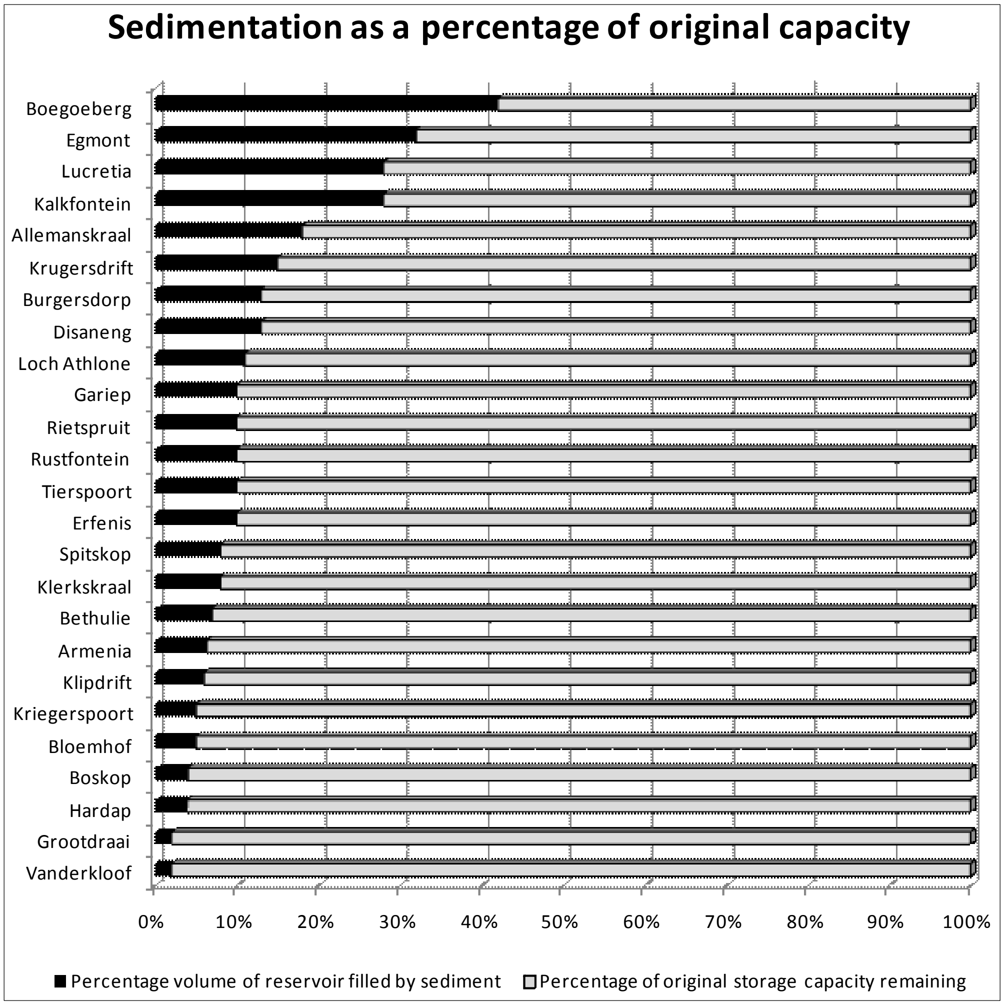

Figure 3.9: State of reservoir sedimentation (storage lost as a percentage of the original storage capacity)

Table 3.5 shows the annual storage loss in reservoirs in South Africa and the Basin due to sediment deposition.

Table 3.5: Sedimentation in reservoirs (annual storage loss)

Annual storage loss (%)	Percentage of selected dams (SA)	Cumulative percentage of dams (SA)	Percentage of dams (the Basin)	Cumulative percentage of dams (the Basin)
0 – 0.1	28	28	13	13
0.1 – 0.2	25	53	24	37
0.2 – 0.5	31	84	40	77
0.5 – 1	8	92	23	100
1 - 1.5	8	100	0	100

Figure 3.10 shows the observed sediment volumes in the Basin reservoirs graphically. Gariep Dam has by far the highest deposited sediment volume in SA and the Basin.

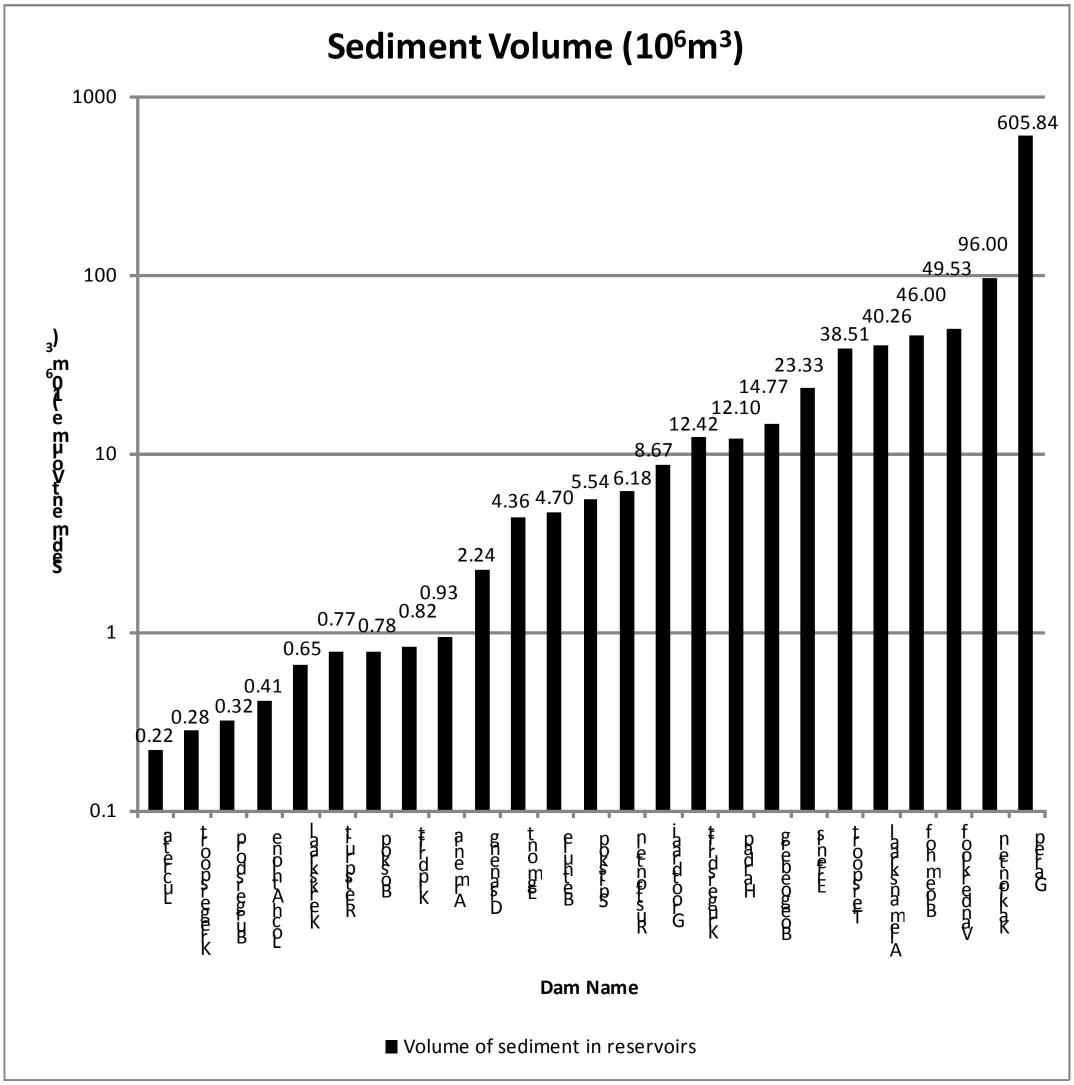

Figure 3.10: Observed reservoir sedimentation volumes

Analysis of the results showed that the average annual storage loss due to sedimentation in South African reservoirs is approximately 0.3%. This scenario adversely affects the long term sustainability of the reservoirs. However, the international average annual storage loss due to sedimentation is 0.8% (ICOLD, 2009). The global storage capacity of water comprises mainly of water that is used for hydro power generation and the rest is for other uses. Over the recent years, there has been very little increase in the storage capacity of water, Nevertheless, reservoir sedimentation rates continue to increase resulting in loss of storage capacity of water for both hydroelectric power generation and other uses (Figure 3.11). The reservoir sedimentation rate in South Africa is fortunately on average lower than the global rate (Figure 3.12).

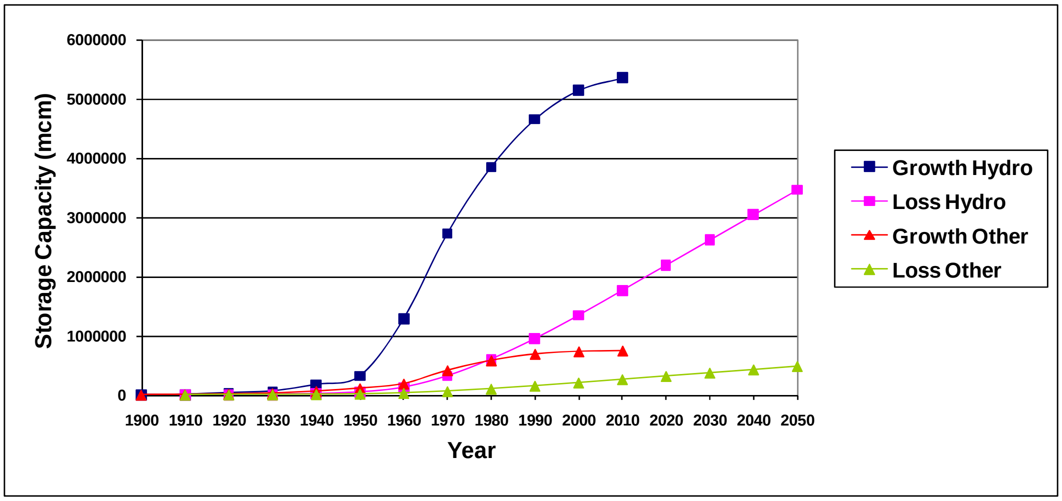

Figure 3.11: Global reservoir sedimentation rates (ICOLD, 2009)

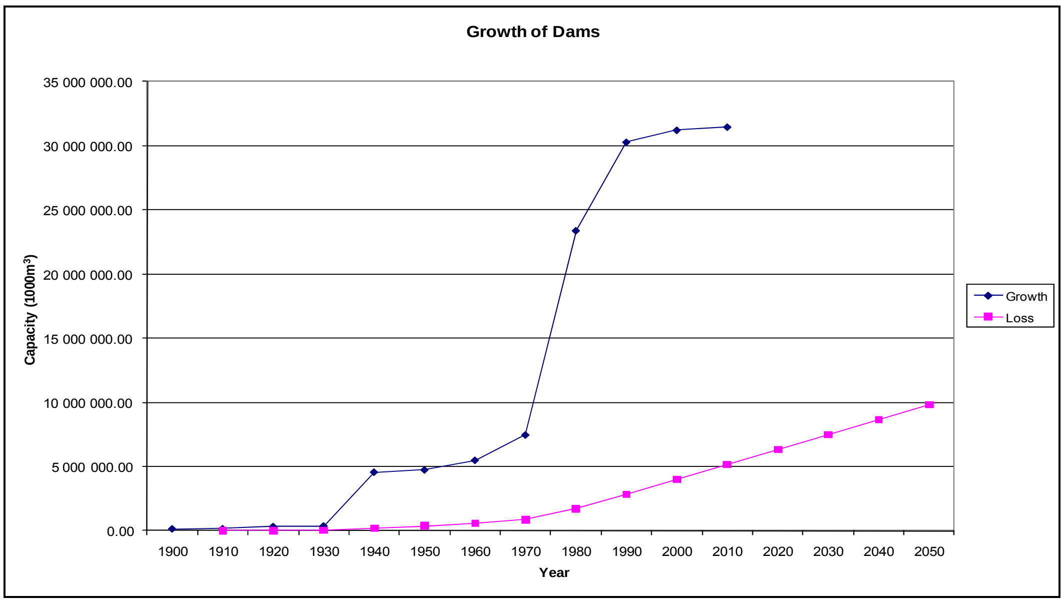

Figure 3.12: Predicted reservoir sedimentation in South Africa *(ICOLD, 2009)*

3.4.4 Impacts of Reservoir Sedimentation on the Fluvial Morphology

3.4.4.1 Upstream impacts: Welbedacht Dam case study (De Villiers and Basson, 2007)

Damming created by a dam results in reduced sediment transport capacity upstream of the dam and sediment deposition occurs. Sediment deposition results in the loss of live storage capacity. In many cases the sediment deposition also occurs above the full supply level of the reservoir, sometimes more than 10 % of the deposited sediment. As sediment deposition continuous, the sediment delta grows higher and eventually flood levels start to rise. Not only flood levels are affected, but also drainage from agricultural land, bridge discharge capacity, pump station operation and navigation

Welbedacht Dam on the Caledon River was commissioned in 1973. The original storage capacity was 114 million m³, but a third of the capacity was lost within 3 years due to reservoir sedimentation. Figure 3.13 shows the historical loss in capacity and the recent survey indicated less than 10 million m³ storage capacity is left. Upstream sedimentation has raised the river bed level and flood levels so much that large parts of the town Wepener, located about 50 km upstream of the dam had to be expropriated (Figure 3.14), and the R702 Road bridge had lost most of its opening as the bed aggraded and had to be raised.

Bloem Water started with flushing operation of the dam in 1991, which decreased the rate of sedimentation. The flushing operation is however not very effective because the five large gates are located about 15 m above the original riverbed level. The flushing canal upstream of the dam will eventually reach equilibrium and will be the only storage capacity remaining in the reservoir . In recent years vegetation established on the sediment in the reservoir and this additional hydraulic roughness will raise flood levels even further. Enough excess water is available for hydraulic flushing at Welbedacht Dam but low level gates should be added to flush effectively. It is estimated that with suitable outlets the reservoir storage capacity can be restored to 35 million m³. However, if the current operation is continued without reconstruction, the ultimate mean storage capacity could be less than 5 million m³ and can be lost completely during a single flood for short periods of time, before subsequent flushing would restore some of the capacity again.

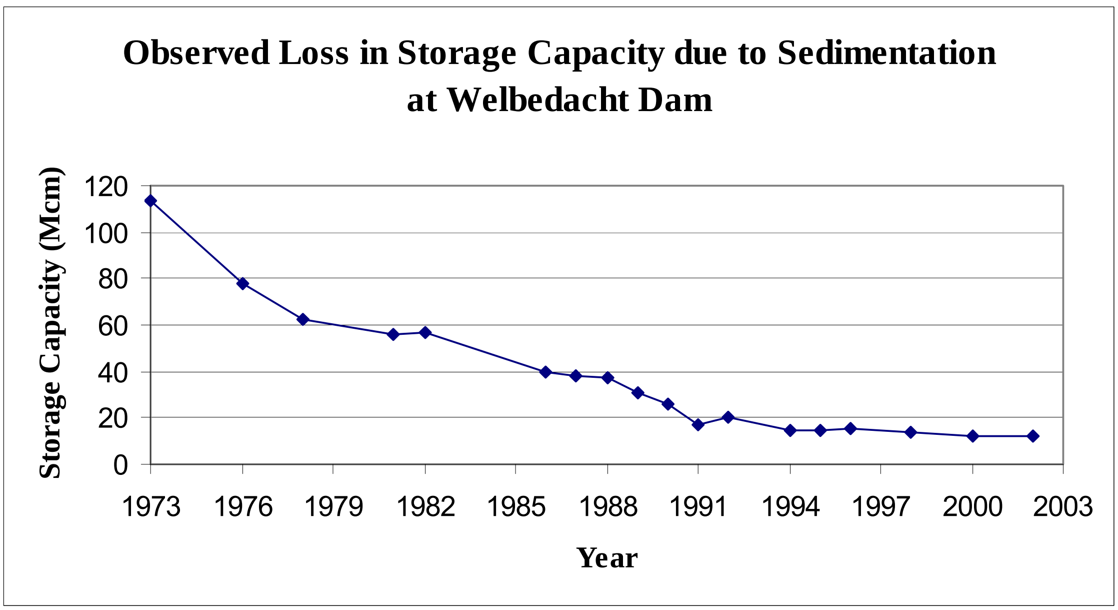

Figure 3.13: Storage capacity loss at Welbedacht Dam

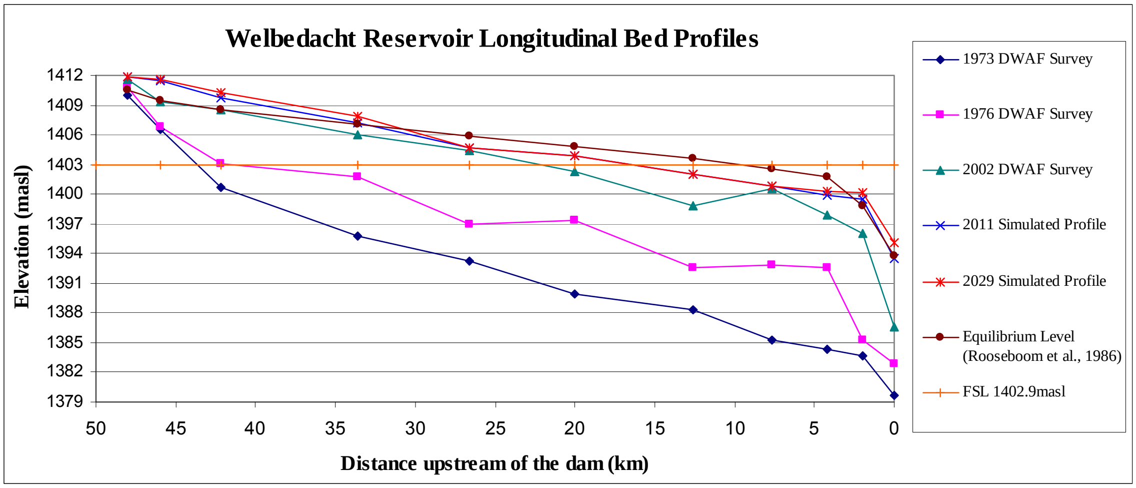

Figure 3.14: Historical longitudinal bed profiles with future sedimentation levels of Welbedacht Reservoir (De Villiers and Basson, 2007)

3.4.4.2 Downstream impacts: Katse Dam case study

When post-dam floods are relatively small and infrequent, they have to transport more sediment than usual and this often skews the sediment load-discharge relationship, as is the case downstream of Katse Dam as well as observed at the Koma-Koma station downstream of the Malibamatso River on the Senqu River (Figure 3.15). This situation can be improved by installation and judicious operation of environmental flood release works at dams.

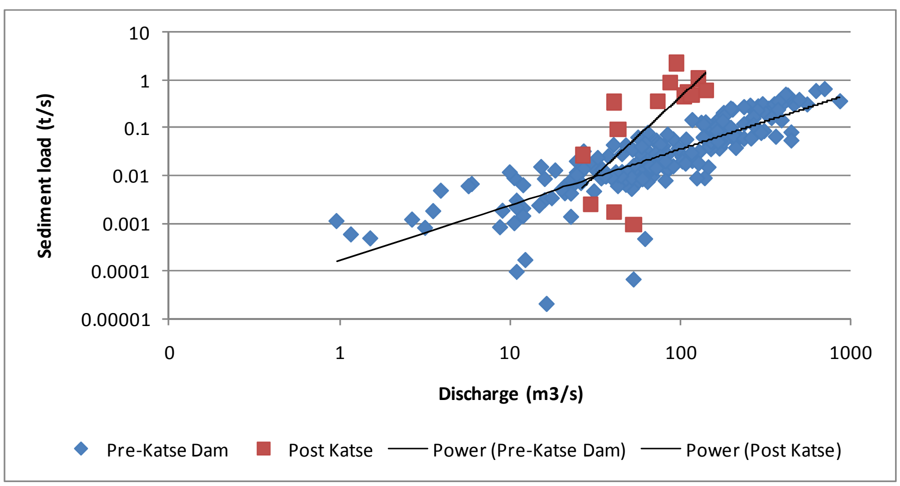

Figure 3.15: Observed sediment load-discharge relationship downstream of Katse Dam at Paray

3.5 ORANGE RIVER ESTUARY

3.5.1 Introduction

The RAMSAR Convention accepted the Orange River Mouth Wetland as an area of 'International Environmental Importance' in 1991. The wetland is considered as the 6th most important and first transborder wetland in Southern Africa. In terms of this agreement, South

Africa must protect areas that are of environmental importance with respect to wetlands used by waterfowl. The Orange River Mouth Wetland (Figure 3.16) stretches from the sea up to the Ernest Oppenheimer Bridge (EOB). It can be described as a delta type river mouth with a braided channel system during low flow months. It consists of a floodplain, tidal basin, sandbanks, the river mouth and a salt marsh on the south bank of the river mouth. The Orange River usually flows directly into the Atlantic Ocean, but during low flow periods a sand bar can form across the mouth to block the river, which then rises in level and spills over the salt marsh area. As it is dominated by fresh water it has few estuarine characteristics[3]. It is therefore called a river mouth.

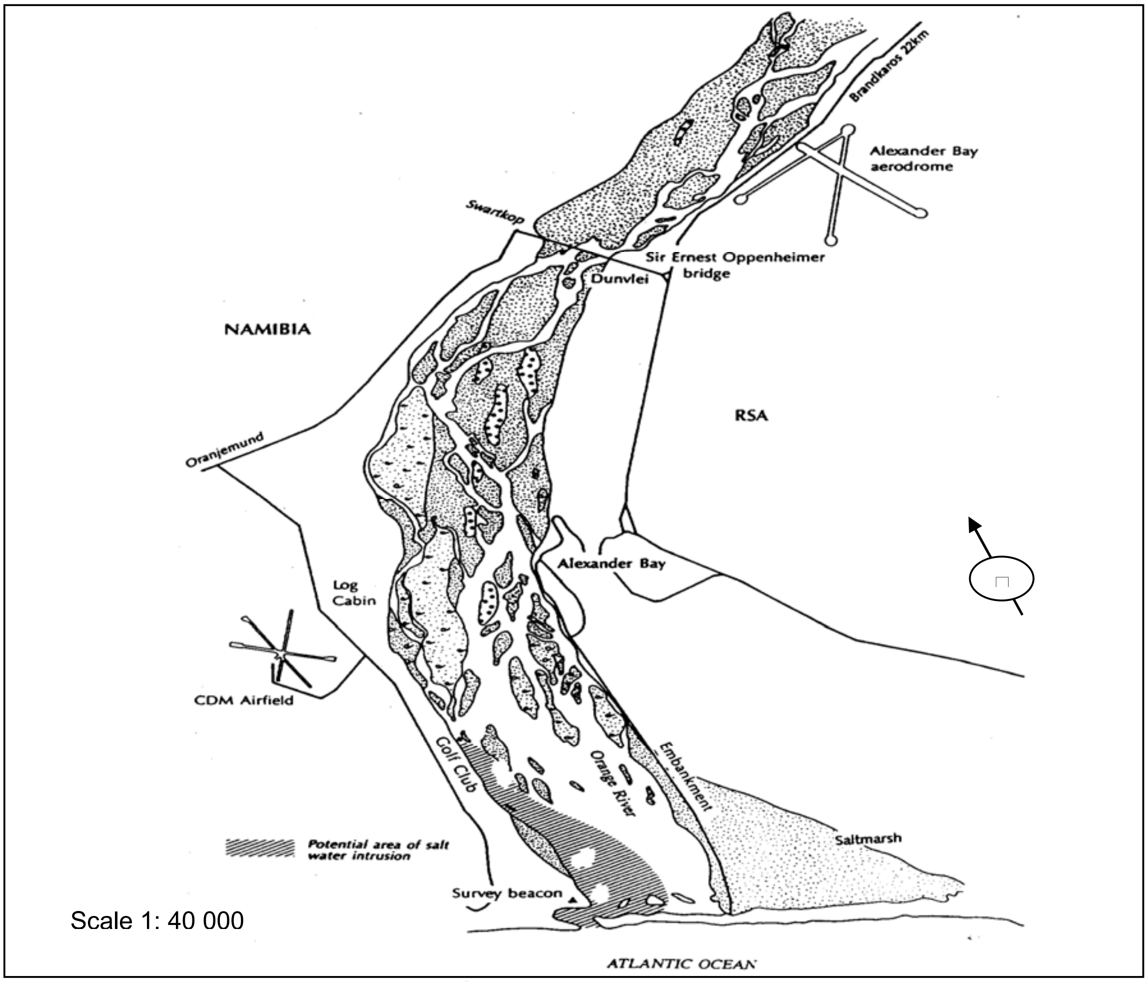

Figure 3.16: Map of the Orange River Mouth ***(CSIR, 1997)***

The Orange River estuary is dominated by river flow and the tidal flows are minor in comparison to river flows. Therefore sedimentation and fluvial sediment characteristics are dependent on river flows. Marine sediment deposition is not dominant in the case of Orange mouth. The Orange-Senqu River estuary average sediment load is estimated at 44 million m^3 per year based on the calculated sediment load at the closest upstream location. Therefore, it can be concluded that substantial volumes of fluvial sediment are delivered to the estuary.

3.5.2 Fluvial Morphology and Changes

Naturally, the fluvial sediment is generally flushed out by floods. The extent of floods reaching the estuary is dependent of the flood releases and attenuation from upstream dams. In the event that flood frequencies and extent are affected within the Basin, sedimentation of the estuary can become a real concern.

The width of the Orange River mouth (B) changes with river flow and can be described as follows: $B=10^{0.55}Q^{0.7}S_f^{0.18}$ based on historical aerial photos, where Q is the river flow and S_f the energy slope of the flow. The energy slope was found to be 1:1 920 for small floods and 1:5 750 for large floods.

3.5.3 Managing of Sedimentation in the Orange River Estuary with Regard to the Fluvial Morphology and Changes

According to Hosking (2010), some of the key impacts on estuaries that are of concern to management agencies are mainly related to freshwater inflow alterations followed by other issues. These are caused by the operation of dams, abstraction aspects and forest plantation development. Some of the issues associated with this are:

- Reduction of the base flow into the estuary;
- Changes to the salinity gradient of the estuary;
- Reduction in small scale flood events that results in an accumulation of sediments in estuaries and allows pollutants to settle. This can also cause prolonged closure of estuaries and
- Possible retention of coarser sediments by dams and resultant impacts on the coastal sediment balance and scouring potential of inflows.

These issues in turn impact on the biodiversity of the estuary concerned and can interfere with recreational use because of low water levels. Threats to property can also be experienced through prolonged estuary closure and through a greater than normal build up of sediments that are a threat in large scale flood events. (Hosking et al., 2010).

3.6 Sustainable development and management of the Orange-Senqu River Basin

3.6.1 Introduction

Sustainable development can be defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). Sustainable development and management of water basins with respect to sedimentation and sediment transport demand that sediment problems and their consequences should be addressed without adverse effects on the environmental resources and economic and social systems. In addition, major development within the Basin requires not only that the present river and reservoir sedimentation situation be predicted but also the future sediment transport patterns due to present and future projects. The knowledge of long-term fluvial morphology and associated changes is essential in the optimal design and management of river basin projects. The long-term sediment yield, loads and balance can be predicted using analytical, probabilistic and mathematical modelling techniques.

The physical nature of sedimentation is dependent on the processes of erosion and sediment yield. Watershed management programmes should be based on detailed analysis of catchment soil erosion in order to sustainably manage the river Basin. Catchment soil erosion is responsible for the generation of sediment that is transported to a river. Overland flow and sometimes wind are responsible for the transport of sediment from the catchment. An understanding of catchment soil erosion is important in the prediction of sources of sediment, particularly the sub catchments within the Basin that generate more sediment and how it is transported to the river.

Sediment is also generated from stream channel erosion particularly from river banks and river bed scouring during floods. Together with sediment from catchment soil erosion, they constitute the main contributors of sedimentation in rivers and reservoirs.

3.6.2 Catchment Soil Erosion

Based on the erosion index and observed sediment yields, it has been shown that the upper Orange River basin sub catchments have high sediment yields particularly the Caledon River catchment. This catchment is very large. Mathematical modelling can be used to predict the critical sources of sediment and to analyse the existing options for the sustainable management of ecosystems. The results can be used to select the appropriate solutions to control soil erosion from respective sub catchments within the Basin.

Considering that some catchments are shared between two or more countries, there is a need for concerted trans-boundary efforts to the management of sedimentation. The relevant sediment and erosion data from the concerned countries must be shared in order to apply standardised information in the analysis and management of catchment soil erosion in the Basin. In this way, catchment erosion prediction tools and models can be effectively used to undertake trans-boundary integrated sediment load and mass balance assessments and to analyse the impact of possible future changes on the fluvial morphology of the river basin.

The current rate of catchment soil erosion can be addressed through effective conservation initiatives which should identify catchment erosion significant areas for conservation action. Mathematical modelling can be applied to determine and set targets for catchment erosion control activities. The extent of erosion can be quantified and spatially represented within the significant areas. The portion of the Basin in South Africa already has an erosion hazard index which can be utilized in the conservation planning and management.

3.6.3 River and Reservoir Sedimentation Aspects

An understanding of stream channel erosion is significant in the prediction of current condition and trend in river and reservoir sedimentation. Sedimentation poses a serious threat to operational efficiency and effective lifetime of reservoirs within the Basin. Future fluvial morphological changes can be analysed based on the current trends. Future adverse river and reservoir sedimentation aspects can be predicted and the appropriate solutions can be developed.

One mitigation measure to limit sediment deposition of reservoirs is to construct off channel dams, and water is typically pumped to these reservoirs using suitable river abstraction works.

Another method to control sedimentation is by sluicing of high sediment loads through reservoir or by flushing of previously deposited sediments during floods such as at Welbedacht Dam on the Caledon River. This requires water level drawdown during a flood, large outlet gates and excess water.

3.6.4 Climate change and land use changes

The impact of climate change on sediment load and mass balance is bound to be exacerbated by land use changes within the Basin. Climate change is characterised by extreme events such as droughts and floods. Floods are related to sediment load considering that the greatest proportion of sediment is transported during floods. On the other hand, during periods of droughts, people are bound to use land that is close to the river channels particularly with respect to agricultural activities. This could increase the availability of sediment for transport. In an event of extreme floods, such sediment is transported down the river channel.

Therefore, the occurrence of extreme floods could increase the average sediment load over a longer period of time. It can be concluded that dams that have not yet been adversely affected by sedimentation could potentially be vulnerable as a result of land use and climate changes. In addition, areas that were not previously affected by floods could be easily inundated during flooding as a result of increased deposition of sediment in river channels. The Basin is characterised by variable rainfall patterns both spatially and temporally. There is need for improved land use and water resources use efficiency. More adaption initiatives are required within the Basin in order to minimise the adverse effects of climate change and land use changes on sediment load and mass balance. This can be achieved through raising awareness on the adverse effects of human induced erosion and the building of the relevant capacity for the management of land and water resources within the Basin in order to ensure that there is little or no disturbance of the fluvial morphology. Governance systems are already in place with regard to climate change adaptation. In view of this, the impact of climate change on sediment load and mass balance can be managed within the existing governance systems that deal with adaptation and sustainable development particularly those initiatives that are aimed at reducing vulnerability and enhancing resilience to extreme events through efficient catchment management.

4. GROUNDWATER

4.1 INTRODUCTION TO GROUNDWATER IN THE ORANGE-SENQU CATCHMENT

Increased demand for water in the Basin has driven greater exploitation of groundwater, often draining aquifers at an unsustainable rate. As increased demand has stressed or even exhausted surface water resources, national and regional authorities have increasingly turned to groundwater, a resource largely ignored and misunderstood in the past, as a solution.

The dependence on groundwater is to a large degree a reality in the Basin. Villages, towns, farmers, municipalities and private homes use groundwater as the only means of supplying water for domestic and farming purposes.

4.2 INFLUENCE OF LAND USE ON THE AQUIFER

Groundwater and surface water bodies can be closely linked and may be interactive with each other especially during surface water and or groundwater recharge periods. During these periods, surface water contamination may reach groundwater aquifers especially in the agricultural sector where nutrients or contamination may reach the water table below large scale irrigation practices. This may also be true for the mining sector where polluted groundwater from slime dams may reach surface water bodies.

Although the arid western part of the catchment is less developed, irrigated agriculture occurs extensively along the lower reaches of the river (UNDP-GEF, 2008) and negative impacts are evident on surface water and groundwater quality. Irrigation return flows to the Vaal River and Upper Orange-Senqu River from agricultural fields can result in significant changes in water quality. In surface water bodies algal blooms occur in the Lower Orange River presenting potentially toxic effects for humans and aquatic ecosystems.

The land uses in the Basin include activities such as mining, large scale crop irrigation, livestock farming, industries and villages and towns with the related contamination sources such as landfill sites, sewerage treatment plants and contaminated surface runoff. Surface contamination can be transported in various ways to groundwater aquifers. Contamination can occur from percolation directly via groundwater infiltration into aquifers below or it can be transported via surface water towards the river systems to be later pumped out as surface water sources to be used for irrigation purposes, industrial use or domestic use. Groundwater contamination can then be reintroduced after use as infiltration into the groundwater regime which affects the groundwater quality far away from the original contamination source.

Surface water quality often receives significant attention, as the impacts are frequently visually obvious and the causal chain leading to the reduction in quality is often clear. However, the quality of groundwater is equally important, particularly in much of the Basin where it is an important supply of water.

One of the primary sources of groundwater pollution in urban areas is leakage from pit-latrines in areas with poor sanitation. Poorly maintained sanitation infrastructure can allow effluent to contaminate the groundwater. In addition, agriculture (irrigated cultivation and livestock) can degrade groundwater quality, for instance by inorganic nitrates originating from fertilisers containing potassium nitrate and ammonium nitrate. High levels of nitrates can be hazardous to the health of children, nursing mothers, the elderly and those with compromised immune systems. Other groundwater pollutants include herbicides and pesticides.

The quality of groundwater can also be impacted on a local scale by the mineralogy of rocks in which it resides and flows. Certain rock formations can increase the Total Dissolved Salt levels in groundwater to a point where it is not potable without treatment, which may or may not be economically viable. This treatment decision is dependent on whether alternative groundwater or surface water sources are close by. The different land uses and possible effects resulting from the land use are described below.

Normal livestock farming conducted in a sustainable manner probably have the lowest impact on groundwater sources. Volumes taken are normally small and the impact on groundwater quality in general will also be small.

Large scale irrigation practices are having a significant influence on the water quality of groundwater along the river systems, especially along the Vaal and Orange rivers. Silt loads resulting from soil erosion in the upper reaches of the river and increased salt and nutrient loads, present significant water quality issues for agriculture in the Basin.

The nutrient and salt load of groundwater along these river systems, especially in the Lower Orange basin where the Orange River may become a losing stream, i.e. has bedlosses, will ultimately increase in time due to infiltration into the groundwater regime. The upper part of the Vaal River, known for low surface water quality will have an impact on the groundwater regime where used for irrigation purposes.

The mining sector is a large contributor to the decreasing surface water quality in the Vaal Basin. Mine activities such as the gold, platinum and coal mines add to the salinity of the water and contaminants such as heavy metals and lowered pH values. The decanting of highly saline water is of particular significance in the Upper and Middle Vaal areas. Ultimately the low quality surface water will be used for irrigation purposes or will be used as drinking water and will ultimately lead to salinisation of the subsurface soils.

Sewage effluent discharge from waste water treatment works located on or along the tributaries of the Vaal River system is considered to be a major contributor to the salinity problems currently experienced in the Vaal River.

Salinity refers to the saltiness of water caused by the dissolution of minerals in rocks, soils and decomposing plant material. The level of salinity in a river, for instance, depends on the geological and climatic environments through which the river flows. Salinity increases downstream, as salts are continuously added through natural and anthropogenic processes such as mining, industry and agriculture, but are only minimally removed through technological interventions or diluted by precipitation.

High levels of salinity can lead to the "salinisation of irrigated soils, diminished crop yields, increased scale formation and corrosion in domestic and industrial water pipes, and changes in the biotic communities." A salinity level of 1 000 mg/L is considered moderate salinity and is generally tolerated by humans. However, at levels above 3 000 mg/L (high salinity), fatal intestinal damage and renal damage can occur.

Human activities can affect water quality in different ways. In the Basin, the main human sources of salt load are identified and reported in UNDP-GEF, 2008 and summarised below.

- The discharge of sewage effluent from waste water treatment works;
- Water pumped from underground mine workings;
- Runoff and seepage from areas disturbed by mining and mine waste dumps;
- Runoff and seepage from industrial areas;
- Runoff and seepage from urban areas, especially those without formal sewerage and sanitation systems and
- Irrigation return flows.

4.3 Ground and Surface Water Interaction

Groundwater and surface water can be closely linked even when separated spatially. Each contributes to the other, with these interactions playing an important role in the hydrology of a region (USGS, 2009). Most commonly, groundwater contributes to a stream or rivers base flow, and can be a significant contributor to surface water recharge, especially in higher rainfall regions. The interaction is often bidirectional, depending on the elevation of the groundwater level. If the groundwater level is low then groundwater may be recharged by the surface water body; alternatively if the groundwater level is high then it may be contributing to the surface water body. In shallow alluvial aquifers or riverbed sand aquifers, this normally depends on the seasonal cycle of rainfall and corresponding water level in the river banks.

Studies have shown that under natural conditions in South Africa, groundwater contributes very little to base flow in rivers. It is, however, common to observe surface recharge occurring in normally dry riverbeds. This is further supported by Hughes et al., 2007, who state that very few or no rivers in the drier western part of South Africa receive a base flow contribution. Water quality problems are currently experienced in the Vaal, and the middle and lower Orange River, where water-logging has resulted from irrigation activity along these riverbanks. This indicates increased interaction between groundwater and surface water, with the saturated zone reaching right to the surface.

4.4 Sub Basins in the ORASECOM Orange-Senqu Catchment

For the purposes of analysing groundwater, the Basin has been sub-divided into five sub-basins which are:

- The Vaal River sub-basin including the Upper Vaal WMA, Middle Vaal WMA and Lower Vaal WMA;
- The Upper Orange-Senqu River basin (Upper Orange WMA);
- The Lower-Orange River basin. The Lower Orange considered in this groundwater analysis is slightly smaller than the one reported in ORASECOM, 006/2011. In the latter case, the Lower Orange included the entire reach that extends to the Ocean. In this groundwater analysis, the Orange River Mouth area is taken as the Orange Mouth Sub-basin, which is treated separately;

- Northern Ephemeral Rivers comprising the Molopo, Kuruman, Nossob, Auob and Fish rivers distributed among South Africa, Namibia and Botswana and

- The Orange River Mouth. The Orange River downstream of the Orange and the Fish River confluence, up to the Atlantic Ocean, is considered the Orange River Mouth. This small geographic area is located around the estuary of the Orange River where it meets the Atlantic Ocean. The Orange River Mouth is a Ramsar site wetland. The Orange River sub-basin refers to the area forming most of the estuary and river interface. The Orange River estuary is 9.5km upstream and is the stretch of river located between the mouth and the Ernest Oppenheimer Bridge. The estuary covers a surface area of about 30km^2. It comprises the river channel between sand banks, a tidal basin, the river mouth confined by a sandbar and a salt marsh towards the south bank.

Figure 4.1 shows the groundwater sub-catchments. The Orange River mouth is too small to show.

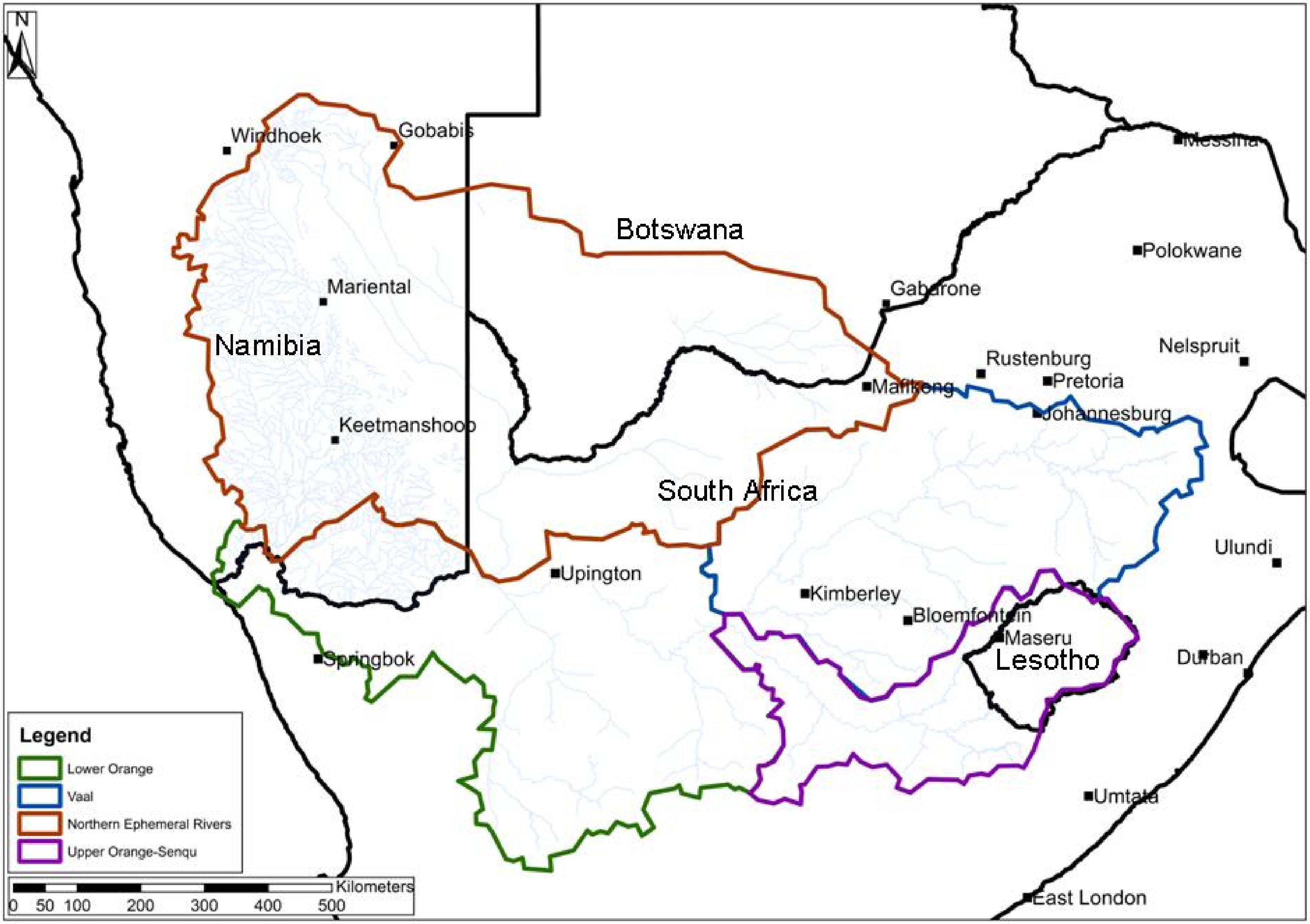

Figure 4.1: Map indicating sub-basins in the Basin

4.5 GEOLOGY OF THE ORASECOM ORANGE-SENQU CATCHMENT

The present landscape of the Basin was formed by geological events that occurred over millions of years. A very simplified model of a fraction of the geological time is that, after a period of continental erosion, thick layers of sedimentary material in the form of sand, silt and mud were deposited on mainly granite, basalt and dolomite host rock. The deposition of sand and silt was followed by periods of active lava flows deposited on top of the sedimentary material. The youngest volcanic material represented by the basalt lava, currently forming the top of the Drakensberg, are to be found on top of the sedimentary material with the oldest strata at the bottom.

Periods of erosion reformed the landscape with the different geologies responding differently to the erosion periods. The Orange River with all its tributaries carved the landscape during an extensive time period to the present form.

4.5.1 The Vaal River sub-basin

The simplified geology of the Vaal River sub-basin consists of mainly basalt and tillite, to form the base rocks of the north-western part of the sub-basin. In the most northern and western side of this sub-basin, carbonaceous dolomite and limestone rocks, can be found. In the south eastern part of the sub-basin the Karoo Supergroup are to be found. The majority of the tributaries of the Vaal River originate in the arenaceous and argillaceous strata of the Beaufort Group.

4.5.2 The Upper Orange-Senqu River basin

The Lesotho Highlands consist of basalt lava which to a large degree resisted the erosion process to form the Drakensberg Mountain Range. The Highlands of Lesotho are characterised by the relative young rock types belonging to two series of the Karoo system. The first series, the upper layer, consists largely of dissected basalt lavas, up to 1500m thick and underlain by cave sandstone and molten beds. The second rock system is the upper Beaufort beds, which generally have steep gradients.

The rest of the geology of the Upper Orange-Senqu basin is predominantly composed of sedimentary rocks from the Karoo Supergroup The Karoo Supergroup is a combination of several lithostratigraphic units including the Dwyka Group, the Ecca Group, the Beaufort Group, the Molteno Formation, the Elliot Formation, the Clarens Formation and the Drakensberg Group. Towards the north-west the Ventersgroup Supergroup is apparent and along the valleys and rivers alluvium is present.

4.5.3 The Lower-Orange River basin

The sub-basin is bordered by the Upper Orange-Senqu and the Vaal sub-basins and extends from an area reaching above 1 500 mamsl in the eastern peripheries, descending to lower elevations north-westerly towards the Orange River. Mudstone and sandstone dominate the lithology. The dominant rock formation is sedimentary with patches of igneous formations occurring in several places in the sub-basin. The rock is associated with the Karoo complex.

The geology of the Lower Orange River basin consists of the Namaqualand-Natal Basement Complex, the Ventersdorp Supergroup, Griqualand West Sequence, Abbis and Kheis Groups, Damara sequence, the Karoo Sequence and the Kalahari sand from Quaternary and Tertiary dune deposits.

The Karoo Supergroup which forms a large part of this sub-basin, consists of shales, sandstone and mudstone with dolerite in the form of intrusive material.

4.5.4 Northern Ephemeral Rivers

At Omaheke, in the Namibian portion of the sub-basin, the sandveld constitutes mainly an Aeolian sand mantle about 50 m thick. It has a low relief of vegetated ancient longitudinal sand dunes and windblown sand. The flat topography, together with these sandy soils have produced the poorly developed drainage lines of the region, all of which can be observed rising in the west. The harder landscape surfaces to the west, together with the more gentle relief, result in better-defined drainage lines.

In the northern most part of the Basin, Damara schists and Nosib quartzites seem to predominate. The Stampriet Artesian basin lies in the central eastern section of the area and stretches into Botswana. Here artesian Nossob and Auob sandstone are separated and overlain by shale horizons under sediments of the Kalahari Sequence. In the Fish River catchment to the west, the area mainly consists of Nama-aged sandstone, shale and limestone. Karoo and Nama lithologies as well as dolerite intrusions can be found in the southern section and Kalahari sediments occasionally overlie these lithologies

In the Botswana portion of the Molopo sub-basin system, outcrops of bedrock are restricted to the river valley and the Mosi Ridge. The area is characterised by sands, loamy sands and occasional clays.

In the North-West Province in South Africa, dunes associated with the arid environment of the Kalahari occur in the extreme western region. The area also has an interesting and ancient geological heritage and is rich in minerals and palaeontological artifacts. Igneous rock formations dominated the north-eastern and north-central regions of the province as a result of the intrusion of the Bushveld Complex. Ancient igneous volcanic rocks dating back to the Ventersdorp age (more than 2 000 million years) appear to be the dominant formations in the western, eastern and southern regions of the Province (UNDP-GEF, 2008).

4.5.5 The Orange River Mouth

The estuary is located on hard rock formations and is made up of greywacke, quartzite and lava. The corresponding geology is a composite of unconsolidated superficial deposits, conglomerates, limestone, sandstone, marl and high level gravel. Phyllite, lava, quartzite, schist, tillite and hornfels can also be found in many places.

Figure 4.2 shows the geological map of the Basin.

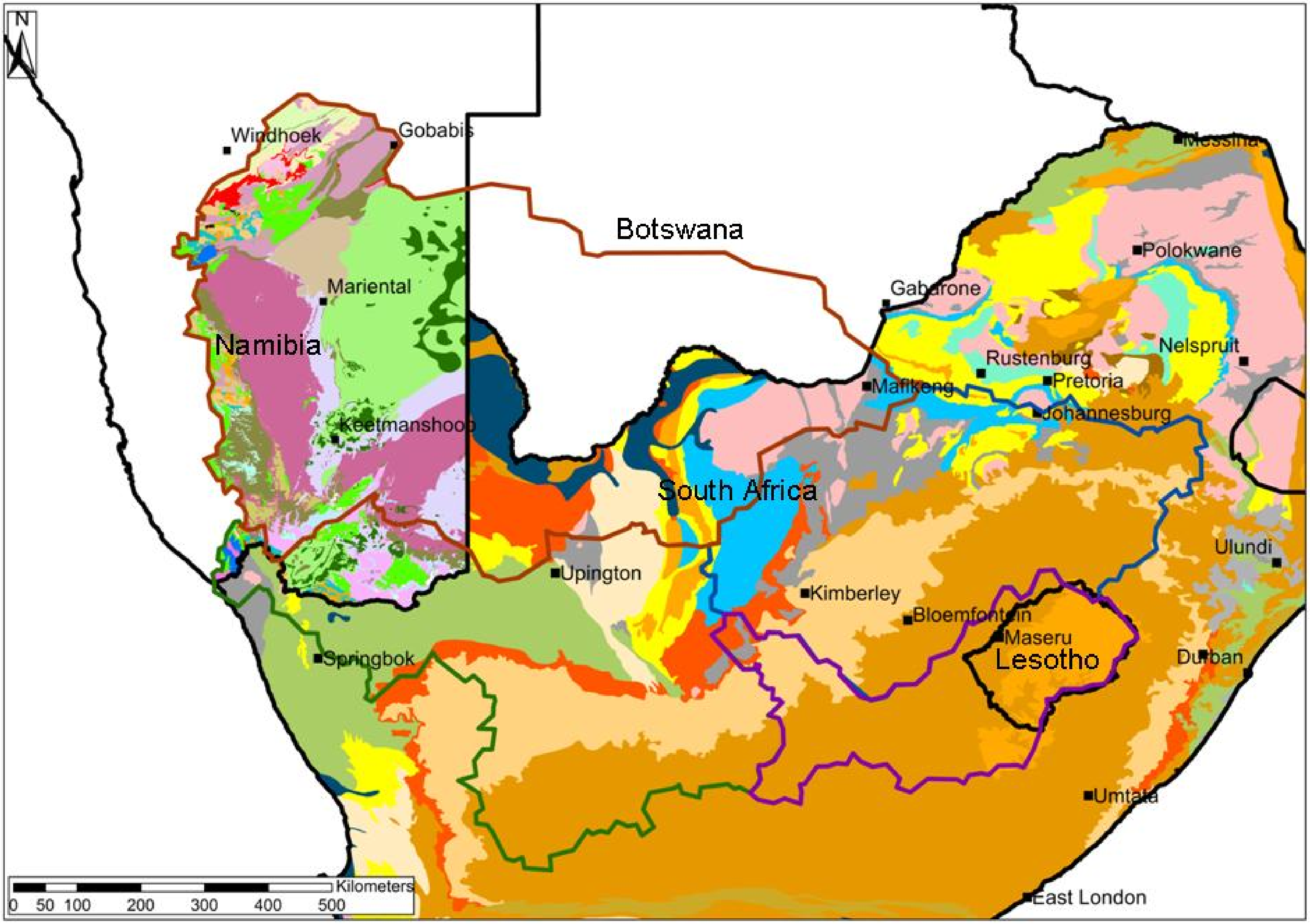

Figure 4.2: Geology Map

Legend

Namibia Geology

ROCKTYPES

- Aeolian sandstone
- Alluvium, sand, gravel, calcrete
- Andesite, dacite, rhyolite
- Basalt, andesite, arkose, quartzite, conglomerate, felsite, tuff / gabbro, norite, monzonite
- Breccia
- Calcrete terraces and partially consolidated dune deposits of the Namib Desert
- Carbonaceous shale
- Carbonatite plugs and dykes
- Charnockite, gabbronorite, ultramafic rocks
- Coastal salt pan
- Conglomerate, arkose, shale, quartzite
- Dolerite sills and dykes
- Dolomite, limestone, shale, conglomerate
- Felsite, tuff, quartzite, schist
- Granite
- Granodiorite
- Green/red shale and sandstone
- Intraformational mixtite, grit
- Limestone
- Marble, schist, ortho-amphibolite, quartzite
- Mica schist, minor quartzite, graphitic schist, marble
- Mixtite
- Ortho-amphibolite
- Para-/orthogneiss, metasedimentary rocks, granite, metabasite dykes
- Pre- to syntectonic biotite-rich augen gneiss
- Pretectonic gneiss, ortho-amphibolite, metasedimentary rocks
- Quartzite, black limestone, conglomerate, shale, dolomite
- Red/grey sandstone and shale
- Rhyolite, basalt, andesite, ortho-amphibolite, greenschist, quartzite, phyllite, limestone, n
- Sand, calcrete, gravel
- Sandstone
- Schist, marble, quartzite, conglomerate, graphitic schist
- Serpentinite, chlorite schist, talc schist
- Shale, limestone, siltstone
- Syn- to post-tectonic gneissic granite, granite, pegmatite
- Syntectonic gneissic leucogranite
- Tillite, boulder shale, shale, sandstone, limestone
- Trachyte, phonolite
- Undifferentiated metamorphic/intrusive rocks of the Namaqua Complex

Legend

Simplified Geology RSA

Simplified Geology (WR90)

- Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks
- Intercalated assemblage of compact sedimentary and extrusive rocks
- Compact sedimentary strata
- Porous unconsolidated and consolidated sedimentary strata
- Tillite
- Assemblage of tillite and shale
- Assemblage of tillite, shale and sandstone
- Principally arenaceous strata
- Principally argillaceous strata
- Intercalated arenaceous and argillaceous strata
- Dolomite and limestone
- Acid and intermediate lavas
- Basic / Mafic lavas
- Acid and intermediate extrusives
- Basic / Mafic and ultramafic intrusives

4.6 GROUNDWATER OCCURRENCE IN THE BASIN

Increased demand for water has driven greater exploitation of groundwater, often draining aquifers at an unsustainable rate. As increased demand has stressed or even exhausted surface water resources, national and regional authorities have increasingly turned to groundwater, a resource largely ignored and misunderstood in the past. Groundwater is used in the Basin for industrial, agricultural and domestic uses. Groundwater occurrence, recharge and volumes used in the Basin however differ to a large degree in the five sub-basements. The factors dictating groundwater use, volumes available and water quality range from aspects such as the geology, rainfall volumes, groundwater recharge volumes and evapotranspiration to name a few.

The geology of the Basin affects the distribution, availability, quantity and quality of groundwater in the region. Most of aquifers of the Basin are situated in hard rock, characterized by dual porosity, or secondary aquifers associated with fracturing of the matrix and weathering (Cobbing *et al.,* 2008).

Dolerite Intrusions: Numerous dolerite dykes and sills have intruded the sediments of the Karoo Supergroup throughout the Basin. In the dolerite host rock or the baked contact zones between the dolerite and the surrounding country rock are fractured and thus act as secondary aquifers. Dolerite intrusions in competent host rocks such as the thick sandstones have generally higher groundwater potential than intrusions in less competent rocks such as shales. The highest groundwater yields would occur where a fractured dolerite contact zone is overlain by saturated alluvium or crossed by a perennial watercourse as this would facilitate and promote aquifer recharge.

Fractured Sedimentary Rocks: Tectonic stress, for example, and the resultant folding and faulting, have caused the fracturing of sedimentary rocks and these fractures result in the formation of secondary aquifers. The fracturing is most pronounced in competent hard sandstone units such as those found in the Beaufort Group.

Weathered Zone: Weathered zones in which secondary porosity is created may also act as aquifers. Shales and mudstones are more easily eroded than sandstone and this form of aquifer often developed within the shales of the Ecca Group.

Alluvial Deposits: These have primary porosity and are developed to a limited extent along certain sections of rivers.

Karstic Fractured Aquifers: These are represented by the Transvaal dolomite units, which are relatively smaller in areal extent found mainly in the Northern Ephemeral Rivers sub-basin area.

4.6.1 The Vaal River sub-basin

In the largest part of Vaal River sub-basin the Karoo Supergroup is the most prominent host rock. The Karoo Supergroup forms aquifers with a groundwater harvest potential of 10 000 to 25 000 $m^3/km^2/a$ whereas in the most northern and western areas it is higher at 15 000 to 50 000 $m^3/km^2/a$.

Intrusive material in the form of dykes and sills are formed during the intrusive process into the Karoo Supergroup. These intrusive structures formed by mostly diabase normally forms water bearing contact zones on the diabase and shale or sandstone contacts. These form ideal groundwater occurring structures, well known and targeted by farmers, drilling contractors and geologists as water bearing features.

4.6.2 The Upper Orange-Senqu River basin

Groundwater occurs within the fractured Karoo Supergroup sedimentary and basalt rock aquifers, alluvial sediments and within fracture and dolerite intrusion zones.

Numerous dolerite dykes and sills have intruded the sediments of the Karoo Supergroup throughout the Basin. In the dolerite themselves or the baked contact zones between the dolerite and the surrounding country rock are fractures and act as secondary aquifers. Dolerite intrusions in competent host rocks such as the thick sandstones have generally higher groundwater potential than intrusions in less competent rocks such as shales. The highest groundwater yields would occur where a fractured dolerite /contact zone is overlain by saturated alluvium or crossed by a perennial watercourse as this would facilitate and promote aquifer recharge.

Underlain by hard formations, no large porous aquifers are found in the Upper Orange WMA. Even though relatively large quantities of groundwater are abstractable from fracture zones at dolorite intrusions, recharge rates and therefore sustainable yields are low over most of the WMA. However, in localised areas, for example where lime bogs are found, higher recharge rates do take place. In the drier parts of the WMA, groundwater constitutes the main, and in many cases the only, source of water for rural domestic supplies.

4.6.3 The Lower-Orange River basin

The dolerite material was intruded as sheet and dyke structures. When these structures intruded as thin sheet like vertical material, the cooling process is relative fast with the result that fractures are formed which quickens the weathering process. If these structures dissect a valley feature the weathering process is much more progressive if water is constantly available. These weathered geological contact zones then form an ideal position for water abstraction via a production borehole.

No major well fields are to be found in the Basin. Dependence on groundwater however is very high, particularly in the Lower Orange River region, the Northern Ephemeral River basin and at the Orange River mouth.

4.6.4 Northern Ephemeral Rivers

Groundwater is the most widely used resource in the Basin as little or no runoff is expected in the river except the Fish River which flows part of the year. In Namibia, the groundwater potential or natural recharge of the country has not yet been fully determined. It is estimated that between one and two percent of rainfall actively recharges the Namibian groundwater. The groundwater potential in all the riparian states is well developed. ORASECOM recently commissioned a project to evaluate the groundwater potential and develop a harmonised groundwater management system in the riparian states.

Groundwater is found in the porous and unconsolidated sedimentary strata formed in this Basin. The dolomite and limestone located to the east of the Basin forms a productive aquifer, however ground water recharge volumes are low due to low rainfall figures and low groundwater recharge abilities. Quaternary and Tertiary sand covers large areas of the Basin. To a large extent drainage features are not developed in the central and northern part of the Basin due to the sand cover.

4.6.5 The Orange River Mouth

The alluvial material found at the Orange River mouth consisting of a complex of unconsolidated superficial deposits, conglomerates, limestone, sandstone, marl and high level gravel forms the ideal aquifer for shallow sandpits and shallow boreholes. Deeper situated boreholes will tap water from the fractured hard rock formations which is made up of greywacke, quartzite and lava. Fresh water will be found at the top of the aquifer with more saline water in depth.

4.7 GROUNDWATER RECHARGE

Groundwater is a renewable resource but for groundwater to remain available for supply, it has to be continually replenished by recharge from surface water sources. These sources usually include rainfall and stream flow.

The recharge process and rate depend on the nature of the aquifer as this affects its ability to receive and store groundwater and controls its movement within the aquifer. For instance, from fractured aquifers, rainfall can be a source of significant recharge that eventually re-emerges as base flow into streams during dry seasons.

Groundwater recharge is affected by a number of factors as mentioned below. The intensity of rainfall and the consistency of yearly precipitation are important factors. Areas such as the northern and southern parts of the Vaal River sub-basin and the Upper Orange-Senqu River sub-basin have mean annual recharge figures of 25 - 100 mm/a. Groundwater recharge occurs by:

- Infiltration of precipitation through the sub surface layers;
- Lake and river water seepage through the beds and the banks;
- Leakage from adjacent groundwater sources and
- Artificial recharge from irrigation, pipeline leakage, direct injection, etc.

Other factors such as evapotranspiration also play a major role in groundwater recharge figures. The central part of the northern Ephemeral Rivers Basin does have very high evaporation figures of 1 500 mm and more. The mean annual recharge occurrence to a large degree mimics the evapotranspiration occurrence. High evapotranspiration areas have low mean annual groundwater recharge figures and low evapotranspiration areas have high mean annual recharge figures.

Geology on a much smaller scale has an influence on mean annual groundwater recharge figures. The dolomite and limestone aquifers have a much higher mean annual groundwater recharge figure than competent granite host rock or competent shale.

The effect of climate change may have huge impacts on a number of climate factors such as rainfall, surface temperatures, stream flow, evapotranspiration and ultimately groundwater recharge figures. The areas with low groundwater recharge are the areas with the highest temperature increase predicted. The northern Ephemeral Rivers sub-basin, for example is predicted to have a mean temperature increase of 3.5°C by the year 2045. The evapotranspiration may increase accordingly and the groundwater recharge figures may plummet to figures below 5 mm/a.

Figure 4.3 shows the recharge rates in the Basin.

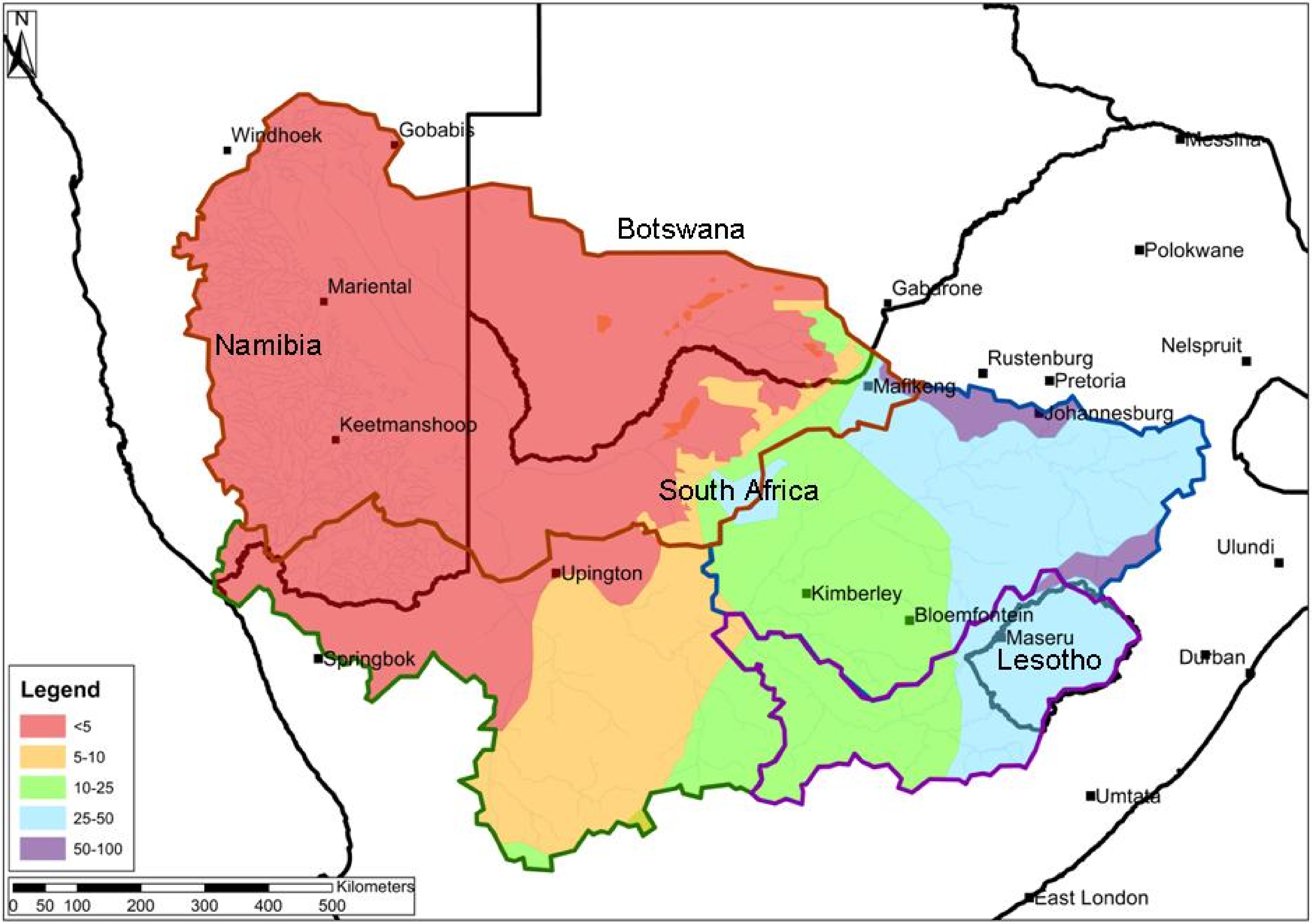

Figure 4.3: Mean annual recharge (in mm/a)

4.8 GROUNDWATER MOVEMENT

Groundwater movement is largely dictated by topography. On a regional scale groundwater contours normally mimic the surface water contours. Groundwater flow directions in general will follow surface water flow directions. Even groundwater flow in geologies such as the dolomite and limestone series which forms compartmental units are dictated by the topography. For instance the dolomite compartment located from Lichtenburg to Krugersdorp (just outside of the Basin) decant into the Vaal River System (as well as Maloney's Eye and the Fountains in Pretoria which are outside of the Basin) which flows to the west to form part of the Basin drainage.

4.9 WATER USES AND QUANTITIES OF GROUNDWATER USE

4.9.1 Introduction

Boreholes are most commonly used to abstract water from an aquifer. The groundwater use can be studied by the borehole density distribution in the Basin. The borehole density map cannot effectively represent the groundwater volumes abstracted in the Basin, but can represent the reliance on groundwater for human and animal life. The highest concentration or density of boreholes is to be found around the urban areas and throughout the agricultural areas of the Basin.

Recent estimates put groundwater abstraction in South Africa between 1 771 million m^3/a and 1 900 million m^3/a (Baron and Seward, 2001; Hughes, 2005). However, the actual usage of groundwater is largely unknown; there is currently no formal data collection on groundwater usage in South Africa, or in any of the other countries in the Basin.

4.9.2 The Vaal River sub-basin

Boreholes are extensively used in the Vaal River sub-basin, available data indicates areas with borehole densities ranging between 26 and greater than 100 boreholes per 10 km^2 (conservative figure).

Areas such as the southern parts of Johannesburg, Krugersdorp, Koster and Swartruggens make use of boreholes on a large scale of 100 boreholes per 10 km^2 and more.

A large number of small and medium scale villages in this sub-basin partially or entirely rely on groundwater as a domestic water source. Farming communities in this sub-basin do not have additional water sources to supply water. Self-sustaining and commercial farming communities use groundwater as sole source for farming purposes. Although small scale groundwater abstraction is synonymous with livestock farming, large economic spin-offs and job creations are generated by this sector.

The mining sector abstract large groundwater volumes during mining procedures and use large volumes of groundwater in processes such as slime dam operations, dewatering of mines and washing plants. The mining sector is responsible for large volumes of groundwater interchange practices such as artificial groundwater recharge at slimes dams where surface water is used in processes and will ultimately be recharged into aquifers. Mine water abstraction also takes place, to be ultimately released as surface water into surface water drainage features. During these processes the risk of groundwater water contamination is high and must be carefully managed.

4.9.3 The Upper Orange-Senqu River basin

The Upper Orange-Senqu basin includes Lesotho and the upper portions of the Orange River and its tributaries down to the convergence with the Vaal River at Douglas. Existing data indicates two prominent areas where high densities of boreholes can be found. The most prominent is the western part of Lesotho from the Fiksburg area to Wepener in the south which have a high density of boreholes ranging from 26 to greater than 100 boreholes per 10 km^2. The second prominent area with a high density of boreholes is the agricultural area north of the Gariep Dam and includes villages such as Springfontein, Trompsburg and Philippolis.

4.9.4 The Lower-Orange River basin

Groundwater utilisation is of major importance in the Lower Orange sub-catchment as it constitutes the only source of water over much of this sub-catchment. It is mainly used for rural domestic supply, stock watering and supply to inland towns. Recharge is limited as a result of low rainfall over the catchment, therefore only small quantities can be abstracted on a sustainable basis. The hard geological formation underlying most of this Basin also makes its aquifer characteristics (borehole yields and storage of groundwater) rather unfavourable.

In the Orange Tributaries sub-area, about 60% of the available water is supplied from groundwater sources. Groundwater, even though it is a very small component of the available water in the vicinity of the Orange River, also constitutes an important source for rural water supply in this sub-area. Much of the groundwater abstracted near the river is induced recharge from the river. Groundwater availability in the coastal region is also extremely limited as a result of the lack of rainfall and risk of seawater intrusion into coastal aquifers which increases saltiness of the water.

Farming communities located in this Basin use groundwater on a regional scale for farming activities. Throughout the Basin borehole density is in the order of 1 to 25 boreholes per 10km^2.

4.9.5 Northern Ephemeral Rivers

In Namibia, groundwater extraction from the Basin is estimated at 13.81 million m^3/a and in Botswana 1.12 million m^3/a (Lange *et al.,* 2007). The Northern Ephemeral River basin covers the south eastern part of Namibia, the southern part of Botswana and the northern part of South Africa. It is estimated that groundwater is the largest source for drinking and livestock water supply, with approximately 37% of the population of the SADC existing solely on groundwater resources.

4.9.6 The Orange River Mouth

A number of mining settlements exist in the area. One of them, Oranjemund, is a small mining town located at the north bank of the Orange River Mouth in Namibia.

4.10 GROUNDWATER AND RURAL WATER SUPPLY

A few million people, living on subsistence and commercial farms in Namibia, Botswana, Lesotho and South Africa, located in the Basin, daily use groundwater for domestic and animal use. Without groundwater sources, these farms and villages will be unproductive and desolate. In localized areas, for example where lime bogs are found, higher recharge rates do take place. In the drier parts of the Basin, groundwater constitutes the main and in many cases the only source of water for rural domestic supplies. About half of Namibia's population of 2.1 million people relies on subsistence farming for their livelihood. Commercial farmers who also form a huge percentage of the population, make use of groundwater sources. Surface water sources in Namibia are scarce which makes groundwater the best alternative for small scale users and farmers.

4.11 Cross Boundary Aquifers

Trans-boundary groundwater commonly implies a body of groundwater intersected by a political border with the potential threat of dispute over a shared resource. This definition is inadequate in many parts of Southern Africa. Approximately 96% of South Africa's borders are underlain by low-yielding aquifers and coupled with a low demand for water due to low population density, the risk of over-pumping or pollution leading to dispute is low.

The general lack of technical cooperation, data sharing, training and research between the riparian states on hydrogeology hampers a mutual understanding of the resources. The concept of trans-boundary groundwater must necessarily include aquifers where little cross-border flow occurs, but where cross-border cooperation will help to ensure sustainable cooperative utilisation of shared aquifer resources. This is imperative if future disputes are to be averted. Agreement between scientists is a necessary precursor to broader transnational governance agreements in regard to shared water resources. Recent initiatives by the Orange-Senqu River Commission promise closer integration (Cobbing, 2008).

Two distinct trans-boundary aquifers exist. These aquifers are both located on the Karoo system and stretch over fairly regional extent. The first system is the Karoo Sedimentary Aquifer which is located in Lesotho, Eastern Free State and parts of the Eastern Cape. The second trans-boundary aquifer is the South-east Kalahari Karoo Aquifer which is located in the Eastern part of Namibia, the south-western part of Botswana and the northern part of the Kgalagadi Trans-boundary Park.

4.11.1 Karoo Sedimentary Aquifer

The trans-boundary area of south-eastern South Africa and lowland western Lesotho has a semi arid to temperate climate, receiving annual rainfall of 500 to 1 150 mm that falls mainly during October to April. The international boundary is marked by the perennial Caledon, Senqu, Mohokare/Clarens and Makhaleng rivers, many of whose tributaries are episodic or ephemeral. The Beaufort and Stormberg Groups of the Karoo Supergroup underlying the trans-boundary area comprise horizontal to sub-horizontal dipping sedimentary rocks of the Burgersdorp, Molteno, Elliot and Clarens Formations. These include fluvio-deltaic mudstones, siltstones and sandstones with dolerite ring dyke intrusions. Formation groundwater storage and flow are functions of porosity. Primary effective porosities are low due to sediment cementation and the fine grained nature of the sediment, as well as compaction and high mudstone contents. Secondary porosities are enhanced by fracturing and dolerite dyke intrusion. Whilst groundwater quality is mainly good, aquifer characteristics are summarized as follows. The 200 m thick Burgersdorp Formation found in much of the trans-boundary area is composed of low permeability mudstones and siltstones with minor sandstones. It is a semi-confined to confined aquifer with a mean transmissivity of 20 m^2/d supporting borehole yields less than 0.5 ℓ/s, except where intruded by dolerite dykes. Within the Burgersdorp Formation, many boreholes have been drilled into the baked margins of dolerite ring dyke intrusions to supply water to farms and small rural communities. The Molteno Formation varies in thickness from greater than 250 m in the south to less than 50 m in the north. It is the best aquifer present, especially where permeability is enhanced by intruded dolerite dykes or fracturing. This semi-confined aquifer with mean transmissivity of 20 m^2/d has been developed at Roma and Teyateyaneng, where wellfields with individual borehole yields of greater than 3 ℓ/s have been installed. Outcrops of the Molteno Formation also form an important spring line with individual spring discharges as high as 0.5 ℓ/s.

The Elliot Formation varies in thickness from 200 m in the south to 100 m in the north and is often in hydraulic continuity with the underlying Molteno Formation. Although good water strikes are recorded at the contact between these formations, the Elliot Formation is regarded as a poor aquifer due to its compact nature. Given the fractured nature of the main aquifer units, the few available aquifer parameter values (mean transmissivity of 24 m^2/d and storativity of 0.0005) determined from the analysis of test pumping results for these aquifers should be applied with extreme caution, since they probably overestimate sustainability. The 130 m thick Clarens Formation supports the lowest mean borehole yield of 0.9 ℓ/s and transmissivity of 5 m^2/d.

The low transmissivities and consequent low borehole yields of the Karoo Supergroup rocks straddling the Lesotho/South Africa border mean that the trans-boundary impact of groundwater abstraction is likely to be very small. The area is designated as a “major groundwater basin” with medium recharge on the world trans-boundary aquifer map, yet is likely to need management approaches that are different to those applied to trans-boundary aquifers with much higher transmissivities.

4.11.2 The South-east Kalahari/Karoo Aquifer

The South-east Kalahari/Karoo aquifer is shared by Namibia, Botswana and South Africa, although it is predominantly utilized in Namibia where most recharge probably occurs. There is a comparatively good understanding of the aquifer’s geology and hydrogeology in Namibia. Water occurs in the Auob and Nossob sandstone of the Ecca Group (Lower Karoo Sequence), as well as in the overlying Kalahari. The dip of the formations is slightly towards the Southeast and in general the water quality deteriorates also in that direction.

Population on the Namibian side is generally sparse. Water use is therefore primarily for irrigation and stock farming. Although the system is large, because of present uncertainty about recharge it is not known if it can sustain large irrigation schemes, the appropriate balance between irrigation and sustainability is currently unresolved.

The Southeast Kalahari Artesian aquifer is bordered by the South-west part of Botswana, the South African Kalahari National Game Park and the Gordonia District. In Gordonia, water quality of the Karoo aquifers appears to be very poor, as in the so-called Salt block in the south eastern part of the Artesia basin in Namibia. At present, water is used in Namibia for stock watering and increasingly for irrigation purposes. This system also supplies five smaller villages with water. The largest portion of the aquifer falls within Namibia which is expected to have the largest demand from the system and where need is expected to rise in the future.

An examination of South African trans-boundary aquifer systems suggests that each possesses good development potential. However, the development potential of each aquifer needs to be assessed against factors such as surface water / groundwater interactions and groundwater dependent ecosystems before establishing the sustainable utilization as a trans-boundary resource. Such assessments will inform the joint development and management of these resources to the mutual benefit of the riparian states. Based on this study of South African trans-boundary aquifers, it is proposed that the traditional understanding of trans-boundary groundwater issues as a potential source of conflict be modified.

For most of the length of South Africa's border, potential dispute over trans-boundary groundwater is not a major concern. In general, trans-boundary aquifers such as the "Karoo Sedimentary Aquifer and the Southeast Kalahari/Karoo Basin" are potentially misleading in terms of the level of management required. Given the sparse data on southern African trans-boundary aquifers and the relatively low levels of technical cooperation between the riparian states, the region would be better served by using trans-boundary groundwater as a vehicle to improve technical cooperation, data sharing, training and research.

This is crucial if potential future disputes over shared groundwater resources are to be averted. Agreement between scientists is postulated as a necessary precursor to broader transnational governance agreements.

Figure 4.4 shows the two major aquifers in the Basin.

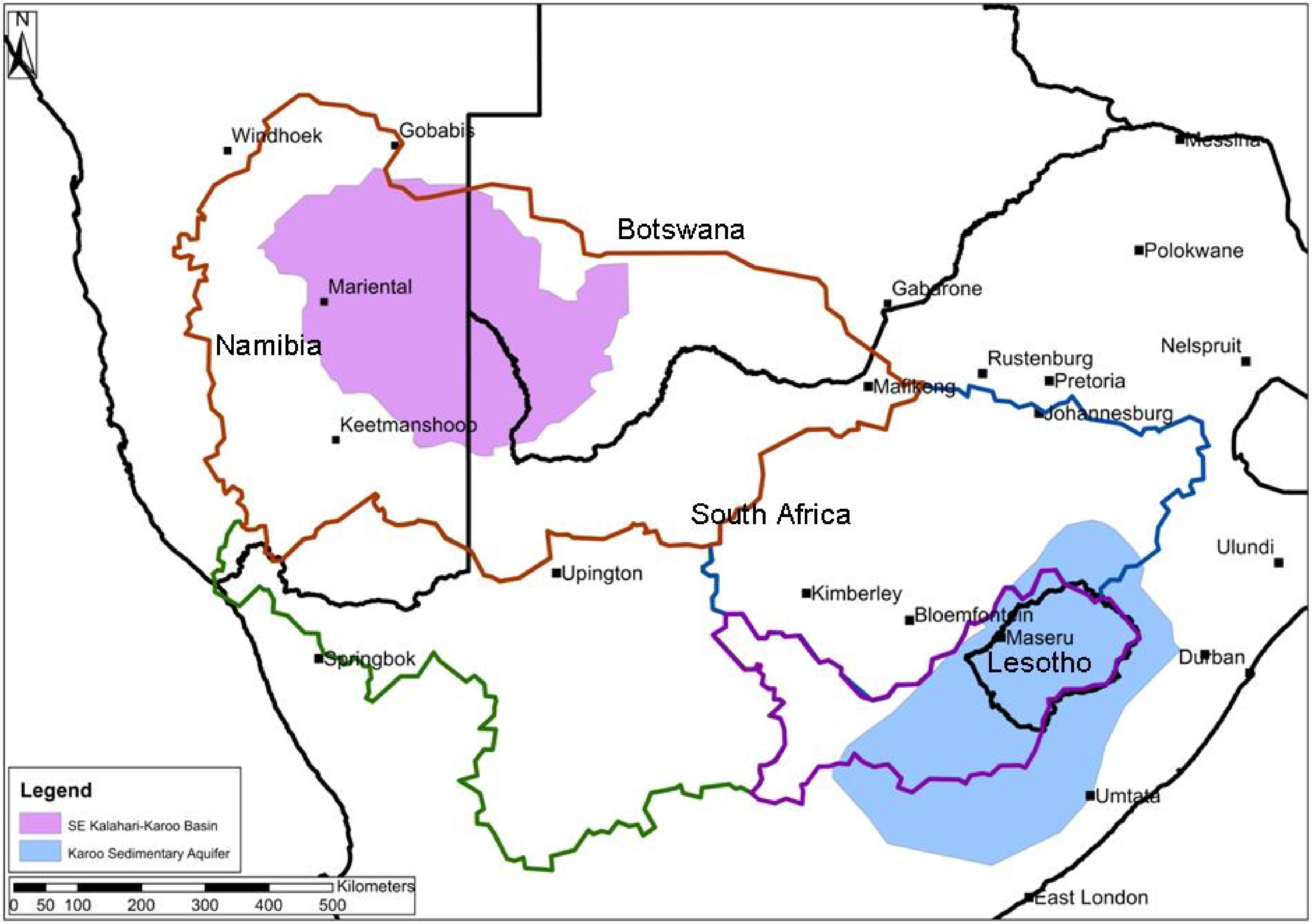

Figure 4.4: Major Aquifers

4.12 AQUIFER TYPES AND VULNERABILITY

There are two main types of aquifers governing the occurrence and distribution of groundwater in the Basin namely shallow alluvial primary aquifers along the rivers and a variety of deeper hard rock secondary aquifers. As the alluvial aquifers are recharged only by surface water they are generally considered part of that resource. The secondary aquifers mainly supply smaller rural towns, rural domestic use and stock watering, with no major production well-fields serving large concentrated demands. The sandstone aquifers of the Beaufort Group (the main subdivision of the Karoo Supergroup) are considered to be a weak primary aquifer. The secondary aquifers are formed in weathered rock, fractures or faults such as in the Karoo Supergroup.

The level of water in a body of rock is known as the water table. In a primary aquifer, this is a physical level in the rock, up to which water is present. In a secondary aquifer, the water table is an abstract representation of the quantity of water held in the spaces between the rocks.

In a confined aquifer, the upper boundary of the aquifer meets with a body of impermeable, unfractured rock that blocks both flow of water into the aquifer from above (recharge) and extraction of water from above. Confined aquifers must be recharged by groundwater flowing in laterally from an adjacent recharge zone. An unconfined aquifer is not restricted by an impermeable layer; it can be recharged by water percolating down from the soil and if it is under pressure, water can seep unrestricted up to the surface. Aquifer types in the Northern Ephemeral Rivers are as follows:

- The fractured porous type, represented by the Karoo sandstones;
- The porous aquifers, represented by alluvial and Kalahari bed aquifers;
- The fractured aquifer, which includes the Archaean Basement and Proterozoic aquifers and Karoo Basalts and
- The Karstic fractured aquifers, which are represented by the Transvaal dolomite units, which are relatively smaller in areal extent.

5. CONCLUSIONS AND RECOMMENDATIONS

As with any water resources assessment, data is generally lacking to some degree. The critical input for any water resource model is rainfall. Use was made of the detailed WR2005 Study in which the water resources of South Africa, Lesotho and Swaziland were appraised. Also of value were previous studies as referenced in the text. Although the South African part of the catchment has been endowed with relatively good rainfall data as well as good observed streamflow and land use data in the past, there has, however, been a decline over the past decade or two in the quantity of rainfall stations and observed streamflow stations. In general (including other countries in the Basin as well as South Africa), additional and improved data is recommended. It is therefore recommended that more effort is spent by the relevant authorities to re-open stations that have closed and consider some new stations both for rainfall and observed streamflow. These recommendations have also been made in other study reports, the National Water Resources Strategy and major conferences in South Africa. Along with land use data, this recommendation cannot be emphasized strongly enough as poor data can lead to misleading analyses being made.

Water is a finite resource whereas the demands for potable domestic water, water for industry and mining, irrigation, livestock, afforestation and recreation are steadily increasing. The quality of water is deteriorating due to increased population, urbanization and industrialization which results in water being returned to river systems with an ever decreasing quality. This is despite efforts to maintain the ecological status of rivers in South Africa and other countries by means of EWR legislation and analysis. Constructing new dams is largely a thing of the past and we are now looking to other interventions such as water conservation and demand management, re-use of water, desalination (especially in coastal areas), water transfers, etc. to provide for growing water demands. For this reason it is vital that water is used in the most beneficial and efficient manner in the Basin and to achieve that we need reliable data and accurate analysis using the models such as WRSM2000, the WRYM and NAMRON.

Groundwater is of major importance in the dryer Lower Orange Basin and constitutes the only source of water over large areas. It is mainly used for rural domestic supplies, stock watering and water supplies to some inland towns. As a result of low regional rainfall, recharge is limited and generally only small quantities can be abstracted on a sustainable basis. In the tributaries to the Lower Orange River, about 60% of the water supplied originates from various groundwater sources. Most, if not all, of the abstractions near the river are directly from induced river recharge. The scale of flow reduction in the Lower Orange will in time therefore lead to a reduction in the near river groundwater resource. Groundwater availability in the coastal region is extremely limited as a direct result of the lack of rainfall and risk of seawater intrusion. With the surface water resources in many parts of the Basin now approaching full utilisation, almost the only opportunity left for further development lies with the exploitation of groundwater. An obvious concern therefore is the likelihood of an interaction between groundwater and surface water. If the interaction is strong then additional use of aquifers may simply reduce the surface water resource naturally available. There is an increasing focus of modeling of surface water and groundwater interaction and different methods are being compared. Groundwater provides a strategic resource during droughts to supplement the reduced surface water availability. In the central parts of the Basin the general low aquifer permeability and storage and low borehole yield makes them unsuitable for meeting urban water demands. In the region as a whole the trans-boundary implications of groundwater use are not particularly significant at present. In the future, cross-border cooperation will no doubt be required to ensure sustainable cooperative utilisation of shared aquifer resources. Reduced flows in the Lower Orange will inevitably lead to a significant reduction in aquifer resources close to the river. Conservation of surface and groundwater sources should receive high priority. Sources of contamination such as sewerage treatment plants, mining sector and agriculture irrigation water return need to be managed optimally to help to eradicated contamination of surface and groundwater sources in the Basin.

It can be concluded that for efficient and effective management of the Basin, the various aspects of sediment load and mass balance must be dealt with based on concerted efforts and shared understanding of the current and future trends in sedimentation in the Basin by all the four countries sharing the Basin. This is necessarily in order to harmonise management and adaptation efforts and to avoid the duplication of activities. The average annual sediment load at the outlet of a catchment does not necessarily mean a constant sediment yield from the sub-catchments. Concerted efforts are needed so that more resources are made available to deal with specific problematic sediment sources within the Basin based on the average annual sediment loads that have been highlighted. More field data is required for improved understanding and management of the sediment loads. Suspended sediment sampling should be carried out in river reaches where sediment load data are limited, such as in the Lower Orange River, in Botswana and in the Lower Fish River. Daily samples are required for a minimum period of five years, and should be carried out.

A number of water resource issues that were investigated, namely : floods and droughts, , water and food security, climate change and water and energy were seen to be inextricably linked and cannot be analysed in isolation from each other.

Regarding floods and droughts, there are several large reservoirs on the Orange-Senqu River and on its main tributary – the Vaal. These reservoirs play a significant role in the attenuation of flood waves: however, only three large dams in the Vaal are fitted with flood gates whereby significant attenuation may be achieved by judicious operation. One of the aims in operation of the Vaal dams is to avoid coincident flood peaks arriving at the Orange-Vaal confluence. Owing to the considerable length of the Orange-Senqu River there is sufficient time for flood warnings to be transmitted to stakeholders situated on the lower reaches of the Orange and Vaal Rivers. While all four countries have Disaster Management Plans it is felt that these should be more detailed and that a more integrated approach should be pursued. Floodlines for a range of floods should be prepared for all areas susceptible to flooding and Emergency Preparedness Plans should be compiled for all major dams. Various problems associated with flood forecasting should be investigated and an integrated solution proposed to stakeholders. All dams in the Basin are built for the purpose of water supply which, in its broadest sense, can be construed as drought management. However, all dams have an impact on the flow regime of rivers on which they are built. Water from many dams is transferred to consumers remote from the river and, in some cases, to adjacent river basins. An analysis of four major dams indicates that, during drought periods, flows released by dams are usually greater then inflows, due to the need to supply riparian consumers downstream. Apart from the dams constructed as part of the LHWP, all major dams in the Basin were built before an EWR became a required release from a reservoir. EWRs are designed to maintain the environmental integrity of rivers downstream of dams, but in all cases the EWR flows do not exceed the natural flow in the river.

While the Basin has adequate agricultural production to feed its population, many people suffer from malnutrition due to insufficient food security. Rainwater harvesting and groundwater use is being advocated and researched. Education of farmers on tillage methods will improve the situation.

The impact of climate change on water resources is the subject of extensive research at the University of Cape Town (UCT) and the University of Kwazulu-Natal. The Climate Systems Analysis Group of UCT use nine leading international climate change models and it is important to note that climate change is an evolving science and models are constantly being improved and updated. There are many extremely complex phenomena such as cloud physics that require modelling and there is obviously certain uncertainty relating to these processes. Rainfall is a harder meteorological parameter to project than temperature, wind, etc. and it is therefore sensible to analyse data obtained for all nine models in order to investigate the envelope of possible future change. The broad conclusions of the study of Crerar et al. (2011) using a limited data set are:

- Temperature increases are expected throughout the Basin varying from about 1-3 °C;
- The impacts on runoff are different for different areas. The Lesotho Highlands and source of the Caledon River in South Africa may experience an increase in precipitation and
- Temperature increases, coupled with a significant reduction in precipitation, will make irrigation and stock-farming more difficult.

South Africa although not rich in water resources, has two large Eskom hydro schemes at Gariep and Vanderkloof dams which play a major role in power generation and river management. There are also hydro schemes in Lesotho and the Thukela/Upper Vaal catchment in Lesotho Highlands and the Drakensburg Pumped Storage Scheme. Low-cost electricity has, in the recent past, been South Africa’s core competitive advantage and underpinned South Africa’s industrial strategy, however, steep increases in the cost of electricity, climate change concerns and the need for new capacity may require this strategy to be revisited. This is especially so if a low-carbon economic growth path is adopted. The focus is currently being place on improving on the efficiencies of these stations and upgrading the capacities through sustainable development. Southern Africa is blessed with hydro power potential as a source of energy. The Inga Falls in the Democratic Republic of Congo (DRC) has massive hydropower potential of 3 500 MW which could have a power delivery network through the DRC, Angola, Namibia, Botswana and South Africa.

Relevant data and information for the built structures is detailed on the fact sheets for dams, streamflow gauges, water transfers, water purification works and wastewater treatment works within time and budget constraints. This information is available on the WIS system and is easily accessible from infrastructure lists or the GIS maps. The valuable DWA documents that are available have been included as links on the fact sheets. It is recommended that where gaps do exist or where water infrastructure changes, that these fact sheets are updated as this information will be of great value for different purposes. In line with the fact sheets on built structures, schematic diagrams have been produced to provide an overview of the water system. It is recommended that these schematics are also periodically updated to reflect changes.

The Vaal River with its numerous dams and with abstractions, return flows and transfers is highly regulated. The Senqu and Orange River is less regulated but if one considers the yield of this combined system, it is highly governed by infrastructure. Further infrastructure development is probably limited to further Lesotho Highland and Thukela schemes. There has been a major shift away from constructing dams to water conservation and demand management, re-use of water and desalination in coastal areas. In some parts of South Africa, there have been shifts in water use among the various sectors, for example from irrigation to mining. This may have an impact on future water requirements. And the necessity for new infrastructure or other schemes.

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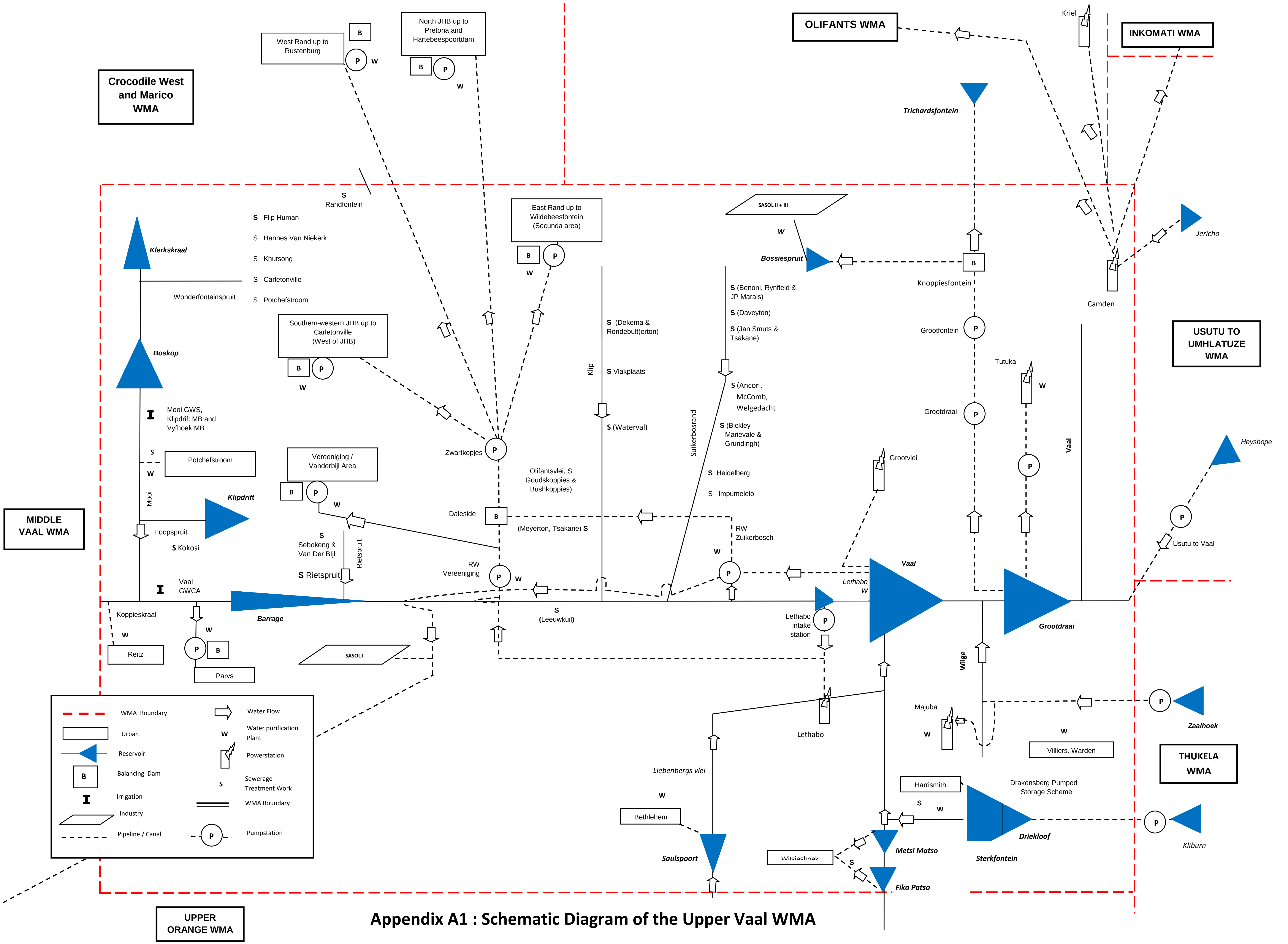
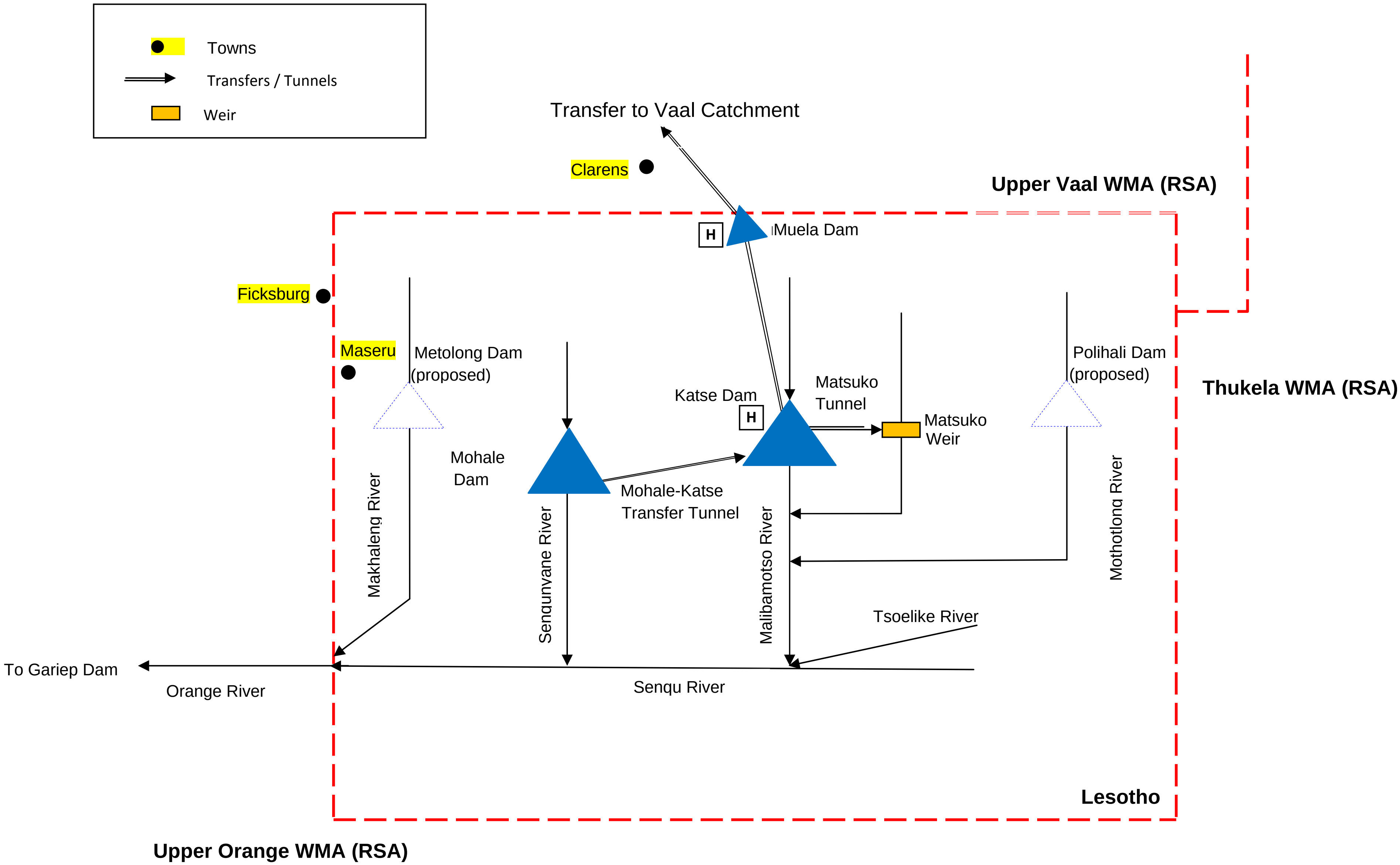
Appendices

Appendix A : Schematic layouts

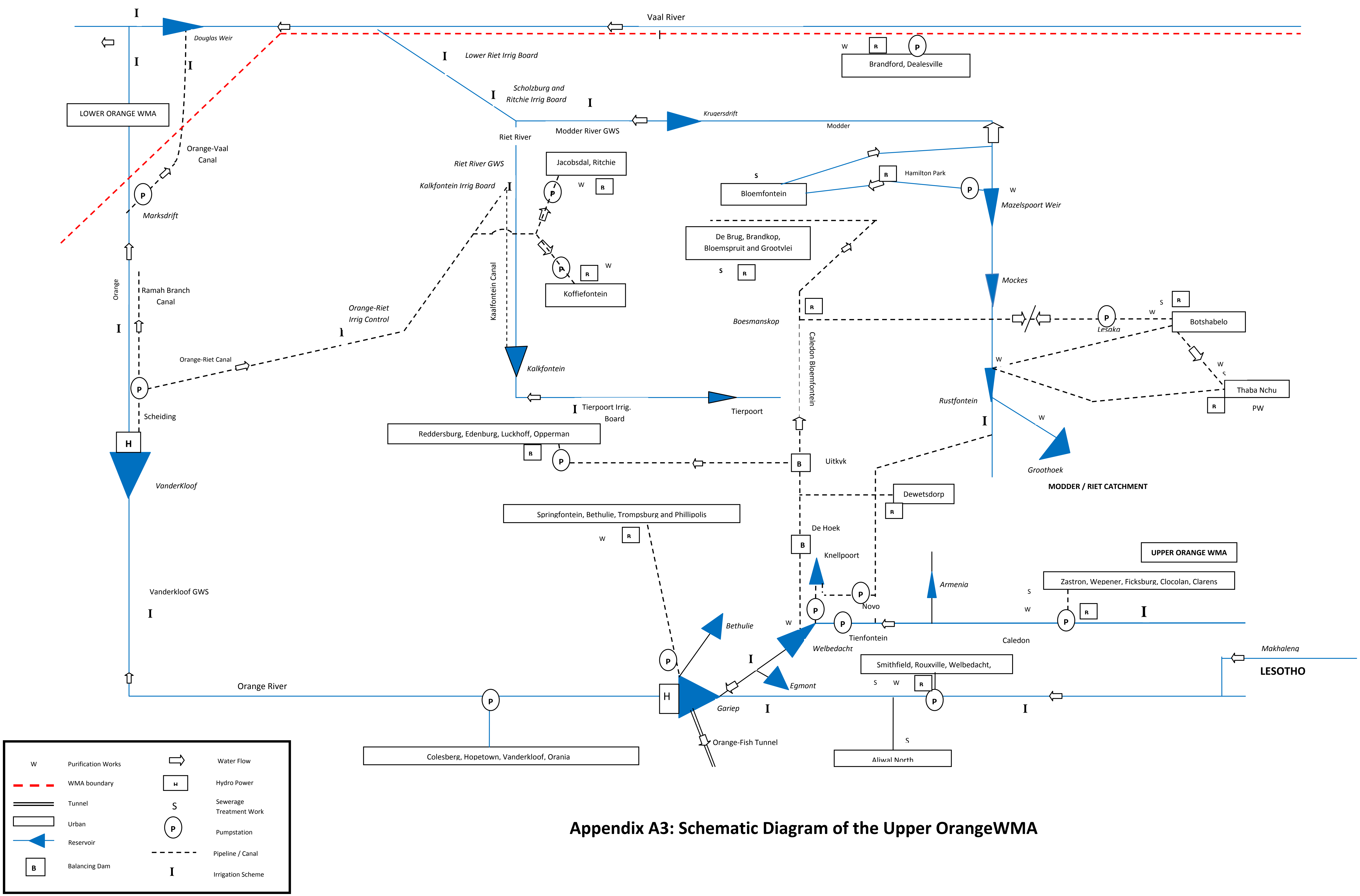
A1: Upper Vaal WMA
A2: Lesotho
A3: Upper Orange WMA
A4 and A5: Middle Vaal and Lower Vaal WMA
A6: Lower Orange WMA
A7: Namibia



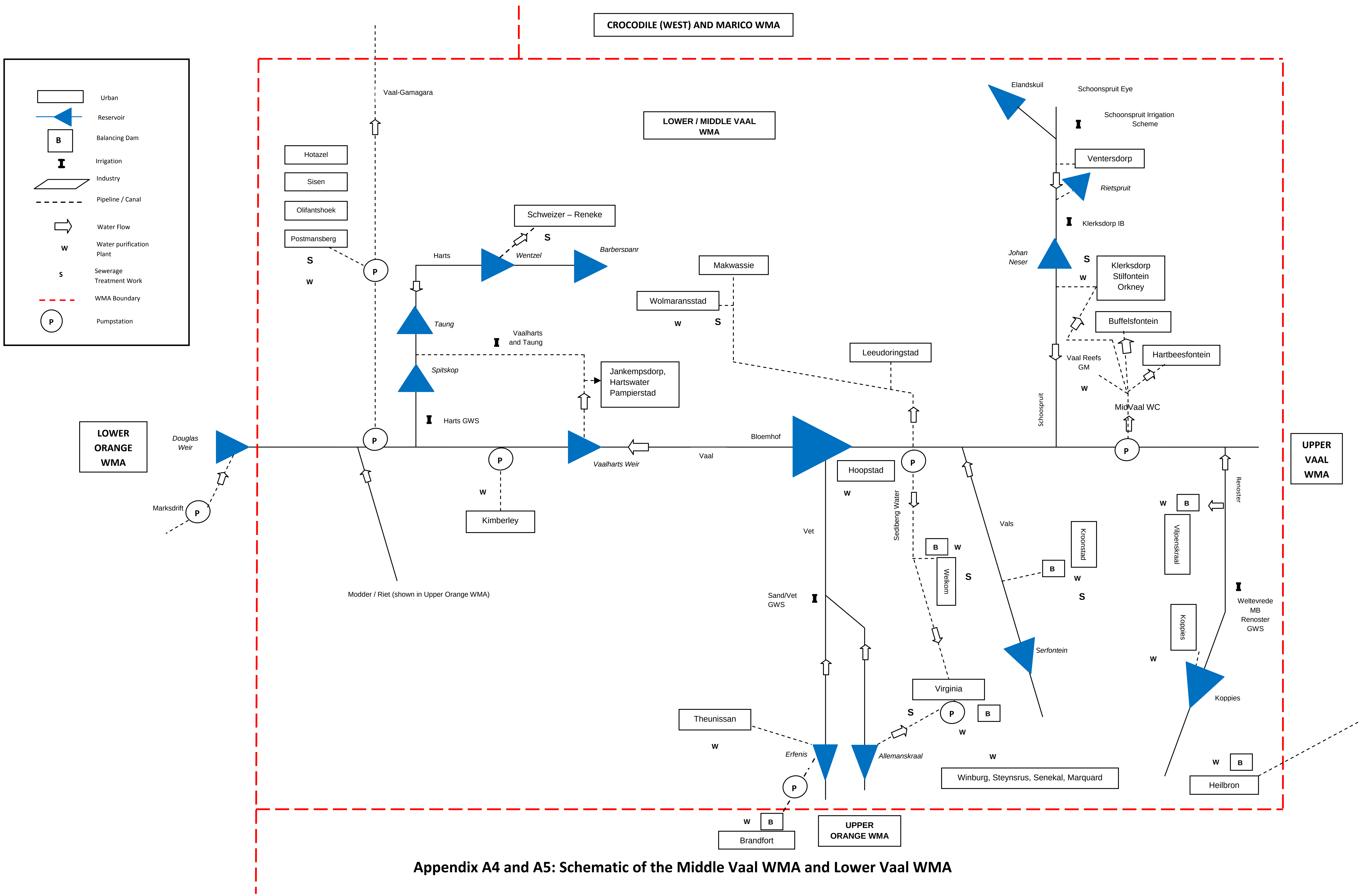
Appendix A1 : Schematic Diagram of the Upper Vaal WMA



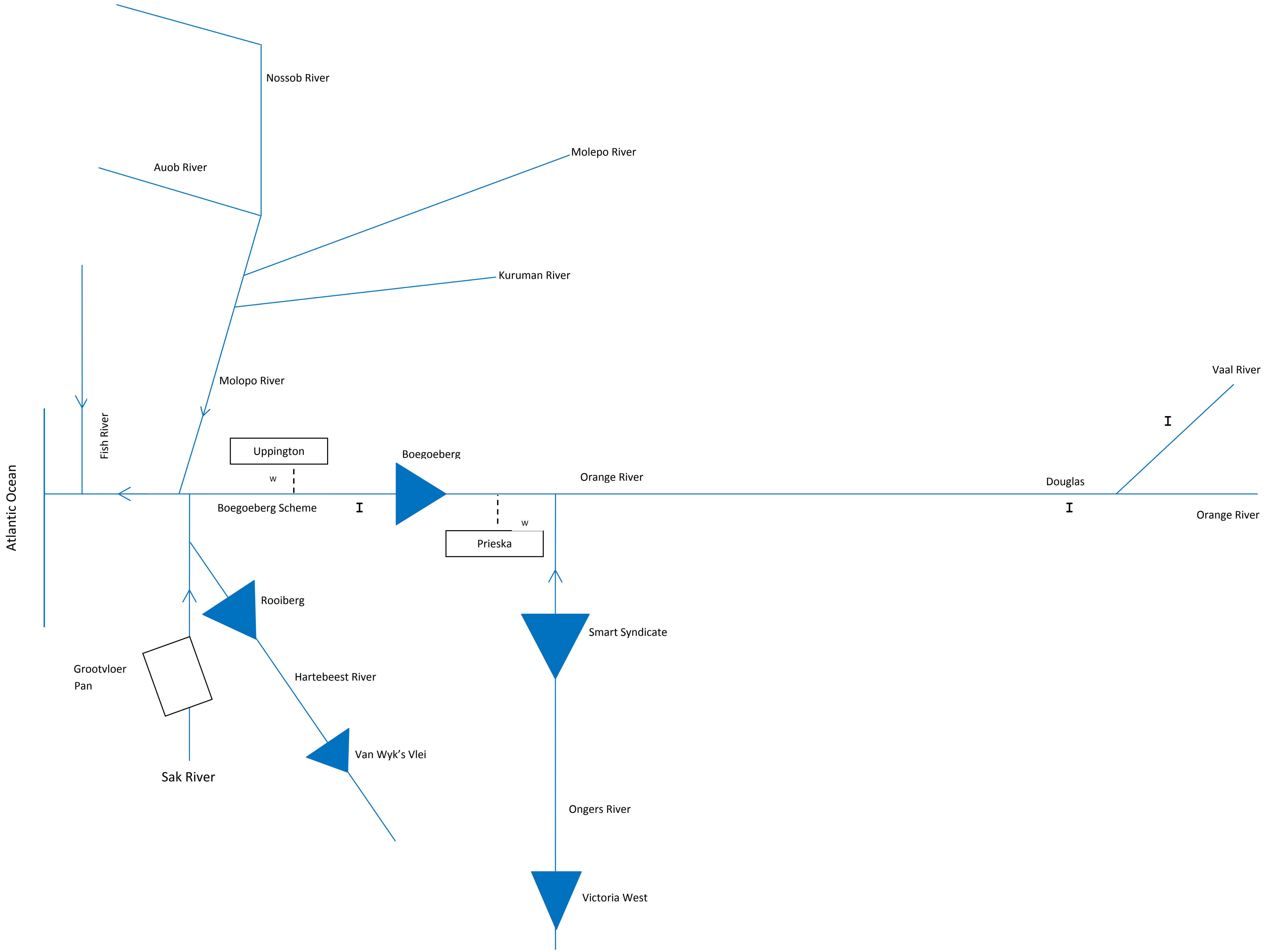
Appendix A2 : Schematic Diagram of the LESOTHO Sub-System



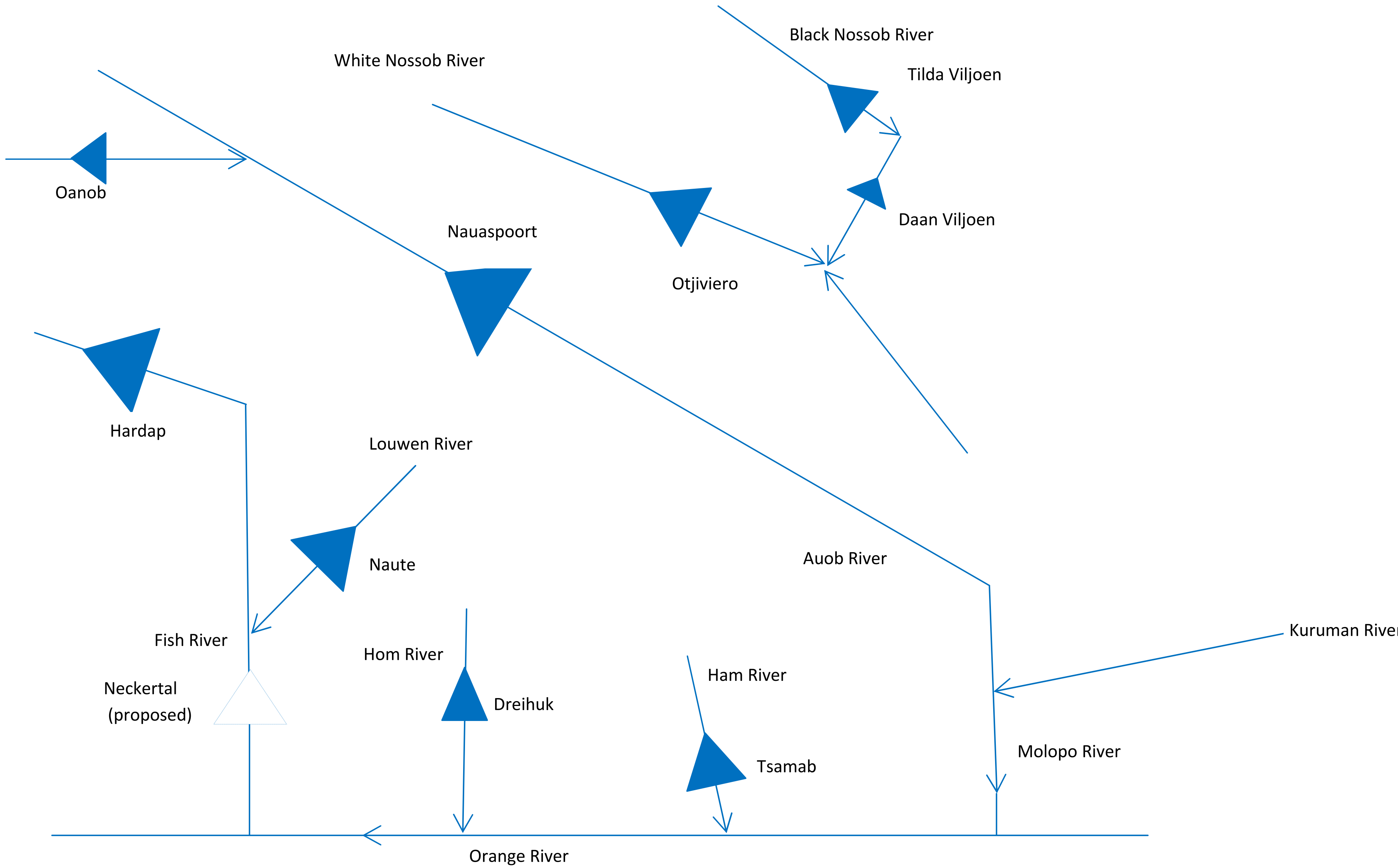
Appendix A3: Schematic Diagram of the Upper OrangeWMA



Appendix A4 and A5: Schematic of the Middle Vaal WMA and Lower Vaal WMA



Appendix A6 : Schematic Diagram of the Lower Orange WMA



Appendix A7 : Schematic Diagram of the NAMIBIA Sub-system

Appendix B : Sediment loads for catchments

Quaternary	Gross	Net	Cumulative Sub-catchment			
Catchment	(km^2)	(km^2)	Sediment Load (t/a)	Sediment Load (t/a)	Sediment Yield ($t/km^2.a$)	Station Name
C11A	721	721	45,423		63	
C11B	536	536	79,191		63	
C11C	450	450	107,541		63	
C11D	373	373	131,040		63	
C11E	1157	1157	203,931		63	
C11F	931	931	262,584		63	
C11G	433	433	289,863		63	
C11H	1104	1104	359,415		63	
C11J	1002	1002	422,541		63	
C11K	340	340	443,961		63	
C11L	948	948	503,685	488,574	63	Grootdraai Dam
C11M	796	796	144,859		163	
Tertiary	8791	8791				
C12A	485	485	79,055		163	
C12B	479	479	157,132		163	
C12C	666	666	265,690		163	
C12D	899	899	412,227		163	
C12E	498	498	493,401		163	
C12F	835	835	629,506		163	
C12G	571	571	722,579		163	
C12H	355	355	780,444		163	
C12J	344	344	836,516		163	
C12K	479	479	914,593		163	
C12L	887	887	1,059,174	4,850,563	163	Vaal Dam
Tertiary	6498	6498				
C13A	595	595	96,985		163	
C13B	616	616	197,393		163	
C13C	837	837	333,824		163	
C13D	896	896	479,872		163	
C13E	603	603	578,161		163	
C13F	611	611	677,754		163	
C13G	435	435	748,659		163	
C13H	589	589	844,666		163	
Tertiary	5182	5182				
C21A	707	707	26,866		38	
C21B	431	431	43,244		38	

Quaternary	Gross	Net	Cumulative Sub-catchment			
Catchment	(km^2)	(km$^{2)}$	Sediment Load (t/a)	Sediment Load (t/a)	Sediment Yield (t/km^2.a)	Station Name
C21C	438	438	59,888		38	
C21D	446	446	76,836		38	
C21E	629	629	100,738		38	
C21F	427	427	116,964		38	
C21G	463	463	134,558		38	
Tertiary	3541	3541				
C22A	548	548	20,824		38	
C22B	392	392	35,720		38	
C22C	465	465	53,390		38	
C22D	345	345	66,500		38	
C22E	532	532	86,716		38	
C22F	440	440	103,436		38	
C22G	831	831	135,014		38	
C22H	454	454	152,266		38	
C22J	669	669	177,688		38	
C22K	434	434	194,180		38	
Tertiary	5110	5110				
C23A	258	258	9,804		38	
C23B	701	701	36,442		38	
C23C	1069	1069	77,064		38	
C23D	510	510	19,380		38	
C23E	850	633	32,300		38	
C23F	1324	1001	23,832	22,402	18	Klerkskraal Dam
C23G	613	613	24,724		38	
C23H	451	451	17,138		38	
C23J	890	890	5,340	5,180	6	Klipdrif
C23K	396	396	9,300	8,742	10	Boskop
C23L	1211	1211	152,380		38	
Tertiary	8273	7733				
C81A	382	382	62,266		163	
C81B	576	576	156,154		163	
C81C	250	250	196,904		163	
C81D	195	195	228,689		163	
C81E	643	643	333,498		163	
C81F	689	689	445,805		163	
C81G	435	435	516,710		163	
C81H	358	358	575,064		163	

Quaternary	Gross	Net	Cumulative Sub-catchment			
Catchment	**(km^2)**	**(km$^{2)}$**	**Sediment Load (t/a)**	**Sediment Load (t/a)**	**Sediment Yield (t/km^2.a)**	**Station Name**
C81J	392	392	638,960		163	
C81K	359	359	697,477		163	
C81L	795	795	827,062		163	
C81M	1093	1093	1,005,221		163	
Tertiary	6167	6167				
C82A	582	582	94,866		163	
C82B	493	493	175,225		163	
C82C	353	353	232,764		163	
C82D	572	572	326,000		163	
C82E	623	623	427,549		163	
C82F	484	484	506,441		163	
C82G	581	581	601,144		163	
C82H	783	783	728,773		163	
Tertiary	4471	4471				
C83A	746	746	81,314	78,875	109	Saulspoort Dam
C83B	251	251	23,845	23,130	95	Loch Athlone & Gerrands Dams
C83C	828	828	138,119		163	
C83D	465	465	213,914		163	
C83E	426	426	283,352		163	
C83F	875	875	425,977		163	
C83G	695	695	539,262		163	
C83H	547	547	628,423		163	
C83J	222	222	664,609		163	
C83K	548	548	753,933		163	
C83L	826	826	888,571		163	
C83M	1100	1100	1,067,871		163	
Tertiary	7529	7529				