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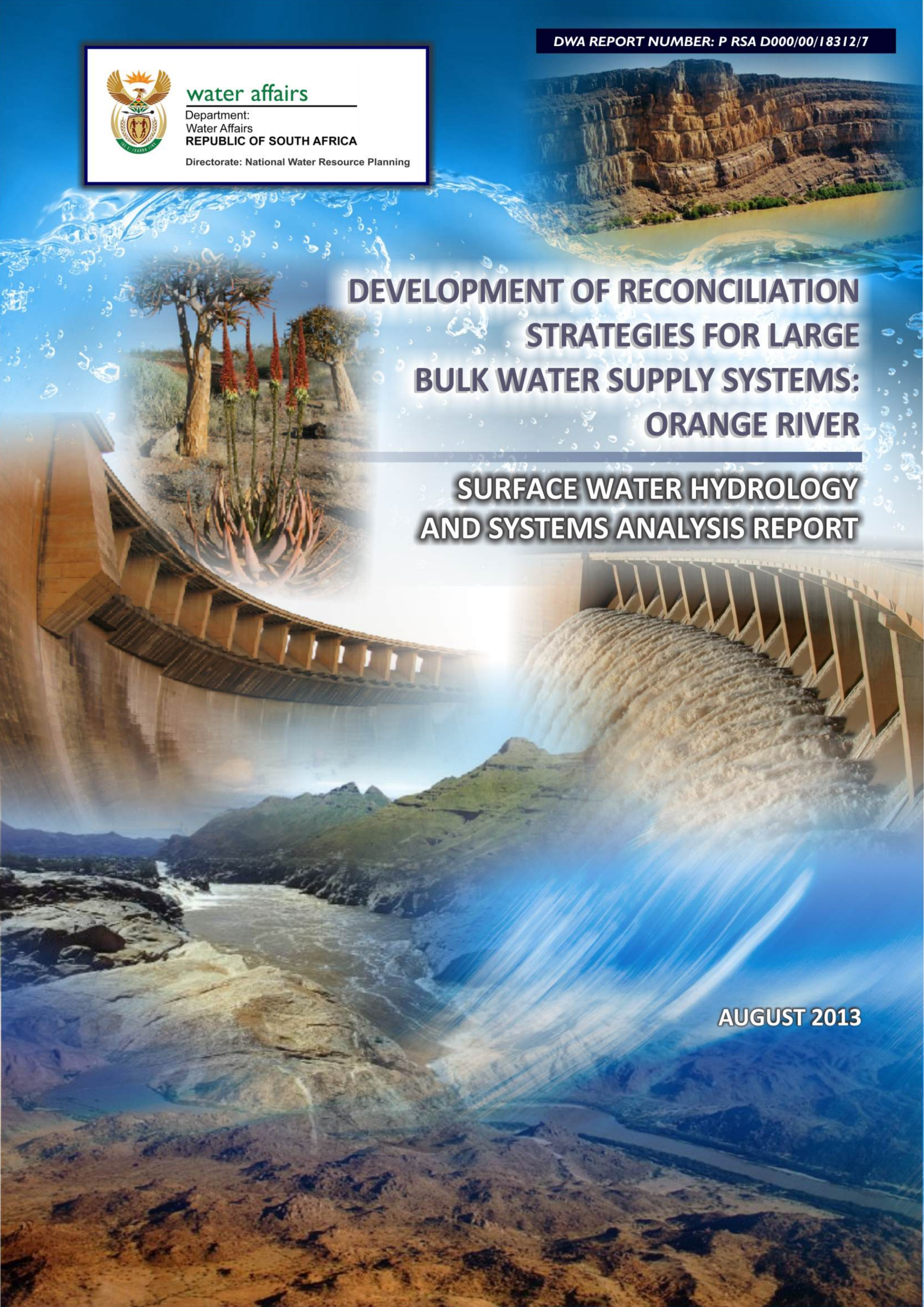

DEVELOPMENT OF RECONCILIATION STRATEGIES FOR LARGE BULK WATER SUPPLY SYSTEMS: ORANGE RIVER

SURFACE WATER HYDROLOGY AND SYSTEMS ANALYSIS REPORT

AUGUST 2013

DEVELOPMENT OF RECONCILIATION STRATEGIES FOR BULK WATER SUPPLY SYSTEMS:

ORANGE RIVER

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Prepared by:

WRP Consulting Engineers Aurecon, Golder Associates Africa, and Zitholele Consulting.

Report No. P RSA D000/00/18312/7

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Authors:	*Study Team*
Project Name:	***Development of Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River***
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LIST OF REPORTS

The following reports form part of this study:

Report Title	Report number
Inception Report	P RSA D000/00/18312/1
Literature Review Report	P RSA D000/00/18312/2
International obligations	P RSA D000/00/18312/3
Current and future Water Requirements	P RSA D000/00/18312/4
Urban Water Conservation and Water Demand Management	P RSA D000/00/18312/5
Irrigation Demands and Water Conservation/Water Demand Management	P RSA D000/00/18312/6
Surface Water Hydrology and System Analysis	**P RSA D000/00/18312/7**
Water Quality	P RSA D000/00/18312/8
Reserve Requirement Scenarios and Scheme Yield	P RSA D000/00/18312/7
Review Schemes and Update Cost Estimates	P RSA D000/00/18312/9
Preliminary Reconciliation Strategy Report	P RSA D000/00/18312/10
Final Reconciliation Strategy Report	P RSA D000/00/18312/11
Executive Summary	P RSA D000/00/18312/12

EXECUTIVE SUMMARY

The Department of Water Affairs (DWA) has identified the need for detailed water resource management strategies as part of their Internal Strategic Perspective (ISP) planning initiative which recommended studies to identify and formulate intervention measures that will ensure enough water can be made available to supply the water requirements for the next three to four decades.

As part of this process the need for the Reconciliation Strategy Study for the Large Bulk Water Supply Systems in the Orange River was also defined. Given the location of the Orange River System and its interdependencies with other WMAs as well as other countries, various water resource planning and management initiatives compiled during the past few years as well as those currently in progress will form an integral part of the strategy development process.

Since 1994, a significant driver of change in the water balance of the Orange River System was brought about by the storing of water in Katse Dam as the first component of the multi-phase Lesotho Highlands Water Project (LHWP). Currently Phase 1 of the LHWP (consisting of Katse, and Mohale dams, Matsoku Weir and associated conveyance tunnels) transfers 780 million cubic metres per annum via the Liebenbergsvlei River into the Vaal Dam to augment the continuously growing water needs of the Gauteng Province. Phase 2 of the LWHP comprising of Polihali Dam and connecting tunnel to Katse Dam is already in its planning stages. Polihali Dam is expected to be in place by around 2022. Flows that are currently still entering into Gariep and Vanderkloof dams will then be captured by Polohali Dam, thus reducing the inflow to Gariep and Vanderkloof dams. This will result in a reduction in yield of the Orange River Project (Gariep and Vanderkloof dams) to such an extent that shortages will be experienced in the ORP system. Some sort of yield replacement is then required in the Orange River to correct the yield versus demand imbalance in the ORP system. The objective of the study is to develop a reconciliation strategy for the bulk water resources of the Orange River System, to ensure that sufficient water can be made available to supply the current and future water needs for a 25 year planning horizon. This Strategy must be flexible to accommodate future changes in the actual water requirements and transfers, with the result that the Strategy will evolve over time as part of an on-going planning process.

Appropriate integration with other planning and management processes as well as cooperation among stakeholders will be key success factors in formulating coherent *recommendations and action plans.*

The purpose of this report

The Task reported on in this document is Task 10 of the study and is titled ***Surface Water Hydrology****. As part of the recently completed ORASECOM Study "Support to Phase II ORASECOM Basin Wide Integrated Water Resources Management Plan" (****ORASECOM, 2011****) the hydrology for the entire Orange basin was extended and improved in some places, now covering the total record period 1920 to 2004 hydrological years. The objective of this task was to review the hydrology as obtained from the ORASECOM Study with the focus on the sub-catchments of higher importance for existing and possible future schemes and related Reserve requirements. The review includes an assessment of the historical records, as well as carrying out the validation and verification tests on the stochastic hydrology. In addition, a parameter file including all the necessary stochastic variables was prepared for use in the systems models (under Task 12 of this study). The final objective was to undertake yield analyses using the new hydrology in order to determine any significant changes the hydrology may have on previously obtained system yields. Any differences were assessed in detail and explained.*

The hydrology was assessed and it was concluded that it can be used for systems analyses purposes. The extension confirmed that the additional years that were added on (mostly 1994-2004) have been comparatively wet years, and the extension should therefore not affect the yield of the system. The stochastic checks highlighted a potential issue in that the additional years resulted in a different ARMA model selection to that of before. This resulted in higher stochastic flows being generated. It was decided to select the same ARMA model as previously selected until further work can take place on this. A summary of the hydrology per subcatchment is presented in the following table.

Subcatchment	***Natural runoff (million m3/a)***	***Percentage of total natural runoff (%)***
Senqu	*4105*	*35*
Renoster	*132*	*1*
Riet - Modder	*380*	*3*
Vaal	*3201*	*27*
Lower Orange Main stem	*135*	*1*
Fish	*739*	*6*
Caledon	*1377*	*12*
Molopo	*135*	*1*
Upper Orange	*1191*	*10*
Schoonspruit	*109*	*1*
Lower Orange Tributories	*162*	*1*

Subcatchment	*Natural runoff (million m3/a)*	*Percentage of total natural runoff (%)*
Lower Vaal	*191*	*2*
TOTAL	*11858*	

The surplus system yield was determined to be 193 million m^3/a. This is slightly higher than the 120 million m^3/a previously determined in the LORMS study. The increase is mainly due to the update of demands in this study.

TABLE OF CONTENTS

APPENDICES

APPENDIX A: Detailed hydrology rating table

APPENDIX B: Stochastic review document

APPENDIX C: Vaal demands and return flows

APPENDIX D: Detailed Senqu, Caledon and Upper Orange water balance

APPENDIX E: Study Area

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

The Department of Water Affairs (DWA) has identified the need for detailed water resource management strategies as part of their Internal Strategic Perspective (ISP) planning initiative, which recommended studies to identify and formulate intervention measures that will ensure enough water can be made available to supply the water requirements for the next three to four decades.

The DWA Directorate: National Water Resource Planning (NWRP) therefore commenced the strategy development process in 2004 by initially focusing on the water resources supporting the large metropolitan clusters, followed by the systems supplying the smaller urban areas to systematically cover all the municipalities in the country.

As part of this process the need for the Reconciliation Strategy Study for the Large Bulk Water Supply Systems in the Orange River was also defined. Given the location of the Orange River System and its interdependencies with other WMAs as well as other countries (see study area description in **Section 1.3**), various water resource planning and management initiatives compiled during the past few years as well as those currently in progress will form an integral part of the strategy development process.

Major water resource infrastructure in the study area are the Gariep and Vanderkloof dams with associated conveyance conduits supporting large irrigation farming in the provinces of the Free State, Northern Cape and the Eastern Cape - through the Orange-Fish Tunnel. This system is currently almost in balance.

The Caledon-Modder System supplies water to the Mangaung-Bloemfontein urban cluster (largest urban centre in the study area). The 2 200 km long Orange-Senqu River is the lifeline for various industries, mines, towns and communities located along the way until the river discharges into the Atlantic Ocean in the far west at Alexander Bay.

Since 1994, a significant driver of change in the water balance of the Orange River System was brought about by the storing of water in Katse Dam as the first component of the multi-phase Lesotho Highlands Water Project (LHWP). Currently Phase 1 of the LHWP (consisting of Katse, and Mohale dams, Matsoku Weir and associated conveyance tunnels) transfers 780 million cubic metres per annum via the Liebenbergsvlei River into the Vaal Dam to augment the continuously growing water needs of the Gauteng Province. Phase 2 of the LWHP comprising of Polihali Dam and connecting tunnel to Katse Dam is already in its planning stages and is expected to be in place by 2022. Flows that are currently still entering into Gariep and Vanderkloof dams wil then be captured by Polohali Dam, thus reducing the inflow to Gariep and Vanderkloof dams. This will result in a reduction in yield of the Orange

River Project (Gariep and Vanderkloof dams) to such an extent that shortages will be experienced in the ORP system. Some sort of yield replacement is then required in the Orange River to correct the yield versus demand imbalance in the ORP system.

The above description illustrates the complex assortment of interdependent water resources and water uses which spans across various international and institutional boundaries that will be considered in the development of the Orange River Reconciliation Strategy.

1.2 Main Objectives of the Study

The objective of the study is to develop a reconciliation strategy for the bulk water resources of the Orange River System, to ensure that sufficient water can be made available to supply the current and future water needs of all the users up to the year 2040. This Strategy must be flexible to accommodate future changes in the actual water requirements and transfers, with the result that the Strategy will evolve over time as part of an on-going planning process.

Appropriate integration with other planning and management processes, as well as cooperation among stakeholders, will be key success factors in formulating coherent recommendations and action plans.

The outcomes of the Strategy will be specific interventions with particular actions needed to balance the water needs with the availability through the implementation of regulations, demand management measures, as well as infrastructure development options.

1.3 Study Area

As depicted in **Figure E-1** of **Appendix E**, the study will focus on the water resources of the Upper and Lower Orange River Water Management Areas (WMAs), while also considering all the tributary rivers and transfers affecting the water balance of the system. This core area forms part of the Orange-Senqu River Basin, which straddles four International Basin States with the Senqu River originating in the highlands of Lesotho, Botswana in the north eastern part of the Basin, the Fish River in Namibia and the largest area situated in South Africa.

The focus area of the study comprises only the South African portion of the Orange River Basin, excluding the Vaal River Catchment. The Vaal River is an important tributary of the Orange River, but since the Vaal River Reconciliation Strategy has already been developed, the Vaal River Catchment will not form part of the study area. However, strategies developed for the Vaal River System that will have an impact on the Orange River, will be taken into account as well as the impacts of flows from the Vaal into the Orange for selected Integrated Vaal system scenarios.

The Orange River is an international resource, shared by four countries i.e. Lesotho, South Africa, Botswana and Namibia. Any developments, strategies or decisions taken by any one of the countries that will impact on the water availability or quality in South Africa must be taken into account and will form part of this study. The opposite is also applicable. If this strategy plans anything in South Africa that will impact on any of the other countries, this impact must be considered as part of this study in terms of South Africa's international obligations.

The Orange River, the largest river in South Africa, has its origin in the high lying areas of Lesotho. The river drains a total catchment area of about 1 million km², runs generally in a westerly direction and finally discharges into the Atlantic Ocean at Alexander Bay.

The Caledon River, forming the north-western boundary of Lesotho with the Republic of South Africa (RSA), is the first major tributary of the Orange River. The Caledon and the Orange (called the Senqu River in Lesotho) rivers have their confluence in the upper reaches of the Gariep Dam.

Other major tributaries into the Orange River are:

- The Kraai River draining from the North Eastern Cape;
- The Vaal River joining the Orange River at Douglas;
- The Ongers and Sak Rivers draining from the northern parts of the Karoo;
- The Molopo and Nossob Rivers in Namibia, Botswana and the Northern Cape Province have not contributed to the Orange River in recorded history as the stream bed is impeded by sand dunes; and
- The Fish River draining the southern part of Namibia.

A separate study was also done for the Greater Bloemfontein Area i.e. Water Reconciliation Strategy Study for Large Bulk Water Supply Systems: Greater Bloemfontein Area with it's follow up continuation study currently in process. The recommendations of this strategy and its continuation study will also be taken into account in this study.

Although the Senqu River Catchment in Lesotho does not form part of the focus study area, the development in this catchment impacts directly on the water availability in the study area.

The South African portion of the Orange River Basin is currently divided in two Water Management Areas, i.e. the Upper and Lower Orange WMAs. The Upper WMA stretches from the headwaters of the Caledon River and Lesotho boundary down to the confluence of the Vaal River and the Lower Orange WMA from this point to the sea. (See **Figure E-1 in Appendix E**). It should be noted that the DWA recently proposed that the two WMAs are managed as a unit.

1.4 Purpose of this Report

The Task reported on in this document is Task 10 of the study and is titled **Surface Water Hydrology**. As part of the recently completed ORASECOM Study ‘‘Support to Phase ll ORASECOM Basin Wide Integrated Water Resources Management Plan” (**ORASECOM, 2011**) the hydrology for the entire basin was extended and improved in some places, now covering the total record period 1920 to 2004 hydrological years. The natural hydrology is in general not available on a quaternary catchment level but is based on larger sub-catchments that in most cases co-inside with key points in the basin such as dams and gauging weirs.

The objective of this task was to review the hydrology as obtained from the ORASECOM Study with the focus on the sub-catchments of higher importance for existing and possible future schemes and related Reserve requirements. The review includes an assessment of the historical records, as well as carrying out the validation and verification tests on the stochastic hydrology. In addition, a parameter file including all the necessary stochastic variables was prepared for use in the systems models (under Task 12 of this study). The final objective was to undertake yield analyses using the new hydrology in order to determine any significant changes the hydrology may have on previously obtained system yields. Any differences were assessed in detail and explained.

1.5 Structure of Report

This report has been structured into a number of different sections. Following this introduction is a section where the hydrology is reviewed. The entire basin and relevant neighboring catchments have been broken up into a number of hydrological zones, which are each reported on in their own sub-section. Each zone includes a locality map, a description of the zone, an explanation of the historical development of the hydrology and a rating score of the hydrology included in the zone. **Section 3** presents the results of the stochastic verification and validation tests, while **Section 4** presents the results of the yield analyses using the updated hydrology. **Section 5** includes conclusions and recommendations resulting from the work. The report also includes **Appendices** which contain additional and supporting information.

2 REVIEW OF HYDROLOGY

This chapter includes a review of the hydrology included in the Integrated Orange-Vaal systems models. The entire Orange Basin and relevant neighboring catchments have been divided up into 16 hydrological zones. These are presented in **Figure 2-1**. Each zone includes a number of different time series files representing different sub-catchments within the hydrological zone. There are a total of 207 different hydrological files included in the systems models. A summary of selected statistics per hydrological zone provides an overview of the Orange Basin in **Figure 2-2**, **Figure 2-3** and **Figure 2-4**.

Each review sub-section includes a locality map of the zone, indicating where the zone is located in the basin, as well as the boundaries of the various sub-catchments within the zone. These sub-catchments have been allocated reference numbers on the locality map which are included in a descriptive table within the section. The statistics of both the updated hydrology and the previous hydrology have been included for comparison purposes.

A description of the hydrological zone is provided along with an explanation of its importance to the Orange system. A history of the development of the hydrology within the zone is included, presenting all modifications that have taken place over time. A description of the methodology used to prepare the final ORASECOM hydrology is also included for each zone.

Finally, an overall rating of the hydrology has been assigned to each zone. This rating has been developed using a scoring system representing a number of factors including the density of rainfall gauges over the zone, the availability of observed streamflow data within the zone and available information regarding landuse data in the zone necessary for calibration. The score is somewhat subjective; however, it does provide a comparable indication of the confidence in hydrology between zones.

Figure 2-1: Orange River catchment base map and main hydrological zones

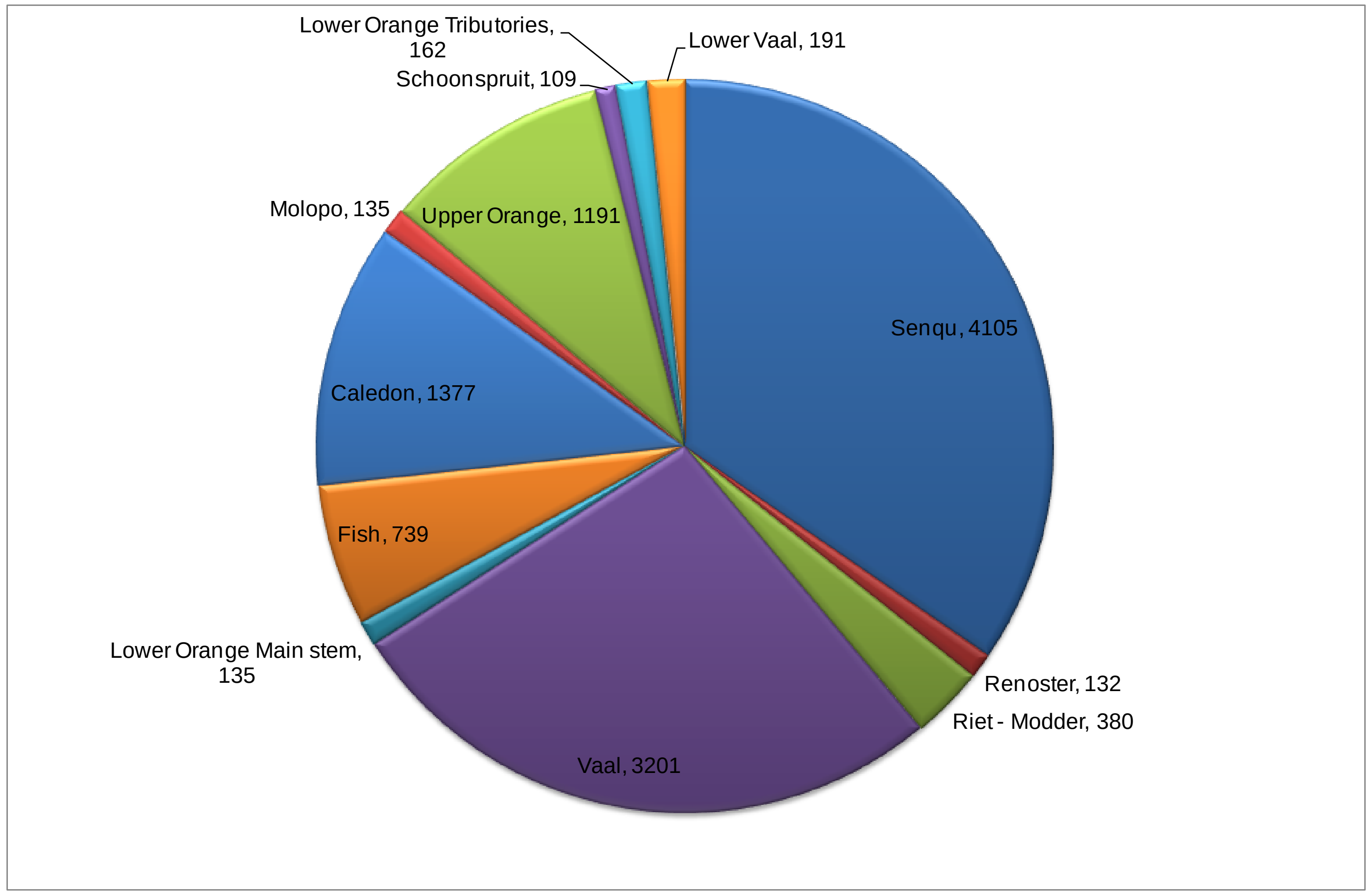

Figure 2-2: Orange basin runoff (million m^3/a) per hydrological zone, total: 11 858 million m^3/a

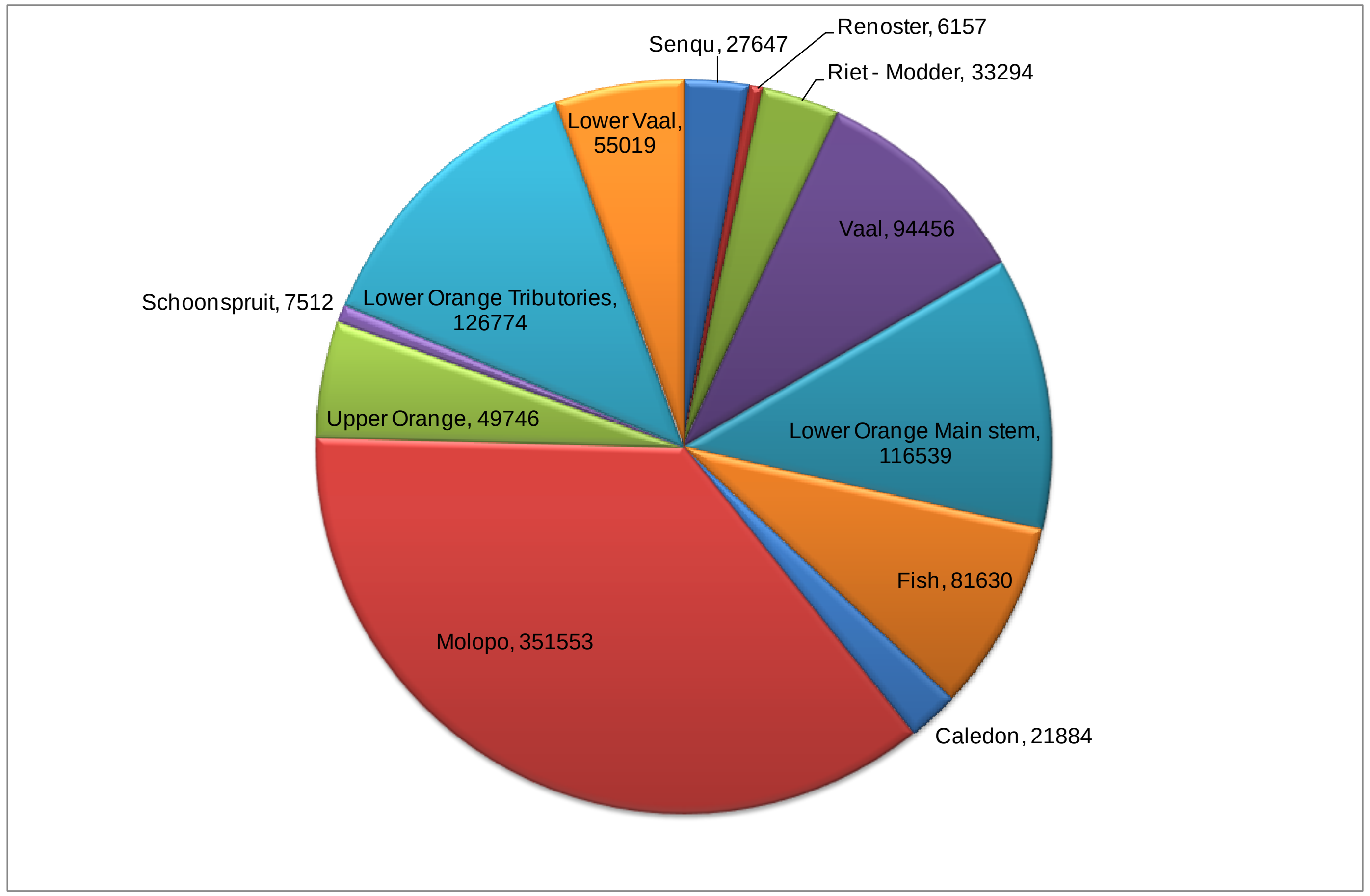

Figure 2-3: Orange basin hydrological zone areas (km^2), total: 972 211 km^2

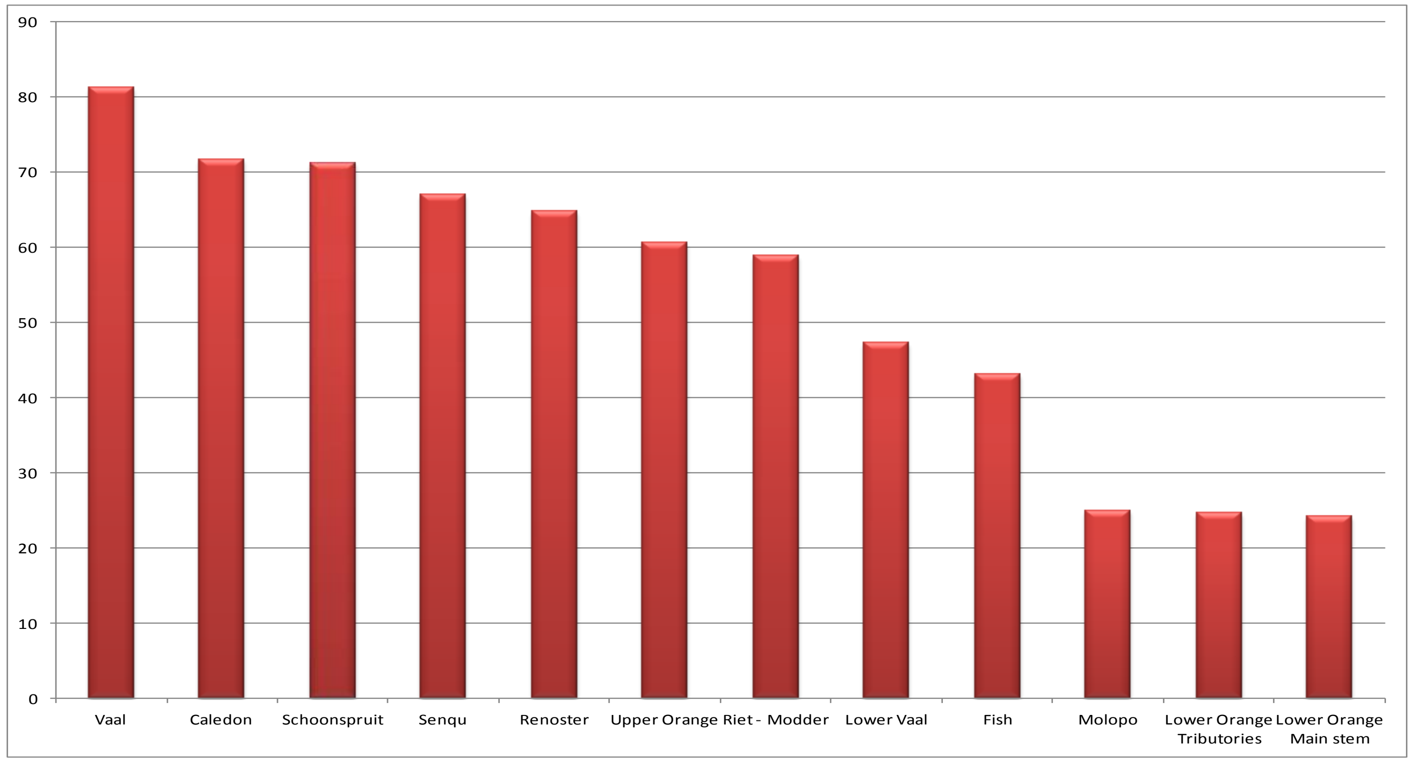

Figure 2-4: Rating score (%) per hydrological zone

2.1 Vaal

2.1.1 Locality Map

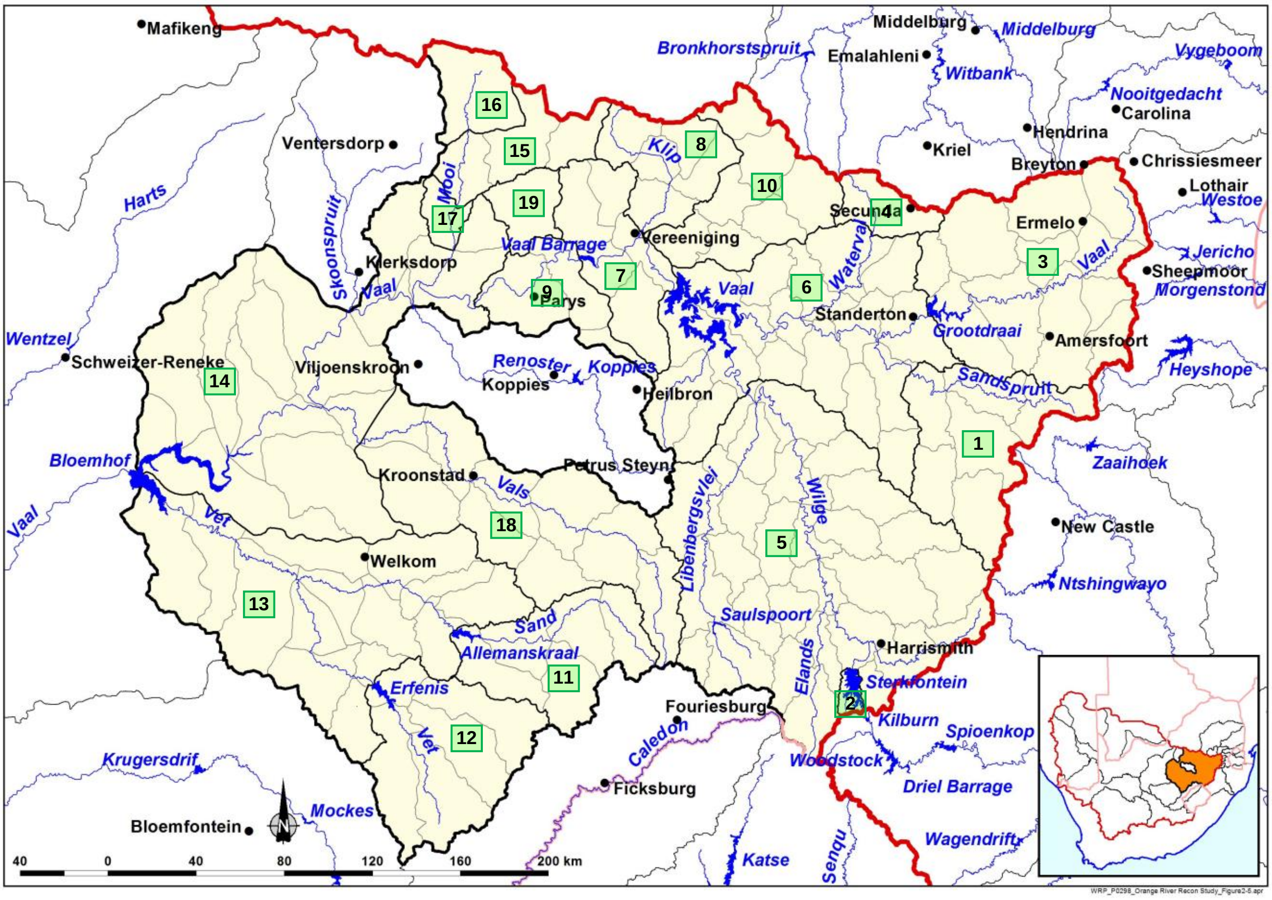

Figure 2-5: Vaal catchment locality map

2.1.2 Brief overview of hydrology

The Vaal River system is the main tributary of the Orange River and the most important water resource system in South Africa as it provides water to approximately 40+ % of South Africa's inhabitants and supports the production of approximately 50% of the country's gross domestic product. The catchment area contains 6 large dams and supplies major urban areas such as Johannesburg and Pretoria. It also supplies large industries such as SASOL, ESKOM and a multitude of gold and other mines. Several major inter-basin transfers occur from 4 adjacent catchments to supply the urban and industrial demands, and make the main stem highly regulated. The area of the Vaal River as indicated in **Figure 2-5** contributes 27% of the total natural runoff at the Orange River estuary. However due to the River being highly regulated and developed it currently only contributes significant flows to the total flow in the lower Orange River in above normal, high flow periods. The Vaal does, however contribute towards demands at Douglas via spills and return flows, which has downstream benefits.

2.1.3 Previous Hydrology History

The first time hydrology was produced for the Vaal River System, covering the period October 1920 to September 1984, was in 1985, during the Vaal River System Analysis Study (**DWAF, 1988**).

2.1 Vaal

In 1995 DWAF decided an update was required and the Vaal River System Analysis Update (VRSAU) study (**DWAF, 2001a**) was commissioned which included updates of the hydrology (period October 1920 to September 1995) and physical characteristics of the system. The hydrology was updated to include the drought in the eighties and the extremely low inflow during the early nineties, improving the confidence of the calibration of the hydrological models significantly. The only other modification to the Vaal catchment subsequent to the VRSAU was a split in the Vaal hydrology to separate quaternary catchment C12D in the Waterval River around SASOL Secunda (**DWAF, 2005a**).

2.1.4 ORASECOM hydrology development

During the GIZ Study for the Support to Phase 2 of the ORASECOM Basin-wide Integrated Water resources Management Plan (**ORASECOM, 2011**), the VRSAU hydrology (and other update studies for the area) was extended to cover the period 1920 to 2004. This was carried out by extending catchment rainfall records with new observed data and simulating the natural runoff sequences up to 2004 using the same model calibration parameters as used during the VRSAU and update studies.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	**MAR (million m^3/annum)**	**Locality map reference**	**Param.dat order no.**	**Hydrology reference name**	**MAR (million m^3/annum)**	**Standard deviation**	**Coefficient of variation**
FRAN9	733.31	1	7	FRAN4	760.01	645.15	0.85
STERK9	18.12	2	19	STERK4	19.53	14.83	0.76
GROOTD9	457.68	3	8	GROOTD4	462.02	375.21	0.81
C12D	76.08	4	205	C12D4	77.38	49.17	0.64
DELA9	249.49	5	5	DELA4	261.14	216.56	0.83
VAAL9R	441.94	6	21	VAAL4	493.19	463.45	0.94
BARR9	68.50	7	2	BARR4	72.24	55.66	0.77
KLIPR9	96.24	8	12	KLIPR4	102.66	79.22	0.77
KROMN3	40.86	9	14	KROMN4	42.04	40.23	0.96
SUIK9	92.34	10	20	SUIK4	99.87	98.20	0.98
ALLEM9	96.13	11	1	ALLEM4	94.90	85.21	0.90
ERF9	167.46	12	6	ERF4	163.59	151.48	0.93
SANDN3	156.65	13	18	SANDN4	160.21	162.66	1.02
BLOEMN3D	129.27	14	3	BLOEMN3D4	130.60	148.06	1.13
BOSK9	35.78	15	4	BOSK4	37.54	17.24	0.46
KLERK9	37.69	16	9	KLERK4	39.73	29.17	0.73
LAKESN3	9.39	17	197	LAKESN4	9.68	7.32	0.76
KLIPBN3	150.77	18	10	KLIPBN4	153.29	147.05	0.96
KLIPDN3	20.26	19	11	KLIPDN4	21.19	23.10	1.09

2.1.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 81% is given to this area. The lowest score is for rainfall density due to some oversights in available rainfall data in the Upper Vaal area. The detailed scoring table is presented in **Appendix A**.

2.2 Schoonspruit

2.2.1 Locality Map

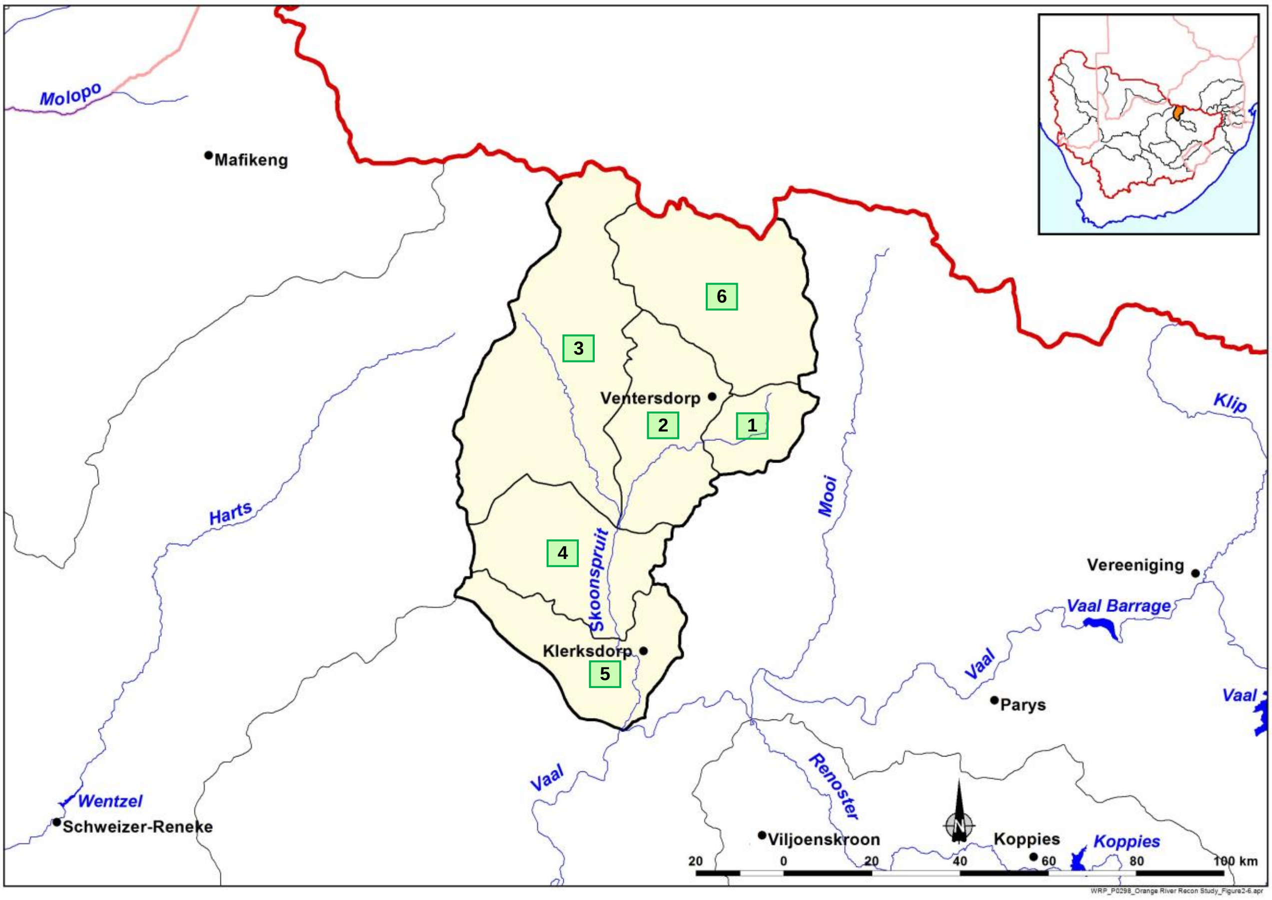

Figure 2-6: Schoonspruit catchment locality map

2.2.2 Brief overview of hydrology

The Schoonspruit River is a tributary of the Vaal River. It only contributes approximately 1% of the total natural runoff at the Orange River Estuary and 3% to the natural runoff of the Vaal River. The River therefore does not contribute significantly to the flow in the Orange River, especially for present day conditions. The upper reaches of the River is fed by a large dolomitic aquifer that contributes 46% of the Rivers natural runoff. The catchment has a few small dams and direct use of the dolomites for irrigation and Ventersdorp town prompted a surface-groundwater investigation to estimate the effects of dolomitic abstractions on downstream users.

2.2.3 Previous Hydrology History

The Vaal River System Analysis Study (**DWAF, 1988**) of 1985 was the first analysis of the Schoonspruit River, which was subsequently updated during the Vaal River System Analysis Update (VRSAU) (**DWAF, 2001a**) study during 1995, where the hydrology and physical characteristics of the system were updated. In 2006 a Schoonspruit Sub-System Analysis Study (**DWAF, 2006**) was undertaken on the Schoonspruit Eye, since abstractions from the dolomitic aquifer started influencing allocation decisions in the downstream Johan Neser Dam. This was the first time that the Sami Groundwater-Surface water interaction model (which was recently incorporated into the DWA Systems Models) was successfully used to simulate large scale abstractions from dolomitic aquifers, improving the surface water hydrology significantly.

2.2 Schoonspruit

2.2.4 ORASECOM hydrology development

During the GIZ/ORASECOM hydrology extension the Schoonspruit Sub-System Analysis Study hydrology was improved by extending catchment rainfall records with new observed data and simulating extended natural and present day scenario runoff sequences to 2004 using the same Sami model calibration parameters as used during the Sub-System Study.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	**MAR (million m^3/annum)**	**Locality map reference**	**Param.dat order no.**	**Hydrology reference name**	**MAR (million m^3/annum)**	**Standard deviation**	**Coefficient of variation**
C24D	7.29	1	128	C24D4	7.35	10.35	1.41
C24E	9.81	2	129	C24E4	9.81	14.78	1.51
C24F	19.50	3	130	C24F4	19.55	28.77	1.47
C24G	16.85	4	131	C24G4	16.91	24.68	1.46
C24H	8.83	5	132	C24H4	8.50	13.41	1.58
C24C	47.90	6	59	C24CEYE4	46.82	24.94	0.53

2.2.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 71% is given to this area. The lowest score is given to the coverage of the flow gauging stations. The detailed scoring table is presented in **Appendix A**.

2.3 Renoster

2.3 Renoster

2.3.1 Locality Map

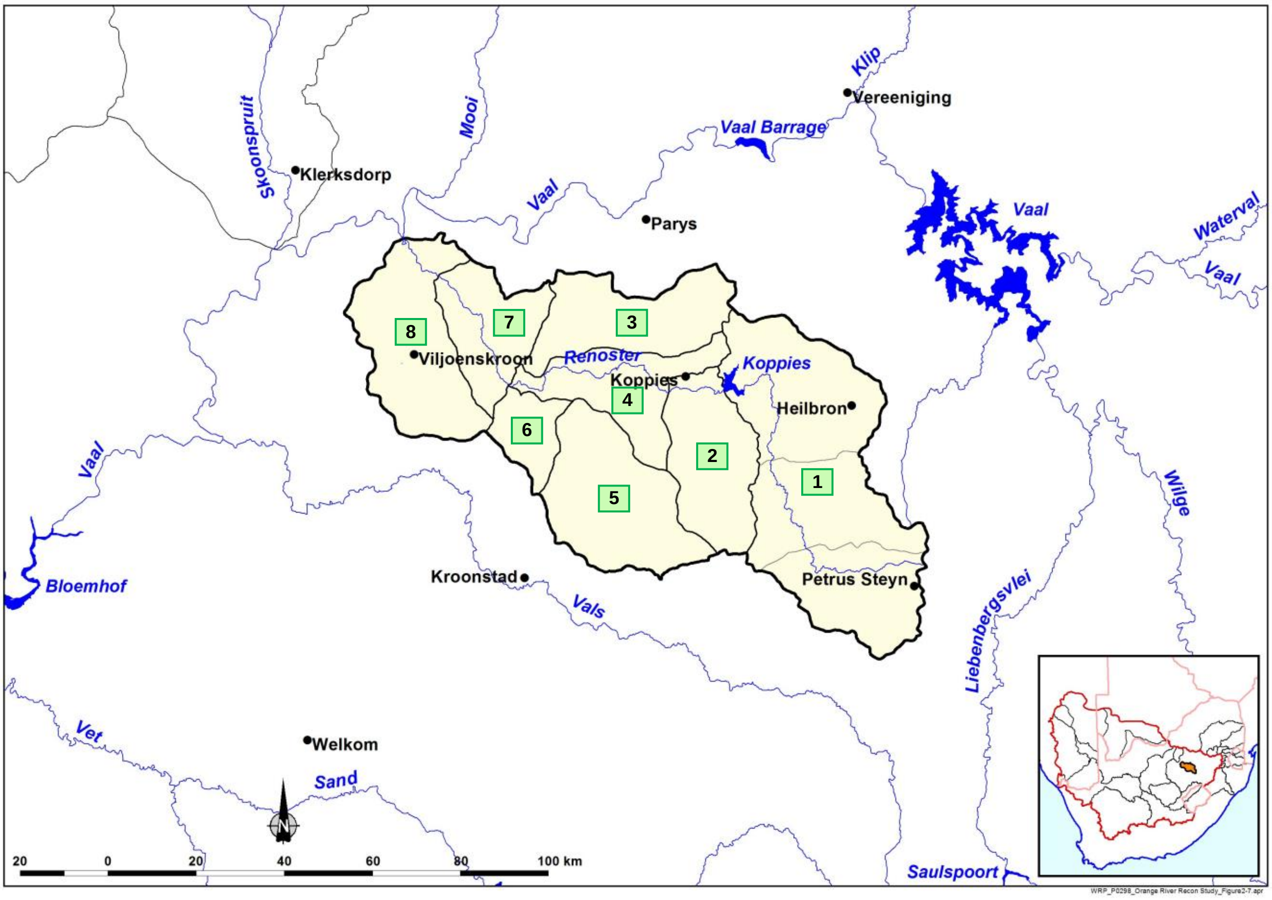

Figure 2-7: Renoster catchment locality map

2.3.2 Brief overview of hydrology

The Renoster River is a tributary of the Vaal River. Koppies Dam is the only major dam in the catchment and is mainly used for irrigation purposes. As with the Schoonspruit, the Renoster only contributes approximately 1% of the total natural runoff at the Orange River Estuary and 3% to the natural runoff of the Vaal River. The River therefore does not contribute significantly to the flow in Orange River especially for present day conditions.

2.3.3 Previous Hydrology History

The Renoster River was first calibrated as part of the Vaal River System Analyses study (**DWAF, 1988**). At that stage the hydrology extended from 1920 to 1987 and was simulated as one file. The hydrology was updated and extended to 1994 as part of the Vaal River Systems Analysis Update study (**DWAF, 2001a**). The hydrology was further refined as part of the System Analysis of the Renoster River for Voorspoed Mine Assurance of Supply (**DWAF, 2005b**). The VRSAU hydrology was refined to a finer spatial resolution during this study

2.3 Renoster

2.3.4 ORASECOM hydrology development

The most recent hydrology available for the Renoster catchment was prepared as part of the GIZ/ORASECOM study. The hydrology was extended from an end date of 1994 till 2004 by extending catchment rainfall records from the Voorspoed Mine study model configurations and simulating natural hydrology up to 2004 using the same calibration parameters.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
KOP9	59.14	1	13	C70ABC4	61.11	52.91	0.87
C70D	12.58	2	191	C70D4	12.60	11.52	0.91
C70E	11.96	3	192	C70E4	11.97	10.89	0.91
C70F	9.46	4	193	C70F4	9.46	8.60	0.91
C70G	13.95	5	194	C70G4	14.16	12.64	0.89
C70H	3.99	6	195	C70H4	3.98	3.62	0.91
C70J	8.58	7	196	C70J4	8.58	7.76	0.90
C70K	10.92	8	127	C70K4	10.25	11.08	1.08

2.3.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 65% is given to this area. The lowest score is for coverage of flow gauging stations. The detailed scoring table is presented in **Appendix A**.

2.4 Lower Vaal

2.4.1 Locality Map

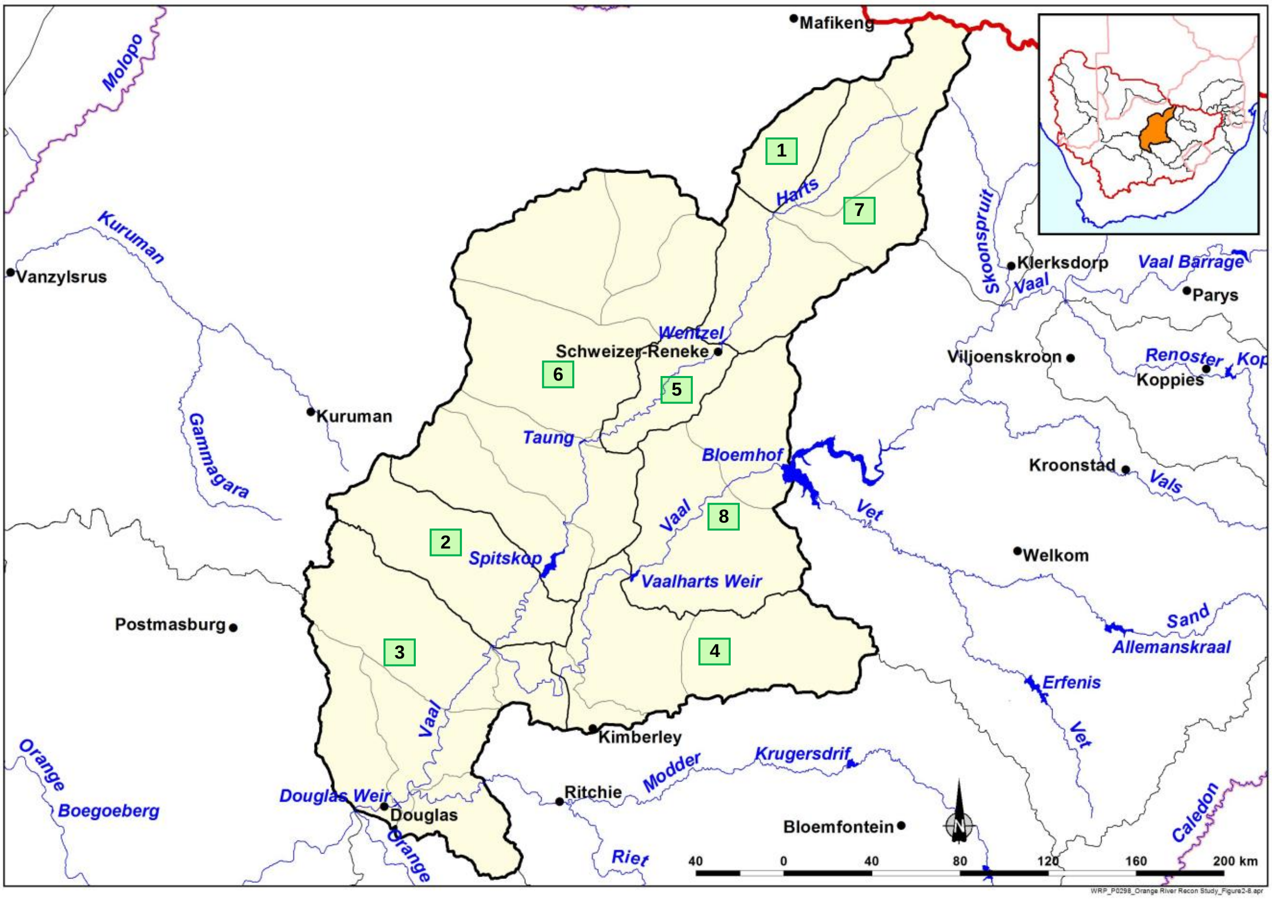

Figure 2-8: Lower Vaal catchment locality map

2.4.2 Brief overview of hydrology

The Lower Vaal catchment includes the Harts River and three sub-catchments on the Vaal main stem. The Harts River is a tributary of the Vaal River that joins the Vaal just before the confluence of the Vaal and the Orange Rivers. This relatively large arid area has a very low natural runoff (3 mm/a) and only contributes 2% of the total natural runoff at the Orange River Estuary and 6% of the natural runoff of the Vaal River (excluding losses). The area indicated in **Figure 2-8** is dominated by the Vaalharts Irrigation Scheme and the upstream Bloemhof Dam which makes this stretch of River highly regulated up to the confluence with the Orange. The flows from the Harts River and the Bloemhof Dam releases, however, have an effect on the water supply at Douglas Weir, due to their close proximity to the Weir. The Harts River flow at the confluence with the Vaal mainly consists of releases from Spitskop Dam for the Vaal-Harts Irrigation Scheme as well as return flows from the scheme.

2.4.3 Previous Hydrology History

The Vaal-Harts System was first calibrated as part of the Vaal River System Analyses study (**DWAF, 1988**). At that stage the hydrology extended from 1920 to 1987. The hydrology was updated and extended to 1994 as part of the Vaal River Systems Analysis update study (**DWAF, 2001a**). A detailed study took place in the area assessing the Feasibility of Taung Dam (**DWAF, 2007**), however the hydrology was not modified.

2.4 Lower Vaal

2.4.4 ORASECOM hydrology development

During the GIZ/ORASECOM project, the VRSAU hydrology for this area was extended to cover the period 1920 to 2004. Additional work, however, had to be carried out for this catchment since the VRSAU hydrology was found to have significant long term trends in the natural runoff time series. The rainfall had to be corrected and the models recalibrated against the part of the original natural runoff time series that did not show any trend.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
BARBERS	3.18	1	180	BARBERS4	2.94	4.44	1.51
C3H013	11.69	2	183	C3H0134	11.71	39.08	3.34
C9H007	18.59	3	184	C9H0074	18.63	62.15	3.34
DEHOOP9	12.93	4	35	DEHOOP4	15.32	25.07	1.64
DSWENTZD	13.09	5	182	DSWENTZD4	12.11	18.27	1.51
SPITS9	77.49	6	37	SPITS4	81.29	141.23	1.74
USWENTZD	42.69	7	181	USWENTZD4	39.49	59.58	1.51
VHARTS9	11.16	8	39	VHARTS4	9.97	18.29	1.84

2.4.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 47% is given to this area. The lowest score is for the flow gauging stations density (number). The detailed scoring table is presented in **Appendix A**.

2.5 Riet - Modder

2.5 Riet - Modder

2.5.1 Locality Map

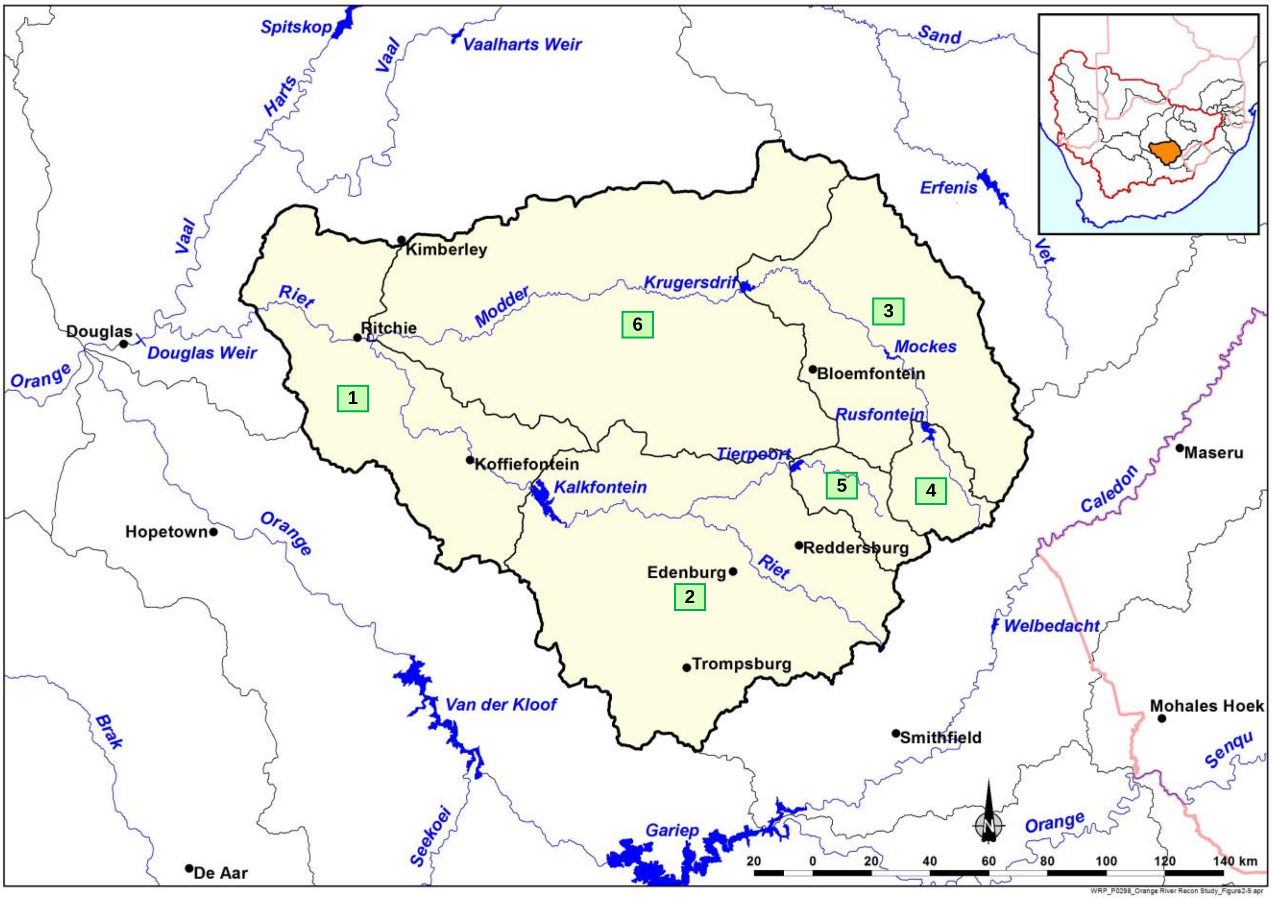

Figure 2-9: Riet - Modder catchment locality map

2.5.2 Brief overview of hydrology

The Riet River is a tributary of the lower Vaal River, and in turn has the Modder River as tributary. The Riet-Modder River contributes approximately 3% of the total natural runoff at the Orange River Estuary and 8% to the natural runoff of the Vaal River. The hydrology of this catchment is characteristically high unit runoff in the upstream areas (between 22 - 33 mm/a) and low unit runoff (1 and less than 1 mm/a) for downstream areas. There are 5 relatively large dams in the catchment area with large amounts of irrigation water use as well as support to urban and rural towns and some mining demands. A transfer takes place from the neighboring Caledon River to Rustfontein Dam to support demands downstream on the Modder River. The Riet-Modder River system does not have a significant contribution to the total flows in the Lower Orange but does play a role in supplying the demands at Douglas weir by means of spills and return flows.

2.5.3 Previous Hydrology History

The Riet-Modder System was first calibrated as part of the Vaal River System Analyses study (**DWAF, 1988**). At that stage the hydrology covered the period from 1920 to 1987. The hydrology was updated and extended to 1994 as part of the Vaal River Systems Analysis Update study (**DWAF, 2001a**). Other studies were also undertaken in this area to improve the estimates of landuse, i.e. Kalkfontein Dam: Hydrology and Yield Analysis Desktop Study (**DWAF, 2002a**) and Upper Orange River and Modder-Riet Rivers Validation and Verification Study (**DWAF, 2008a**)

2.5 Riet - Modder

2.5.4 ORASECOM hydrology development

During the GIZ/ORASECOM project, the VRSAU hydrology for this area was extended to cover the period 1920 to 2004. Additional work, however, had to be carried out for this catchment since the VRSAU hydrology was found to have significant long term trends in the natural runoff time series. The rainfall had to be corrected and the models recalibrated against the part of the original natural runoff time series that did not show any trend. This caused a 5% reduction in the MAR

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
AUCH9	6.37	1	40	AUCH4	5.80	18.13	3.12
KALKF9	215.88	2	41	KALKF4	185.85	270.33	1.45
KRUG9	114.43	3	42	KRUG4	118.06	129.84	1.10
RUSTF9	30.67	4	43	RUSTF4	30.96	41.80	1.35
TIER9	23.76	5	44	TIER4	23.23	29.43	1.27
TWEE9	14.38	6	45	TWEE4	15.67	24.36	1.56

2.5.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 59% is given to this area. The lowest score is for the number and coverage of flow gauging stations in the lower parts of the catchment. The detailed scoring table is presented in **Appendix A**.

2.6 Senqu

2.6 Senqu

2.6.1 Locality Map

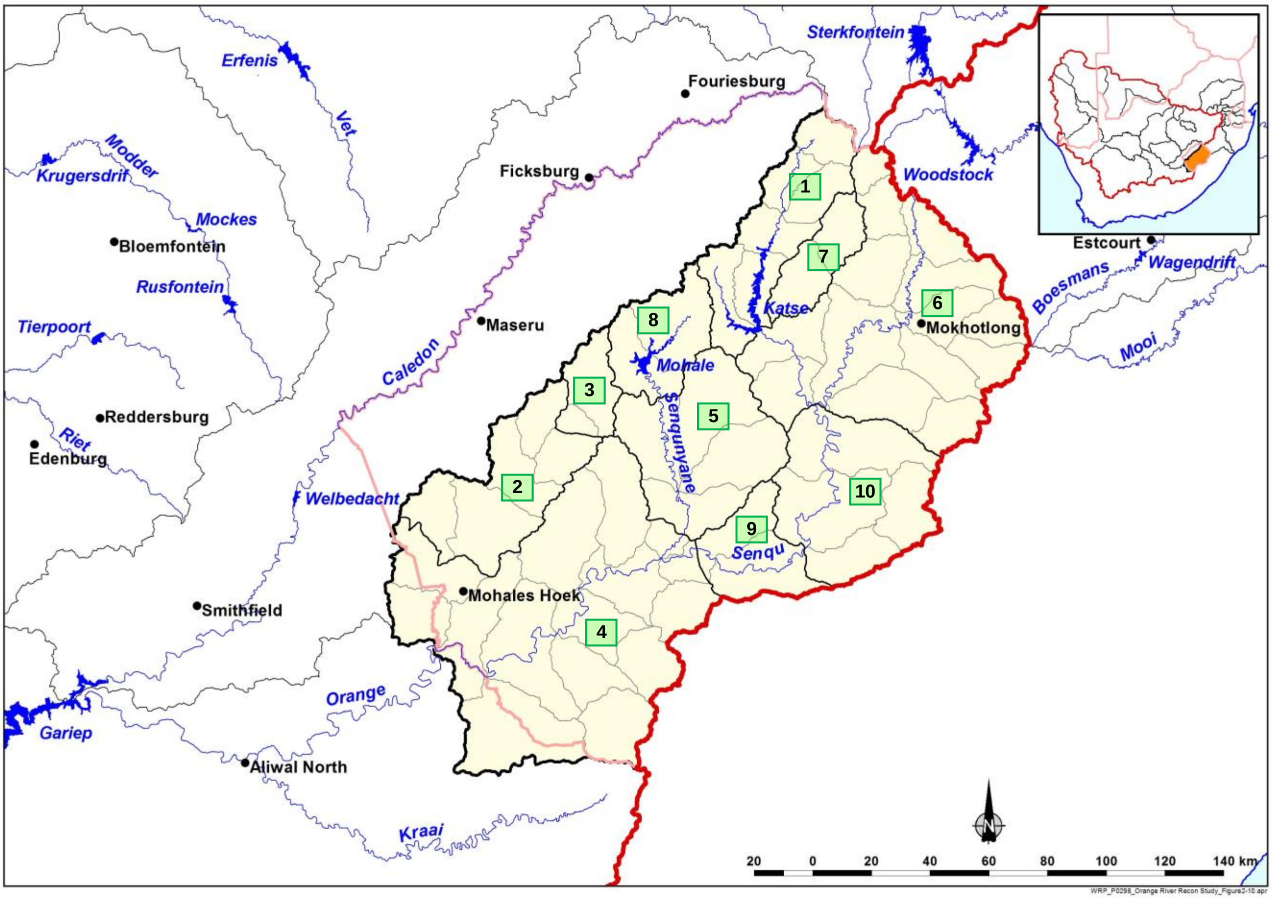

Figure 2-10: Senqu catchment locality map

2.6.2 Brief overview of hydrology

The Senqu River originates in the mountainous Kingdom of Lesotho and (along with the Caledon River) is the main source of the Orange River. It contributes 35% of the total natural runoff at the Orange River Estuary, although the gross area of the catchment is only 2.8% of the total Orange River catchment area. The Senqu catchment has a natural unit runoff of 155 mm/a. The Senqu contributes approximately 68% of the present inflow to Gariep Dam. Two large dams (Katse and Mohale Dams) have been built in the high runoff areas to export water to South Africa. The rest of the catchment has very low water demands from rural towns with no significant irrigation or farm dams.

2.6 Senqu

2.6.3 Previous Hydrology History

A number of studies have been carried out in the past to estimate monthly River flows at the various dam sites planned for inclusion in the Lesotho Highlands Water Project (LHWP) for design purposes and in computation of royalties payable to Lesotho. Some of the earliest studies were done in the mid-80s, however, the hydrology that was eventually agreed on was developed in the Joint Lesotho Highlands Development Authority and South African Department of Water Affairs and Forestry Study on the Senqu River Basin (**LHDA/DWAF, 1996**). The study was carried out in close cooperation between the two countries and resulted in a hydrological and rainfall database that stretched from 1935 to 1995. The hydrology and rainfall data was subsequently extended to start in 1920 for use in the VRSAU study (**DWAF, 2001a**). The Makhaleng catchment was closely assessed as part of the Lesotho Lowlands Water Supply Scheme Feasibility Study (**LLWSSF, 2004**) which was commissioned by the Kingdom of Lesotho. Hydrology for the Makhaleng catchment, previously part of the Oranjedraai catchment hydrology was produced.

2.6.4 ORASECOM hydrology development

During the ORASECOM Study the hydrological models were configured using the original patched rainfall data to ensure consistency with the original study. Although Lesotho flow data was used for incremental calibration purposes, the Oranjedraai weir in South Africa was used as the main check for calibration purposes. In addition, an inflow record was calculated for Katse Dam from detailed measured information and calibrated against. The original hydrology was only extended. The hydrology produced during the Lesotho Lowlands Study for Makhaleng was considered for inclusion in the ORASECOM hydrology. However, the calibrated Makhaleng hydrology of the ORASECOM study was very different when compared with the Lesotho Lowlands Study hydrology, especially with regards to low flows, and it was therefore not incorporated into the final hydrological database. The Lesotho Lowlands Hydrology is available for scenario analysis purposes when needed.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality Map Ref.	Param.dat order no	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of Variation
KAT9	546.00	1	27	KAT10	559.44	231.28	0.41
ORAN9	1542.68	2	178	MAKABS	354.83	182.01	0.51
		3	179	MAKDAM	169.70	87.05	0.51
		4	33	ORAN10	1018.20	522.31	0.51
MAL9	284.42	5	28	MAL10	291.72	146.16	0.50
MAS9	775.15	6	29	MAS10	792.91	440.50	0.56
MAT9	93.96	7	30	MAT10	98.11	51.36	0.52
MOH9	301.79	8	31	MOH10	303.24	125.23	0.41
NTO9	150.89	9	32	NTO10	154.55	87.00	0.56
TSO9	353.80	10	34	TSO10	362.64	180.92	0.50

2.6.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 67% is given to this area. The lowest score is for the rainfall station density. The detailed scoring table is presented in **Appendix A**.

2.7 Caledon

2.7.1 Locality Map

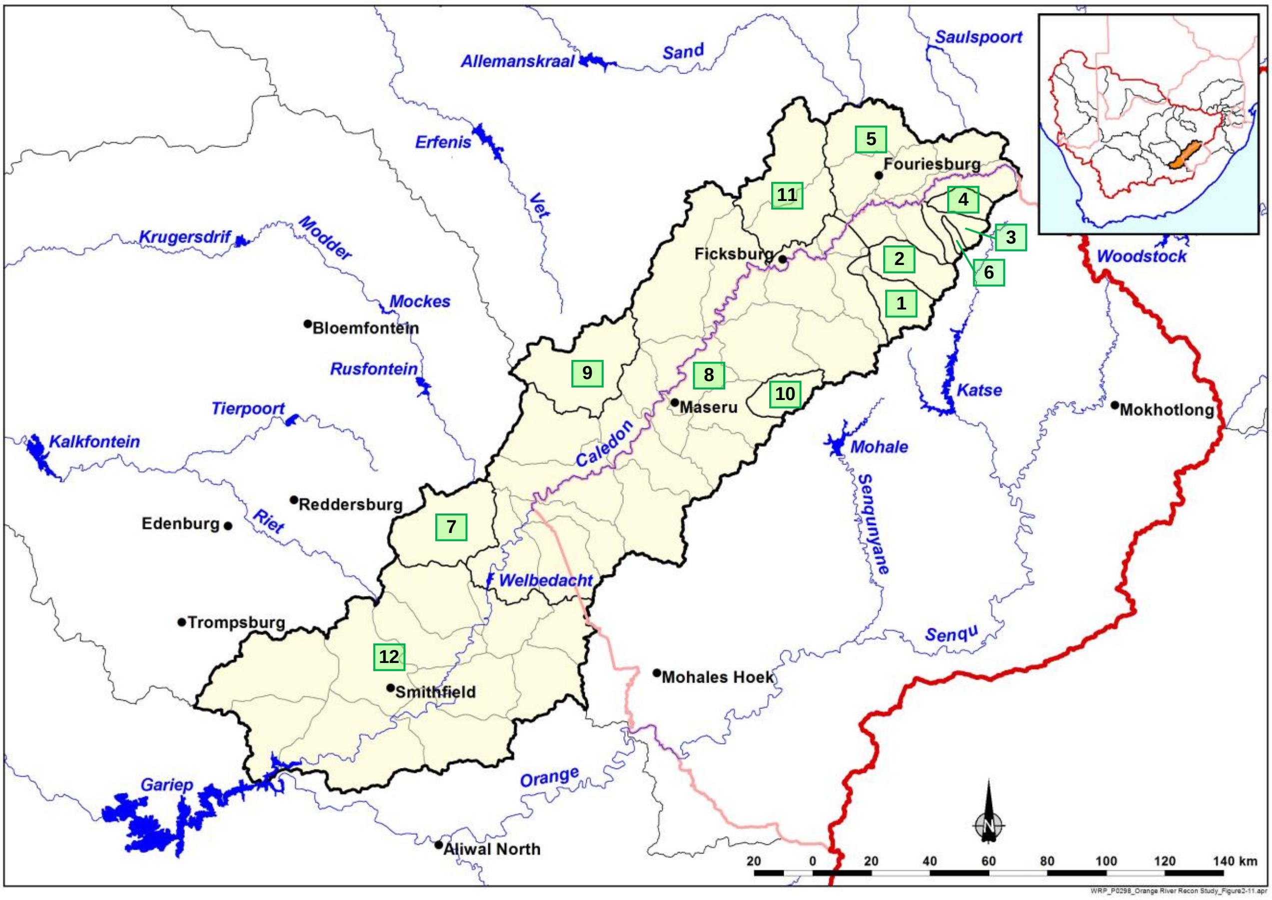

Figure 2-11: Caledon catchment locality map

2.7.2 Brief overview of hydrology

The Caledon River is an important catchment for the Orange River and it also originates in the same Lesotho mountainous areas as the Senqu River. It contributes 12% of the total natural runoff at the Orange River Estuary, with a gross area of 2.3% of the total Orange catchment area, and a natural unit runoff of 62 mm/a (between 21 and 282 mm/a). There are several major dams and a multitude of farm dams in the catchment, an inter-basin transfer to Rustfontein Dam in the neighboring Modder catchment, and extensive irrigation throughout the catchment. The Caledon also supports the town of Maseru in Lesotho and several smaller towns in South Africa including Ficksburg and Ladybrand. The Caledon contributes approximately 19% of the present inflow to Gariep Dam.

2.7.3 Previous Hydrology History

The first systems analysis for this region was carried out during the Orange River Systems Analysis Study (ORSA) (**DWAF, 1993**), where hydrology was generated for the period 1920 to 1987. The Vaal Augmentation Planning Study (VAPS) (**DWAF, 1994**) was the most recent review of the system and was carried out in 1994. No improvements were made to the hydrology from the ORSA study during the VAPS – the hydrology was only disaggregated into a finer spatial resolution to investigate augmentation options.

2.7 Caledon

The VAPS hydrology was the information used in the DWA Systems model before the ORASECOM update to the hydrology. The Lesotho Lowlands Water Supply Scheme Feasibility Study which was commissioned by the Kingdom of Lesotho to investigated potential water resource developments for the Lesotho Lowlands areas was also applicable for the Caledon catchment (**LLWSSF, 2004**). Several dam sites and abstraction points were considered, including the Hololo and Hlotse catchments. The Kingdom of Lesotho also carried out a study for the Metalong Dam (**LWSPU, 2003**) which is under construction and falls in the Caledon Catchment.

2.7.4 ORASECOM hydrology development

During the GIZ/ORASECOM study it was decided to recalibrate the hydrological models for the Caledon catchment, since the previous hydrological analysis was carried out more than 15 years ago and no proper calibration could be obtained at the time. To a large extent, the WR2005 hydrological model configurations were used as a basis, with several improvements to the rainfall data, network configuration, irrigation and primary use demands, dam characteristics and farm dam estimates. During this study, Lesotho flow gauge information was used to verify high flow runoff areas, and the models were calibrated at 5 gauging stations. The hydrology from the Lesotho Lowlands Project was incrementally used for the Hololo and Hlotse catchments, however the Metalong hydrology was not used due to the hydrology having significantly different low flows when compared with the Welbedacht Dam and Jammersdrift incremental catchment hydrology as generated during the ORASECOM study. The original Metalong hydrology is however available for scenario analysis.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
HLOTS9	188.94	1	173	HLOABS	103.94	43.72	0.42
		2	70	HLODAM	99.48	43.39	0.44
KATJE9	296.87	3	175	HOLABS	43.72	24.71	0.57
		4	174	HOLDAM	36.34	16.59	0.46
		5	71	KATJREST	206.83	138.47	0.67
		6	177	MUELA	5.91	3.34	0.57
KNEL9	20.83	7	72	KNELL	17.57	23.20	1.32
WELB9	629.80	8	78	WELINC	556.42	430.91	0.77
		9	176	ARMEN	30.08	27.63	0.92
		10	172	METO	61.83	47.88	0.77
WATER9	80.38	11	77	WATER	63.64	59.84	0.94
Previously part of HFDU9 and VERW9 (see Upper Orange)		12	207	D24	151.65	221.84	1.46

2.7.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 72% is given to this area. The lowest score is for the density of observed flow gauges. The detailed scoring table is presented in **Appendix A**.

2.8 Upper Orange

2.8.1 Locality Map

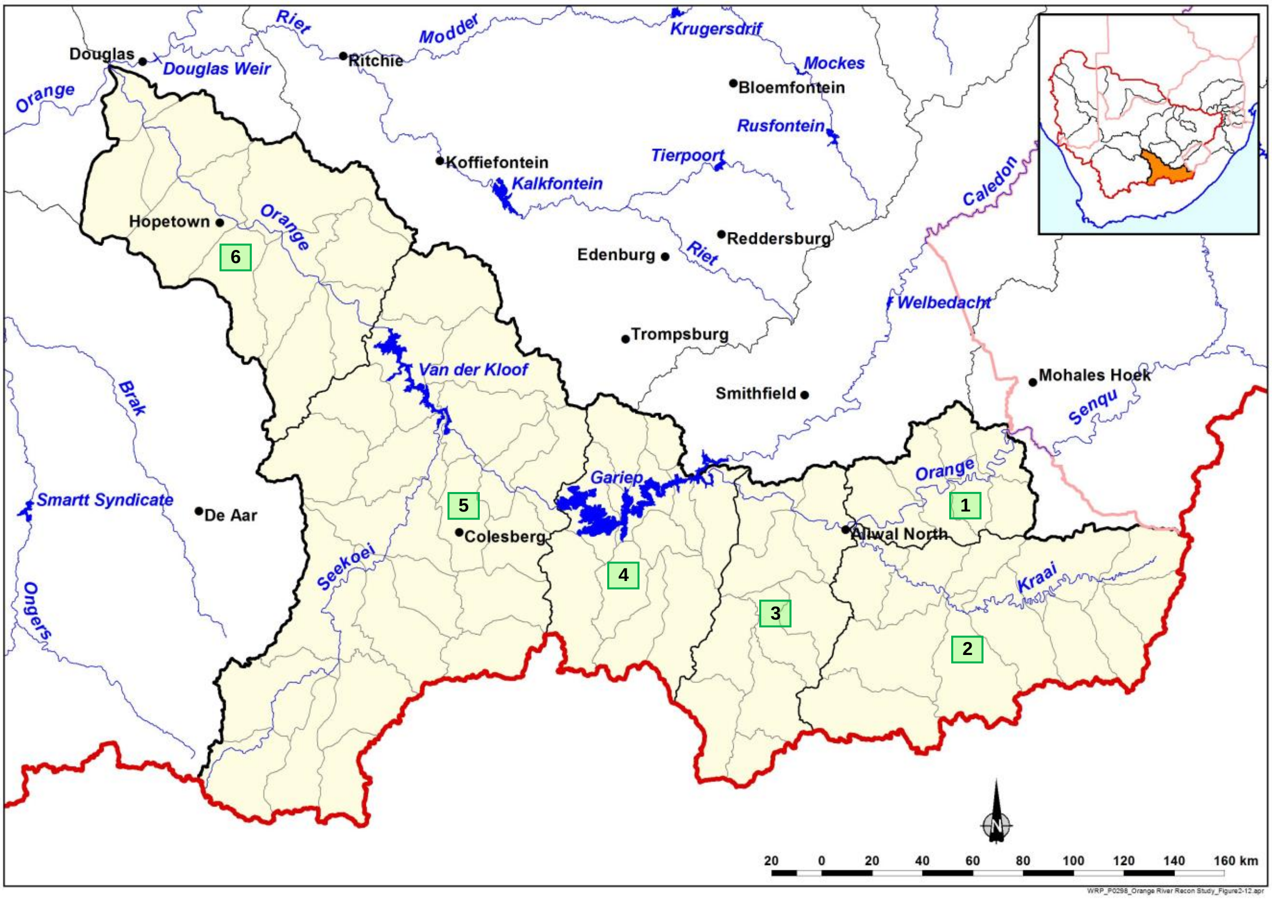

Figure 2-12: Upper Orange catchment locality map

2.8.2 Brief overview of hydrology

As for the Caledon River, the Upper Orange catchment has high runoff areas in the upper reaches (Kraai River) and very low runoff in the lower reaches. The natural unit runoff varies between 1 and 70 mm/a, and contributes approximately 10 % of the natural runoff at the Orange River Mouth. The flow in the main stem of the Orange River in this catchment is largely due to upstream inflows from the Senqu and Caledon catchments (+/- 90%). The local runoff is, however, important for water supply of numerous rural towns and irrigation from farm dams. The catchment boasts the two largest dams in South Africa (Gariep and Vanderkloof Dams) which supply urban and significant irrigation demands in the Eastern Cape as well as large scale irrigation downstream from Vanderkloof Dam plus several towns along the main Orange.

2.8.3 Previous Hydrology History

As for the Caledon, the Upper Orange was also part of the Orange River Systems Analysis (**DWAF, 1993**) and the Vaal Augmentation Planning Studies (**DWAF, 1994**) (ORSA/VAPS), where hydrology was generated for the period 1920 to 1987. The VAPS that was done in 1994 also improved the hydrology's fine spatial resolution for this area for augmentation options analysis. The VAPS hydrology was used in the DWA Systems model before the ORASECOM update to the hydrology.

2.8 Upper Orange

2.8.4 ORASECOM hydrology development

During the GIZ/ORASECOM study it was decided to recalibrate the hydrological models for the entire area as for the Caledon, since the previous hydrological analysis was done more than 15 years ago and difficulties were experienced at the time to obtain a reasonable calibration. To a large extent, the WR2005 hydrological model configurations were used as basis with several improvements to the rainfall data, network configuration, irrigation and primary use demands, dam characteristics and farm dam estimates. Although good calibrations were obtained for the Gariep and Vanderkloof inflows, there were only 4 local flow gauging stations that could be used to estimate the low runoff of the local catchments for this large catchment area. These limited calibrations were then used for parameter transfer to other non-gauged catchments.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
ALIW9 and ROOD9	905.74	1	67	D12	165.74	167.66	1.01
		2	74	D13	719.01	509.55	0.71
HFDU9 and VERW9(1)	397.23	3	75	D14	127.82	193.47	1.51
		4	69	D35	56.62	106.97	1.89
PKDU9	147.41	5	73	VDK	108.05	258.49	2.39
Previously part of BOEG9 (see Lower Orange Main Stem)		6	15	D33	14.24	29.95	2.10

Notes: (1) HFDU9 and VERW9 includes D14, D34, and D24

2.8.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 61% is given to this area. The lowest score is for the density of local hydrology observed flow gauges. The detailed scoring table is presented in **Appendix A**.

2.9 Lower Orange Main Stem

2.9.1 Locality Map

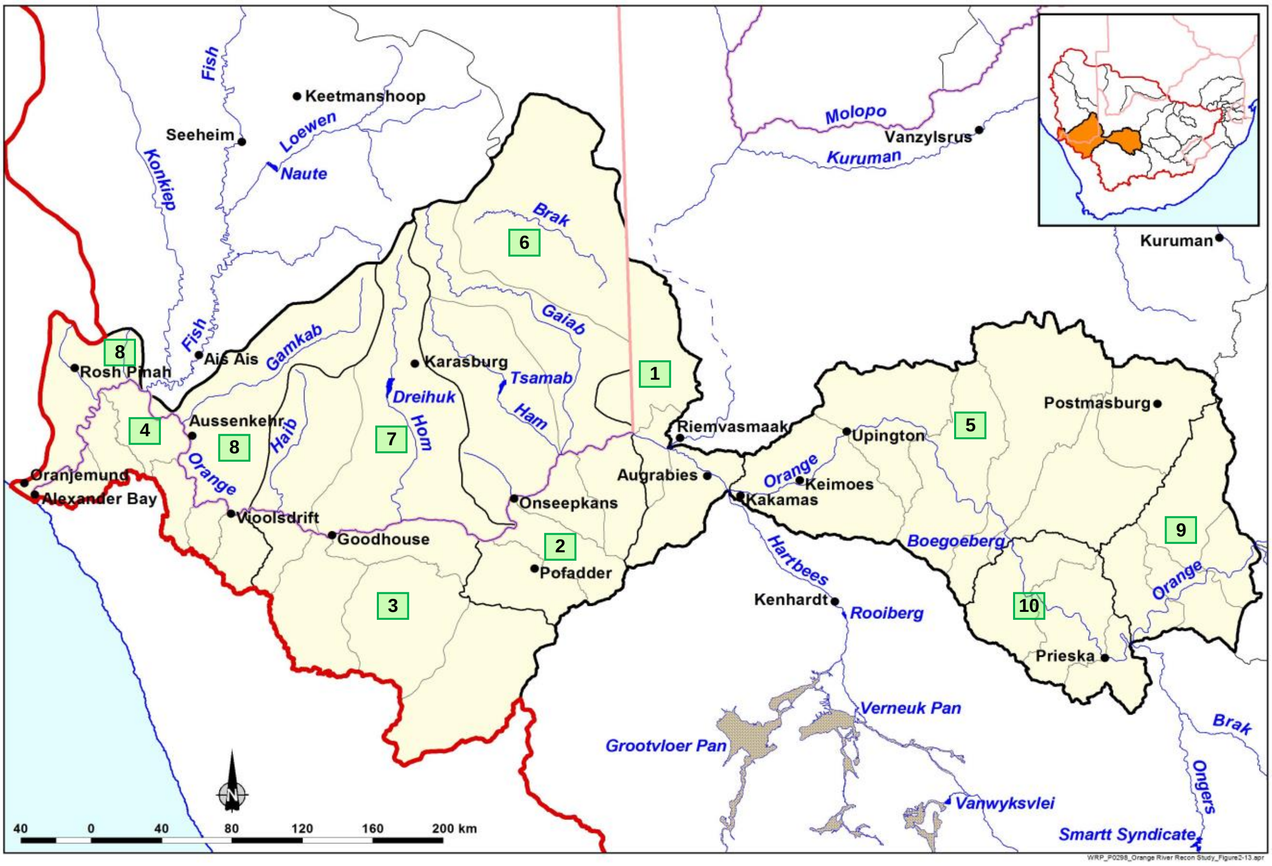

Figure 2-13: Lower Orange Main Stem catchment locality map

2.9.2 Brief overview of hydrology

The Lower Orange Main Stem is a very arid area with nearly no local runoff and only contributes 1% of the total natural runoff at the Orange River Estuary. The average MAE this area is 2600 mm/a. The combination between high evaporation and water availability make this area very suitable for high levels of irrigated commercial agriculture all along the main stem of the River. The main stem of the River is highly regulated through the upstream Gariep, Vanderkloof and Bloemhof Dams. There is a significantly large amount of commercial irrigation supplied from weirs in the main stem of the Orange. In addition, water use consists of minor dams on the Namibian side of the main stem and towns such as Upington, Prieska, Gabis, Oranjemund and Alexander Bay. The main stem of the Orange has very large evaporative losses and the catchment area has large endoreic areas that both contribute to the low local runoff.

2.9.3 Previous Hydrology History

Due to the limited local runoff flow gauging stations and the overwhelming flow in the main stem that dwarfs the local runoff, it is nearly impossible to calibrate a hydrological model on the main stem to estimate local runoff. The only previous estimates for natural runoff in this area came from the Surface Water Resources of South Africa Study (WR90) (**WRC, 1990**) completed by the Water Research Commission during the 1990s. The flow records were mostly generated by parameter transfers from measured areas over the period 1920 – 1989 and only extended to the main stem on the South African side. The WR90 estimates were used in the DWA Systems model until recently.

2.9 Lower Orange Main Stem

2.9.4 ORASECOM hydrology development

During the GIZ/ORASECOM Study the update to the WR90 Study (Water Resources of South Africa, 2005 (WR2005)) (**WRC, 2005**) hydrological model configurations were used as a basis to extend the natural hydrology to 2004. The WR2005 data were, however, revised by improving the network configuration and obtaining flow data from Namibia and including natural runoff estimates for the catchments on the Namibian side of the Orange River main stem.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
VIOOL9(1)	140.60	1	165	LOGR13	4.48	9.84	2.20
		2	166	LOGR14	3.14	5.84	1.86
		3	167	LOGR16	4.59	9.42	2.05
		4	169	LOGR18	1.60	5.71	3.58
		5	157	LOGR5	21.07	47.98	2.28
Portions not included previously		6	171	LOGR15	53.08	123.63	2.33
		7	168	LOGR17	13.02	31.75	2.44
		8	170	LOGR19	4.49	11.02	2.45
BOEG9(2)	77.55	9	155	LOGR3	17.45	41.89	2.40
		10	156	LOGR4	11.60	28.39	2.45

Notes: (1) VIOOL9 includes LOGR5, LOGR6, LOGR7, LOGR8, LOGR9, LOGR10, LOGR11, LOGR12, LOGR13, LOGR14, LOGR16, LOGR18, COM1113, COM2124, COM22, COM2327, GRO, D41ARED, D41B, D41C, D41D, D41E, D41F, D41G, D41J, D42A, D42B, D42C, D42D, D42E, D42F, D42G, D43C, D44C, D44D, D45C, D45D

(2) BOEG9 includes LOGR3, LOGR4, LOGR1, LOGR2 and D33

2.9.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 24% is given to this area. The lowest score is for the limited observed flow gauges that measures local runoff. The detailed scoring table is presented in **Appendix A**.

2.10 Molopo

2.10.1 Locality Map

2.10 Molopo

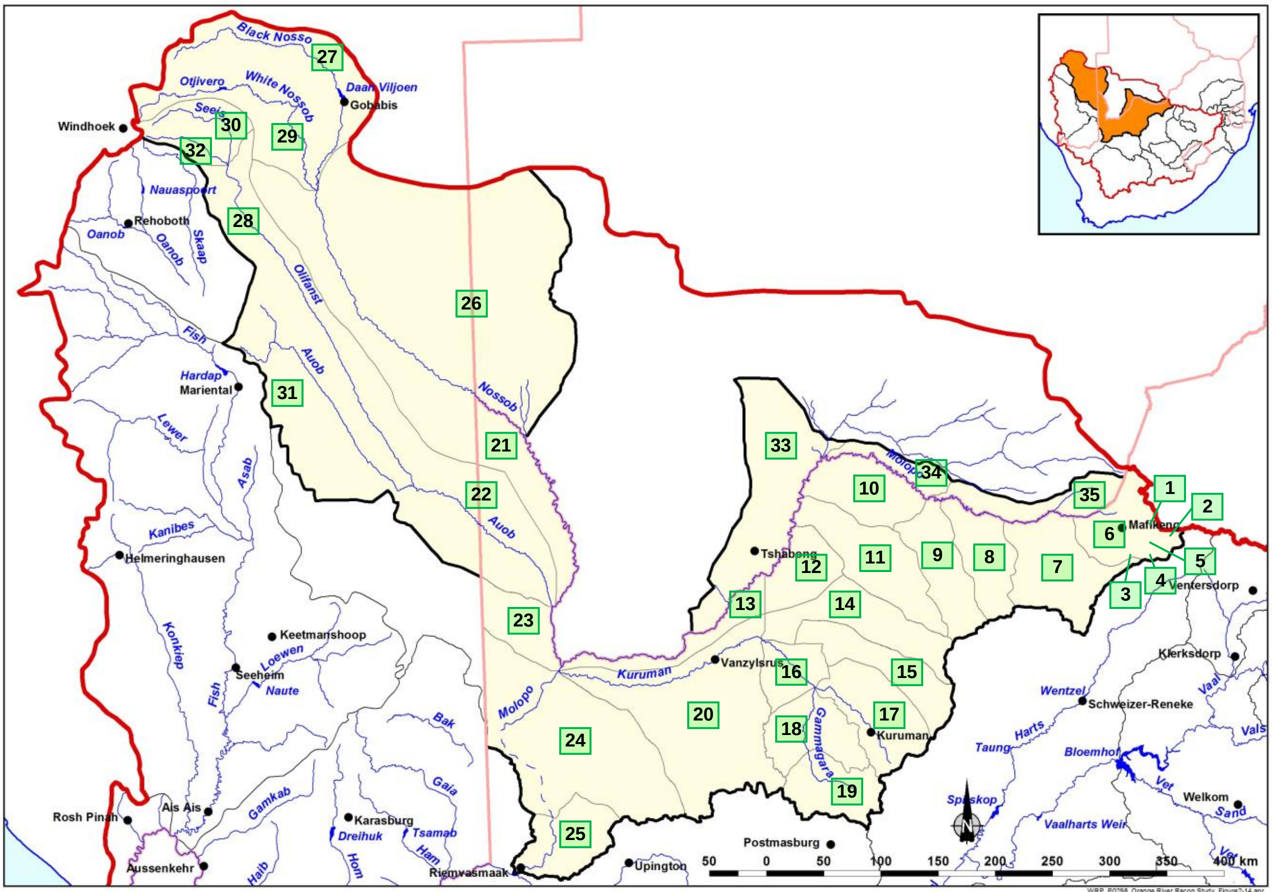

Figure 2-14: Molopo catchment locality map

2.10.2 Brief overview of hydrology

The Molopo River is an ephemeral tributary of the Orange–Senqu system, with its main tributary the Kuruman River, receiving the majority of its flow from tributaries in the Republic of South Africa, most of which have now been dammed for urban and agricultural purposes. As a result, inflow to the main stem of the Molopo River, which forms the boundary between Botswana and South Africa, has become heavily reduced and even non-existent in some years. The Nossob River, and its main tributary the Auob River, originate in Namibia and later form the south-western boundary between Botswana and South Africa down to its confluence with the Molopo River. Dams have been constructed in the upper reaches of the Nossob River in Namibia. The controversial contribution of the River system to the Orange River Estuary would be less than 1% under natural conditions, due to large endoreic areas and sand dunes before the confluence with the Orange. None of the flows generated in the catchment reach the Orange Main Stem, however, the River system is important for a local supply perspective.

2.10.3 Previous Hydrology History

The DWA Systems models have previously not had any estimates of runoff contributions from the Molopo/Nossob catchment. ORASECOM undertook a study during 2009 called the Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse (**ORASECOM, 2009**). The study generated hydrological time series for this arid area with nearly non-existing observed flow data. WR90 parameter transfers were used for the Botswana and Namibia areas and assumptions were made regarding endoreic areas and River losses. A detailed investigation into the D41A quaternary catchment refined this hydrology further in the preparation of an operating rule for Mafikeng in the Stand Alone Dams Study (**DWA, 2012b**).

2.10.4 ORASECOM hydrology development

2.10 Molopo

The GIZ/ORASECOM Study used the ORASECOM Molopo/Nossob feasibility study hydrology and loss estimates as is. The only changes that were made were the catchment delineations and the introduction of the South African quaternary catchment numbering system to avoid catchment borders following political boundaries and to ensure that catchment numbers reflect major Rivers. The hydrology prepared in the Stand Alone Dams Study for D41A was used without modifications.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
Previously part of VIOOL9 (see Lower Orange Main Stem)		1	151	COM1113	0.27	0.88	3.30
		2	66	COM2124	10.82	4.95	0.46
		3	154	COM22	2.78	1.21	0.43
		4	153	COM2327	0.02	0.14	6.89
		5	152	GRO	0.12	0.74	6.22
		6	17	D41ARED	5.06	8.12	1.61
		7	48	D41B	12.76	18.49	1.45
		8	49	D41C	9.65	17.03	1.76
		9	50	D41D	5.99	11.05	1.84
		10	51	D41E	0.67	1.30	1.94
		11	52	D41F	1.94	3.81	1.96
		12	60	D41G	0.85	1.86	2.21
		13	139	D41J	0.10	0.40	3.96
		14	61	D42A	1.58	3.43	2.18
		15	53	D42B	7.13	12.67	1.78
		16	65	D42C	0.89	1.64	1.85
		17	64	D42D	18.02	45.45	2.52
		18	63	D42E	4.53	12.37	2.73
		19	62	D42F	3.66	10.07	2.75
		20	140	D42G	1.05	3.89	3.69
		21	136	D43C	0.22	0.88	3.97
		22	137	D44C	0.01	0.05	5.51
		23	138	D44D	0.01	0.06	4.80
		24	141	D45C	0.03	0.12	4.42
		25	142	D45D	0.24	1.04	4.29
Portions not included previously		26	150	D43B	15.83	38.37	2.42
		27	144	DVILJ	1.15	2.53	2.19
		28	36	LOLIF	2.10	7.73	3.67
		29	143	OTJV	1.15	2.53	2.19
		30	56	SEEIS	0.88	2.48	2.82
		31	24	UAUB	4.17	15.01	3.60
		32	55	UOLIF	0.59	1.66	2.82
		33	47	D41K	0.64	1.52	2.37
		34	46	D41M	3.57	11.38	3.19
		35	38	D41N	16.84	56.73	3.37

2.10.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 25% is given to this area. The lowest score is for the density of observed flow gauges. The detailed scoring table is presented in **Appendix A.**

2.11 Lower Orange Tributaries

2.11 Lower Orange Tributaries

2.11.1 Locality Map

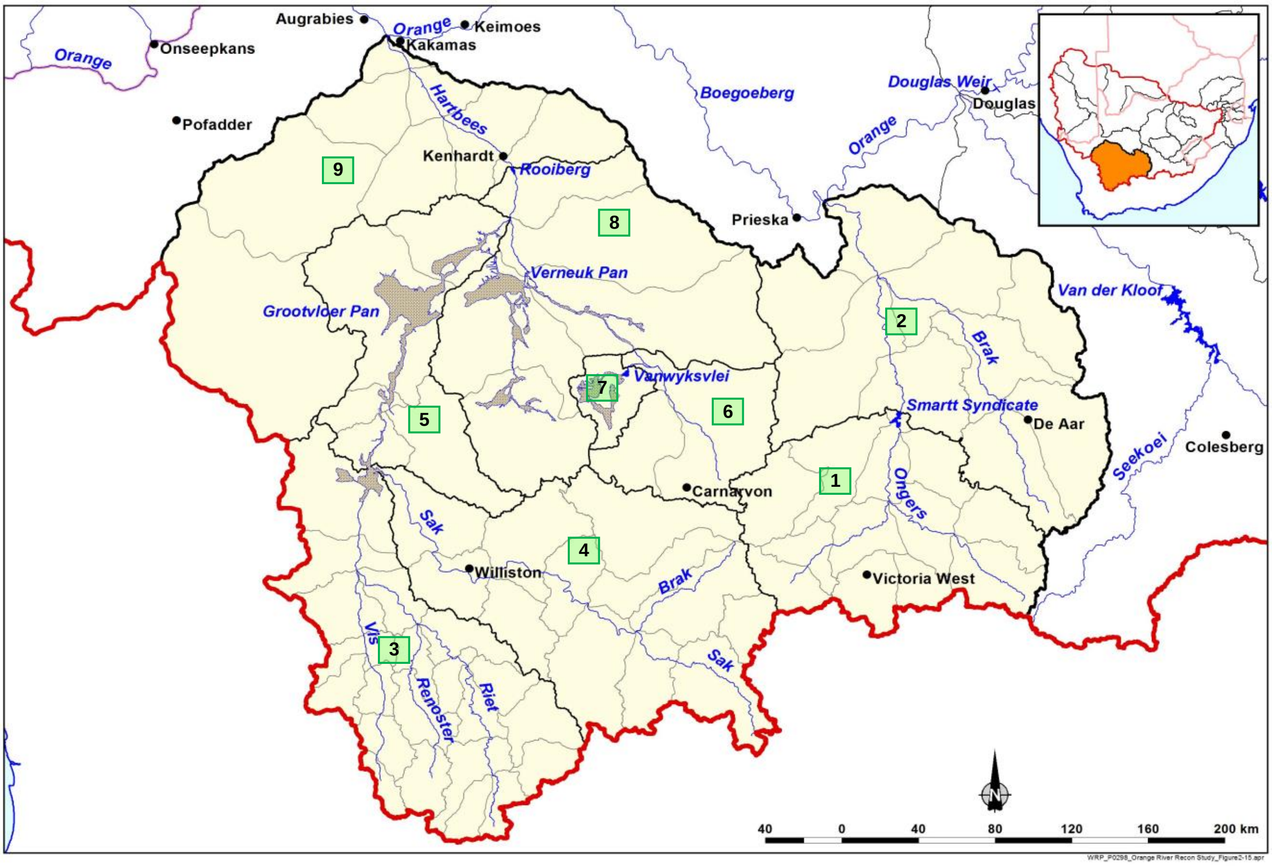

Figure 2-15: Lower Orange Tributaries catchment locality map

2.11.2 Brief overview of hydrology

The Sak, Ongers, Brak and Hartbees Rivers are (as with the Molopo/Nossob) situated in a highly arid region. The contribution of these River systems to the Orange River Estuary would also be less than 1% under natural conditions, but presently there is rarely any inflow to the Orange due to large endoreic areas, high evaporation (2200mm/a), high River losses and large pans in the catchment. However, the River system is important for a local supply perspective.

2.11.3 Previous Hydrology History

The only previous estimates for natural runoff in this area came from the Surface Water Resources of South Africa Study (WR90) study (**WRC, 1990**) completed by the Water Research Commission during the 1990s. The flow records were mostly generated using parameter transfers from the few measured catchments in the area (4 in 130 000 km^2) over the period 1920 – 1989. The WR90 estimates were used in the DWA Systems model until the ORASECOM hydrology update.

2.11 Lower Orange Tributaries

2.11.4 ORASECOM hydrology development

During the GIZ/ORASECOM Study the WR2005 Study (Water Resources of South Africa, 2005) (**WRC, 2005**) hydrological model configurations were used to update the natural hydrology to 2004. The WR2005 data were, however, revised by improving to the network configuration. Estimates for the pans and related losses as well as some additional dams that was not included in the WR2005 were included and the models were recalibrated.

Previous (1920-1994)		ORASECOM (1920-2004)					
Hydrology reference name	**MAR (million m^3/annum)**	**Locality map reference**	**Param.dat order no.**	**Hydrology reference name**	**MAR (million m^3/annum)**	**Standard deviation**	**Coefficient of variation**
Previously part of BOEG9 (see Lower Orange Main Stem)		1	68	LOGR1	22.12	50.99	2.31
		2	76	LOGR2	30.20	64.97	2.15
Previously part of VIOOL9 (see Lower Orange Main Stem)		3	158	LOGR6	46.36	99.09	2.14
		4	159	LOGR7	22.11	45.52	2.06
		5	160	LOGR8	3.89	8.89	2.28
		6	161	LOGR9	9.58	25.54	2.67
		7	162	LOGR10	1.37	3.65	2.67
		8	163	LOGR11	15.95	42.10	2.64
		9	164	LOGR12	10.88	31.34	2.88

2.11.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 25% is given to this area. The lowest score is for the density of observed flow gauges. The detailed scoring table is presented in **Appendix A**.

2.12 Fish

2.12 Fish

2.12.1 Locality Map

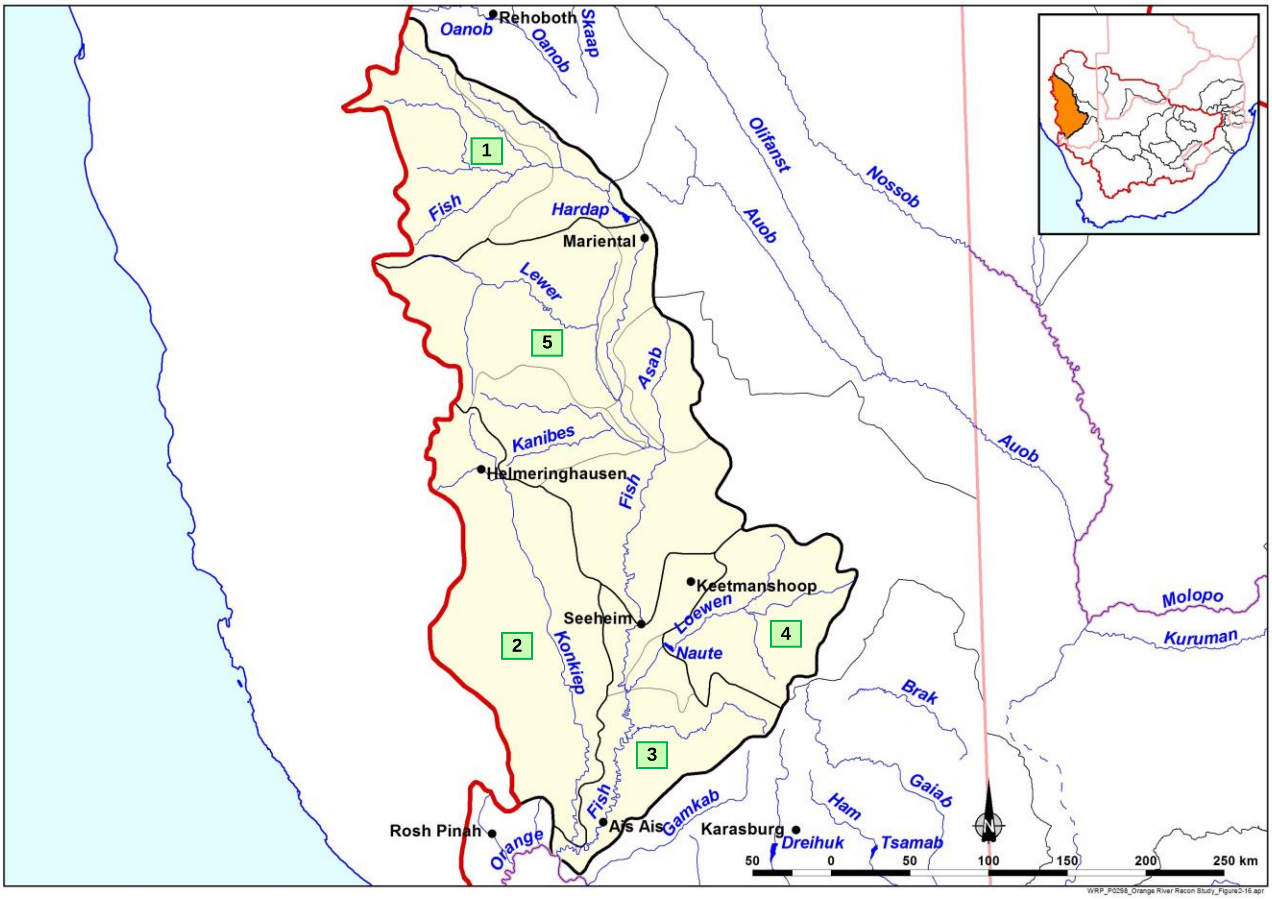

Figure 2-16: Fish catchment locality map

2.12.2 Brief overview of hydrology

The Fish River has one of the largest catchment areas in Namibia. The River basin falls in an arid region with rainfall ranging between 50 and 230 mm/a, with MAEs ranging from 2950 and 3800mm/a. The catchment is relatively under-developed and has a low population density, largely due to the highly arid and generally infertile nature of the land. There are, however, two major dams on this River system, the Hardap Dam in the Middle Fish River and the Naute Dam on the Löwen River, a major tributary positioned towards the lower end of the catchment. A third large Dam, Neckertal is in final planning stages. Groundwater plays an important role in supplying demands in the area. Water requirements include urban and industrial, stock watering and irrigation. The Fish River contributes 6% to flow at the Orange River Estuary under natural conditions (excluding losses). Due to the Fish River's confluence with the Orange River being close to the Estuary, the River plays a role in the estuary's hydrological characteristics.

2.12 Fish

2.12.3 Previous Hydrology History

The Fish hydrology was first prepared during the Orange River Replanning Study (**DWAF, 1998**) and covered the period 1920 to 1987. In 2002 a study was completed as part of the Pre-Feasibility Study into Measures to Improve the Management of the Lower Orange River (also known as the LORMS study) (**DWAF, 2002b**). It included an update of the hydrology of the Fish River Catchment. The hydrological data available covered the period 1920 to 1999.

2.12.4 ORASECOM hydrology development

During the GIZ/ORASECOM Study no update of the Fish River hydrology was undertaken. For this reason, the Fish hydrology is currently the limiting factor in the systems analyses models as it ends in 1999, while all other hydrologies have been extended till 2004. This is only the case in historical analyses, as the end date is not relevant for stochastic analyses. A study, running concurrently with this one, assessing Ecological Water Requirements at the Orange Estuary is in the process of revising the Fish hydrology and it is hoped that this can be incorporated into this study. This has not yet occurred at the time of writing this report.

Previous (1920-1994)		ORASECOM (1920-2002)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
HARDP	194.67	1	186	HARDP4	194.67	242.22	1.24
KONKP	48.16	2	187	KONKP4	48.16	85.38	1.77
LOWF	88.01	3	188	LOWF4	88.01	156.01	1.77
NAUT	61.22	4	189	NAUT4	61.22	86.72	1.42
SEEH	346.49	5	190	SEEH4	346.49	614.22	1.77

2.12.5 ORASECOM hydrology quality review

Using a rating score for rainfall data and flow gauge density and coverage, as well as the resolution and level of measured land and water use, a quality score of 43% is given to this area. The lowest score is for the density of observed flow gauges. The detailed scoring table is presented in **Appendix A**.

2.13 Thukela

2.13 Thukela

2.13.1 Locality Map

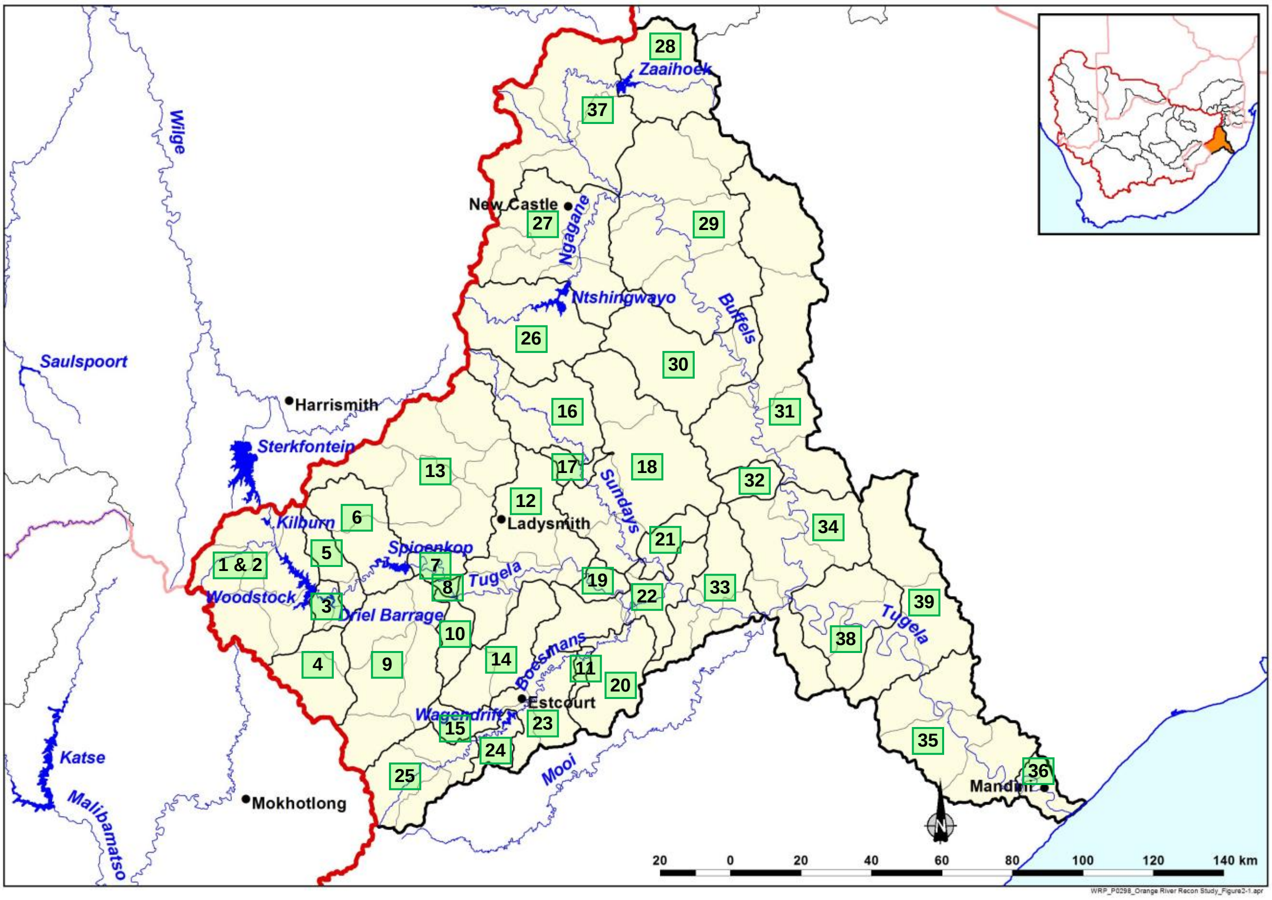

Figure 2-17: Thukela catchment locality map

2.13.2 Brief overview of hydrology

The Thukela River is not a tributary of the Orange River, and in fact drains East into the Indian Ocean. The Thukela catchment has, however, been included into the integrated Vaal-Orange systems models as a small portion in the Upper Catchment upstream of Driel Barrage affects transfers into Sterkfontein Dam in the Vaal system. Future options analyses for the Vaal and Orange often include scenarios using Thukela transfers, and for this reason it is necessary to have the Thukela as part of the system. Any changes (for example environmental requirements) in the Thukela operation can affect the Vaal. Due to the current operation of the system, however, the Thukela only affects the Vaal which in turn only affects Douglas demands and therefore has little impact on the Orange catchment.

2.13.3 Previous Hydrology History

The Thukela hydrology was first prepared in the Vaal River System Analyses study (**DWAF, 1988**). At that stage the hydrology covered the period from 1920 to 1987. The hydrology was updated and extended to 1994 as part of the Thukela Water Project Feasibility Study (**DWAF, 2000**). Refinements to catchment boundaries took place in the Thukela Water Project Decision Support Phase study (**DWAF, 2003**) in order to simulate environmental requirements at specified locations.

2.13 Thukela

2.13.4 ORASECOM hydrology development

Only the four catchments (1,2,3 and 4 in **Figure 2-17**) directly impacting the Thukela transfer into Sterkfontein Dam were extended as part of the ORASECOM study. All other Thukela hydrologies remained as refined in the Decision Support Study, with an end date of 1994. The shorter record period is not a problem as most scenarios carried out involving the Thukela are based on stochastic flows, and a common end date is not required for this purpose. The extended hydrologies in the Vaal catchment near the Thukela were used for the extension. The extended portions of the Vaal records were compared with the original portion. A year was then selected with similar characteristics to the required year in the extended portion. That year was selected for use in the Thukela extension, using the original Thukela record.

Previous (1920-1994)		ORASECOM (1920-2004 records 1-4, 1920-1994, other records)					
Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
TM019	73.63	1	79	TM0194	76.30	31.62	0.41
TM029	359.50	2	80	TM0294	372.50	154.40	0.41
TM039	19.43	3	81	TM0394	20.24	9.96	0.49
TM049	219.40	4	82	TM0494	227.95	87.53	0.38
TM05A	37.86	5	83	TM05A4	37.86	21.18	0.56
TM05B	81.50	6	84	TM05B4	81.50	47.06	0.58
TM07A	12.86	7	198	TM07A4	12.86	10.20	0.79
TM07B	2.82	8	85	TM07B4	2.82	2.24	0.79
TM08A	289.30	9	86	TM08A4	289.30	143.51	0.50
TM08B	16.23	10	202	TM08B4	16.23	12.12	0.75
TM099	7.10	11	87	TM0994	7.10	6.26	0.88
TM109	91.60	12	88	TM1094	91.60	73.99	0.81
TM119	231.30	13	89	TM1194	231.30	132.94	0.57
TM129	37.27	14	90	TM1294	37.27	31.87	0.86
TM139	20.05	15	91	TM1394	20.05	10.30	0.51
TM149	85.52	16	92	TM1494	85.52	58.18	0.68
TM15A	7.78	17	99	TM15A4	7.78	6.22	0.80
TM15B	107.00	18	93	TM15B4	107.00	74.55	0.70
TM16A	7.66	19	101	TM16A4	7.66	7.47	0.98
TM16B	15.66	20	100	TM16B4	15.66	13.81	0.88
TM16C	3.81	21	94	TM16C4	3.81	3.72	0.98
TM16D	56.00	22	203	TM16D4	56.00	47.47	0.85
TM179	33.55	23	95	TM1794	33.55	23.29	0.69
TM189	26.25	24	96	TM1894	26.25	14.74	0.56
TM199	207.10	25	97	TM1994	207.10	80.12	0.39
TM249	110.83	26	102	TM2494	110.83	67.84	0.61
TM259	140.39	27	103	TM2594	140.39	84.11	0.60
TM269	99.99	28	104	TM2694	99.99	60.56	0.61
TM279	164.72	29	105	TM2794	164.72	145.25	0.88
TM289_A	65.93	30	106	TM289_A4	65.93	47.33	0.72
TM289_B	142.69	31	199	TM289_B4	142.69	113.47	0.80
TM289_C	13.59	32	200	TM289_C4	13.59	10.51	0.77
TM29A	38.52	33	98	TM29A4	38.52	40.02	1.04
TM29B	81.19	34	107	TM29B4	81.19	58.65	0.72
TM30A	160.98	35	108	TM30A4	160.98	111.52	0.69
TM30B	35.33	36	204	TM30B4	35.33	24.48	0.69
TM319	148.16	37	109	TM3194	148.16	98.53	0.67
TM329_A	63.79	38	110	TM329_A4	63.79	44.49	0.70
TM329_B	97.95	39	201	TM329_B4	97.95	68.32	0.70

2.13.5 ORASECOM hydrology quality review

A quality review has not taken place on the Thukela hydrology due to the very minor impact it has on the Orange River.

2.14 Olifants

2.14.1 Locality Map

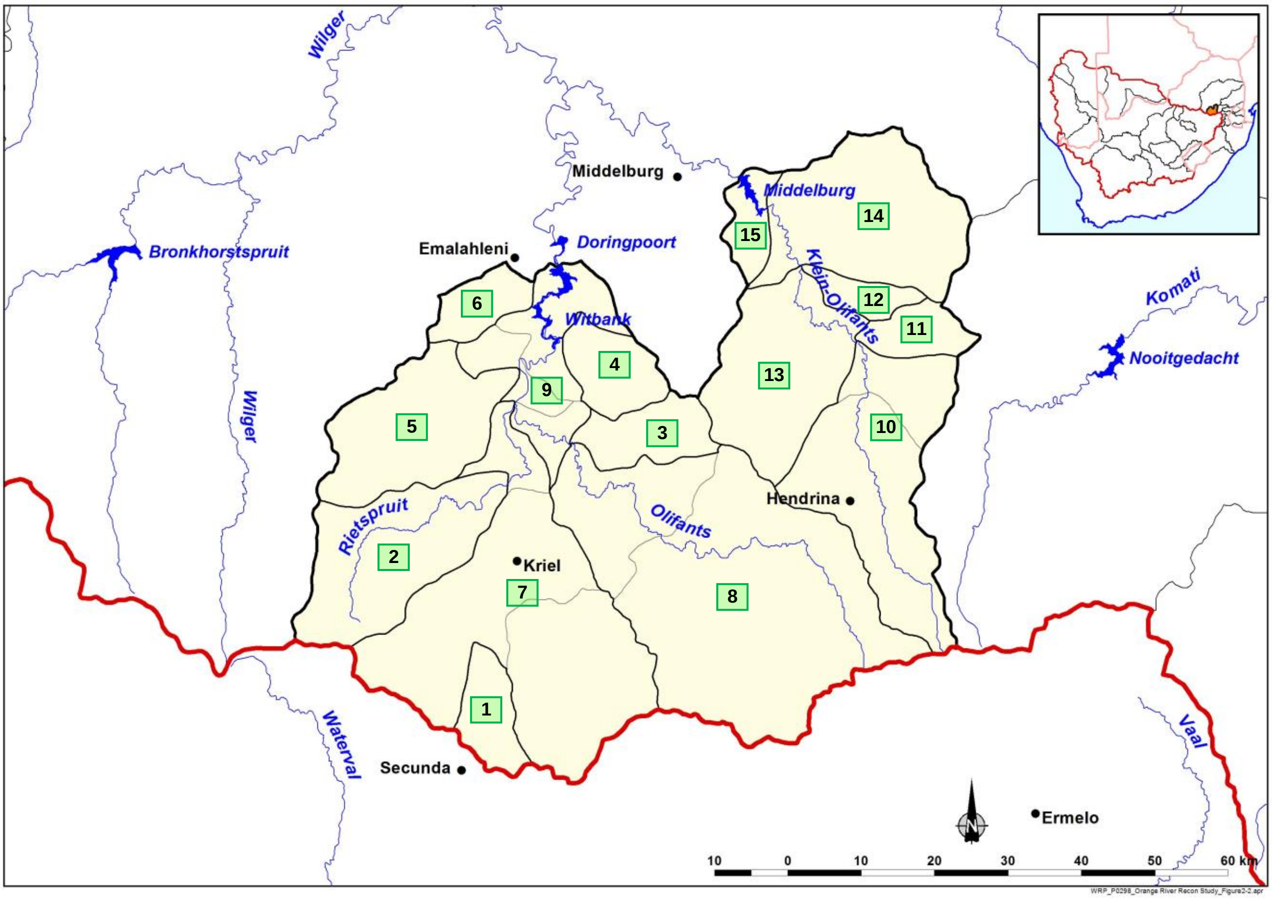

Figure 2-18: Olifants catchment locality map

2.14.2 Brief overview of hydrology

The Olifants River is not a tributary of the Orange River, and in fact drains East into the Indian Ocean. A portion of the Olifants catchment (upstream of Witbank and Middelburg Dams) has, however, been included in the systems models due to a previous need to supply the Olifants system with Vaal River water. Scenarios were previously assessed to determine the impact of supplying the Olifants catchment from the Vaal catchment. The portion of the catchment remains part of the integrated Vaal-Orange systems models in case future inter basin scenarios are required, however it has remained dormant for quite some time now, and in fact would require significant updates should the need arise.

2.14.3 Previous Hydrology History

The current hydrology representing the portion of the Olifants catchment upstream of Witbank and Middelburg Dams that is included in the Integrated Orange-Vaal WRPM (not WRYM) was developed as part of the Development of an Integrated Water Resources Model of the Upper Olifants River (Loskop Dam) Catchment study (**DWAF, 2001a**). This hydrology is outdated as the Development of an Integrated Water Resource Management Plan for the Upper and Middle Olifants Catchment Study (**DWAF, 2008b**) updated this hydrology. The new hydrology has not been incorporated into the Orange-Vaal WRPM due to a lack of requirement presently.

2.14 Olifants

2.14.4 ORASECOM hydrology development

No changes took place on the Olifants hydrology as part of the ORASECOM study, as it has no impact on the Orange system at present.

Previous (1920-1994)					
Locality map reference	**Param.dat order no.**	**Hydrology reference name**	**MAR (million m^3/annum)**	**Standard deviation**	**Coefficient of variation**
1	121	MU1	3.51	3.72	1.06
2	122	MU2	11.75	12.38	1.05
3	123	MU3	5.31	5.51	1.04
4	124	MU4	4.16	4.40	1.06
5	125	MU5	12.22	12.75	1.04
6	126	MU6	2.98	3.17	1.07
7	145	MU7	27.62	29.43	1.07
8	146	MU8	49.76	50.90	1.02
9	147	MU9	9.55	9.84	1.03
10	148	MU10	12.92	11.68	0.90
11	149	MU11	2.73	2.46	0.90
12	16	MU12	1.71	1.54	0.90
13	133	MU13	9.26	8.37	0.90
14	134	MU14	12.47	11.27	0.90
15	135	MU15	2.10	1.91	0.91

2.14.5 ORASECOM hydrology quality review

A quality review has not taken place on the Olifants hydrology as it has no impact on the Orange River.

2.15 Komati

2.15 Komati

2.15.1 Locality Map

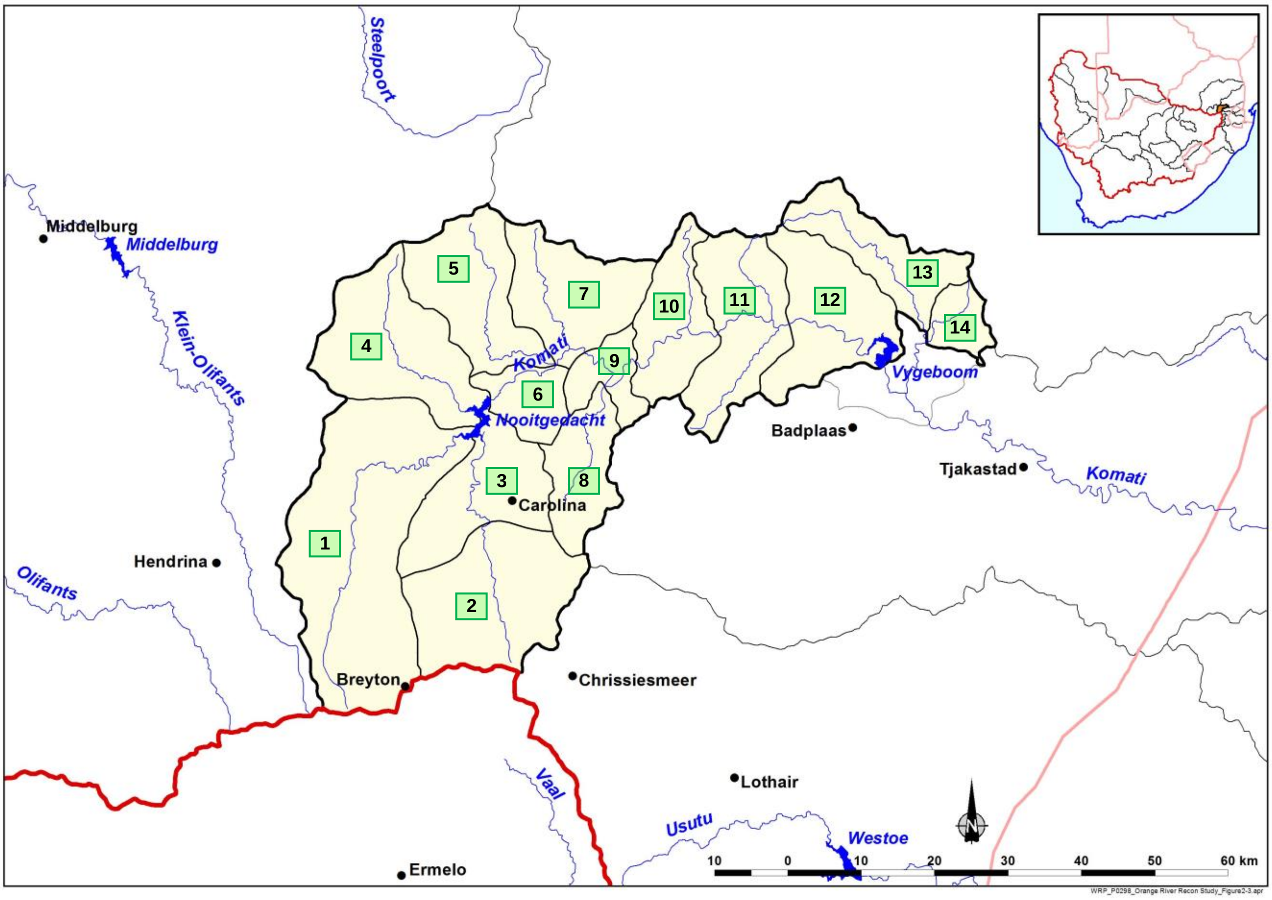

Figure 2-19: Komati catchment locality map

2.15.2 Brief overview of hydrology

The Komati River is not a tributary of the Orange River, and in fact drains East towards the Indian Ocean. The catchment is however included in the current Integrated Vaal-Orange system WRPM (not WRYM) as it represents an interbasin transfer into the Vaal system. Water from the Komati catchment is transferred over for key strategic industrial use. This reduces the demands on the Vaal system, which in turn has a minor affect on the Orange system.

2.15.3 Previous Hydrology History

The Komati System upstream of Swaziland was first calibrated as part of the Vaal River System Analyses study (**DWAF, 1988**). At that stage the hydrology covered the period from 1920 to 1987. The hydrology was updated and extended to 1994 as part of the Vaal River Systems Analysis Update study (**DWAF, 2001a**). The hydrology was then updated as part of the Inkomati Water Availability Assessment Study (**DWAF, 2009b**) and extended to an end date of 2004.

2.15.4 ORASECOM hydrology development

No changes took place on the updated Komati hydrology as part of the ORASECOM study.

Previous (1920-1994)	IWAAS (1920-2004)

2.15 Komati

Hydrology reference name	MAR (million m^3/annum)	Locality map reference	Param.dat order no.	Hydrology reference name	MAR (million m^3/annum)	Standard deviation	Coefficient of variation
NOOIT9	66.28	1	25	X11A1	26.31	24.63	0.94
		2	206	X11B1	17.73	15.21	0.86
		3	111	X11B2	12.01	10.52	0.88
		4	112	X11C1	11.35	10.08	0.89
GEMS9	92.84	5	26	X11D1	21.03	12.44	0.59
		6	22	X11D2	6.22	3.73	0.60
		7	113	X11D3	20.24	11.95	0.59
		8	116	X11E1	14.76	8.47	0.57
		9	118	X11E2	6.84	4.10	0.60
		10	185	X11F1	22.13	12.40	0.56
VYG9	101.43	11	54	X11G1	45.28	20.17	0.45
		12	57	X11H1	54.48	24.73	0.45
GLAD9	48.16	13	23	X11J1	49.20	20.22	0.41
		14	58	X11K1	13.74	5.96	0.43

2.15.5 ORASECOM hydrology quality review

A quality review has not taken place on the Komati hydrology due to the very minor impact on the Orange River.

2.16 Usutu

2.16 Usutu

2.16.1 Locality Map

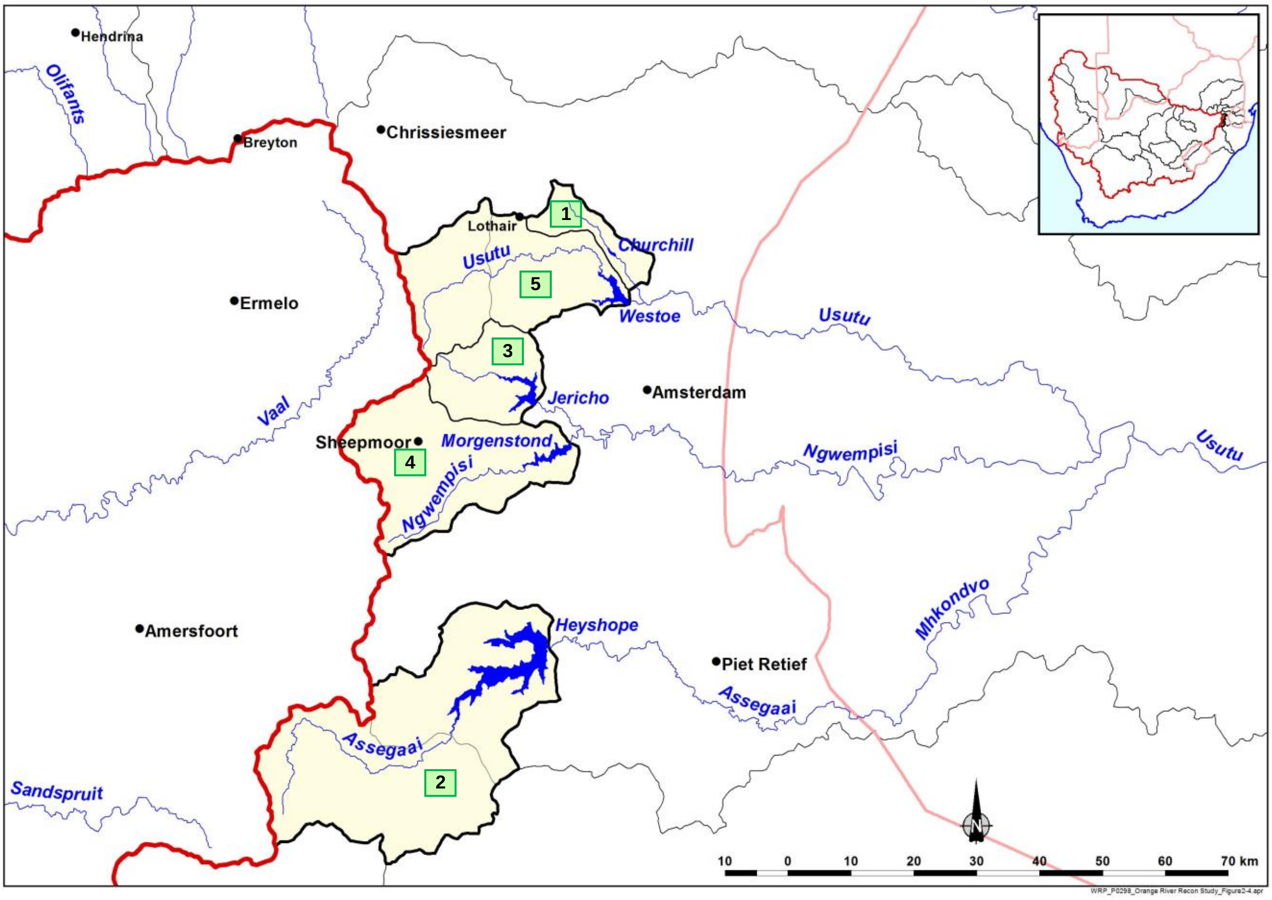

Figure 2-20: Usutu catchment locality map

2.16.2 Brief overview of hydrology

The Usutu River is not a tributary of the Orange River, and in fact drains East towards the Indian Ocean. The catchment is however included in the current Integrated Vaal-Orange system WRPM (not WRYM) as it represents an interbasin transfer into the Vaal system. Water from the Usutu catchment is transferred over for key strategic industrial use. This reduces the demands on the Vaal system, which in turn has a minor affect on the Orange system.

2.16.3 Previous Hydrology History

The Usutu System upstream of Swaziland was first calibrated as part of the Vaal River System Analyses study (**DWAF, 1988**). At that stage the hydrology covered the period from 1920 to 1987. The hydrology was updated and extended to 1994 as part of the Vaal River Systems Analysis Update study (**DWAF, 2001a**). The hydrology was then updated as part of the Usutu – Joint Maputo River basin Study **(TPTC, 2009)** and extended to an end date of 2004. Upon assessment, it was decided that this updated hydrology would not be adopted for use in the Integrated Vaal-Orange system model as the accuracy thereof was questionable. The shorter record period of the previous hydrology is not a problem as most scenarios carried out involving the Usutu are based on stochastic flows, and a common end date is not required for this purpose.

2.16 Usutu

2.16.4 ORASECOM hydrology development

No changes took place on the Usutu hydrology as part of the ORASECOM study.

Previous (1920-1994)					
Locality map reference	**Param.dat order no.**	**Hydrology reference name**	**MAR (million m^3/annum)**	**Standard deviation**	**Coefficient of variation**
1	114	CHURCH9	6.88	3.87	0.56
2	115	HEYS9	129.03	83.54	0.65
3	117	JERI9	23.69	15.58	0.66
4	119	MORG9	56.33	38.51	0.68
5	120	WEST9	43.61	29.04	0.67

2.16.5 ORASECOM hydrology quality review

A quality review has not taken place on the Usutu hydrology due to the very minor impact on the Orange River.

3 VALIDATION AND VERIFICATION TESTS

3.1 Background and Results

As the need for information on reliability grows, the use of stochastic flow sequences is becoming increasingly popular in water resource studies. It is no longer satisfactory to say that the yield from a system is 20 million m^3/a. Such a figure could for example indicate 20 million m^3/a, with a risk of failure of either once in every 10 years or once in every 200 years. Clearly the reliabilities of the two yields are completely different, hence the need to be more specific and to relate each yield value to a particular reliability.

The major objective of using stochastic generation software is to provide alternative realistic flow sequences that can be analysed in the same manner as the historic flow sequence. One of the main problems associated with the use of generated flow sequences concerns the validity of such sequences. Before the end user can place his/her confidence in results based on stochastically generated flow sequences, it is first necessary to provide confirmation that the stochastic flow sequences are in fact realistic and plausible.

The statistical analysis of streamflows was undertaken in this Study using the *Stochastic Model of South Africa* (STOMSA). STOMSA incorporates Mark 7.1 of the ANNUAL and CROSSYR programs, both of which have been used extensively in South Africa over the past ten years for such purposes. The analysis was based on the natural historical streamflow sequences for the subcatchments in the integrated Orange-Vaal catchment, obtained from the hydrological analysis undertaken as part of the ORASECOM Study.

Each sequence covers the period 1920 to 2004 (hydrological years). After having performed the cross correlation analysis, STOMSA was used to create the statistical parameter file called the PARAM.DAT-file, which summarises the results of the statistical analyses, including the marginal distribution and serial correlation parameters as well as the B-matrix of the cross correlation. The PARAM.DAT-file provides direct input data to the WRYM and WRPM and is used by the models, at runtime, to generate the stochastic streamflow sequences applied in a stochastic yield and planning analysis. Included in the PARAM.DAT-file is control information for the validation and verification testing. A combined PARAM.DAT file was created for the entire integrated Orange-Vaal system. The file contains parameters for all 207 hydrology time series files.

The marginal distribution of a streamflow sequence provides a measure of the relationship between its annual total flows. The appropriate distribution for modelling annual flows is selected using the so-called *Hill Algorithm* (HILL, HILL and HOLDER, 1976). The Hill algorithm is based on the *Johnson Transform Suite*, which uses the first four moments of the marginal distribution to classify the type of distribution function as one of the following:

- 2-parameter Log-normal (LN2);
- 3-parameter Log-normal (LN3);
- 3-parameter Bounded (SB3);
- 4-parameter Bounded (SB4).

The Log-normal (LN) and Bounded (SB) distribution functions are defined as shown in **Equations 3.1** and **3.2**, respectively. More information in this regard is provided in the document *Stochastic Modelling of Streamflow* (BKS, 1986):

$\mathbf{y} = \gamma + \delta^{*}\mathrm{Ln}(x - \xi)$, where $\mathbf{x} > \xi$ (3.1)

$\mathbf{y} = \gamma + \delta^{*}\mathrm{Ln}(x - \xi) / (\lambda + \mathbf{x} - \xi)$, where $\lambda > \mathbf{x} > \xi$ (3.2)

It should be noted that each of the above distributions has its strengths and weaknesses with the result that careful checking is undertaken by the program to ensure that realistic and meaningful results are produced. A summary of the selected Johnson-Transform distributions and the values of the associated model parameters, as determined by STOMSA for the sub-quaternary catchments, is provided in **Table 3-1**.

Table 3-1: Summary of selected Johnson-Transform distributions and values of associated model parameters for selected[(1)] simulated catchments

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
ALLEM4	LN3	-5.0324095	1.1962513	1.0000000	0.0000000
ARMEN	SB4	2.0237190	0.9136617	216.7413689	0.0000000
AUCH4	LN3	-0.1014556	0.5615228	1.0000000	0.0000000
BARBERS4	LN3	-0.4029140	0.8976931	1.0000000	0.0000000
BARR4	SB4	1.1264274	0.7463220	268.5964115	7.4331160
BLOEMN3D4	SB4	1.7920447	0.6910949	949.2854887	11.0879088
BOSK4	LN3	-8.2404410	2.3331421	1.0000000	0.0000000
C12D4	SB4	0.6721991	0.7441580	228.6229968	0.0000000
C24CEYE4	SB4	0.6181649	0.6449110	100.9355834	13.1037226
C24D4	SB4	1.6511545	0.5550652	56.9050988	0.2341942
C24E4	LN3	-0.7940559	0.6733485	1.0000000	0.3978835
C24F4	SB4	1.8477440	0.5764144	179.5782764	0.8019454
C24G4	SB4	1.8144248	0.5729379	150.7783773	0.6794406
C24H4	LN3	-1.0901380	0.8126356	1.0000000	0.0000000
C3H0134	LN3	-0.6449259	0.6280898	1.0000000	0.0000000
C70ABC4	SB4	1.6823822	0.7818893	347.9445278	6.5448140

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
C70D4	SB4	1.3163511	0.6374766	57.9956665	1.8390029
C70E4	SB4	1.3479384	0.6414824	56.3407684	1.7862673
C70F4	SB4	1.3731280	0.6501577	45.2464906	1.3910653
C70G4	SB4	1.4032206	0.6515650	68.2629242	2.3751019
C70H4	SB4	1.4101860	0.6611108	19.5238038	0.5792340
C70J4	SB4	1.3861583	0.6552868	41.3063226	1.2661323
C70K4	SB4	2.1459100	0.7574313	99.3482528	0.6064468
C9H0074	LN3	-0.9411216	0.6301517	1.0000000	0.0000000
CHURCH9	SB4	1.0142641	1.0726074	22.1871622	0.0000000
COM1113	SB4	1.4341320	0.4747541	14.6100000	0.0000000
COM2124	LN3	-3.5966883	1.8351633	1.0000000	2.5720396
COM22	LN3	-1.2612820	1.9488668	1.0000000	0.5982169
COM2327	LN3	0.9647700	0.9309082	1.0000000	0.0000000
D12	SB4	2.0821413	0.8578492	1355.8255150	0.0000000
D13	LN3	-8.9680324	1.4140401	1.0000000	0.0000000
D14	LN3	-3.0195891	0.7600850	1.0000000	4.7030959
D24	LN3	-3.2607267	0.7875416	1.0000000	11.2948773
D33	LN3	-1.0453343	0.6577605	1.0000000	0.0000000
D35	LN3	-1.9749798	0.6667121	1.0000000	0.0000000
D41ARED	LN3	-0.6900257	0.8204485	1.0000000	0.0000000
D41B	SB4	1.7576645	0.6009246	114.8267524	0.0000000
D41C	SB4	1.5989213	0.4349698	105.2005303	0.0000000
D41D	SB4	1.5860517	0.4196521	68.4522406	0.0000000
D41E	SB4	1.8334718	0.5210570	9.4322265	0.0000000
D41F	SB4	1.6720082	0.4482869	24.9055314	0.0000000
D41G	SB4	1.8445156	0.5230584	12.5655281	0.0000000
D41J	LN3	1.8490169	0.6451562	1.0000000	0.0000000
D41K	SB4	1.8395603	0.4889565	10.9350027	0.0000000
D41M	LN3	0.3869183	0.4393829	1.0000000	0.0000000
D41N	LN3	-0.2212373	0.4481866	1.0000000	0.0000000
D42A	SB4	1.6674038	0.4527692	20.1096551	0.0000000
D42B	SB4	1.8567814	0.5270517	84.6641096	0.0000000
D42C	SB4	1.8826198	0.5342040	11.1556114	0.0000000
D42D	LN3	-0.8758388	0.5550351	1.0000000	0.0000000
D42E	LN3	-0.1480936	0.6010878	1.0000000	0.0000000
D42F	LN3	-0.0053321	0.5957496	1.0000000	0.0000000
D42G	LN3	0.7903999	0.5164654	1.0000000	0.0000000
D43B	SB4	1.4349462	0.3359690	199.6750886	0.0000000
D43C	LN3	1.3979181	0.6099443	1.0000000	0.0000000
D44C	LN3	2.1335380	0.7351035	1.0000000	0.0000000

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
D44D	LN3	2.4830986	0.7386328	1.0000000	0.0000000
D45C	LN3	2.2675920	0.6978739	1.0000000	0.0000000
D45D	LN3	1.2920199	0.5497017	1.0000000	0.0000000
DEHOOP4	LN3	-2.0724009	0.9669514	1.0000000	0.0000000
DELA4	SB4	1.9169340	0.9674597	1629.9609458	0.0000000
DSWENTZD4	LN3	-1.7042491	0.9115293	1.0000000	0.0000000
DVILJ	LN3	0.4875748	0.5794146	1.0000000	0.0000000
ERF4	LN3	-5.3003973	1.1241286	1.0000000	0.0000000
FRAN4	SB4	1.4125173	0.7358445	3449.2383808	108.7189670
GRO	LN3	-0.0877840	0.6527987	1.0000000	0.0000000
GROOTD4	LN3	-7.2679376	1.2464345	1.0000000	0.0000000
HARDP4	SB4	2.2342493	0.7603095	2316.1228111	0.0000000
HEYS9	SB4	1.9572541	1.1826959	680.2351558	0.0000000
HLOABS	SB4	1.7425696	1.6447187	381.2186554	0.0000000
HLODAM	SB4	1.4475733	1.5104362	338.3896968	0.0000000
HOLABS	SB4	1.9407314	1.3218443	206.8027894	0.0000000
HOLDAM	LN3	-7.7925851	2.2297452	1.0000000	0.0000000
JERI9	SB4	1.4759606	1.0513880	101.5389804	0.0000000
KALKF4	LN3	-4.8454441	1.0336212	1.0000000	0.0000000
KAT10	LN3	-14.9253515	2.3911270	1.0000000	0.0000000
KATJREST	SB4	1.6291055	1.0843305	957.1388903	0.0000000
KLERK4	LN3	-3.3954442	1.1792580	1.0000000	13.3210167
KLIPBN4	SB4	1.5936593	0.7592068	858.1797256	10.0228134
KLIPDN4	SB4	1.6727071	0.6460460	142.8232737	2.5289484
KLIPR4	LN3	-4.9880191	1.2265474	1.0000000	19.9587096
KNELL	LN3	-2.0619398	0.9247696	1.0000000	0.8393577
KONKP4	SB4	2.0276857	0.5560352	687.3550877	0.0000000
KROMN4	SB4	1.9036414	0.7915598	294.8887104	3.7053956
KRUG4	LN3	-4.3045500	1.0006262	1.0000000	0.0000000
LAKESN4	LN3	-2.9299098	1.4373994	1.0000000	0.0000000
LOGR1	LN3	-0.9563432	0.5474165	1.0000000	0.0000000
LOGR10	LN3	0.5906312	0.5243565	1.0000000	0.0000000
LOGR11	SB4	2.0949245	0.4466185	338.1747437	0.0000000
LOGR12	SB4	1.9543647	0.4041443	211.9632851	0.0000000
LOGR13	SB4	1.9731483	0.4855821	68.1185248	0.0000000
LOGR14	LN3	-0.0360457	0.6337880	1.0000000	0.0000000
LOGR15	LN3	-1.3355068	0.5273411	1.0000000	0.0000000
LOGR16	SB4	2.0112391	0.4983866	72.8970783	0.0000000
LOGR17	SB4	1.9681019	0.4272591	223.6530954	0.0000000
LOGR18	LN3	0.6377091	0.5141000	1.0000000	0.0000000

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
LOGR19	LN3	-0.0317810	0.5538042	1.0000000	0.0000000
LOGR2	LN3	-1.2325573	0.5632409	1.0000000	0.0000000
LOGR3	LN3	-0.9088238	0.5778754	1.0000000	0.0000000
LOGR4	LN3	-0.5815379	0.5580307	1.0000000	0.0000000
LOGR5	LN3	-1.0416327	0.5721382	1.0000000	0.0000000
LOGR6	SB4	1.8803753	0.4714924	595.3067646	0.0000000
LOGR7	SB4	1.7781034	0.4445190	307.3247195	0.0000000
LOGR8	SB4	2.0789182	0.4922791	76.4093583	0.0000000
LOGR9	LN3	-0.2996438	0.4812090	1.0000000	0.0000000
LOLIF	LN3	0.4464721	0.4325911	1.0000000	0.0000000
LOWF4	SB4	2.0279740	0.5560980	1256.2300052	0.0000000
MAKABS	SB4	1.2078818	1.2381327	1191.4300052	0.0000000
MAKDAM	SB4	1.2079222	1.2381299	569.8176453	0.0000000
MAL10	SB4	1.8586603	1.4320238	1241.2079950	0.0000000
MAS10	LN3	-11.9169960	1.8251638	1.0000000	0.0000000
MAT10	LN3	-8.8887039	1.9923711	1.0000000	0.0000000
METO	SB4	1.5375129	0.9187238	305.3904644	0.0000000
MOH10	SB4	1.7211694	1.6312331	1108.6473912	0.0000000
MORG9	SB4	1.1334459	0.9296946	208.5748945	0.0000000
MUELA	SB4	2.0519931	1.3487599	29.1488653	0.0000000
NAUT4	SB4	1.5979517	0.5595078	510.7227410	0.0000000
NTO10	SB4	1.7083497	1.2448753	675.1570411	0.0000000
ORAN10	SB4	1.2076177	1.2380218	3418.5472371	0.0000000
OTJV	LN3	0.4875748	0.5794146	1.0000000	0.0000000
RUSTF4	LN3	-2.3249325	0.8392926	1.0000000	0.0000000
SANDN4	SB4	1.8873966	0.8233875	1145.3978696	0.0000000
SEEH4	SB4	2.0280574	0.5561137	4945.9996629	0.0000000
SEEIS	LN3	0.8357464	0.5623081	1.0000000	0.0000000
SPITS4	LN3	-3.4635108	0.9124131	1.0000000	0.0000000
STERK4	SB4	1.3624266	0.8247884	91.7912199	0.0000000
SUIK4	LN3	-4.0364741	1.0184475	1.0000000	13.6077864
TIER4	LN3	-2.1419627	0.8440399	1.0000000	0.0000000
TM0194	SB4	1.2106338	1.5180073	234.4463050	0.0000000
TM0294	SB4	1.2108160	1.5179819	1144.7421551	0.0000000
TM0394	SB4	0.8540535	1.1803768	58.2957279	0.0000000
TM0494	SB4	1.1992463	1.6286903	677.9433739	0.0000000
TSO10	SB4	1.3865972	1.3250754	1285.0364152	0.0000000
TWEE4	LN3	-2.0440545	0.9416637	1.0000000	0.0000000
UAUB	LN3	0.1451519	0.4352437	1.0000000	0.0000000
UOLIF	LN3	1.0293263	0.5800123	1.0000000	0.0000000

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
USWENTZD4	LN3	-2.7800327	0.9110660	1.0000000	0.0000000
VAAL4	SB4	1.7884372	0.7323218	3279.5527869	59.4093122
VDK	LN3	-1.7214046	0.5533473	1.0000000	0.0000000
VHARTS4	LN3	-1.0010816	0.6895374	1.0000000	0.0000000
WATER	SB4	1.0494072	0.6489263	265.5493067	0.0000000
WELINC	SB4	1.5376065	0.9187317	2748.5070307	0.0000000
WEST9	SB4	1.1896098	0.9530159	165.4384163	0.0000000
X11A1	SB4	1.6655918	0.6518071	154.7766802	5.6145256
X11B1	SB4	1.4595948	0.6496603	88.3497122	3.3096776
X11B2	SB4	1.4821480	0.6431559	61.5633362	2.2612641
X11C1	SB4	1.4840267	0.6317479	59.0760489	2.1742883
X11D1	SB4	1.3602345	0.8638405	70.4262595	5.4954636
X11D2	SB4	1.7397328	0.9381864	25.4074923	1.7111260
X11D3	SB4	1.3168584	0.8545133	66.3320306	5.2429852
X11E1	SB4	1.2074739	0.8546816	45.3446756	3.6536634
X11E2	SB4	1.4130345	0.8827306	23.8349667	1.7048862
X11F1	LN3	-5.0600926	1.7220413	1.0000000	0.0000000
X11G1	LN3	-8.0997930	2.1815777	1.0000000	0.0000000
X11H1	LN3	-8.3035699	2.1324444	1.0000000	0.0000000
X11J1	LN3	-9.1331817	2.3958886	1.0000000	0.0000000
X11K1	LN3	-5.9206300	2.3393088	1.0000000	0.0000000

Note: Only catchments having direct impact on Orange System presented, eg. No Olifants, Thukela downstream of Driel

SB4: 4-parameter bounded, LN3: 3-parameter log normal

The Johnson-Transform parameters are applied in STOMSA to transform the annual total flows of each streamflow sequence to *normalised flow residuals* so that the data exhibit zero mean and unit variance. This transformation is undertaken by means of the linear stochastic difference equation models of time-series, called *ARMA (Φ,Θ)*, which are defined as follows (see BKS, 1986):

$$\mathbf{x}t - \Phi1^*xt{-}1 - \Phi2^*\mathbf{x}t{-}2 = at - \Theta1^*at{-}1 - \Theta2^*at{-}2 \qquad (3.3)$$

Any one of nine ARMA models may be selected, based on a set of standard selection criteria applied in STOMSA. These models are ARMA(0,0), ARMA(0,1), ARMA(1,0), ARMA(1,1), ARMA(0,2), ARMA(1,2), ARMA(2,0), ARMA(2,2) and ARMA(2,2). It should be noted that, as part of the *Vaal River System Analysis Update* study (DWAF, 2001a), a new selection criterion was developed in addition to the standard set applied in previous versions of STOMSA. The new criterion evaluates the particular performance of each ARMA model with respect to the yield-capacity validation test.

A summary of the selected ARMA distributions and the values of the associated model parameters, as determined by STOMSA, is provided in the following **Table** for each sub-quaternary catchment.

Table 3-2: Summary of selected ARMA distributions and values of associated model parameters for selected[(1)] simulated catchments

Catchment	ARMA Parameters			
	Φ1	**Φ2**	**Θ1**	**Θ2**
ALLEM4	-0.67890	0.00000	-0.74780	0.22290
ARMEN	0.85943	0.00000	0.97633	0.00000
AUCH4	0.00000	0.00000	0.00000	0.00000
BARBERS4	0.00000	0.00000	0.00000	0.00000
BARR4	0.00000	0.00000	0.00000	0.00000
BLOEMN3D4	0.00000	0.00000	0.00000	0.00000
BOSK4	0.41490	0.00000	0.00000	0.00000
C12D4	0.00000	0.00000	0.00000	0.00000
C24CEYE4	1.11347	-0.21281	0.00000	0.00000
C24D4	0.00000	0.00000	0.00000	0.00000
C24E4	0.00000	0.00000	0.00000	0.00000
C24F4	-0.74470	0.01280	-0.98670	0.00000
C24G4	-0.74530	0.01050	-0.98670	0.00000
C24H4	0.98360	-0.19870	0.97870	0.00000
C3H0134	0.00000	0.00000	0.00000	0.00000
C70ABC4	0.00000	0.00000	0.00000	0.00000
C70D4	0.77650	0.00000	0.99090	0.00000
C70E4	0.78160	0.00000	0.99080	0.00000
C70F4	0.78550	0.00000	0.99100	0.00000
C70G4	-0.82750	0.00000	-0.98950	0.00000
C70H4	0.78800	0.00000	0.98970	0.00000
C70J4	0.78870	0.00000	0.98970	0.00000
C70K4	-1.00605	-0.19773	-0.96685	0.00000
C9H0074	0.00000	0.00000	0.00000	0.00000
CHURCH9	0.00000	0.00000	-0.14500	-0.25260
COM1113	0.00000	0.00000	0.00000	0.00000
COM2124	0.79478	0.00000	-0.58623	0.00000
COM22	0.77965	0.00000	-0.52829	0.00000
COM2327	0.00000	0.00000	0.00000	0.00000
D12	0.00000	0.00000	0.00000	0.00000
D13	-0.14010	0.18320	0.00000	0.00000
D14	-0.18299	0.00000	0.00000	0.00000
D24	-0.17737	0.00000	0.00000	0.00000
D33	0.00000	0.00000	0.00000	0.00000
D35	-0.15428	0.00000	0.00000	0.00000

Catchment	ARMA	Parameters		
	Φ1	Φ2	Θ1	Θ2
D41ARED	0.00000	0.00000	0.00000	0.00000
D41B	0.00000	0.00000	0.00000	0.00000
D41C	0.00000	0.00000	0.00000	0.00000
D41D	0.00000	0.00000	0.00000	0.00000
D41E	0.00000	0.00000	0.00000	0.00000
D41F	0.00000	0.00000	0.00000	0.00000
D41G	0.00000	0.00000	0.00000	0.00000
D41J	0.00000	0.00000	0.00000	0.00000
D41K	0.00000	0.00000	0.00000	0.00000
D41M	0.00000	0.00000	0.00000	0.00000
D41N	0.00000	0.00000	0.00000	0.00000
D42A	0.00000	0.00000	0.00000	0.00000
D42B	0.00000	0.00000	0.00000	0.00000
D42C	0.00000	0.00000	0.00000	0.00000
D42D	0.00000	0.00000	0.00000	0.00000
D42E	0.00000	0.00000	0.00000	0.00000
D42F	0.00000	0.00000	0.00000	0.00000
D42G	0.00000	0.00000	0.00000	0.00000
D43B	0.00000	0.00000	0.00000	0.00000
D43C	0.00000	0.00000	0.00000	0.00000
D44C	0.00000	0.00000	0.00000	0.00000
D44D	0.00000	0.00000	0.00000	0.00000
D45C	0.00000	0.00000	0.00000	0.00000
D45D	0.00000	0.00000	0.00000	0.00000
DEHOOP4	0.00000	0.00000	0.00000	0.00000
DELA4	0.18216	0.00000	0.00000	0.00000
DSWENTZD4	0.00000	0.00000	0.00000	0.00000
DVILJ	0.00000	0.00000	0.00000	0.00000
ERF4	0.00000	0.00000	0.00000	0.00000
FRAN4	0.00000	0.00000	0.00000	0.00000
GRO	0.00000	0.00000	0.00000	0.00000
GROOTD4	0.00000	0.00000	-0.03180	-0.14350
HARDP4	0.61539	0.00000	0.64674	-0.40598
HEYS9	0.00000	0.00000	0.00000	0.00000
HLOABS	0.00000	0.00000	0.00000	0.00000
HLODAM	0.00000	0.00000	0.00000	0.00000
HOLABS	0.00000	0.00000	0.00000	0.00000
HOLDAM	0.00000	0.00000	0.00000	0.00000
JERI9	-0.14101	0.00000	0.00000	0.00000
KALKF4	-0.22709	0.00000	0.00000	0.00000

Catchment	ARMA	Parameters		
	Φ1	Φ2	Θ1	Θ2
KAT10	0.00000	0.00000	-0.28380	0.12230
KATJREST	0.00000	0.00000	0.00000	0.00000
KLERK4	0.35600	0.08430	0.00000	0.00000
KLIPBN4	0.29450	0.00000	0.20190	0.02270
KLIPDN4	0.00000	0.00000	0.00000	0.00000
KLIPR4	0.00000	0.00000	0.00000	0.00000
KNELL	0.83923	0.00000	0.97459	0.00000
KONKP4	0.00000	0.00000	0.00000	0.00000
KROMN4	0.00000	0.00000	0.00000	0.00000
KRUG4	0.85396	0.00000	0.98082	0.00000
LAKESN4	0.00000	0.00000	-0.22820	-0.32250
LOGR1	0.00000	0.00000	0.00000	0.00000
LOGR10	0.00000	0.00000	0.00000	0.00000
LOGR11	0.00000	0.00000	0.00000	0.00000
LOGR12	0.00000	0.00000	0.00000	0.00000
LOGR13	0.00000	0.00000	0.00000	0.00000
LOGR14	0.00000	0.00000	0.00000	0.00000
LOGR15	0.00000	0.00000	0.00000	0.00000
LOGR16	0.00000	0.00000	0.00000	0.00000
LOGR17	0.00000	0.00000	0.00000	0.00000
LOGR18	0.00000	0.00000	0.00000	0.00000
LOGR19	0.00000	0.00000	0.00000	0.00000
LOGR2	-0.80712	0.00000	-0.66922	0.00000
LOGR3	0.00000	0.00000	0.00000	0.00000
LOGR4	0.00000	0.00000	0.00000	0.00000
LOGR5	0.00000	0.00000	0.00000	0.00000
LOGR6	0.00000	0.00000	0.00000	0.00000
LOGR7	0.00000	0.00000	0.00000	0.00000
LOGR8	0.00000	0.00000	0.00000	0.00000
LOGR9	0.00000	0.00000	0.00000	0.00000
LOLIF	0.00000	0.00000	0.00000	0.00000
LOWF4	0.00000	0.00000	0.00000	0.00000
MAKABS	0.00000	0.00000	0.00000	0.00000
MAKDAM	0.00000	0.00000	0.00000	0.00000
MAL10	0.00000	0.00000	0.00000	0.00000
MAS10	0.27080	0.00000	0.00000	0.00000
MAT10	0.00000	0.00000	-0.18090	0.00000
METO	0.00000	0.00000	0.00000	0.00000
MOH10	0.00000	0.00000	0.00000	0.00000
MORG9	0.00000	0.00000	0.00000	0.00000

Catchment	ARMA Parameters			
	Φ1	Φ2	Θ1	Θ2
MUELA	0.00000	0.00000	0.00000	0.00000
NAUT4	0.00000	0.00000	0.00000	0.00000
NTO10	0.10410	0.00000	0.00000	0.00000
ORAN10	0.00000	0.00000	0.00000	0.00000
OTJV	0.00000	0.00000	0.00000	0.00000
RUSTF4	-0.11646	0.22706	0.00000	0.00000
SANDN4	0.00000	0.00000	0.00000	0.00000
SEEH4	0.00000	0.00000	0.00000	0.00000
SEEIS	0.00000	0.00000	0.00000	0.00000
SPITS4	-0.73880	0.00000	-0.92000	0.04320
STERK4	0.00000	0.00000	0.00000	0.00000
SUIK4	0.00000	0.00000	0.00000	0.00000
TIER4	0.00000	0.00000	0.00000	0.00000
TM0194	0.00000	0.00000	0.00000	0.00000
TM0294	0.00000	0.00000	0.00000	0.00000
TM0394	-0.99990	-0.18120	-0.99990	0.00000
TM0494	-0.05280	0.00000	-0.09390	-0.10600
TSO10	0.00000	0.00000	-0.17219	-0.26092
TWEE4	0.00000	0.00000	-0.13814	-0.30436
UAUB	0.00000	0.00000	0.00000	0.00000
UOLIF	0.00000	0.00000	0.00000	0.00000
USWENTZD4	0.00000	0.00000	0.00000	0.00000
VAAL4	0.20350	0.09620	0.00000	0.00000
VDK	0.00000	0.00000	0.00000	0.00000
VHARTS4	0.00000	0.00000	0.00000	0.00000
WATER	-0.87853	-0.15355	-0.91532	0.00000
WELINC	0.00000	0.00000	0.00000	0.00000
WEST9	0.00000	0.00000	0.00000	0.00000
X11A1	0.00000	0.00000	0.00000	0.00000
X11B1	0.00000	0.00000	0.00000	0.00000
X11B2	0.00000	0.00000	0.00000	0.00000
X11C1	0.00000	0.00000	0.00000	0.00000
X11D1	0.00000	0.00000	0.00000	0.00000
X11D2	0.00000	0.00000	0.00000	0.00000
X11D3	0.00000	0.00000	0.00000	0.00000
X11E1	0.00000	0.00000	0.00000	0.00000
X11E2	0.00000	0.00000	0.00000	0.00000
X11F1	0.00000	0.00000	0.00000	0.00000
X11G1	0.00000	0.00000	0.00000	0.00000
X11H1	0.00000	0.00000	0.00000	0.00000

Catchment	ARMA	Parameters		
	Φ1	Φ2	Θ1	Θ2
X11J1	0.00000	0.00000	0.00000	0.00000
X11K1	0.00000	0.00000	0.00000	0.00000

Note: Only catchments having direct impact on Orange System presented, eg. No Olifants, Thukela downstream of Driel

3.2 Review of Stochastic Results

The standard stochastic verification plots were carried out on each hydrology. A set of ten plots were prepared. These include the

- Yield Capacity test plots;
- N-month run sums box plots;
- Maximum deficit plot;
- Duration of maximum deficit plot;
- Duration of longest depletion plot;
- Monthly and annual means box plot
- Monthly and annual standard deviations box plot;
- Two sampled cumulative distributions; and
- Correlogram of normalized annual streamflow.

All plots are available in electronic form as part of a CD submitted with this report.

A review of the stochastic verification plots highlighted some issues that required further analyses. The issue occurred for a number of hydrologies where the selected default ARMA model differed from the previous selected default (VRSAU, **DWAF, 2001a**) as a result of adding the 10 additional years of data. The issue is illustrated using the Katse hydrology as an example.

A default ARMA 0-1 model was previously selected for the Katse hydrology with the record dating 1920 to 1994. Having extended the record to 2004 (the first part of the record remained unchanged) the ARMA default shifted to an ARMA 1-2 model. The impact of this was quite severe on the system, resulting in higher stochastic flows being generated. **Figure 3-1** and **Figure 3-2** present the yield capacity curves for the two cases, previous and extended hydrology.

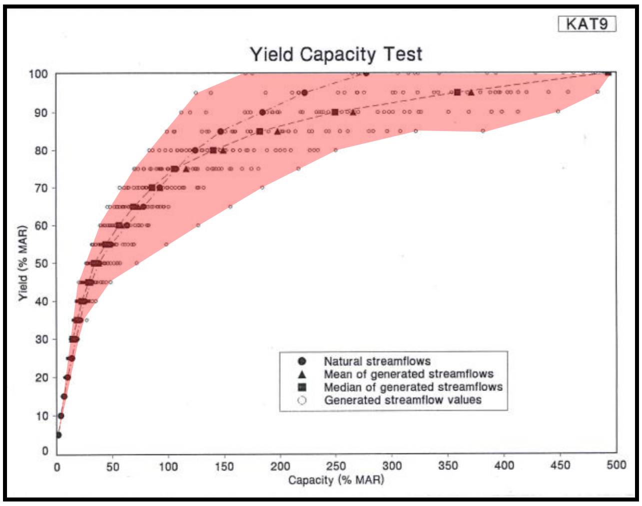

Figure 3-1: Yield capacity test on Katse hydrology dating 1920 to 1994, default ARMA 0-1

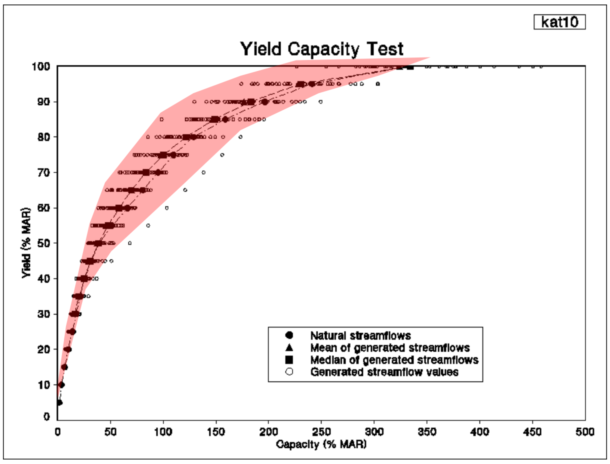

Figure 3-2: Yield capacity test on Katse hydrology dating 1920 to 2004, default ARMA 1-2

The figures show the wider range of stochastic flow sequences generated using the ARMA 0-1 model, with a much narrower range from the ARMA 1-2 default selection. This resulted in significantly higher flows for the Katse catchment in a test WRPM simulation, resulting in Katse dam projections operating at a higher level than previous simulations.

In most cases, the 10 additional years of data are wet years, and one would expect higher stochastic flows as a result. However, the severity of the impact was extreme, and in many situations completely changed the projections that have been used as a basis for future augmentation planning for a number of years.

As a result, Professor Geoff Pegram was requested to assist by carrying out a review of the issue, focusing on the Senqu hydrologies. The review document is presented in **Appendix B**. Two significant conclusions were drawn based on the assessment.

- ARMA model 2-2 should no longer be used as an option; and

- Where the default ARMA model that was selected differed from the previously selected ARMA model as a result of the additional 10 years of data, (ie. the first part of the record remained unchanged), the original ARMA selection should be used. This should be the case until further analyses and research work can take place on the stochastic procedure.

3.3 Modifications to Default Selections

During the review it was determined that the ARMA 2-2 model should no longer be used as an option. In addition, as a result of the differences in stochastic results, it was decided to default back to the originally selected ARMA model for any case where a new ARMA model was selected based on the extended hydrological record. If either the new or previous model selected ARMA 2-2, the second best option fit was used. Hydologies where this occurred are listed in the table below.

Table 3-3: ARMA default selection modifications

Catchment	Original ARMA default based on hydrology record 1920 - 1994	New ARMA default based on hydrology record 1920 - 2004	Selected ARMA model
ALLEM4	1-2	2-2	1-2
BARBERS4	2-2	2-2	0-0
BLOEMN3D4	2-2	2-2	0-0
C12D4	0-0	2-2	0-0
C24D4	2-2	2-2	0-0
C24E4	2-2	2-2	0-0
C24F4	2-2	2-2	2-1
C24G4	2-2	2-2	2-1
C24H4	2-1	2-2	2-1
C70ABC4	0-0	1-1	0-0
C70D4	2-2	2-2	1-1
C70E4	2-2	2-2	1-1
C70F4	2-2	2-2	1-1
C70G4	2-2	2-2	1-1
C70H4	2-2	2-2	1-1
C70J4	2-2	2-2	1-1
CHURCH9	0-2	'2-0	0-2
D13	NA	2-2	'2-0
DSWENTZD4	2-2	2-2	0-0
ERF4	0-0	1-1	0-0
GROOTD4	0-2	0-0	0-2
KAT10	0-1	1-2	0-1

Catchment	Original ARMA default based on hydrology record 1920 - 1994	New ARMA default based on hydrology record 1920 - 2004	Selected ARMA model
KLERK4	'2-0	1-0	'2-0
KLIPBN4	1-2	2-2	1-2
KLIPDN4	0-0	2-1	0-0
LAKESN4	0-2	2-2	0-2
MAS10	2-2	1-0	1-0
MAT10	0-1	1-2	0-1
NTO10	1-0	0-0	1-0
SANDN4	2-2	2-2	0-0
SPITS4	2-2	2-2	1-2
STERK4	0-0	0-1	0-0
SUIK4	0-0	1-1	0-0
TM0194	2-2	0-0	0-0
TM0294	2-2	0-0	0-0
TM0394	2-1	0-0	2-1
TM0494	1-2	0-0	1-2
TM08A4	2-2	2-2	0-0
TM16C4	2-2	2-2	0-0
TM1994	2-2	2-2	0-0
TM29A4	2-2	2-2	0-0
USWENTZD4	2-2	2-2	0-0
VAAL4	2-2	1-0	'2-0

4 HISTORIC YIELD ANALYSES

The objective of the yield analyses part of this task was to determine historic firm yields for the main systems using the updated hydrology and systems configurations prepared as part of the ORASECOM study. The yields were compared with previous yields obtained, and reasons for the differences explained. Historic firm yields for the Bloemhof system and the Orange system were obtained separately. The reason for this was to compare these yields with yields obtained in previous studies where separate Orange and Vaal system configurations were used. For this reason, this section is divided into two sub-sections, one presenting the approach to determine the yield for the Vaal sub-system and one for the Orange sub-system.

4.1 Vaal subsystem

4.1.1 Yield determination methodology

The approach to determine the yield for the Vaal subsystem is divided into two steps. The first step involves determining the historic firm yield for Grootdraai Dam alone. The second step involves determining the yield for the Bloemhof Dam system. When step two is carried out, the yield obtained for Grootdraai Dam in step one is removed from Grootdraai Dam and linked directly with the yield node. This is because Grootdraai Dam is not used to support Vaal Dam and therefore its individual yield should be added to the remaining system yield in order to obtain the total yield for the Bloemhof sub-system.

Abstractions from the Vaal River system take place at two main points in the River. In order to account for this, channels representing these abstractions (at a 2010 development level) are configured at their respective points, and are linked to the yield node. An “open” channel, that represents all additional yield over and above the 2010 development level abstractions already removed, is then placed on Vaal Dam and linked to the yield node. This is represented by **Figure 4-1**. The total yield of the Bloemhof system without the Lesotho transfer and with no support to downstream Lower Vaal demands was determined in order to compare with the VRSAU study.

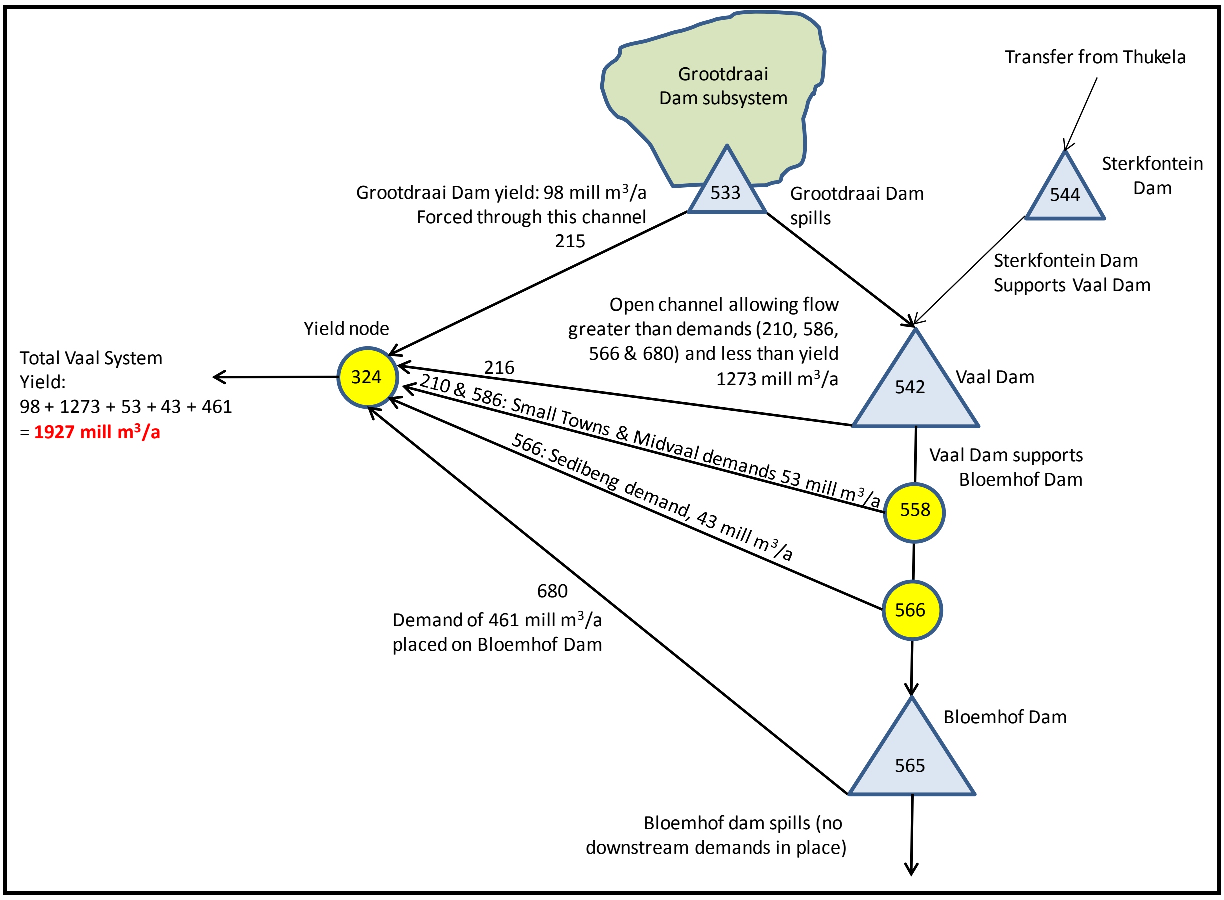

Figure 4-1: Diagram representing Vaal yield determination approach

4.1.2 Yield results

Historic firm yields for selected systems were determined and compared to the yields obtained in previous studies. These are summarised in **Table 4-1**.

Table 4-1: Historic firm yields for selected subsystems

Sub catchment	Yield (mill m^3/a)
Grootdraai	98
Taung Dam	7.85
Koppies Dam (Renoster)	13.0
Bloemhof total yield	1927

4.1.3 Comparisons with previous studies

In order to confirm that the extended hydrology had not impacted on the system yields, detailed checks were carried out using the data sets from previous studies that were used as a basis for updating in the ORASECOM study. Explanations for the differences are included in the following tables. The Taung and Koppies Dam yields remained identical and no explanation is therefore required regarding these yields.

Table 4-2: Grootdraai yield comparison

Yield (million m^3/a)	Comments
123.8	VRSAU original yield
134	VRSAU yield including updated irrigation information (DWAF, 1999)
98	Drop of 36 million m^3/a due to compensation release (average 31.5 million m^3/a) and Standerton demand (10.6 million m^3/a) previously formed part of yield

Table 4-3: Bloemhof yield comparison

Yield (million m^3/a)	Comments
1703	VRSAU original yield
1709	VRSAU yield corrected for inaccurate evaporation demand on one dam
1927	New total yield, obtained by cutting off Lower Vaal system resulting in no support to downstream demands. The increase in yield is mainly due to the return flows that were previously not simulated in the system. They were in the past accounted for in the WRPM and were not included in the yield result.

A system balance comparison is presented in **Table 4-4**. The VRSAU balance covers the period 1920 to 1994, whereas the ORASECOM balance stretches from 1920 to 2004. The increase in hydrology is due to the relatively wet ten years that were added onto the VRSAU hydrology. The increase in inflows is due to the return flows that were included for the first time. As expected, demands at a 2010 development level also increased.

Table 4-4: System balance comparison between VRSAU and ORASECOM yields (all units million m^3/a)

		VRSAU (1920 – 1994)	ORASECOM (1920 – 2004)	Difference
	HYDROLOGY	3889	4055	166
+	INFLOWS	96	706[(1)]	610
-	DEMANDS	696	920	224
-	EVAPORATION	667	709	41
-	STORAGE	-90	-42	48
-	SPILLS	1002	1247	245
=	YIELD	1709	1927	218

Note 1: Mostly return flows and not necessarily a stable flow for yield purposes

A detailed breakdown of the demands and return flows simulated in the two studies is presented in **Appendix C**.

4.2 Orange subsystem

4.2.1 Yield determination methodology

Similar to the Vaal, the approach to determine the yield for the Orange sub-system is carried out in two steps. In order to obtain the correct spills from the Vaal to the Orange River it is important to allow Bloemhof Dam to supply various users in the Lower Vaal, of which the Vaalharts Irrigation scheme is the largest user. Significant return flows are generated from this irrigation scheme and it is therefore important to include this effect on the flows from the Lower Vaal that will eventually spill into the Orange River. A scenario was analysed using the Vaal configuration whereby the yield of Bloemhof dam, under the condition that the Lower Vaal demands are first met before the yield channel, was determined. A yield of 1413 million m^3/a was obtained, and the spills from the Lower Vaal were stored and used as an input file for the Orange system. In this way only the spills from the Lower Vaal sub-system enter the Orange system, with these configured in such a way that they are only able to support the Douglas irrigation demands. All other demands in the Orange River downstream of Gariep and Vanderkloof Dams are supplied by these two dams only, and the Vaal spills cannot be used to support these demands.

In order to accommodate this operating rule, a channel parallel to the main Orange River is configured in the WRYM setup, into which the Vaal spills were directed. In addition to the Vaal spills, the Molopo, Ongers, Hartbeest and all other Lower Orange tributaries enter this parallel channel and can therefore not contribute to the supply of the Lower Orange demands. This is the situation which best represents reality, as these demands are all met via releases from Gariep and Vanderkloof dams.

Katse and Mohale dams are also simulated in such a way that they do not support Gariep Dam. The Lesotho Highlands transfer was placed as a demand on Katse Dam so that the impact of this transfer will be taken into account when determining the Orange River Project system yield. The yield value determined and quoted for the Orange River Project (Gariep and Vanderkloof Dams) is the surplus yield, once all downstream demands and River losses have been met. These demands are given a higher priority (by using a higher penalty) than the yield channel, with the result that they are first supplied before any water is available to the surplus yield channel. The simplified configuration is represented by the following diagram.

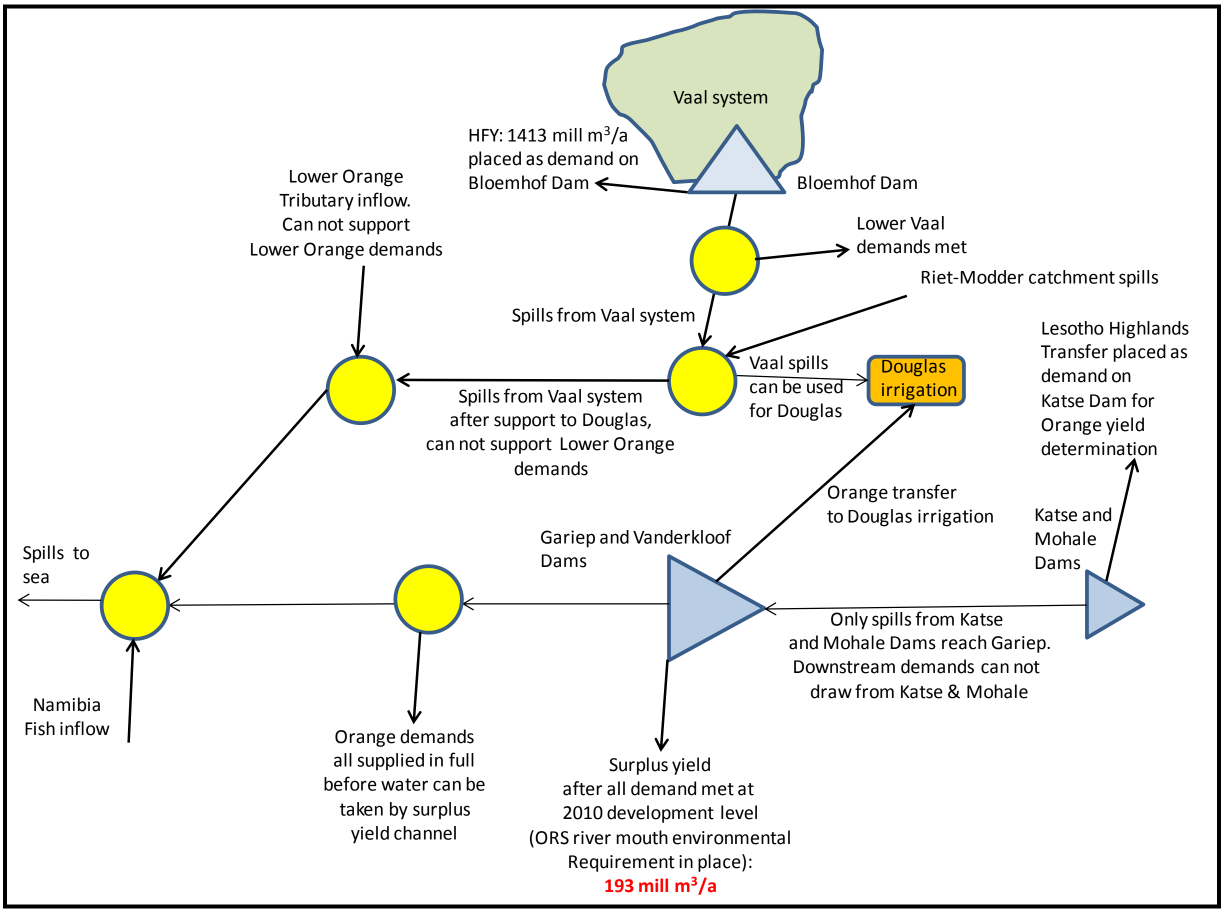

Figure 4-2: Diagram representing Orange yield determination approach

4.2.2 Yield results

The surplus yield obtained for the Orange River Project (ORP including Gariep and Vanderkloof Dams) once all demands on the dams have been met is 193 mill m^3/a. This is in comparison with 120 mill m^3/a obtained in the LORMS study. The main reason for the relatively small increase is a result of improved hydrology in the Caledon River which produced higher inflows, reduction in the operational losses in the ORP (LORMS previously used 270 mill m^3/a, reduced to 195 mill m^3/a for ORASECOM study), and the introduction of the latest Katse and Mohale environmental flow requirements which were not in place in the LORMS and produce higher inflows to Gariep Dam. The total demands supplied at a 2010 development level by the Orange River Project before the surplus yield is taken off amounts to 3124 mill m^3/a. The total yield is therefore 3317 mill m^3/a.

4.2.3 Comparisons with previous studies

The new yield value was compared with that previously obtained in the LORMS. The same record period (1920 – 1987) was used for the comparison. The detailed comparison was carried out only for the catchments upstream of the Gariep and Vanderkloof Dams, as this is where the main hydrological and system configuration changes took place. The detailed comparisons are presented in **Appendix D**, with a summary shown in **Table 4-5**.

Table 4-5: Total Orange system yield (all units million m^3/a)

Water Balance Component	SENQU		CALEDON		UPPER ORANGE	
	LORMS	ORECON	LORMS	ORECON	LORMS	ORECON
+ Hydrology	4065	4065	1217	1244	1450	1334
+ System inflows	0	0	0	0	4272	4285
+ Other inflows	0	0	0	0	0	0
- Demands	806	805	96	123	1505	1307
- Evaporation net	17	16	35	26	697	723
- Storage	-1	7	0	0	50	-2
- Outflow from system	3244	3238	1086	1095	3471	3591
Balance	0	0	0	0	0	0

A balance of the whole system for the two studies is presented in **Table 4-6**.

Table 4-6: Water balance for LORMS and ORECON

		LORMS	ORECON
	HYDROLOGY	7889	8265
+	INFLOWS	1568	1134
-	DEMANDS	4684	4656
-	EVAPORATION	936	983
-	STORAGE	49	-2
-	SPILLS	3668	3569
=	YIELD	120	193

The total demands on the ORP decreased from 3155 million m^3/a used in the LORMS to 3124 million m^3/a used in ORASECOM, mainly due to the decrease in operating losses. A further update in demands will take place as part of this study, where after the yields will again be refined.

Based on the relatively small increase in surplus yield compared to the total system demands, it was decided to accept the hydrology developed in the ORASECOM study for further use in this study.

5 CONCLUSIONS AND RECOMMENDATIONS

The hydrology prepared in the ORASECOM study has been summarised and reviewed in this document. 16 hydrological zones including 207 hydrology time series files have been assessed. The hydrological zones have been given a general confidence rating based on data availability in preparation of the hydrology. The hydrology is generally considered to be have a good confidence rating. Individual hydrologies that have been given a poor confidence rating have a very small contribution to the overall catchment. Stochastic validation and verification checks have been completed and a Parameter file required for use in the systems models has been prepared. Some issues were found with the creation of the Parameter file, and after further review of the matter, it was recommended to revert to defaults used previously until further research can take place.

Preliminary historic yields have been determined using the new hydrologies and system configurations where applicable. The yield in the Vaal system is significantly higher than before mainly as a result of return flows previously not taken into account. The Orange surplus yield has increased from 120 million m^3/a to 193 million m^3/a, which is considered a very small increase when compared with the overall system demands (3124 million m^3/a) and is mainly due to the decrease in operating requirements.

It is recommended that the hydrology developed as part of the ORASECOM study be taken forward and used for the systems analyses to take place as part of this study.

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APPENDIX A

DETAILED HYDROLOGY RATING TABLE

Sub-Area	% Natural Inflow	Gross Area	Hydro-logical Import-ance	Rainfall Gauge Density (/2500 km2)	Rainfall Score	# of Gauges	Gauge Density	Observed Coverage	Observed Score	Landuse Score	Total
Senqu	35%	27647	100	2.4	2.4	8	0.7	5	3.6	4	67%
Vaal	27%	94456	78	3.7	3.7	34	0.9	5	4.5	4	81%
Caledon	12%	21884	34	4.5	4.5	4	0.5	5	2.3	4	72%
Upper Orange	10%	49746	29	3.1	3.1	8	0.4	5	2.0	4	61%
Fish	6%	81630	18								
Riet - Modder	3%	33294	9	4.9	4.9	5	0.4	2.5	0.9	3	59%
Lower Vaal	2%	55019	5	3.4	3.4	5	0.2	3	0.7	3	47%
Lower Orange Tributories	1%	126774	4	0.6	0.6	4	0.1	1	0.1	3	25%
Molopo	1%	351553	3	0.7	0.7	9	0.1	0.5	0.0	3	25%
Lower Orange Main stem	1%	116539	3	0.6	0.6	1	0.0	0.5	0.0	3	24%
Renoster	1%	6157	3	3.7	3.7	2	0.8	2.5	2.0	4	65%
Schoonspruit	1%	7512	3	3.7	3.7	3	1.0	3	3.0	4	71%

APPENDIX B

STOCHASTIC REVIEW DOCUMENT

APPENDIX C

VAAL DEMANDS AND RETURN FLOWS

VRSAU return flows

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Suikerbos	75	75 - SUIKER URB RUNOFF	17.15
Klipbank & Barrage	77	77 - KLIPRIVER URB RUNOFF	50.94
Klipbank & Barrage	80	80 - BARRAGE URB RUNOFF	15.36
Mooi	104	104 - BOSKOP MINE RETURN FLOW	6.24
Klipdrift	149	149 - KLOOF MINE RETURN FLOW	5.63
Renoster	117	117 - HEILBRON RETURN FLOW	0.78
			96

Updated return flows

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Grootdraai	376	376 - VAAL GR URBAN	1.67
Grootdraai	377	377 - VAAL NET URBAN	4.13
Grootdraai	544	544 - VAAL SEEPGR	0.36
Vaal	415	415 - VAAL WAURBAN	9.36
Vaal	416	416 - VAAL SEEPWA	0.12
Vaal	418	418 - VAAL SASOL	4.20
Vaal	476	476 - VAAL BETH HARRI QWA RF	8.99
Vaal	686	686 - VAAL C12D4 URB	6.74
Suikerbos	575	575 - VAAL EASTM1	3.65
Suikerbos	497	497 - VAAL EASTM2	21.73
Suikerbos	570	570 - VAAL RAND WATER	60.26
Suikerbos	689	689 - VAAL SUIK4 URB 92	18.22
Suikerbos	690	690 - VAAL SUIK4 URB 8	1.58
Klipbank & Barrage	578	578 - VAAL CENTM	7.80
Klipbank & Barrage	534	534 - VAAL WESTM	0.00
Klipbank & Barrage	577	577 - VAAL RAND WATER	246.44
Klipbank & Barrage	580	580 - VAAL RAND WATER	13.08
Klipbank & Barrage	579	579 - VAAL RAND WATER	31.87
Klipbank & Barrage	616	616 - VAAL FWESTM	13.44
Klipbank & Barrage	692	692 - VAAL KLIP4 URB 97.6	58.15
Klipbank & Barrage	687	687 - VAAL KLIP4 URB 2.4	1.43
Klipbank & Barrage	688	688 - VAAL BAAR4 URB 47.7	8.42
Klipbank & Barrage	691	691 - VAAL BARR4 URB 52.3	9.23
Mooi	184	184 - VAAL MINE DEWATERING	0.00
Mooi	604	604 - VAAL BOSKRET	51.00
Mooi	654	654 - VAAL RAND WATER	7.50
Mooi	200	200 - VAAL POTCH RET	9.96

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Klipdrift	649	649 - VAAL MINE/URBAN RETURN FLOW	4.54
Schoonspruit	930	930 - SCHOON VENTERSDORP RF	0.59
Schoonspruit	960	960 - SCHOONSPRUIT wetf.lag	4.41
Schoonspruit	931	931 - SCHOON HARTBEESFONTEIN WTW	1.39
Schoonspruit	961	961 - SCHOON ORKNEY WWTW	1.01
Schoonspruit	929	929 - SCHOON KLERKSDORP RF	6.72
	962	962 - SCHOONSPRUIT eyecurf.flo	47.91
Renoster	304	304 - RENOST KOPPIES HEILBRON RF	0.35
Vals	10	10 - VAAL KROONS	5.93
Sand - Vet	138	138 - VAAL WELKOM	1.40
Sand - Vet	137	137 - VAAL SEEPVET	1.80
Sand - Vet	145	145 - VAAL TAILWATER	10.78
Bloemhof	590	590 - VAAL WTVLRWC ret flow	1.55
Bloemhof	217	217 - VAAL MINE DEWATERING	18.00
Bloemhof	353	353 - VAAL BLOEM.EXC	0.00
			706

VRSAU Demands

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Grootdraai	52	52 - GROOTDUMMY ABSTRACTION	3.84
Thukela	203	203 - WOODSTOCK DUMMY IRR	2.24
Thukela	205	205 - WOODSTOCK MAINSTREAM IRR	4.95
Thukela	207	207 - WOODSTOCK DEMAND	6.44
Thukela	210	210 - TUGELA NODE 45 IRR	2.35
Thukela	87	87 - LOSS DRIEL TRANSFER	26.50
Wilge	58	58 - WILG DUMMY IRR	19.89
Wilge	57	57 - WILG DUMMY ABSTR.	12.57
Wilge	64	64 - STERKFONTEIN LOSSES	34.90
Wilge	59	59 - SAULSPOORT ABSTR.	6.60
Vaal	54	54 - VAALDUMMY ABSTRACTION	7.50
Suikerbos	70	70 - SUIKER IRR ABSTR	12.67
Suikerbos	76	76 - SUIKER ABSTR	4.81
Klipbank & Barrage	78	78 - KLIPRIVER IRR ABS	26.26
Klipbank & Barrage	79	79 - VAAL-BARRAGE IRR	1.92
Krom	69	69 - KROMDRAAI DUMMY ABSTR	1.38
Krom	157	157 - VAAL BED LOSS AT KROMDRAAI	15.49
Mooi	102	102 - KLERKSKRAAL ABSTR.	23.92
Mooi	100	100 - BOSKOP DUMMY IRR	0.16

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Mooi	105	105 - BOSKOP ABSTR.	38.67
Klipdrift	114	114 - KLIPDRIFT DUMMY IRR	0.78
Klipdrift	107	107 - KLIPDRIFT ABSTRACTION	5.00
Schoonspruit	119	119 - RIETSPRUIT DAM DEMAND	11.24
Schoonspruit	128	128 - SCHOONSPRUIT NODE 90 IRR	2.08
Schoonspruit	126	126 - JOHAN NESER DUMMY IRR	3.35
Schoonspruit	121	121 - JOHAN NESER DEMAND	10.51
Renoster	118	118 - RIETFONTEIN DUMMY IRR	2.33
Renoster	116	116 - KOPPIES DUMMY IRR	1.31
Renoster	110	110 - KOPPIES DAM DEMAND	9.92
Vals	143	143 - KLIPBANK DUMMY IRR	6.27
Vals	144	144 - KROONSTAD ABS	8.99
Sand - Vet	136	136 - ALLEMANSKRAAL DUMMY IRR	2.91
Sand - Vet	131	131 - ALLEMANSKRAAL DEMAND	32.44
Sand - Vet	139	139 - ERFENIS DUMMY IRR	3.25
Sand - Vet	133	133 - ERFENIS DAM DEMAND	39.28
Sand - Vet	138	138 - BLOEMVET DUMMY DEMAND	4.25
Bloemhof	99	99 - GOUDVELD BED LOSS	39.45
Bloemhof	152	152 - VAAL BED LOSS NODE 73	18.81
Bloemhof	151	151 - VAAL IRR NODE 73	39.61
Bloemhof	147	147 - BLOEM-VAAL DUMMY IRR	7.23
Bloemhof	153	153 - BLOEMHOF DAM LOSSES	193.45
			696

Updated demands

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Grootdraai	552	552 - VAAL GROOT94.ABS	2.69
Grootdraai	681	681 - VAAL GROOTDRAAI LOSSES	6.25
Thukela	707	707 - UP THUK DEMAND 2	1.81
Thukela	587	587 - UP THUK WILGE RIVER LOSSES	0.00
Thukela	705	705 - UP THUKELA RIVER	3.31
Thukela	703	703 - UP THUKELA RIVER	1.48
Thukela	710	710 - UP THUKELA RIVER	1.51
Wilge	564	564 - VAAL STERKFONTEIN LOSSES	31.27
Wilge	557	557 - VAAL WILG94.ABS	12.09
Wilge	559	559 - VAAL SAUL94	4.91
Wilge	404	404 - VAAL SAULSPOORT LOSSES	0.00
Vaal	457	457 - VAAL STANDERTON	10.63

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Vaal	554	554 - VAAL VAAL94.ABS	0.74
Suikerbos	576	576 - VAAL ERGO.Q	4.56
Suikerbos	516	516 - VAAL Balfour Abstr	1.55
Suikerbos	650	650 - VAAL EWR	0.00
Suikerbos	498	498 - WETLAND AND BEDLOSS	16.22
Klipbank & Barrage	533	533 - BEDLOSS	3.60
Klipbank & Barrage	496	496 - WETLAND	5.65
Klipbank & Barrage	617	617 - WETLAND	1.17
Krom	657	657 - VAAL RIVER BEDLOSS U/S	15.49
Mooi	185	185 - VAAL	27.68
Mooi	605	605 - VAAL BOSKOP ABSTRACTION	0.00
Mooi	602	602 - VAAL KLERKSKRAAL ABSTRACTION	0.02
Mooi	196	196 - VAAL POTCH DEM	12.56
Mooi	197	197 - VAAL POTCH GROWTH	3.69
Klipdrift	607	607 - VAAL KLIPDRIFT ABSTRACTION	6.41
Schoonspruit	956	956 - SCHOON WETLAND LOSSES	1.21
Schoonspruit	928	928 - SCHOON VENTERSDORP	0.59
Schoonspruit	950	950 - SCHOON CANAL 1 LOSSES	5.15
Schoonspruit	955	955 - SCHOON CANAL 3 LOSSES	2.71
Schoonspruit	951	951 - SCHOON CANAL 2 LOSSES	1.04
Schoonspruit	953	953 - SCHOON CANAL 4 LOSSES	0.14
Schoonspruit	959	959 - SCHOONSPRUIT wetf.dem	14.45
Renoster	307	307 - RENOSTER KOPPIES GWS CANAL	0.98
Renoster	312	312 - RENOSTER KOPPIES GWS RIVER	0.81
Renoster	311	311 - RENOST KOPPIES URBAN ABS	0.98
Renoster	333	333 - RENOSTER RELEASES TO VOORSPOED	2.62
Renoster	336	336 - RENOST VOORSPOED MINE DEMAND	2.62
Renoster	338	338 - RENOST VILJOENSKROON URBAN	1.19
Renoster	323	323 - RENOSTER RIVER C70E.MIR	0.05
Renoster	326	326 - RENOSTER RIVER C70G.DIR	0.05
Renoster	327	327 - RENOSTER RIVER C70G.MIR	0.10
Renoster	331	331 - RENOSTER RIVER C70H.MIR	0.02
Renoster	341	341 - RENOSTER RIVER C70J.MIR	0.06
Renoster	347	347 - RENOSTER RIVER C70K.MIR	0.15
Vals	644	644 - VAAL KROONSTAD ABSTRACTION	8.86
Sand - Vet	631	631 - VAAL ALLEMANSKRAAL ABSTRACT	25.72
Sand - Vet	132	132 - VAAL ALLEM URBAN	15.21
Sand - Vet	633	633 - VAAL ERFENIS DAM ABSTRACTION	7.42
Bloemhof	599	599 - VAAL GOUDVELD BEDLOSS	39.45
Bloemhof	652	652 - VAAL RIVER BEDLOSS D/S	18.81

Catchment	Channel number	Channel detail	Flow (million m^3/a)
Bloemhof	653	653 - VAAL BLOEMHOF LOSSES	193.45
Bloemhof	683	683 - VAAL IRRIG DEMAND	0.00
Bloemhof	684	684 - VAAL IRRIG DEMAND	0.00
			519.11

Catchment	Irrigation block	Demand (million m^3/a)	Return flow (million m^3/a)	Net demand (million m^3/a)
sand-vet	199	2.40	0.48	1.92
sand-vet	210	2.40	4.46	-2.07
sand-vet	212	2.94	0.35	2.58
sand-vet	213	35.58	4.75	30.83
sand-vet	81	0.59	0.14	0.45
sand-vet	83	2.46	0.12	2.33
sand-vet	87	9.39	0.41	8.98
vals	8	0.00	0.00	0.00
vals	6	6.01	0.67	5.34
vals	205	5.10	0.96	4.13
vals	208	6.31	0.94	5.37
bloem	115	4.34	0.69	3.65
bloem	116	14.81	2.36	12.45
bloem	120	3.58	0.28	3.30
bloem	118	31.60	4.81	26.80
mooi	103	2.60	0.11	2.48
mooi	104	1.61	0.06	1.55
mooi	107	4.74	0.28	4.46
mooi	111	13.28	0.73	12.55
mooi	112	5.49	0.33	5.15
klipd	95	0.28	0.04	0.24
klipd	99	0.00	0.00	0.00
klipd	96	0.33	0.04	0.29
klipd	100	0.00	0.00	0.00
krom	101	3.78	0.72	3.06
krom	102	2.04	0.41	1.63
wilge	135	19.21	2.36	16.85
wilge	136	12.65	1.56	11.09
wilge	137	0.91	0.27	0.64
wilge	139	2.90	0.74	2.16
wilge	142	1.79	0.40	1.39
wilge	144	9.84	1.36	8.48
wilge	146	0.81	0.20	0.61

Catchment	Irrigation block	Demand (million m^3/a)	Return flow (million m^3/a)	Net demand (million m^3/a)
wilge	145	3.92	0.89	3.04
wilge	149	0.76	0.11	0.65
wilge	148	0.81	0.11	0.70
wilge	152	15.69	2.04	13.65
wilge	151	14.83	1.87	12.96
vaal	184	5.48	2.37	3.10
vaal	181	1.96	0.94	1.01
vaal	189	7.09	2.93	4.16
vaal	190	4.29	1.79	2.50
vaal	180	9.10	4.29	4.81
vaal	178	16.42	7.49	8.93
vaal	160	1.85	0.84	1.01
vaal	159	1.14	0.52	0.62
vaal	157	0.30	0.14	0.17
vaal	164	2.01	0.84	1.17
vaal	166	1.23	0.51	0.72
vaal	167	1.93	0.82	1.11
vaal	163	3.22	1.35	1.87
vaal	173	2.86	1.19	1.67
vaal	170	1.91	0.80	1.11
vaal	175	1.17	0.49	0.68
vaal	193	6.31	2.78	3.53
vaal	196	39.24	16.56	22.68
vaal	197	13.15	5.55	7.60
vaal	198	2.36	0.99	1.37
vaal	174	4.67	1.95	2.72
grootdraai	124	0.15	0.04	0.11
grootdraai	123	0.62	0.13	0.49
grootdraai	128	4.62	0.89	3.72
grootdraai	126	4.49	0.65	3.84
grootdraai	131	5.29	0.66	4.63
grootdraai	134	4.14	0.51	3.63
suikerbos	214	1.22	0.27	0.94
suikerbos	216	3.57	0.78	2.79
suikerbos	220	1.35	0.19	1.16
suikerbos	222	6.26	0.90	5.36
suikerbos	233	0.53	0.08	0.45
suikerbos	227	1.20	0.18	1.03
suikerbos	230	0.39	0.06	0.34
suikerbos	236	2.17	0.31	1.86
klip and barr	241	8.54	1.53	7.01

Catchment	Irrigation block	Demand (million m^3/a)	Return flow (million m^3/a)	Net demand (million m^3/a)
klip and barr	243	19.08	3.60	15.48
klip and barr	246	10.56	1.42	9.14
klip and barr	247	21.29	2.16	19.12
schoonspruit	253	3.73	0.82	2.91
schoonspruit	254	5.07	1.15	3.92
schoonspruit	255	9.76	2.16	7.60
schoonspruit	257	0.68	0.08	0.60
schoonspruit	256	0.44	0.06	0.38
schoonspruit	266	0.87	0.11	0.76
schoonspruit	262	0.60	0.08	0.52
schoonspruit	258	5.37	0.33	5.04
schoonspruit	259	0.53	0.05	0.48
schoonspruit	269	0.81	0.06	0.76
schoonspruit	270	0.08	0.02	0.05
schoonspruit	271	1.10	0.17	0.93
renoster	273	2.38	0.32	2.06
renoster	275	0.66	0.09	0.56
renoster	321	0.90	0.02	0.88
renoster	279	0.33	0.01	0.32
renoster	284	0.37	0.01	0.37
renoster	290	1.27	0.18	1.09
renoster	294	0.56	0.02	0.54
renoster	300	0.22	0.04	0.18
renoster	295	1.47	0.07	1.40
renoster	298	0.43	0.07	0.36
renoster	323	2.94	0.36	2.58
renoster	322	3.32	0.42	2.90
		512.86	112.30	400.57

APPENDIX D

DETAILED SENQU, CALEDON AND UPPER ORANGE WATER BALANCE

SENQU CATCHMENT						
	LORMS			ORECON (1987)		
Detail	Flow (million m^3/a)	Chan no.	Channel name	Flow (million m^3/a)	Chan no.	Channel name
hydrology	4065			4065		
system inflows	0			0		
demands	806			805		
	1.70	132	LES HIGH 132 - ORAN IRR AT ORANGE DRAAI NODE	1.71	132	LES HIGH 132 - ORAN IRR AT ORANGE DRAAI NODE
				17.13	2497	LES HIGH 2497 - LOSS IN MAKHALENG
				9.89	2501	LES HIGH 2501 - MOHALE'S HOEK URB
	803.93	139	LES HIGH 139 - LHWP TRANSFER	776.27	139	LES HIGH 139 - LHWP TRANSFER
irrig blocks net	0			0		
evaporation net	17			16		
Storage	-1			7		
outflow from system	3244			3238		
balance	0			0		

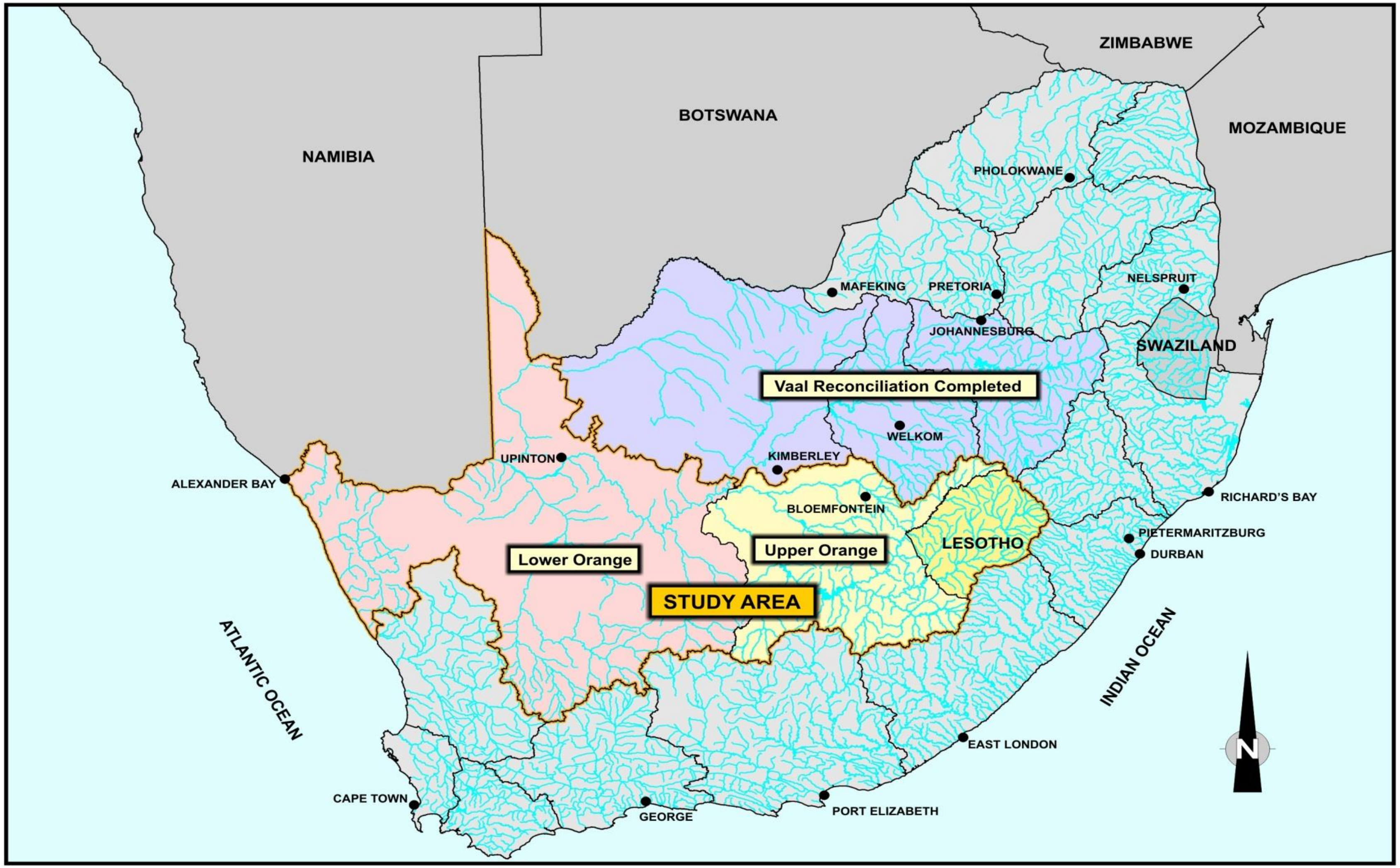
CALEDON CATCHMENT						
	LORMS			ORECON (1987)		
Detail	Flow (million m^3/a)	Chan no.	Channel name	Flow (million m^3/a)	Chan no.	Channel name
hydrology	1217			1244		
system inflows	0			0		
urban demands	15			36.44		
	10.92	66	LESOTHO URBAN DMD	10.63	329	66 - LESOTHO URBAN DMD
				0.00	2510	MASERU DEMAND
				0.88	2483	2483 - HLOTSE LERIBE UR DEM
				11.19	2492	2492 - MAPOTSOE/BUTHA URB
	4.20	51	RSA URB DMD	0.62	314	TWEESPRUIT
				0.22	307	HOBHOUSE/THABA PATSOE
				11.47	310	LADYBRAND /FICKSBURG/ CLOCOLAN
				1.44	316	FOURIESBURG/CLARENS
other demands	7.92			25.29		
	4.17	73	LOSS WELB TO BLOEMF	4.72	73	LOSS WELB TO BLOEMF
	3.76	68	LOSS KNEL TO WELB	1.40	68	LOSS KNEL TO WELB
				10.18	2479	2479 - LOSS IN HLOTSE
				3.74	2487	2487 - LOSS IN HOLOLO
				5.25	561	561 - LOSS WELB comp
irrigation demands	73			63.65		SUM OF 14 IRRIGATION BLOCKS
	8.43	54	54 - LES94.IRG LESOTHO DEMA			
	32.28	57	57 - RSA94.IRG RSA DEMAND			
	31.97	70	70 - WEL94.IRG DEM FROM D/S			
evaporation net	35			26		
Storage	0			0		
outflow from system	1086.24			1093.11		
	1017.16	71	INFLOW TO ORANGE (D24)	1033.43		INFLOW TO ORANGE (D24), 559 + 562 + 138
	31.68	232	KNELLPOORT TO RUST	17.09	232	232 - KNELLPOORT TO RUST
	37.40	147	WELBEDACHT TO BLOEMFONTEIN	42.59	147	WELBEDACHT TO BLOEMFONTEIN
balance	0			0		

UPPER ORANGE CATCHMENT						
	LORMS			ORECON (1987)		
Detail	Flow (million m^3/a)	Chan no.	Channel name	Flow (million m^3/a)	Chan no.	Channel name
hydrology	1450			1334		
system inflows	4272			4283		
	1017.16	71	Flow from Caledon	1033		INFLOW TO ORANGE (D24), 559 + 562 + 138
	3243.93	30	Flow from Senqu	3238	30	Flow from Senqu
	10.79	173	VAAL 173 - RAMAH IRR RFS	12	173	VAAL 173 - RAMAH IRR RFS
urban demands	15			16.36		
	2.11	183	GARIEP TO VANDERKL URB	0.41	321	MOLTENO
	10.70	52	URBAN DMD KRAAI NODE	0.69	320	BURGERSDORP
	1.99	45	HOPETOWN DMD	1.99	45	45 - HOPETOWN DMD
				4.73	317	STERKSPRUIT
				1.93	327	ZASTRON/LADY GREY
				1.77	325	ALIWAL NORTH
				0.50	323	RHODES / BARKLY EAST
				0.28	328	JAMESTOWN
				0.22	322	DORDRECHT
				1.50	326	BETHULIE
				1.01	324	VENTERSTAD/OVISTO N
				0.69	315	CALEDON ROUXVILLE
				0.56	312	CALEDON SMITHFIELD
				0.06	313	CALEDON VAN STADENSRUS
other demands	1073.46			1091.36		
	0.00	248	BOSBERG TRANSFER			
	627.33	130	EASTERN CAPE	647.30	130	EASTERN CAPE
	270.01	251	OPERATIONAL LOSSES	195.17	251	OPERATIONAL LOSSES
	44.24	67	LOSSES REACH 1A	44.25	67	LOSSES REACH 1A
	11.76	238	LOSSES REACH 1B	11.76	238	LOSSES REACH 1B
	120	177	System Surplus Yield	193	177	System Surplus Yield
irrigation demands	416			197		
	41		SFR ROOD9.IRR	41		SUM OF 27 IRRIGATION BLOCKS

	16		SFR ALIW9.IRR			
	22.94	84	84 - GARIEP IRR			
	9.25	181	181 - ORANGE IRR AT ALIWAL NODE			
	18.02	131	131 - ORANGE IRR AT KRAAI NODE			
	95.62	34	34 - GAR87.IRG GARIEP DUMMY			
	49.90	39	39 - VANDERKL. DUMMY DAM IRR			
	123.77	43	43 - IRRIG AREA VDK TO TORQUAY	116.66	43	43 - IRRIG AREA VDK TO TORQUAY
	40.43	234	234 - IRRIG AREA TORQUAY TO OV CONF	39.73	234	234 - IRRIG AREA TORQUAY TO OV CONF
evaporation net	697			723		
Storage	50			-2		
outflow from system	3470.96			3591.35		
	273.73	128	128 - ORANGE RIET CANAL CAP	292.89	128	128 - ORANGE RIET CANAL CAP
	92.0219616	49	49 - O/V CANAL MAX KAP.	96.28	49	49 - O/V CANAL MAX KAP.
	3105.20		225 + 236 OUTFLOW TO LOWER ORANGE	3202.18		225 + 236
balance	0			0		

APPENDIX E

STUDY AREA



WRP_P:\Proposals\W0273_Orange River Reconciliation Strategy_Graphics\Figure 3.cdr
Last updated: 2011/09/02

DEVELOPMENT OF RECONCILIATION STRATEGIES FOR LARGE BULK WATER SUPPLY SYSTEMS: ORANGE RIVER: PROPOSAL	**Study area locality map**

Title:	***Surface Water Hydrology and Systems Analysis Report***
Authors:	*Study Team*
Project Name:	***Development of Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River***
DWA Report No:	*P RSA D000/00/18312/7*
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