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SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE
INTEGRATED WATER RESOURCES MANAGEMENT PLAN
Work Package 2:
Extension and Expansion of the Hydrology of the Orange-Senqu Basin

Extension of Hydrological Records

April 2011

ORASECOM

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Prepared by

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SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE INTEGRATED WATER RESOURCES MANAGEMENT PLAN

Work Package 2:

Extension and Expansion of Hydrology of the Orange-Senqu Basin

Extension of Hydrological Records

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Study Name	**Support to Phase 2 of the ORASECOM Basin-wide Integrated Water resources Management Plan**		
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	Setting up and Testing of the Final Extended and Expanded Models; Changes in Catchment Yields and Review of Water Balance	Report & WP	001/2011
	Modelling software and datasets	Software	None
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	Development of Water Quality Monitoring programme and Data Management Framework	Report	007/2011
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	Downscaling Methodology and Ongoing Climate Modelling Initiatives	WP	007/2010
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	Projection of impacts and Guidelines on Climate Change Adaptation Strategies	WP	009/2011
Work Package 5: ASSESSMENT OF ENVIORNMENTAL FLOW REQUIREMENTS			
	Literature survey and Gap Analysis	WP	008/2010
	Delineation of Management Resource Units	WP	009/2010
	Desktop Eco Classification Assessment	Report	016/2010
	Goods and Services Report	WP	010/2010
	Environmental Flow Requirements	Report	010/2011
Work Package 6: WATER CONSERVATION AND WATER DEMAND IN THE IRRIGATION SECTOR			
	The Promotion of WC WDM in the Irrigation Sector	Report	011/2011
	Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools	WP	012/2011
	Irrigation GIS Database and Interactive Classification Tool	Software	None
	Irrigation Scenario Generation Tool	Software	None

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1 INTRODUCTION

1.1 General Context

The Orange - Senqu River originates in the highlands of Lesotho, some 3 300m above mean sea level and it runs for over 2 300km to its mouth on the Atlantic Ocean. The river system is one of the largest river basins in southern Africa, with a total catchment area of more than 850,000km^2 and includes the whole of Lesotho, as well as portions of Botswana, Namibia and South Africa. The natural mean annual runoff at the mouth is estimated to be in the order of 11 500 Mm^3, but this has been significantly reduced by extensive water utilization for domestic, industrial and agricultural purposes to such an extent that the current flow reaching the river mouth is now in the order of half the natural flow. The basin is shown in **Figure 1-1.** The Orange-Senqu system is regulated by more than thirty-one major dams and is a highly complex and integrated water resource systems, with numerous large inter- and intra-basin transfers.

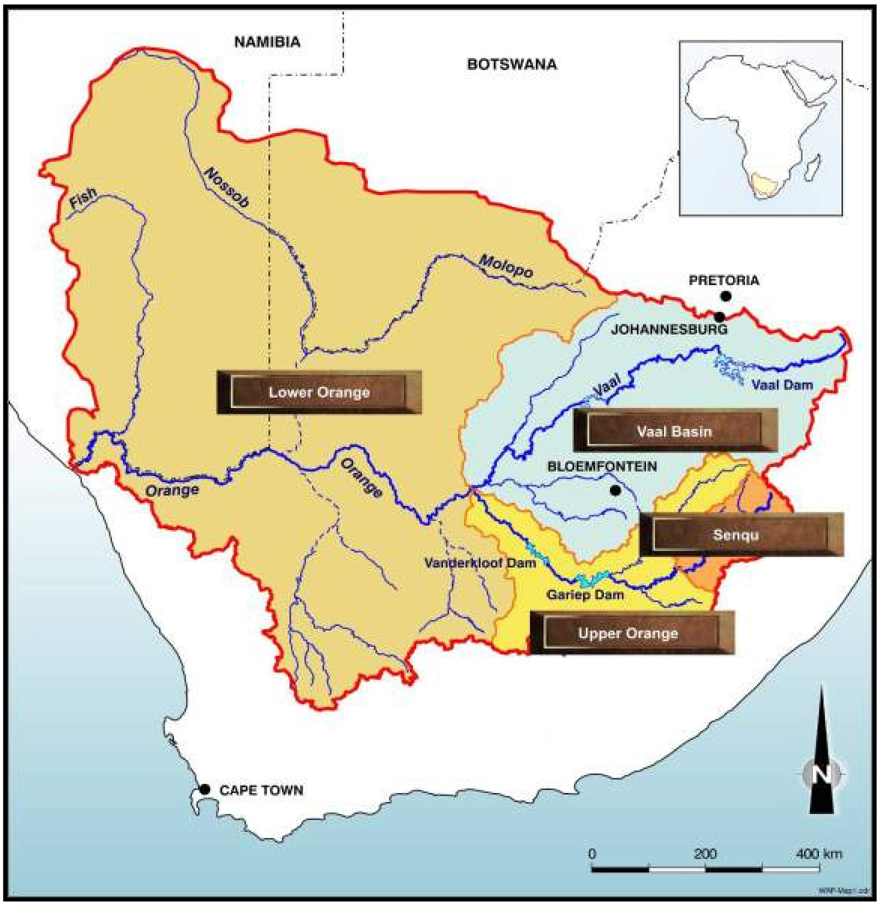


Figure 1-1: Orange-Senqu River Basin

1.2 Management and Environmental Context

1.2.1 General

Management issues, including environmental protection, conservation and sustainable development have to deal with problems relating to water quantity and quality, potential conflicts between users, pollution sources from industry, mining, agriculture, watershed management practices and the need to protect ecologically fragile areas. The riparian countries have, for some time, recognized that a basin-wide integrated approach has to be applied in order to find sustainable solutions to these problems and that this approach must be anchored through strong political will. The development of this strong political will is one of the key initiatives of SADC, in particular the Revised Protocol on Shared Watercourses and the establishment of the Orange-Senqu River Basin Commission (ORASECOM). These initiatives are intended to facilitate the implementation of the complicated principles of equitable and beneficial uses of a shared watercourse system. It is accepted by all countries that the management of water resources should be carried out on a basin-wide scale with the full participation of all affected parties within the river basin.

Water supply, in terms both of quantity and quality for basic human needs, is being outstripped by the demands within and outside of the basin. Meeting the water supply needs of rapidly growing towns and cities at the same time as having sufficient water of an acceptable quality to meet existing and proposed irrigation and other demands (including environmental) further downstream is a challenge for planners and decision makers and stakeholders in the Orange-Senqu river basin.

1.2.2 ORASECOM

Southern Africa has fifteen trans-boundary watercourse systems including the Orange–Senqu system. The Southern African Development Community (SADC) has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development. In this regard, the region recognizes the United Nations Convention on the Law of Non-navigational Uses of International Watercourses, and has adopted the “Revised Protocol on Shared Watercourse Systems in the SADC Region”. Under this Revised Protocol, a further positive step has been the initiatives towards the establishment of river basin commissions in order to enhance the objectives of integrated water resources development and management in the region, while also strengthening the bilateral and multilateral arrangements that have been in existence for some time. The Orange–Senqu River Basin Commission (ORASECOM) which was established on 3 November, 2000 in Windhoek, Namibia, is a legal entity in its own right.

The highest body of the ORASECOM is the Council consisting of three permanent members, including one leader for each delegation from the four riparian states. Support from advisors and ad hoc working groups can be established by the council. The main task of the Council is to “serve as technical advisor to the Parties on matters relating to the development, utilization and conservation of the water resources in the River System”, but the council can also perform such other functions pertaining to the development and utilization of water resources as the parties may agree.

1.3 Context of the Study and this Report

1.3.1 GIZ Support to SADC and ORASECOM

The overall goal of the GIZ-supported 'Transboundary Water Management in SADC' programme is to strengthen the human, institutional, and organisational capacities for sustainable management of shared water resources in accordance with SADC's Regional Strategic Action Plan (RSAP). The programme, which GIZ implements on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), and in delegated cooperation with the UK Department for International Development (DFID) and the Australian Agency for International Development (AusAID), consists of the following components:

- Capacity development of the SADC Water Division;
- Capacity development of the river basin organisations (RBO); and
- Capacity development of local water governance and trans-boundary infrastructure.

The activities of this Consultancy, "Support to Phase II of the ORASECOM Basin-wide Integrated Water Resources Management Plan", being undertaken by WRP (Pty) Ltd and Associates, contributes to Component 2 above. The work of Phase 2 comprises six work packages as briefly outlined in Section 1.3.2.2 below

1.3.2 Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan

1.3.2.1 Objectives of the Overall Consultancy

The main objectives of this consultancy are to enlarge and improve the existing models for the Orange-Senqu Basin, so that they incorporate all of the essential components in the four Basin States and are accepted by each Basin State. These models must be capable of being used to meet the current and likely future information needs of ORASECOM. These needs will likely encompass additional options to achieve water security in each Basin State – including changing configurations for water supply and storage infrastructure - and ensure that ORASECOM is able to demonstrate that its operations are aligned with the principles embodied in the SADC Water Protocol.

1.3.2.2 The Six Work Packages

In order to contribute to the realisation of the above-mentioned objectives, the project includes six work packages as outlined in **Table 1-1.** The first of these work packages is central to Phase 2 of the IWRM Plan and will also be at the core of the final plan to be developed in Phase 3. In work package 1 the WRYM water resources simulation model is being updated and expanded to cover the entire basin.

Table 1-1 Summary of Work Package Objectives and Main Activities

Work Package	Main Objectives	Main Activities
WP 1: Development of Integrated Orange-Senqu River Basin Model	To enlarge and improve existing models so that they incorporate all essential components in all four States and are accepted by each State	• Extension and expansion of existing models • Capacity building for experts and decision-makers • Review of water balance and yields • Design/initiation of continuous review process
WP 2: Updating and Extension of Orange-Senqu Hydrology	Updating of hydrological data, hands-on capacity building in each basin state for generation of reliable hydrological data including the evaluation of national databases,	• Assessment of Required Improvements to the Existing Gauging Networks. • Capacity Development • Extension of Naturalized Flow Data • Review of Existing Data Acquisition Systems, proposals on basin-wide data acquisition and display system.
WP 3: Preparation and development of integrated water resources quality management plan	Build on Phase 1 initial assessment to propose water quality management plan, based on monitoring of agreed water quality variables at selected key points	• Establishment of protocols, institutional requirements for a water quality monitoring programme, data management and reporting. • Development of specifications for a water quality model that interfaces with the systems models. • Capacity building to operate the water quality monitoring system and implement the water quality management plan.
WP 4: Assessment of global climate change	Several objectives leading to assessment of adaptation needs	• Identification of all possible sources of reliable climate data and Global Climate Model downscaling for the Orange-Senqu Basin • Scenario assessment of impacts on soil erosion, evapo(transpi)ration, soil erosion, and livelihoods • Identification of water management adaptation requirements with regards to observed/expected impacts on water resources • Assessment of major vulnerabilities and identification of measures for enhancing adaptive capacities
WP 5: Assessment of Environmental Requirements	Several objectives leading to management and monitoring system responsive to environmental flow allocations	• A scoping level assessment of ecological and socio-cultural condition and importance • Delineation into Management Resource Units and selection of EFR sites. • One biophysical survey to collate the relevant data at each EFR site and two measurements at low and high flows for calibration. • Assessment of the Present Ecological State and other scenarios • Assessment of flow requirements, Goods and Services, and monitoring aspects.
WP 6: Water Demand management in irrigation sector	To arrive at recommendations on best management practices in irrigation sector and enhanced productive use of water	• Establish a standard methodology for collecting data on irrigation water applied to crops, water use by crops and crop yields; • Document best management practices for irrigation in the basin and finalise representative, best-practice demonstration sites through stakeholder consultation • Consider and assess various instruments that support water conservation/water demand management.

The other work packages are both self-standing and intended to provide inputs to an improved and more complete water resources simulation model for the whole basin. The model will be enhanced by a more complete hydrology (WP2), better and more complete water quality information (WP3), allowance for climate change impacts and adaptation (WP4), inclusion of environmental flow requirements at key points (WP5) and modelling of scenarios with improved water Background to Work Package 2 and this Report

1.3.3 Background to Work Package 2 and this Report

1.3.3.1 Work Package Objectives

The central objective of this Work Package is to produce updated and extended hydrological sequences for the basin as a whole. This will help to address certain deficiencies with the existing hydrological data sets which are not consistent throughout the Orange-Senqu river basin. To ensure that the hydrological data sets are easily accessible for any future work, they will be incorporated into an appropriate database system with proper referencing. In addition to the main objectives mentioned above, the hydrological data sets for the river basin should ultimately be improved through the following:

- Recommendations on the upgrading of gauging stations and associated systems and processes;
- Provision of appropriate Capacity Building in a number of key areas to be agreed with each basin state;
- Recommendations on appropriate protocols and procedures for data collection and data sharing throughout the whole basin; and,
- Agreement on a proposed data acquisition and display system to be available to, and adopted by, all four basin states and covering key stations basin-wide.

The main tasks of work package 2 are as follows:

- Assessment of Required Improvements to the Existing Gauging Networks;
- Capacity Development;
- Extension of Naturalized Flow Data; and
- Review of Existing Data Acquisition Systems.

1.3.3.2 This Report

This report details activities and results associated with the central objective of this Work Package, which is to produce updated and extended hydrological sequences for the basin as a whole. This thus addresses certain deficiencies with the existing hydrological data sets which are not consistent throughout the Orange-Senqu river basin.

2 APPROACH AND METHODOLOGY

2.1 Introduction

An incomplete hydrological database existed for large parts of the Orange-Senqu River at the start of this work package. The original hydrological database was developed from data generated during several previous studies undertaken by the South African Department of Water Affairs, the South African Water Research Commission, the Planning Committee of the Permanent Water Commission between Namibia and South Africa and the Namibian Department of Water Affairs. It was this database that was used to feed into the Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM) that was being used to model large parts of the Orange Senqu River Basin.

This section of the report describes the needs identified for improving the existing hydrological database. The sources of data and information used during the development of the original Orange-Senqu River models as well as the source datasets used to improve the hydrological database during this work package are also described. The section concludes with description of the different approaches applied to improve the data in the different parts of the river basin.

2.2 Data Improvement Needs

The natural flow records available at the beginning of the study are listed in **Table 2-1.** Some of the record periods end as long ago as 1987. Extending the records to 2004/2005 captures a significant amount of additional information and greatly improves the quality of the subsequent yield estimates to be made in future phases of the project. It is therefore important that the hydrology is updated every 10 to 20 years. In this case, where there is also much debate on the influences of Climate Change, there is even greater need to ensure that the most reliable hydrological database is used in the subsequent water resources yield analyses.

Table 2-1: Naturalized Flow Record Periods available at start of Study

River	Existing Record
Vaal	1920 – 1994
Senqu	1935 – 1995 (lowlands 1935 – 1999)
Upper Orange	1920 – 1987
Lower Orange	1920 – 1987
Molopo	1920 – 2004
Fish	1920 – 1999

In summary, the following issues had to be addressed in various areas to ensure consistency in the hydrological data throughout the catchment:

- The database had to be extended to include hydrological and rainfall data that spatially covers the entire Orange-Senqu River;
- The hydrological and climate data should cover the period of 1920 – 2004 in all areas; and
- Recalibration of hydrological models had to be done in high runoff areas where the original hydrological analyses were undertaken more than 15 years ago.

2.3 Data sources and information

2.3.1 Original Model Data Sources

The original hydrological database was created using data generated as part of several hydrological catchment studies undertaken by the South African Department of Water Affairs, the South African Water Research Commission, the Planning Committee of the Permanent Water Commission between Namibia and South Africa and the Namibian Department of Water Affairs. No hydrological data were available for some of the catchments and was omitted during the establishment of the previous database. These were, in most cases areas, deemed to generate very little runoff and which do not contribute significantly to the runoff in the Orange-Senqu mainstream or those of its larger tributaries. Such areas included the Molopo-Nossob and some Namibian and South African tributaries in the Lower Orange River.

The following sections in this report provide a brief overview of the catchment studies used during the establishment of the previous hydrology database. **Figure 2-1** provides an overview of the areas covered by the individual studies.

2.3.1.1 Vaal River Systems Analysis Updated Study (VRSAU)

The Vaal River system is the most important water resource system in South Africa as it provides water to more than 40% of the country's inhabitants and, with numerous industries and mines in the supply area, supports the production of more than 50% of the country's gross domestic product. In 1995 the Department of Water Affairs (DWA) of South Africa decided to update the water resources models for this area and the *Vaal River System Analysis Update (VRSAU)* study was commissioned. The VRSAU study included updated hydrology as well as the physical characteristics of the system for the period covering 1920 to 1994.

This study's data was used for the Vaal River's hydrological and physical characteristics in the original water resources model configuration.

2.3.1.2 Joint Lesotho Highlands Development Authority and South African Department of Water Affairs and Forestry Study on the Senqu River Basin (South Africa/Lesotho)

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). These flows were to be used for design purposes and in computation of royalties payable to

Lesotho according to the procedure laid down in the Treaty covering the implementation and operation of LHWP. Some of these studies are summarized below:

- Hydrology Component of the Lesotho Highlands Pre-Feasibility Study undertaken in the mid-1980's;
- Lesotho Highlands Development Authority Interim Hydrology undertaken in 1987;
- Orange River Systems Analysis undertaken in 1993 by BKS for South African DWA; and
- Review of the Lesotho Highlands Hydrology undertaken in 1994 by the Institute of Hydrology for the LHDA.

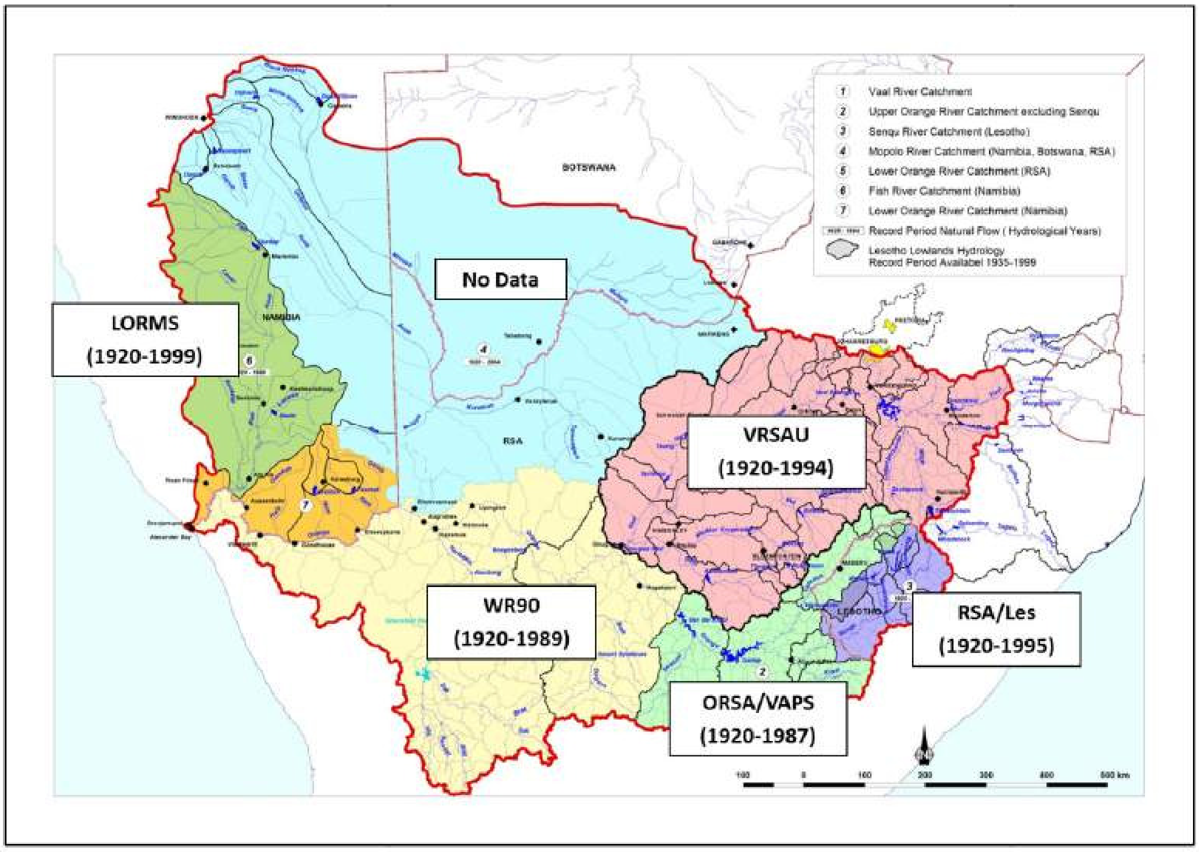


Figure 2-1: Source Studies for Original Orange-Senqu Hydrological Database

None of the studies listed above resulted in hydrology that was accepted by both South Africa and Lesotho. It was therefore decided to undertake a joint LHDA/RSA study in an effort to break the impasse. The work was carried out co-operatively by LHDA's Water Resources Division and consulting engineers, acting on behalf of South African DWA. The resulting study was done in close cooperation between the two countries and approval was reached at the end of each step in the process. The study resulted in an accepted hydrological and rainfall database that stretched from 1935 to 1995 for the entire Senqu

River Basin up to the border with the RSA. The hydrology and rainfall data was subsequently extended to start in 1920 for use in the VRSAU study.

The results of the joint LHDA/RSA study were used for the Senqu River catchment's configuration in the original model.

2.3.1.3 Orange River Systems Analysis and the Vaal Augmentation Planning Studies (ORSA/VAPS)

The hydrological component of the *Orange River Systems Analysis (ORSA)* project was completed in 1991 and the analysis period was from 1920 to 1987. This work covered most of the upper parts of the Orange River Basin and the aim of the study was to define the water use situation, at that time, with respect to the available water resources. Future development scenarios and their impact on the water resources would provide valuable input for planning and decision making. Hydrological and yield analyses were undertaken at key points throughout the catchment.

A study that followed the Orange River Systems Analysis was the *Vaal Augmentation Planning Study (VAPS)* completed in 1994. This study investigated three alternatives for further augmentation of the Vaal River System after the completion of the Lesotho Highlands Water Project (LHWP) Phases 1A and 1B. During this study the hydrology generated during the ORSA Study was refined and improved in some areas of concern.

The VAPS results were used for the configuration of the Caledon and Upper Orange catchments in the original model.

2.3.1.4 Surface Water Resources of South Africa Study 1990 (WR90)

During the 1990s the Surface Water Resources of South Africa Study (WR90) was completed by the South African Water Research Commission (WRC). This study provided water resources information for all of South Africa, Lesotho and Swaziland. The study played a major role in providing key hydrological information to water resource managers, planners, designers, researchers and decision makers throughout South Africa. The WR90 study generated information at quaternary level covering information related to dams, evaporation, geology, land cover, rainfall, recorded and simulated runoff, rivers, sediment yield, soils, settlement locations and vegetation types. The WR90 project relied on catchment simulations generated from the WRSM90 computer model. The simulation period for this information covered the period 1920 – 1989.

The WR90 study natural hydrology results for the Lower Orange was scaled to take into account the effects of the pans and dams in the original model configuration

2.3.1.5 Lower Orange River Management Study (LORMS)

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 LORM study). It included a review of the hydrology of the Fish River Catchment. The Fish River has one of the largest catchment areas in Namibia, and is relatively under-developed, with 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 Upper Fish River and the Naute Dam on the Löwen River - a major tributary towards the lower end of the catchment.

The Planning Committee of the Permanent Water Commission between South Africa and Namibia initiated a review of the Fish River hydrology, with a resulting update of the South African systems models with improved hydrological information.

The study required only limited modelling since detailed re-assessments had been completed in 1987 and 1994 for the Naute and Hardap Dams respectively. A new study was initiated in 1995 by the Department of Water Affairs (DWA) (Namibia), but subsequently aborted due to the transfer of staff to the newly created Namibia Water Corporation Ltd (NamWater). The hydrological data available covered the period 1920 to 1999. The hydrology for the Namibian Fish River was obtained from the LORMS Study and used in the original model configuration.

2.3.2 New Source Data

Recently some hydrological studies have been undertaken in parts of the Orange-Senqu basin and these could be used to improve and extend the original hydrological database. The studies used for this purpose are discussed in more detail in the following sections.

2.3.2.1 Water Resources of South Africa, 2005 (WR2005)

The Water Resources of South Africa 2005 is an update to the previous WR90 Study undertaken recently by the WRC of South Africa. The main motivation for the extension of the study data is that in many parts of South Africa the worst drought occurred during the early 1990’s and the time series data had to be extended to make provision for this. In addition, improved water requirement estimation techniques were developed and several major improvements were done to the hydrological model (WR2000) since the previous version of the study in the early 1990’s. The new version of the study incorporated additional elements such as surface-groundwater interaction and water quality parameters, and the simulation period was extended to 2004.

The WR2005 dataset played a key role towards the updating and extension of the Orange-Senqu database. For the most part the patched rainfall data were used to extend the original rainfall-runoff simulations, as used in the original hydrological studies. In some other areas, the WR2005 study’s hydrological model configuration was used as a basis for reassessing the hydrology, after an update was done to the estimated land-use and the model was recalibrated.

2.3.2.2 Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse

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 the tributaries 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 been significantly reduced and is often 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 reduction in the already limited flows in these sub-basins, due to the exploitation of surface water in the upper reaches, has placed a tremendous strain on the sustainability of rural activities in the south-western corner of Botswana and some parts of South Africa along the Molopo and Nossob Rivers. In 2007 ORASECOM commissioned a feasibility study of the potential for the sustainable water resources development in the Molopo-Nossob Sub River Basin. The surface hydrological modelling task aimed at providing first order estimates of typical surface water runoff volumes in the main rivers in the study catchments.

For this purpose, the WRSM2000 rainfall-runoff model was configured for the main sub-catchments in the study area. For the South African catchments, the WRSMS2000 model parameters were based on regionalised catchment parameters which are readily available from “Surface Water Resources of South Africa 1990” (WR90) (Midgley et al., 1994). These parameters were then transferred to the sub-catchments that are located within Botswana and Namibia and used to simulate long-term streamflow sequences based on local observed rainfall records and current land use information. Estimates of surface water runoff have been calibrated based on observed flow records where available as well as on historical records of floods in the Molopo-Nossob catchment.

The Feasibility Study simulation period was from 1920 to 2004, and therefore the results from this study could be used without further action for extending the area of the Orange-Senqu hydrological database to cover the Molopo-Nossob catchment area.

2.3.2.3 Lesotho Lowland Water Supply Scheme - Feasibility Study

Numerous hydrological studies have been undertaken in Lesotho, most of which focused on the Lesotho Highlands Transfer Scheme. The Lesotho Lowlands Water Supply Scheme Feasibility Study was commissioned by the European Development Fund (EDF) for the Lesotho Government to investigate potential water resource developments to ensure the long-term sustainable water supply to the Lowlands area, since this area in particular often suffers from water shortages. The overall objective of the project was to determine the most viable and sustainable water supply schemes for the Lesotho Lowlands. This entailed a phased approach to the investigations. The first phase of the study was a broad desktop assessment of all identified schemes using the hydrological data published in the WR90 document as basis. During the second phase a more detailed hydrological analysis was done for 3 options identified during the first phase.

The detailed modelled hydrology for the three sites was included in the final hydrology database for the Orange-Senqu basin.

2.3.2.4 Improvements to the original Vaal River Systems Analysis Update Study Hydrology

Since the original Vaal River Systems Analysis Update Study was carried out in 1996, the hydrology was adapted to a finer spatial resolution to make provision for additional points of interest. These refinements of the hydrological database were also incorporated into the updated Orange-Senqu database. These refinements included:

- Incorporation of the Schoonspruit Dolomitic Eye hydrology analysis;
- Additional nodes of interest on the Renoster River;
- Updated hydrology for supporting systems such as the Komati and Tugela systems;
- Kalfontein Dam Hydrology was improved; and
- The hydrology of the Watervals River around SASOL Secunda was refined.

All the Improvements to the VRSAU study data were also incorporated into the hydrological database for the Senqu-Orange Basin.

2.3.2.5 Raw measured runoff and rainfall data from basin countries

In certain high runoff areas such as the Caledon, Senqu and Upper Orange catchments, as well as for the Fish River in Namibia, a total re-evaluation of previous hydrology was conducted. As part of this update process observed rainfall and streamflow measurements were obtained from the relevant Namibian, Lesotho and South African Government Departments. Botswana rainfall data were also used during the Molopo-Nossob ORASECOM Study.

2.3.3 Audit of original electronic data

In order for this work package to make improvements to the hydrological data base, the original electronic incremental natural runoff and catchment rainfall time series database were obtained. In addition, the electronic hydrological model data used to create the original data was sourced where possible, as well as the electronic data from the supplementary study. **Table 2-2** provides an overview of the electronic datasets used to improve and extend the original hydrological time series database.

Table 2-2: Electronic Data used to Improve Original Hydrological Time Series Database

Area	Electronic Original Hydrological Study Reports	Electronic data for the original hydrological analysis			Resulting Incremental Natural Hydrology & Catchment Rainfall Time series data
		Patch Point Rainfall/ Catchment rainfall	Patched Flow Data	WRSM2000 model calibration system	
Vaal - Upper	VRSAU (limited appendices)	Both	Grootdraai Only	Grootdraai only	VRSAU Study data as in the WRYM and WRPM models (1920 -1994)
Vaal - Barrage		Catchment Only	Yes	Yes	
Vaal – Middle		Catchment Only	Yes	Yes	
Vaal – Lower		Both	None	None	
Riet – Modder		Both	None	None	
Senqu		Only patched point rainfall	None	None	
Caledon	ORSA and VAPS reports (Only hard copies, scanned)	None	None	None	VAPS Study data as in the WRPM model (1920 – 1987)
Orange – Upper		None	None	None	
Orange - Middle	WR2005 Catchment Reports	Both	Yes	Yes	WR2005 Hydrology and Catchment Rainfall Data (1920-2004)
Orange - Lower		Both	Yes	Yes	
Brak/Ongers		Both	Yes	Yes	
Sak/Harts		Both	Yes	Yes	
Aub, Molopo, Kuruman, Nossob	Nossob-Molopo Hydrology Report	Catchment only	Yes	Yes	Nossob-Molopo Study Hydrology and Rainfall Data (1920 – 2004)
Namibian Fish	LORMS Hydrology Report	None	None	None	WRPM - LORMS as in the WRPM model (1920 – 1999)

2.4 Approach

2.4.1 Introduction

Based on the availability and quality of the data in the different sub-catchments of the Orange-Senqu River, the most effective method for extension of the time series database was selected. The approaches for extending the data ranged from accepting the source study results without any further action, to the total reassessment of the hydrological properties of an area. The general procedure followed to extend the hydrological and rainfall database for the Orange-Senqu basin was:

- Delineation of catchment boundaries;
- Extension of catchment rainfall time series records; and
- Extension of natural runoff time series records.

The following sections will describe the procedures in more detail as they were applied in areas where the data had to be extended.

2.4.2 Delineation of catchment boundaries

The first step in the hydrological improvements was to derive a representative catchment delineation map that would cover the entire Orange-Senqu River Basin. **Figure A-1** in **Appendix A** provides the delineation of the major catchment boundaries for the Orange Senqu River Basin.

In **Table 2-3**, the definition and examples of the catchment hierarchy is provided as used in this report. It should be noted that this naming convention deviates from the South African catchment type definitions except for quaternary catchments.

Table 2-3: Definition and Examples of Catchment Hierarchy for the Purposes of this Report.

Catchment Type	Definition	Example
Primary	The entire Orange Senqu River Catchment	
Secondary	Consists out of 5 main rivers of the Orange Senqu Primary Catchment, each consisting out of a set of tertiary catchments.	(1) Vaal, (2) Upper Orange, (3) Lower Orange, (4) Molopo-Nossob and (5) Namibian Fish.
Tertiary	Consists of 18 tributaries or river stretches within Secondary Catchments which is made up out of a set of quaternaries catchments	Vu = Upper Vaal Tertiary Catchment
Quaternary	Smallest spatial reference, based on an extended South African numbering system.	D42H

In generating the catchment delineation map several issues were taken into account and these are described in more detail in Sections 2.4.2.1 to 2.4.2.5.

2.4.2.1 South African Quaternary Catchment Map

A South African Quaternary Catchment boundary map was developed during the WR90 study and since then has been used as a spatial reference numbering system for all water resource related management and data in South Africa. The boundary map has been legally defined and covers South Africa, Lesotho and Swaziland. Since this spatial reference numbering system covered most of the primary catchment it was decided to extend the numbering system to the Namibian and Botswana areas.

2.4.2.2 Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse

The ORASECOM Molopo-Nossob Water Resources Study produced catchment areas for this part of the Orange-Senqu Basin. The Orange Senqu catchment boundaries map was kept consistent with the boundaries produced by ORASECOM study, and the quaternary numbering system was extended to include these catchments. Slight adjustments were, however, made to the outer boundaries of the Molopo-Nossob secondary catchment at the junction with the Namibian Fish secondary catchment and the border in Botswana. This was completed since the study team previously undertook an improved estimation of the catchment boundaries of the Molopo-Nossob secondary catchment in Botswana. Although the change in the catchment boundaries differed from the ORASECOM study boundaries, the quaternary catchments involved were modelled as endhoric and would therefore not have made any difference to outcome of the hydrological analysis.

2.4.2.3 Namibian Fish River and Lower Orange Tributaries

The quaternary catchments assigned to the Namibian Fish River were based on a spatial coverage that was developed during previous analyses done by WRP Consulting Engineers. The coverage was checked against detailed river coverage to see if the catchment boundaries are adequate. These catchment boundaries have been used in the Namibia Fish analysis and refined where necessary.

2.4.2.4 Depoliticizing of catchment boundaries

The South African Quaternary Numbering System stopped at the border with Namibia and Botswana, causing half quaternary catchments in some places. Keeping the ORASECOM Molopo-Nossob study catchment boundaries in mind, an attempt was made to fix these quaternary catchment boundaries so that they extend over political borders and group the quaternaries to included tertiary catchments, such as the KU (Kuruman River) tertiary catchment. The tertiary catchment boundaries for the Senqu (SE) and the Caledon (CA) catchments were also extended over the South African border to include the whole of the tributaries. The Lower Orange tertiary catchment (O_L) was extended to include quaternary catchments on the Namibian side of the border.

2.4.2.5 Extended quaternary numbering

To facilitate the modelling process, the South African numbering system was also extended to the Namibian and Botswana catchments, with adjustment to some existing South African quaternary catchment numbers to better represent tertiary catchments.

Table 2-4 provides a breakdown of quaternary catchments per tertiary catchment and the catchment areas associated with those areas.

Table 2-4: Tertiary Catchment Areas and Associated Quaternary Catchments

Secondary Catchment	Tertiary Catchment	Quaternary Catchments	Gross Tertiary Catchment Area (km^2)$^{(1)}$	Gross Secondary Catchment Area (km^2)
1. Vaal	Upper Vaal (V_U)	C11A-M, C12A-L, C13A-H, C81A-M, C82A-H, C83A-M	38 638	196 438
	Vaal Barrage (V_B)	C21A-G, C22A-K	8 651	
	Middle Vaal (V_M)	C23A-L, C24A-J, C25A-F, C41A-J, C42A-L, C43A-D, C60A-J, C70A-K	60 836	
	Lower Vaal (V_L)	C31A-F, C32A-D, C33A-C, C91A-E, C92A-C	55 019	
	Riet-Modder (RM)	C51A-M, C52A-L	33 294	
2. Upper Orange	Caledon (CA)	D21A-L, D22A-L, D23A- J, D24A-L	21 884	99 277
	Senqu (SE)	D11A-K, D12A-F, D15A-H, D16A-M, D17A-M,D18A-L	27 647	
	Upper Orange (O_U)	D13A-M, D14A-K, D31A-E, D32A-K, D33A-K, D34A-G, D35A-K	49 746	
3. Lower Orange	Brak/Ongers (BO)	D61A-M, D62A-J	33 733	243 313
	Sak/Harts (SH)	D51A-C, D52A-F, D53A-J, D54A-G, D55A-M, D56A-J, D57A-D, D58A-C	93 041	
	Middle Orange (O_M)	D71A-D ,D72A-C ,D73A-F	40 100	
	Lower Orange (O_L)	D81A-K, D82A-P	76 439	
4. Molopo/Nossob	Kuruman (KU)	D42A-G	41 195	356 788
	Upper Molopo (M_U)	D41A-J	148 167	
	Lower Molopo (M_L)	D45A-D	38 078	
	Nossob (NO)	D43A-C	71 650	
	Auob (AU)	D44A-D	57 698	
5. Namibian Fish	Fish (FI)	D46A-J	81 630	81 630
Total Catchment Area				977 446

Note (1) – The areas reported are as given in the WR2005 Study for quaternaries inside the South African borders and Lesotho, and as measured during this work package for the Namibian and Botswana quaternaries

2.4.3 Catchment rainfall record time series extension

2.4.3.1 Introduction

The main assumptions made for extending the simulation period of the natural hydrology time series database in all areas where the source data period does not cover the period of 1920 to 2004 are as follows:

- The source study's catchment rainfall record is based on the best available selection of point rainfall station that represents the catchment adequately;
- The source study's point rainfall stations were patched adequately; and
- The source study's calibration and naturalization process were undertaken to an adequate level of accuracy.

If the above assumptions are accepted as being reasonable the process of extending the natural runoff time series database can be done by the following general steps:

- Extending the period of the catchment rainfall record as generated during the source study;
- By accepting the calibration parameters for the catchment as generated in the source study, simulating natural runoff using the extended rainfall created in the first step, and
- Only extending the original natural runoff time series with the simulated natural values from the second step so that the time series end in the 2004 hydrological year.

In the WRSM2000 rainfall-runoff model, the monthly rainfall time series for an area is calculated from two elements:

- The area averaged Mean Annual Precipitation (MAP), expressed as mm/annum; and
- An area representative monthly temporal distribution record, expressed as a percentage of the MAP for each month, also known as a catchment rainfall record.

The catchment rainfall time series record is generated by patching point rainfall gauges and selecting representative patched rainfall gauge data in or near the catchment of concern. The catchment rainfall record is then generated as follows:

- The monthly values for each of the individual rainfall stations are expressed as a percentage of the station's MAP;
- For each month in the catchment rainfall record period only rainfall stations with data for the particular month is considered;
- Each monthly catchment rainfall value is calculated from the average of all the percentages of MAPs for all rainfall stations that have data for that particular month;
- A monthly average adjustment is made to each monthly % value to ensure that the mean annual average percentage is 100%

The process of extending the catchment rainfall records in the areas of the primary catchment where the natural runoff had to be extended is described in Section 2.4.3.2.

2.4.3.2 Rainfall data

All the patched rainfall data, and more importantly the original catchment rainfall records used during the source studies, were obtained electronically as far as possible. For certain areas (such as parts of the Vaal secondary catchment), the original patched point rainfall records could not be obtained. It was, however, more important to obtain the original catchment rainfall files as well as information related to which point rainfall stations was used to create the catchment rainfall record with.

Most of the original catchment rainfall files were obtained, either electronically or scanned from the various hydrological reports. In the Senqu (SE) tertiary catchment only the final patched point rainfall data was available. These records were used in conjunction with information obtained from the VRSAU study report on the Senqu Catchment to recreate the catchment rainfall records for the area.

The South African Weather Service (SAWS) numbering system for point rainfall gauges consists of a 7 digit numbering system, where:

- the first 4 numbers indicates a unique sector number indicating where the stations are located on a continental 30 minute by 30 minute grid; and
- the last 3 numbers indicates the position of the stations within the sector.

Figure A-2 in **Appendix A** is a map of all the point rainfall stations used to generate the catchment rainfall records for the source studies as well as for the extension of the rainfall records during this analysis. The map indicates the SAWS number of the station and a consolidated mean annual precipitation (MAP) isohyets map is provided as background for the entire primary catchment. Stations which were still active at the end of the simulation period (2004) are also indicated. It has to be noted that the point rainfall stations used in the source studies that fell outside of South Africa were assigned new numbers according to the South African Weather Service (SAWS) numbering system.

2.4.3.3 Procedure

It should be noted that only the period of the catchment rainfall records (percentage MAP temporal records) were extended, so that all the areas have the same period of 1920 to 2004. The MAP's for the different areas were kept the same as specified in the original source studies.

The process followed for the extension of the catchment rainfall record period is illustrated in **Figure 2-2** and **Figure 2-3** and described in more detail below.

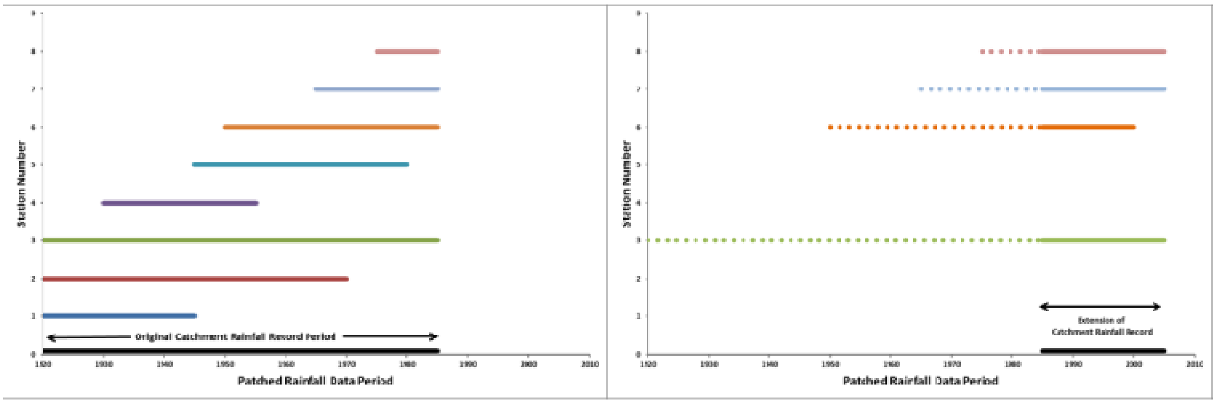


Figure 2-2: Schematic Representation of the process of Extending Catchment Rainfall Time Series

- Step 1: All information regarding the point rainfall stations and record periods used during the creation of the original catchment rainfall records were obtained from the source studies. The illustration on the left of **Figure 2-2** shows the typical temporal distribution of patched point rainfall data used to create of a single catchment rainfall file.
- Step 2: The point rainfall stations which were still open at the end of the original catchment rainfall record period were identified. It was assumed that any rainfall station that was closed before the end date of the original catchment record would not have been reopened during the extension period of the catchment rainfall record, and these stations were not further considered. The illustration to the right of **Figure** 2-2 shows the stations that were still open at the end of the original catchment rainfall record. As can be seen from the map in **Figure A-2** in **Appendix A**, the number of rainfall stations with recent rainfall data are still relatively well distributed over the wetter part of the catchment, but are very sparse in the drier areas.
- Step 3: Generate a new catchment rainfall record for the stations identified in Step 2, using the patched rainfall records for the selected stations from the WR2005 study. The WR2005 patched rainfall data was used since it covered most of South Africa up to 2004. Only the period after the original end date of the catchment rainfall record was appended, with the catchment rainfall record generated during this step. In most cases, only a few additional years of catchment rainfall records were added to the original records. This process is also shown in the illustration to the right of **Figure** 2-2.
- Step 4: A single mass plot and cumulative deviation from the annual mean (Cusum) plots for the catchment rainfall records pre- and post-extension were undertaken to check that no trend was introduced into the catchment rainfall records due to the extension of the record period. **Figure 2-3** illustrates a typical stationarity analysis before and after extending a catchment rainfall record. The single mass plot should form a straight line and the Cusum plot should typically vary around the mean.

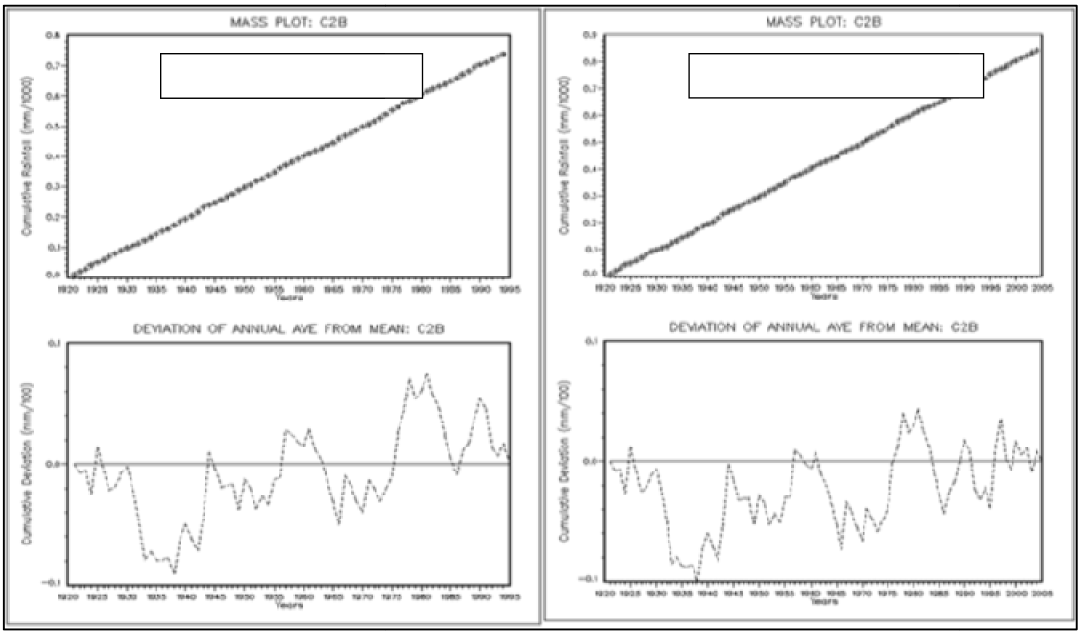


Figure 2-3: Example of Stationarity Tests, pre- and post-extension of the catchment Rainfall Record Period

2.4.3.4 Results

In total there were 95 catchment rainfall records that covered the whole of the Senqu-Orange River Basin area. The catchment rainfall stations were used to generate the natural flows in the WRSM2000 model setups.

A list of all the point rainfall stations used per secondary (and where available tertiary) catchment to create catchment rainfall records with, as well as the period used, is provided in **Table B-1** in **Appendix B**. A map with all the catchment rainfall record boundaries is provided in **Appendix A**, **Figure A-3**.

2.4.4 Extension of Natural Runoff Time Series

2.4.4.1 Introduction

The process of improving the Orange-Senqu River Basin's hydrological database was adapted to suit the particular area's source study runoff data status. The procedures ranged from accepting the data as is, to total recalibration of the hydrological simulation and with combinations in-between to ensure that the data is brought up to relatively the same level of accuracy.

The following sections will provide an overview of three different approaches taken during this work package to extend the natural runoff time series sequences.

2.4.4.2 Revision of WR2005 Study hydrology calibrations

In certain low runoff generating areas it was decided to largely make use of the hydrological calibration configurations as developed during the WR2005 Study. This procedure was undertaken mainly in the Lower Orange secondary catchment. The steps in this process involved the following:

- Evaluate the stationarity of the catchment rainfall records generated during the WR2005 study and extend the records if not stretching from 1920 to 2004;
- Improve the hydrological model's network configuration with additional points of interest and land use such as dams and pans;
- Assess the flow data used during the WR2005 study for calibration;
- Assess the calibration results generated during the WR2005 study and recalibrate if necessary; and
- Regenerate the new natural runoff.

2.4.4.3 Extending original natural runoff with extended rainfall

In certain areas (in particular in the Vaal secondary catchment) the previous hydrological analysis was deemed to be of good quality, but the record period of the data was too short and generally ended in 1994. To extend the data with an additional 10 years of natural runoff the following procedure was followed:

- The generated extended catchment rainfall records (as described in Section 2.4.3) were evaluated to ensure that the records were stationary.
- The source studies' electronic configuration data for the WRSM2000 model were obtained and updated with the extended catchment rainfall file. If the original configuration data could not be obtained, the hydrological calibration network was recreated from reports.
- The WRSM2000 models were tested to see if the natural runoff results from the source study analysis could be reproduced for the original analysis period. It has to be noted that some slight variation from the original results was accepted due to several reasons, of which the main reason was that the model has been significantly changed since the source study was undertaken.
- Simulate the natural runoff from the end of the source study's analysis period up to 2004 hydrological year by using the WRSM2000 model setups from the previous step.
- Add the extended simulated runoff period to the original natural runoff time series.
- Test pre- and post-extension stationarity to ensure no trend has been introduced due to the extension.

2.4.4.4 Generating new natural runoff

In certain of the high-runoff generating areas of the Orange-Senqu basin, the source studies' hydrological analyses were relatively old. This was found in particular areas in the Upper Orange and the Namibian Fish secondary catchments, where the source studies were undertaken in the early 1990s. For the Upper Orange a total revaluation of the natural runoff and a recalibration of the WRSM2000 model were undertaken. The following steps were undertaken during this type of procedure:

- Catchment rainfall records were recreated from source study information, or the WR2005 study's catchment rainfall records were used as a basis. The stationarity of these records were evaluated and corrections made when found to have trends. Where necessary, raw data was obtained for the extension period and patched using the CLASSR and PATCHR programs.
- The WR2005 study's network configuration was used as basis for the new hydrological calibration analysis. The network was evaluated against Google Earth and adapted and aggregated to areas upstream from flow gauging point.
- An assessment of the irrigation areas and farm dams was made using Google Earth and growth assumptions were based on source studies and the WR2005 studies information.
- Flow gauge information was obtained from the relevant country's flow data custodian. The data was patched where necessary.
- A recalibration of the WRSM2000 model was completed.
- After an acceptable calibration was achieved, natural runoff was generated.

For the Fish River in Namibia, the NAMRON rainfall/runoff model, developed and used extensively in Namibia, was used. This monthly time-step model is noticeably different from other models, especially due to the fact that it allows for negative serial correlation leaning that high rainfall in the previous rainfall season will tend to reduce the runoff in the year of analysis. Delays in getting the data and some issues, now resolved, in using NAMRON, mean that this hydrology will not be updated as part of this report.

2.4.5 Summary of Actions per Secondary Catchment

Table 2-5 below provides a summary of the actions undertaken per secondary catchment to improve or extend the hydrological time series database for the Orange-Senqu River System. **Figure 2-4** provides a spatial overview of the information provided in **Table 2-5.**

Table 2-5: Actions per Secondary Catchment to Improve or Extend the Hydrological Time Series Database

Secondary Catchment	Action to improve hydrological time series database
Vaal	Extend natural runoff data to 2004 by extending the catchment rainfall records and incorporating finer spatial resolutions of natural runoff time series data for the V_M.
Upper Orange	Reconfiguration and recalibration of the hydrological model. Creating new natural runoff data.
Lower Orange	Revision and improvement to the network configuration and calibrations of the WR2005 hydrological analysis. Extending the rainfall data to start in 1920 and extending the area to the O_L quaternaries on the Namibian side of the Orange River.
Molopo/Nossob	Accept ORASECOM Study data as is.
Namibian Fish	Reconfiguration and recalibration of the NAMRON hydrological model. Creating new natural runoff data.

2.5 Output

The output of this work package includes the following:

- Electronic time series file, which provides incremental natural runoff and catchment rainfall time series stretching from 1920 to 2004, for the entire primary catchment, for use in the WRYM and the WRPM.
- A DVD product with all the original and extended electronic data gathered and generated during this study.

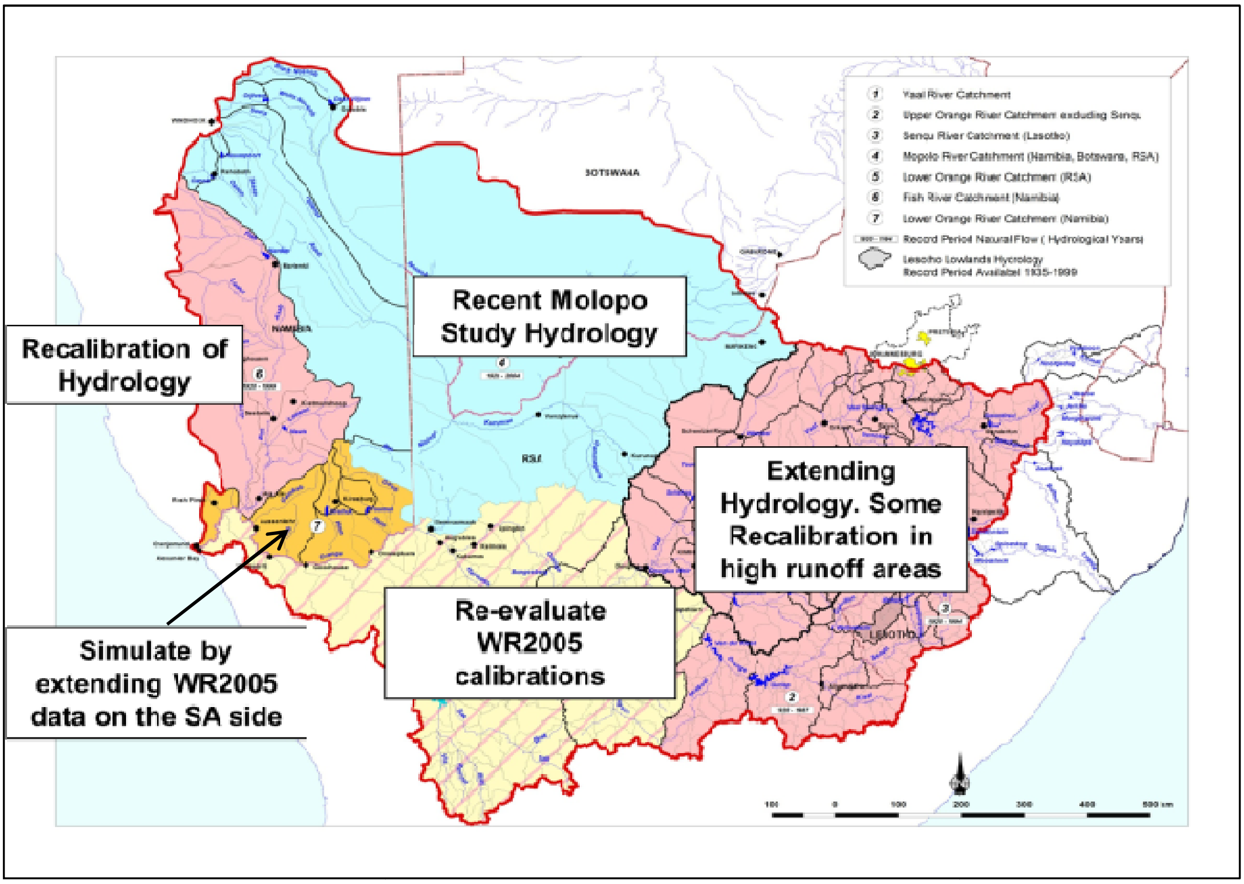


Figure 2-4: Spatial Distributions of Action Taken to Improve/Extend the Hydrological Database

3 RESULTS

3.1 Introduction

This section provides an overview of the data used during the analysis as well as the approach, challenges, natural runoff results and some findings of the hydrological extension work package per secondary catchment.

3.1.1 Data Analysis

3.1.1.1 Flow Gauges

The calibration flow gauging stations, as used in the source studies, as well as the stations used during the detailed analysis in some areas during this study are provided in **Figure A-4** in **Appendix A** and summarized in **Table B-2** in **Appendix B**. The number of flow gauges and the number of open and realible gauges are summarized in **Table 3-1** below.

Table 3-1: Number of Flow Gauges used for Calibration in the Senqu-Orange Basin

Secondary Catchment	Tertiary Catchment	Gross Tertiary Area (km^2)	Secondary Area (km^2)	Flow Gauges Used	Gauges still open and useful	% Still Open
1) Vaal	Upper Vaal (V_U)	38 638	196 438	7	5	71%
	Vaal Barrage (V_B)	8 651		13	9	69%
	Middle Vaal (V_M)	60 836		18	14	78%
	Lower Vaal (V_L)	55.019		5	4	80%
	Riet-Modder (RM)	33 294		5	4	80%
2) Upper Orange	Caledon (CA)	21 884	99 277	9	8	89%
	Senqu (SE)	27 647		8	8	100%
	Upper Orange (O_U)	49 746		8	8	100%
3) Lower Orange	Brak/Ongers (BO), Sak/Harts (SH), Lower Orange (O_L)		243 313	5	4	80%
4) Molopo/Nossob	Kuruman (KU), Upper Molopo (M_U) Lower Molopo (M_L) Nossob (NO), Auob (AU)		356 788	8	6	75%
5) Namibian Fish	Fish (FI)		81 630			
Total (Excluding FI)			895 816	86	70	81%

Although there seems to be a good coverage of the flow gauges in the catchment, the decline in flow gauging stations should be avoided to ensure proper future water resources analysis.

3.1.1.2 Rainfall gauges

The point rainfall stations used during this analysis to generate the catchment rainfall files are provided in **Table B-1** in **Appendix B**, with a map in **Appendix A**, **Figure A-2**. The density of point rainfall gauges and the density of gauges still open after 2004 are summarized in **Table 3-2** below.

Table 3-2: Density of Rainfall Gauges used for Analysis of the Senqu-Orange Basin

Secondary Catchment	Tertiary Catchment	Gross Tertiary Catchment Area (km^2)$^{(1)}$	Gross Secondary Catchment Area (km^2)	Used Rainfall Stations	Rainfall stations Still Open at end of Anlaysis period	% Still Open in 2004	Density of stations (per 2500 km^2)	
							Used	Still Open
	Upper Vaal (V_U)	38 638		21	9	43%	1.4	0.6
	Vaal Barrage (V_B)	8 651		19	8	42%	5.5	2.3
1) Vaal	Middle Vaal (V_M)	60 836	196 438	53	53	100%	2.2	2.2
	Lower Vaal (V_L)	55 019		74	35	47%	3.4	1.6
	Riet-Modder (RM)	33 294		65	27	42%	4.9	2.0
	Caledon (CA)	21 884		39	10	26%	4.5	1.1
2) Upper Orange	Senqu (SE)	27 647	99 277	27	11	41%	2.4	1.0
	Upper Orange (O_U)	49 746		32	15	47%	1.6	0.8
	Brak/Ongers (BO)	33 733						
	Sak/Harts (SH)	93041						
3) Lower Orange	Middle Orange (O_M)	40 100	243 313	59	59	100%	0.6	0.6
	Lower Orange (O_L)	76 439						
	Kuruman (KU)	41 195						
	Upper Molopo (M_U)	148 167						
4) Molopo /Nossob	Lower Molopo (M_L)	38078	356 788	99	49	49%	0.7	0.3
	Nossob (NO)	71 650						
	Auob (AU)	57 698						
5) Namibian Fish	Fish (FI)	81 630	81630					
Total (Excluding FI)			895 816	488	276	57%	0.5	0.3

It has to be noted that, even although relatively few rainfall stations were used in the Upper Vaal, there are numerous available stations in this area that could be used. This seems to be an oversight in the original analysis.

What can be noted from the density table is that there is a marked reduction in stations that were still open at the end of the 2004 hydrological year.

3.1.2 Summary of Results

Table 3-3 below provides a summary of the areas of the Tertiary and secondary catchments, as well as the results of the natural incremental runoff time series as generated by this study. Detailed information on each sub-catchment can be obtained from **Appendix B**, **Tables B-3 to B-6** and the results are discussed in the following section.

Table 3-3: Summary of Results for the Natural Runoff of the Senqu-Orange Basin

Tertiary Catchment	Catchment Area (km^2)		MAP (mm)	MAE (mm)	Natural Incremental Runoff (1920 -2004)		
	Gross	Nett			106m^3/a	mm/a	%MAP
Vaal Upper	38 638	38 638	689	1451	2073.2	54	7.8%
Vaal Barrage	8 651	8 651	658	1650	274.8	32	4.8%
Vaal Middle	60 836	54 121	559	1676	1116.2	18	3.3%
Vaal Lower	55 019	29 030	444	2023	191.5	3	0.8%
Riet-Modder	33 294	20 114	443	1745	379.6	11	2.6%
Secondary Catchment Sub-Total: Vaal	196 438	150 554	537	1740	4035.2	21	3.8%
Senqu	27 647	27 647	756	1397	4275.6	155	20.5%
Caledon	21 884	21 884	659	1487	1366.4	62	9.5%
Orange Upper	49 746	43 038	412	1843	954.9	19	4.7%
Secondary Catchment Sub-Total: Upper Orange	99 277	92 569	562	1640	6596.8	66	11.8%
Brak-Ongers	33 733	24604	248	2205	52.3	2	0.6%
Orange Middle	40 100	21586	229	2479	50.1	1	0.5%
Sak Harts	93 041	76742	161	2267	110.2	1	0.7%
Orange Lower	76 439	72578	107	2599	84.4	1	1.0%
Secondary Catchment Sub-Total: Lower Orange	243 313	195 510	167	2398	297.0	1	0.7%
Molopo Upper	148 167	19 773	372	2160	22.9	0	0.1%
Kuruman	41 195	11 200	313	2404	9.8	0	0.1%
Molopo Lower	38 078	1 182	183	2750	0.0	0	0.0%
Nossob	71 650	7 415	262	1827	6.5	0	0.0%
Auob	57 698	4 153	198	1856	4.4	0	0.1%
Secondary Catchment Sub-Total: Molopo Nossob	356 788	43 723	277	2097	43.7	0	0.1%
Total (Excluding Fish)	895 816	482 356	336	2 050	10 973	12	3.6%

3.1.3 Vaal (VU, VB, VM, VL, RM) Results

3.1.3.1 Approach

For the most part, the Vaal secondary catchment's natural runoff time series records could be extended by making use of extended catchment rainfall records. In the V_L some recalibration was required and in the V_M the original source study's incremental natural runoff spatial distribution was disaggregated to a finer resolution.

3.1.3.2 Challenges

In the Upper Vaal (V_U) it was found that only a limited number point rainfall stations had been used to generate the catchment rainfall record. This meant that only a limited number of rainfall stations could be selected from and eventually used to extend the catchment rainfall record. The extension of catchment rainfall records and the natural runoff records for these areas was, however, achieved.

In the Lower Vaal (V_L) catchment several problems were identified and resolved regarding the stationarity of the catchment rainfall records. Due to this, and due to unrealistic calibration parameters used in the VRSAU source study, some recalibration was required. The naturalized observed part of the incremental natural runoff time series (as generated by the VRSAU study) was used to calibrate against using the WRSM2005 models configured for this area.

3.1.3.3 Natural Runoff Results

Table B-3 in Appendix B provides a comparison between the incremental natural runoff generated from the VRSAU study and the incremental runoff after extension to the 2004 hydrological year as generated during this work package.

3.1.3.4 Findings and recommendations

In general, there was an increase of approximately 3% in the long-term natural runoff when extending the time series with an additional 10 years of record. The RM area, however, indicated an approximately 6% decrease in the natural runoff after the reassessment, and improvement to the rainfall and the calibration in the area.

Only a limited number of rain gauges were used to generate the catchment rainfall records for the V_U catchment's during the VRSAU study. For future analyses, however, it may be advisable to improve the spatial resolution of the rainfall if finer resolutions natural hydrology is required.

The Vaal Secondary Catchment contributes approximately 37% of the total natural runoff of the Senqu-Orange River Basin, but is also the most developed of all the areas.

3.1.4 Molopo/Nossob (AU, NO, MU, ML, KU)

3.1.4.1 Approach

The ORASECOM Molopo/Nossob Study was used as is for the development of the hydrological naturalized runoff time series. The Molopo/Nossob study was also used to establish the catchment boundaries of the areas in conjunction with existing GIS coverages.

3.1.4.2 Challenges

Since the source study's time series data already stretched over the required period from 1920 – 2004 the only challenge was to disaggregate the information into quaternary, tertiary and secondary catchments as well as determine the catchments gross area.

No data was generated for the Skaap River in the source study.

3.1.4.3 Natural Runoff Results

Table B-6 in Appendix B provides the detailed information related to the time series as generated and subsequently disaggregated into the respective quaternary and higher level catchments. It must be noted that the values quoted in **Table B-6** includes the estimated for river losses as stated in the sources study report.

3.1.4.4 Findings and recommendations

There were relatively few gauging stations available to verify the generated data and most of the information was generated by transferring of WRSM2000 calibration parameters from areas with observed data. No mention is also made of how the estimates for losses were derived.

This area is the lowest runoff generating area with only approximately 12% of the gross area contributing towards surface water runoff generation. The total estimated natural runoff is only 0.4% of the total for the entire Senqu-Orange Basin, excluding the Fish.

3.1.5 Lower Orange (OM, OL, BO, SH)

3.1.5.1 Approach

The WR2005 study was used as basis for the simulation of this area. However several landuse changes were incorporated into the WR2005 model configuration and the calibrations were re-evaluated. In addition, simulations were undertaken for areas in the O_L on the Namibian side of the main river. This increased the natural runoff considerably. The large pans at the bottom of the catchment, however, will be modelled explicitly which will reflect the rare contribution of flows to the mainstream of the Orange River.

3.1.5.2 Challenges

Very few flow gauges exist in this area that are suitable for model calibration. In the Ongers/Brak catchment there is only 1 gauge in 30 000 km^2; in the Middle Orange catchment there are no gauges in area of 40 000 km^2; in the Sak/Hartbees catchment there are 3 gauges in 100 000 km^2; and in the Lower Orange there is only 1 gauge in 30 000 km^2.

3.1.5.3 Natural Runoff Results

Table B-6 in Appendix B provides the detailed comparison between the original WR2005 Study results and the natural runoff generated from this study. It should be noted that these results do not reflect any losses.

3.1.5.4 Findings

Overall, there is a 21% increase in the natural runoff generated by this area, mostly due to the additional quaternary catchments added on to the O_L on the Namibian side of the mainstream. This area contributes 2.7% to the total natural runoff before losses.

3.1.6 Upper Orange (CA, OU, SE)

3.1.6.1 Approach

Due to:

- the high runoff generated in this area,
- the age of the previous hydrological analysis (1989), and
- the limited electronic information available for this area,

it was decided to redo the natural runoff time series for the entire Upper Orange. In addition, the hydrology generated for the O_U did not take into account the “accepted” Senqu hydrology as generated by the Joint RSA/Lesotho study.

For the Senqu, the original patched rainfall data and the report was used to simulate the original natural flow period from 1920 -1966 and verify against the patched observed part (1967 -1995) of the incremental natural runoff records generated by the Joint RSA/Lesotho study. No changes could be made to the original agreed hydrology or rainfall, only extension to the natural runoff for the period of 1996 – 2004 was allowed.

The accepted incremental natural runoff time series was calibrated against in the Senqu while verifying against observed data for Katse, Mohale and Lesotho, as well as RSA flow gauging data. Rainfall data was obtained from Lesotho’s Department of Water Affairs. Very limited data (mostly a single station) were available to extend each of the catchment rainfall records by using only the accepted point rainfall gauging stations.

Although some values were patched post 1996, the point rainfall records were mostly used without alteration while checking for stationarity.

For the Caledon and the O_U, the WR2005 network configurations were used although the landuse information was completely revised (irrigation areas and minor dams). In addition, all available flow gauging data were assessed and often different selections of gauging stations were made from the original WR2005 study. In addition, some stationarity problems were identified in some of the Upper Caledon catchments and new catchment rainfall data was generated. Some of the available Lesotho flow gauging data was also used to calibrate within the Caledon catchment.

3.1.6.2 Challenges

It was challenging to replicate both the simulated and patched observed parts of the Senqu data. It was, however, decided to ensure consistency with the simulated part as well as the overall statistics of the original accepted hydrology of the Senqu. In addition there were no calculated inflows information for Katse and Mohale Dams. Detailed observed data was obtained from the TCTA and an inflow was calculated from this. The calculated inflow from 1996 – 2004 was used to extend the Katse natural inflow records.

Other challenges were the calibration of Welbedacht Dam which has had dramatic decrease in storage capacity due to sedimentation problems and which caused problems with the calculated inflow records.

3.1.6.3 Natural Runoff Results

Table B-4 in Appendix B provides detailed comparisons of all areas in this catchment.

3.1.6.4 Findings

In general there has been an overall decrease of 2% in the natural runoff generated by this catchment. This is due mainly to the O_U area which originally did not include the relatively dry conditions experienced in the 1990s.

3.1.7 Fish River, Namibia (FI)

To be completed outside of this report.

4 RECOMMENDATIONS

Rainfall

Although certain areas of the Senqu-Orange Basin still have adequate coverage of rainfall gauges, there has been a significant reduction in open rainfall stations in most of the sub-catchments of the basin. Today, the density of rainfall stations that are still open, and used in the analysis, ranges between 0.3 and 2.3 gauges per 2500 km^2.

When analysing the runoff generating capabilities of the highest runoff generating catchments (SE and CA), the average rainfall gauge density was approximately 1 gauge per 2500 km^2. This may be due to the lack of reliable data or due to the fact that in previous analyses these were the only gauges that were found suitable for rainfall-runoff modeling. For example, there is currently only one station remaining that drives the runoff generation for the upstream catchments of Katse and Mohale Dams. It is recommended that the rainfall data (historic and present day) for the higher runoff yielding catchments (CA,SE, V_U and O_U) be re-evaluated to ensure that the best available point sources are identified. These stations should remain open to ensure that future analyses are still representative.

With the projected effects of climate change, it is very important to safeguard and even expand the rainfall monitoring network to assess if the projected effects are actually occurring. It is also important to assess the possible effects on the meteorological conditions and therefore the projected water resource capabilities.

Streamflow gauges

Although there seem to be an adequate coverage of the flow gauging stations within the Senqu-Orange Basin, it is of the utmost importance that at least the stations used for this analysis be maintained to ensure ongoing monitoring. This will ensure that the effects of the ever-increasing water and land-use impacts can be assessed and that the impact of projected trends in the climate can be monitored. Water resources models can only provide adequate spatial and temporal disaggregation of information if proper streamflow monitoring takes place. Once again, the high runoff areas (such as the SE, CA, V_U and the O_U) should receive adequate attention when it comes to monitoring, especially when large infrastructure is implemented, such as the Katse and Mohale Dams. It is essential that all components necessary for a detailed dam balance of the Katse and Mohale dams are monitored and that an ongoing calculated inflow record is generated. The same applies for all the other large dams in the Senqu-Orange River Basin.

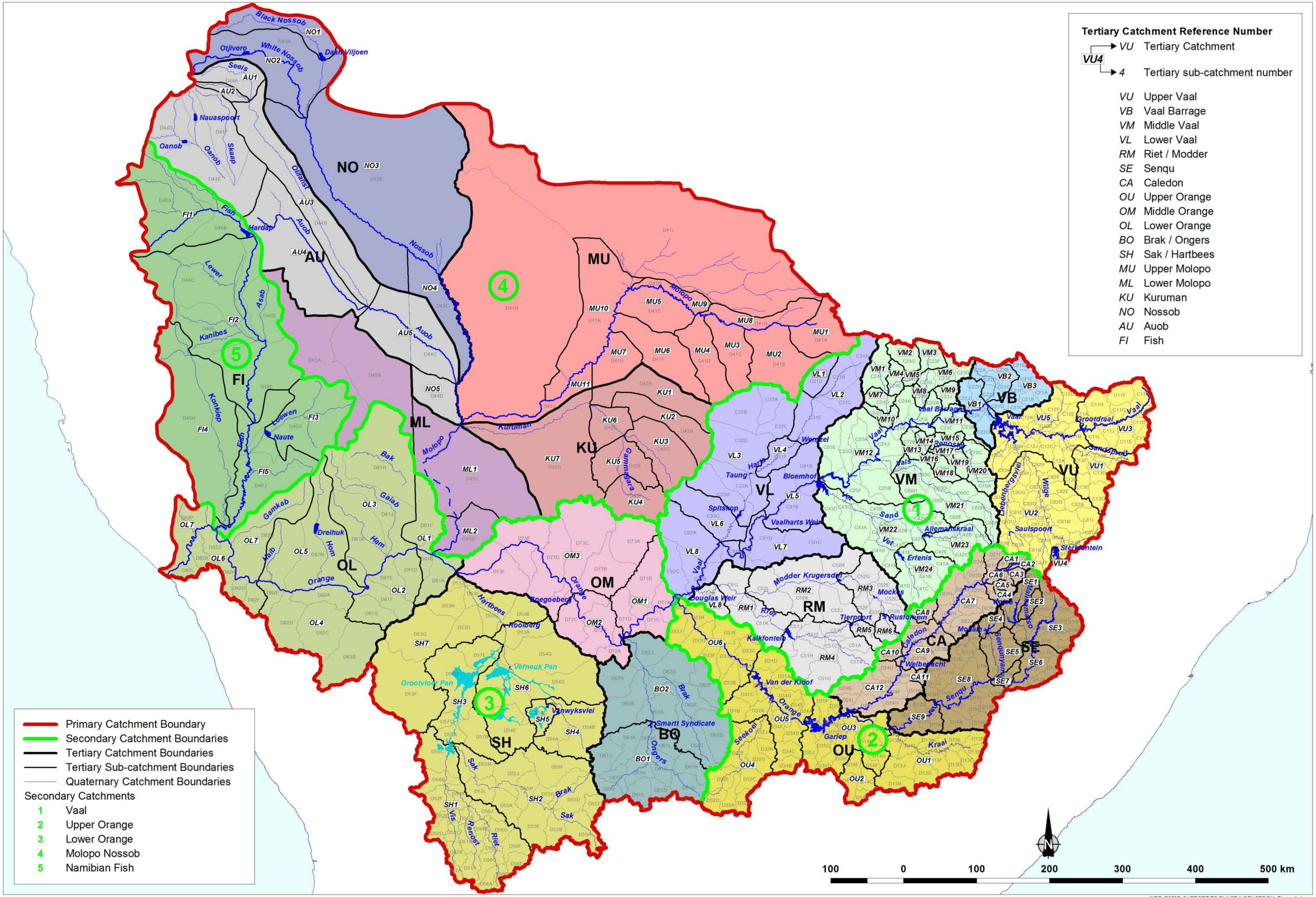
Modelling

A relatively fine spatial resolutions hydrological model has been developed and it is essential to keep the model updated with land-use as it occurs, to ensure that the hydrological database stays representative. In particular, the Senqu River Basin might be required to re-evaluate the simulated part of the original “agreed” hydrology.

5 APPENDICES

APPENDIX A: MAPS AND FIGURES

APPENDIX B: DATA SHEETS

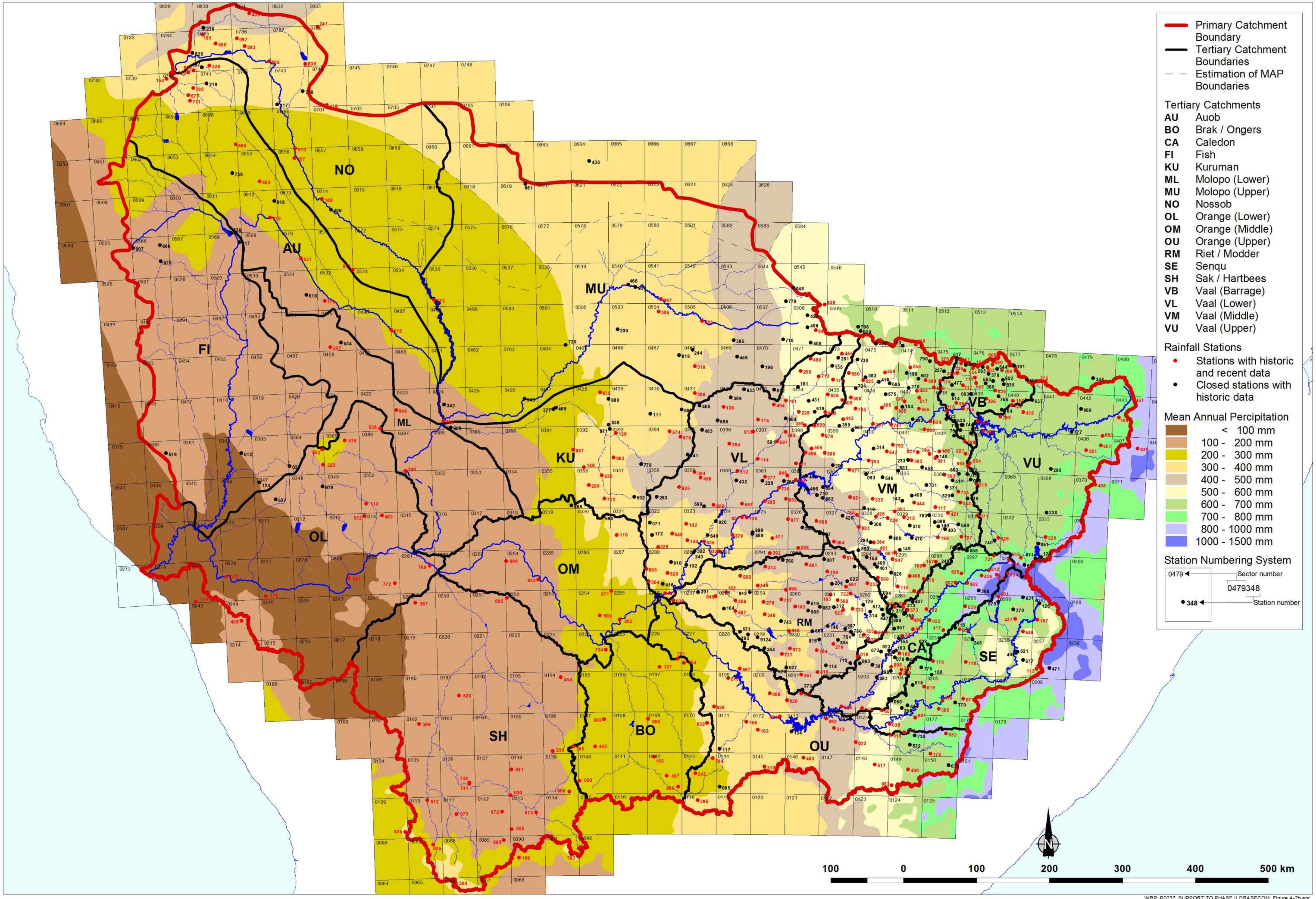


WRP_P0237_SUPPORT TO PHASE II ORASECOM_Figure A-1.apr

INTEGRATED WATER RESOURCES MANAGEMENT PLAN PHASE II
FOR THE ORANGE-SENQU RIVER BASIN

Senqu-Orange Catchment Delineations

A-1

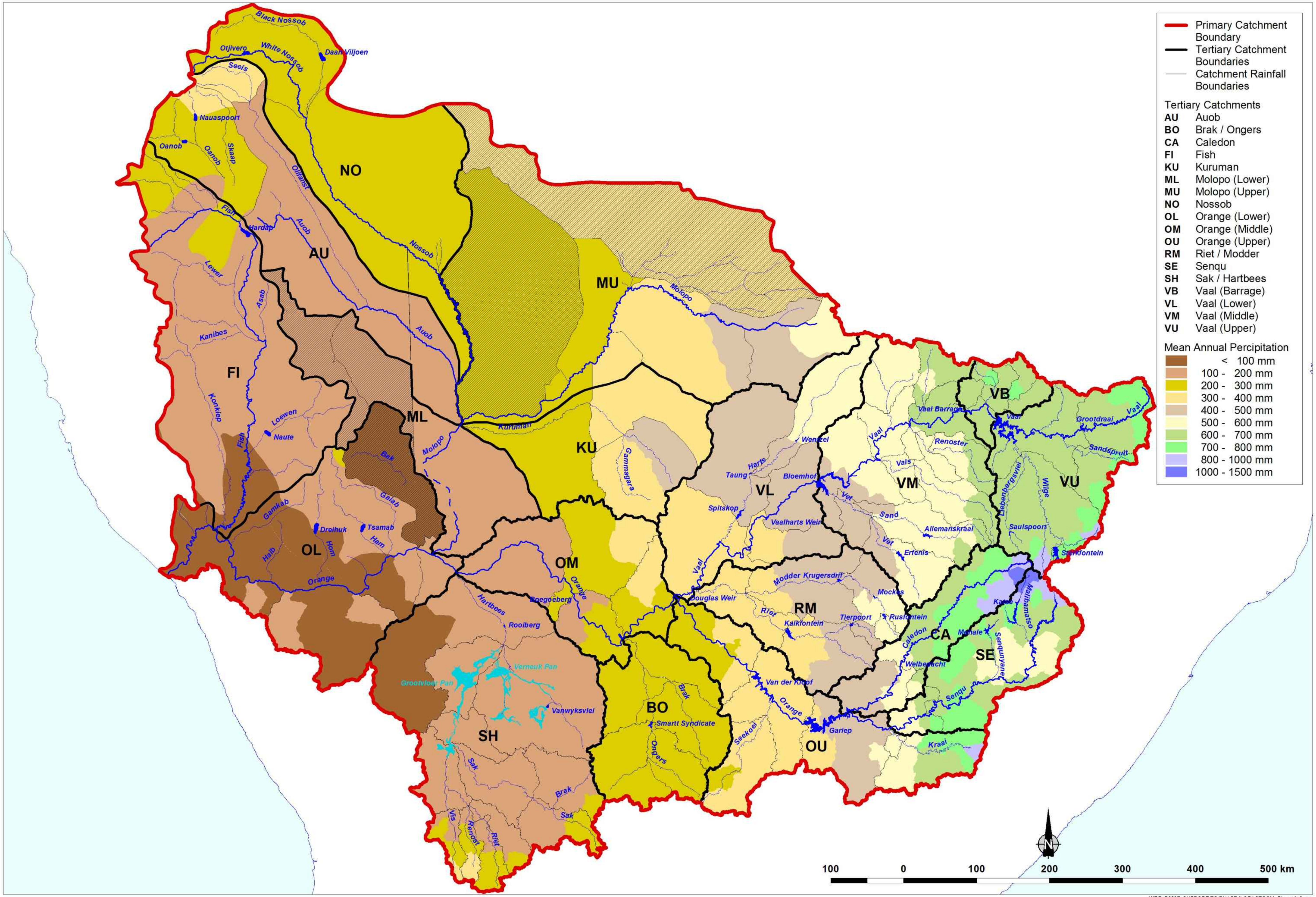


On behalf of Federal Republic of Germany The Federal Government

INTEGRATED WATER RESOURCES MANAGEMENT PLAN PHASE II
FOR THE ORANGE-SENQU RIVER BASIN

Point Rainfall Gauges

A-2



WRP_P0237_SUPPORT TO PHASE II ORASECOM_Figure A-3.apr

ORASECOM giz On behalf of Federal Republic of Germany The Federal Government UKaid from the Department for International Development Australian AID WRP

INTEGRATED WATER RESOURCES MANAGEMENT PLAN PHASE II
FOR THE ORANGE-SENQU RIVER BASIN

Catchment Rainfall Record Boundaries

A-3

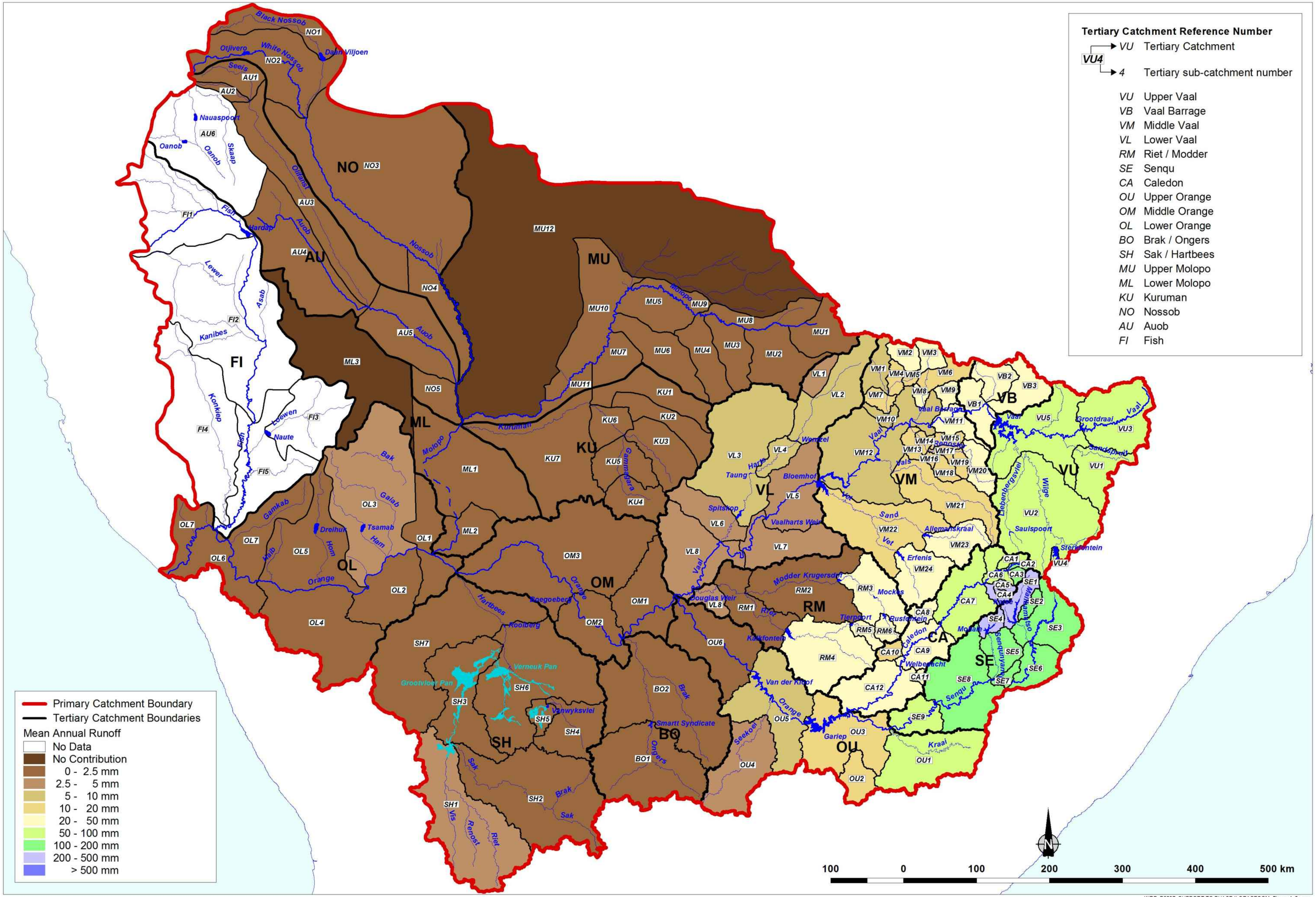
WRP_P0237_SUPPORT TO PHASE II ORASECOM_Figure A-4.apr

On behalf of Federal Republic of Germany The Federal Government

INTEGRATED WATER RESOURCES MANAGEMENT PLAN PHASE II
FOR THE ORANGE-SENQU RIVER BASIN

Calibration Flow Gauging Stations Catchment Boundaries

A-4



WRP_P0237_SUPPORT TO PHASE II ORASECOM_Figure A-5a.apr

On behalf of Federal Republic of Germany The Federal Government

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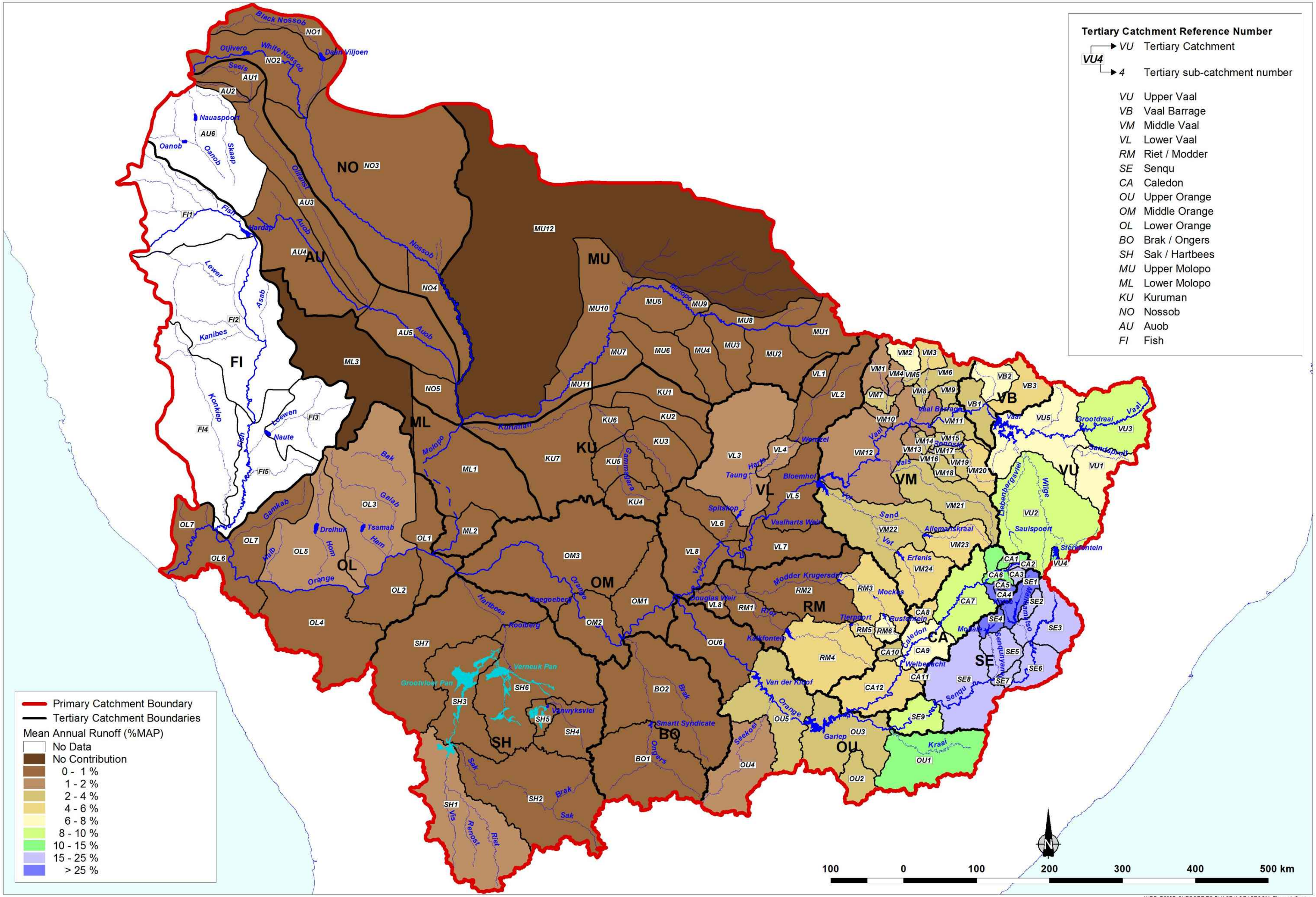
Australian AID

INTEGRATED WATER RESOURCES MANAGEMENT PLAN PHASE II
FOR THE ORANGE-SENQU RIVER BASIN

Natural Incremental Runoff (mm/a)

A-5.1



On behalf of Federal Republic of Germany The Federal Government

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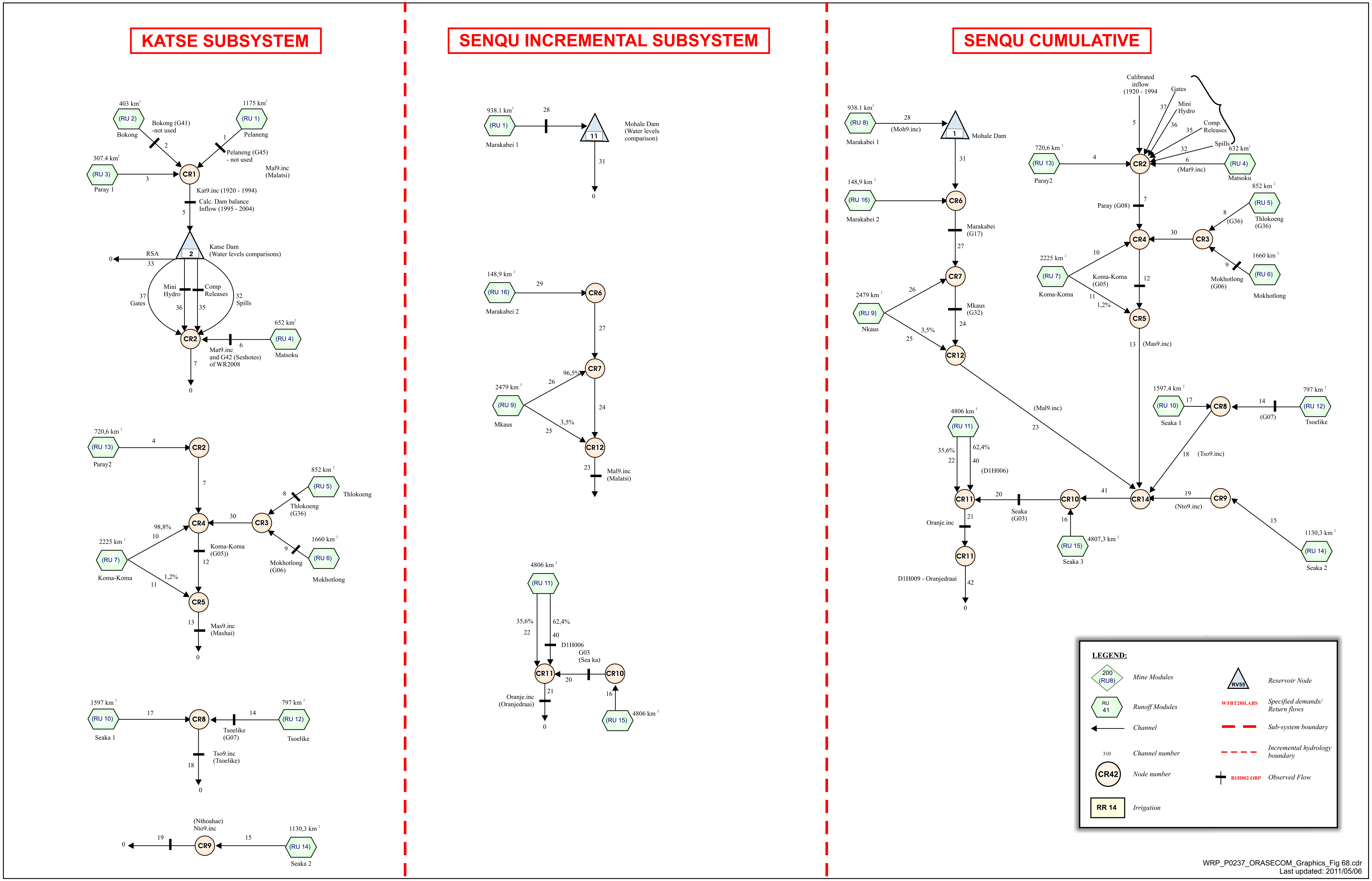
INTEGRATED WATER RESOURCES MANAGEMENT PLAN PHASE II
FOR THE ORANGE-SENQU RIVER BASIN

Natural Incremental Runoff (%MAP)

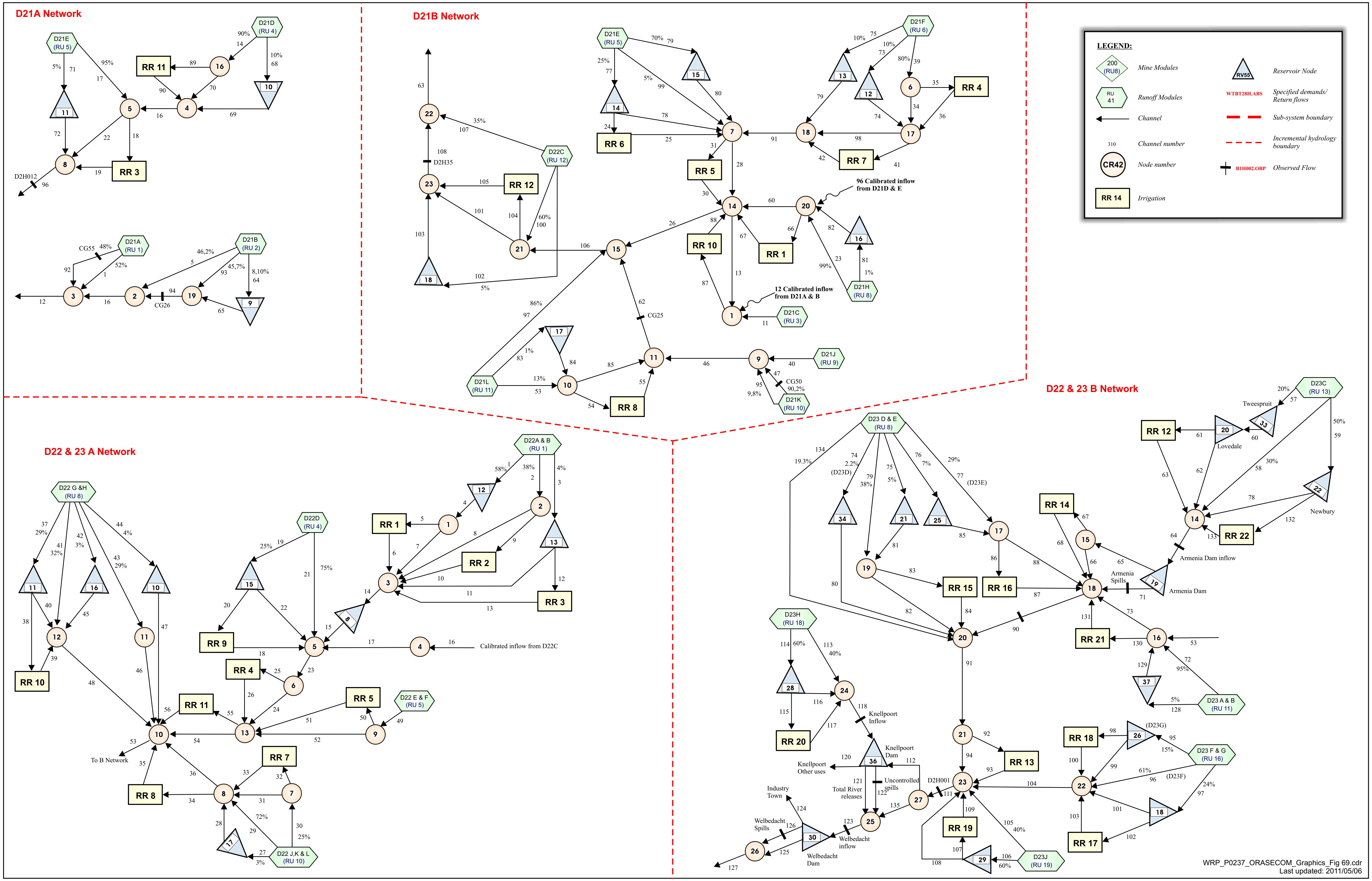
A-5.2



SUPPORT TO PHASE II OF THE
BASIN-WIDE ORASECOM IWRM PLAN

WRSM2000 Network Diagram for the Senqu (SE) up to Oranjedraai

A-6



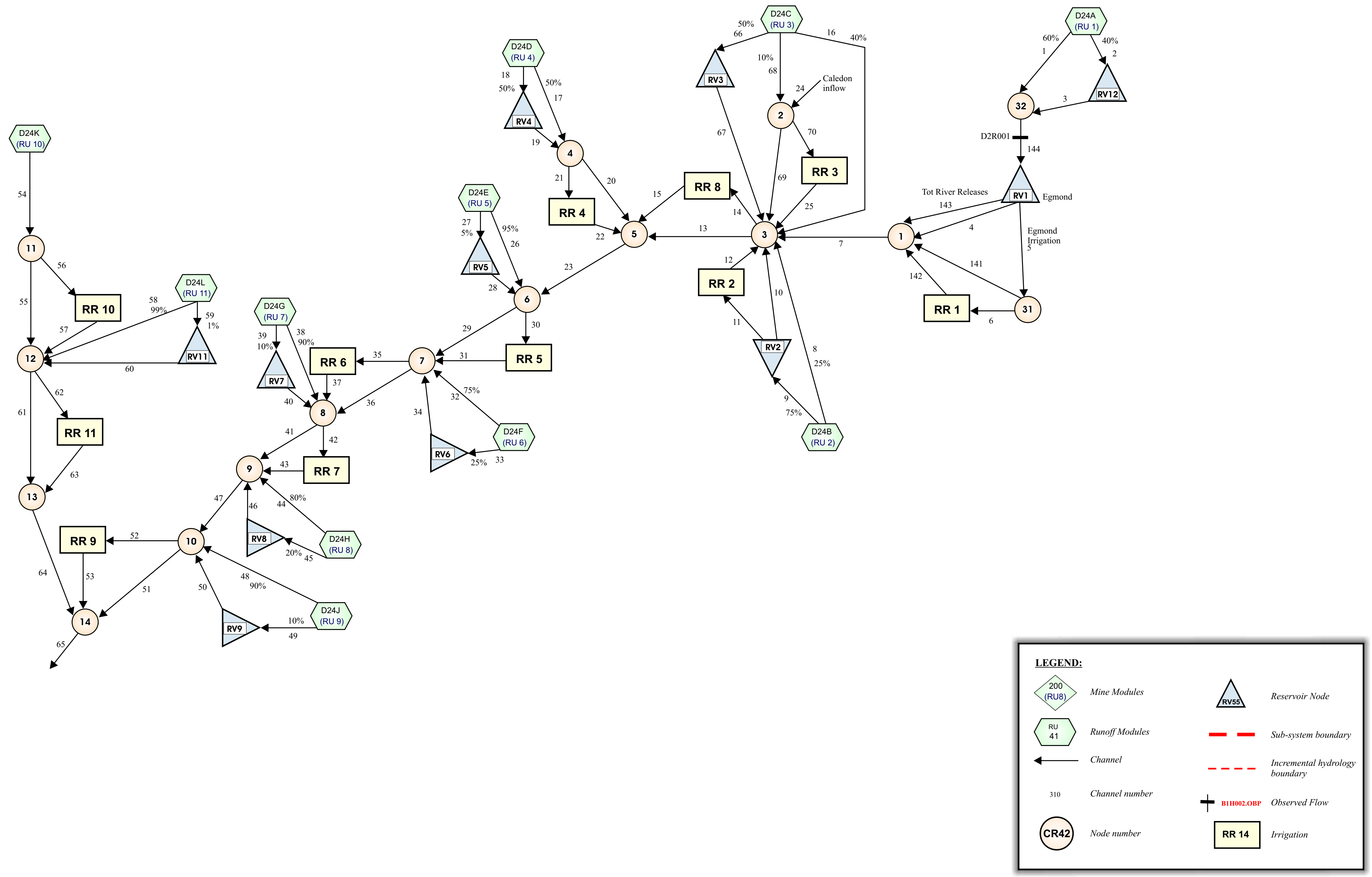
SUPPORT TO PHASE II OF THE BASIN-WIDE ORASECOM IWRM PLAN

WRSM2000 Network Diagram for the Caledon River (CA) up to Welbedacht Dam

A-7

LOWER CALEDON

D24 (D24 Network)

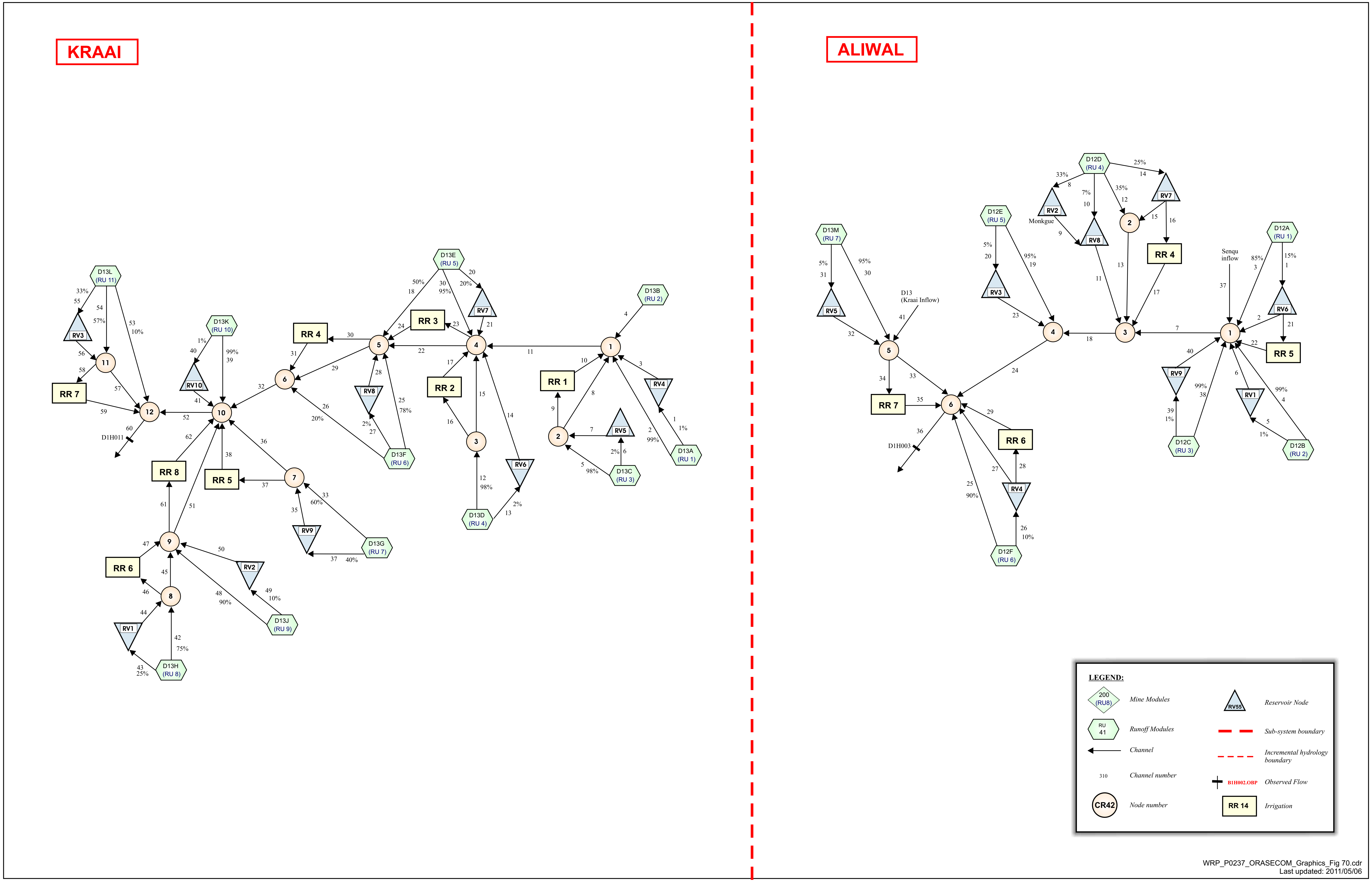


WRP_P0237_ORASECOM_Graphics_Fig 70.cdr
Last updated: 2011/05/06

SUPPORT TO PHASE II OF THE
BASIN-WIDE ORASECOM IWRM PLAN

WRSM2000 Network Diagram for the Caledon River (CA) downstream from Welbedacht Dam

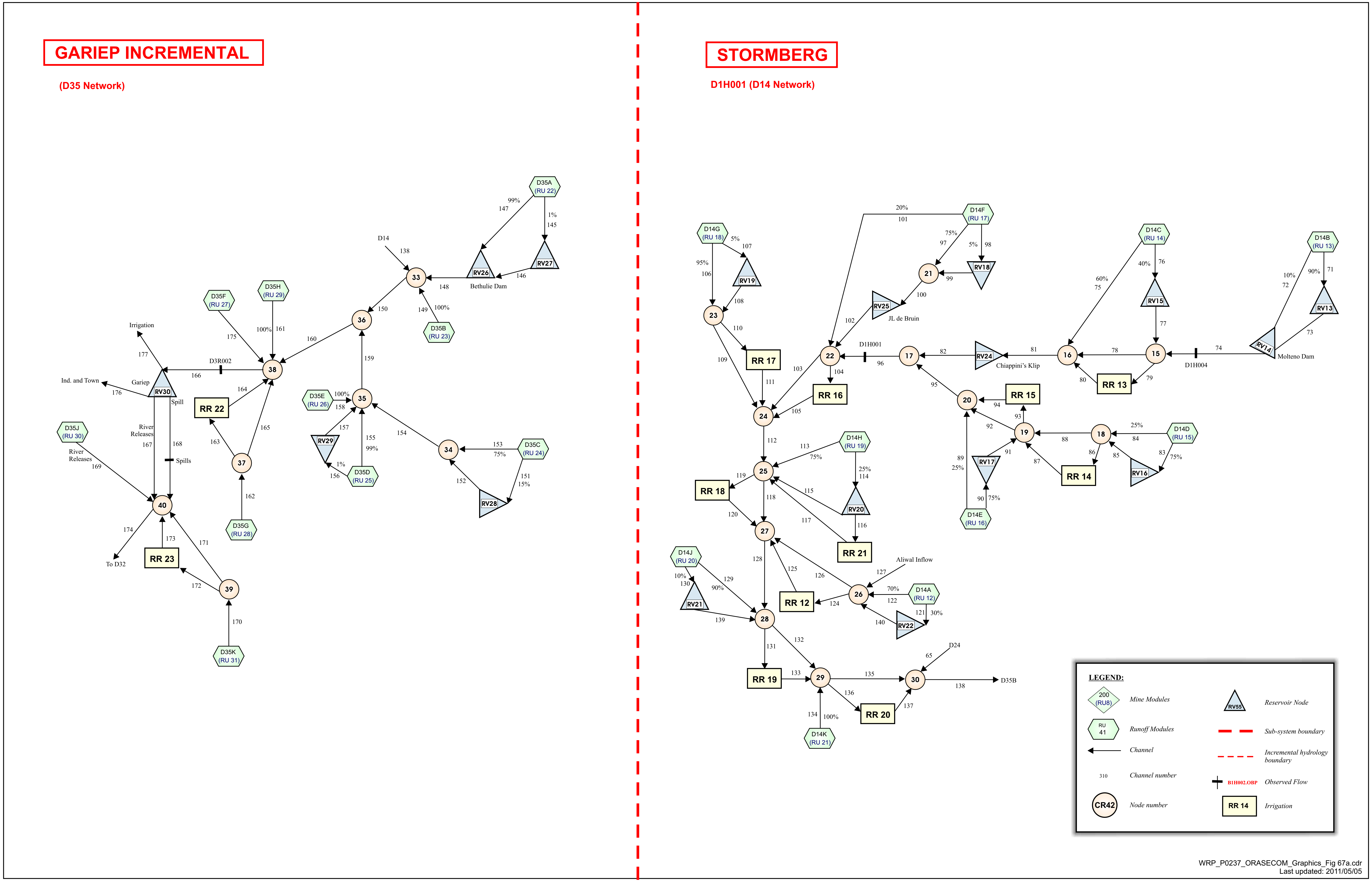
A-8



SUPPORT TO PHASE II OF THE
BASIN-WIDE ORASECOM IWRM PLAN

WRSM2000 Network Diagram for the Upper Orange (OU) - Kraai and Aliwal

A-9.1



WRP_P0237_ORASECOM_Graphics_Fig 67a.cdr
Last updated: 2011/05/05

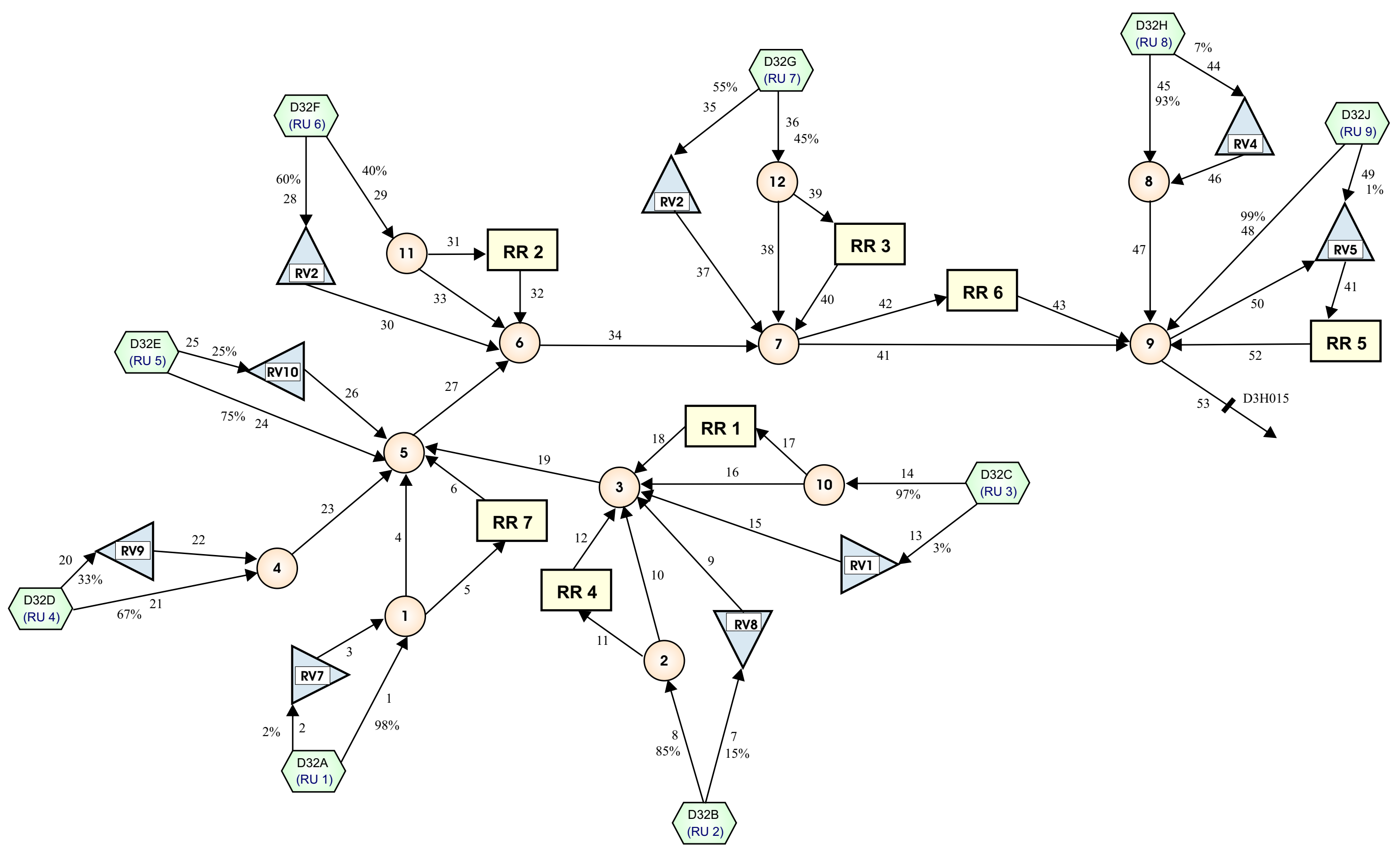
SUPPORT TO PHASE II OF THE BASIN-WIDE ORASECOM IWRM PLAN

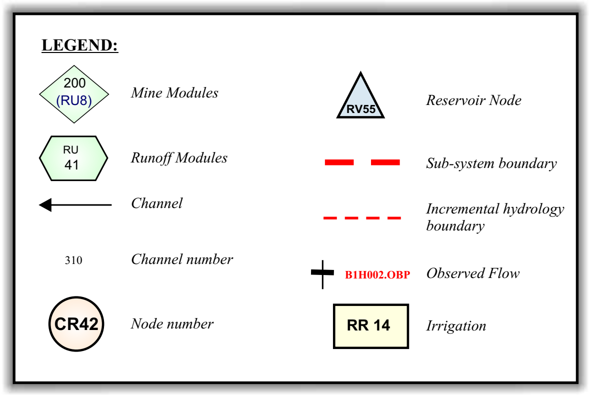
WRSM2000 Network Diagram for the Upper Orange (OU) - D14 and D35

A-9.2

SEEKOEI

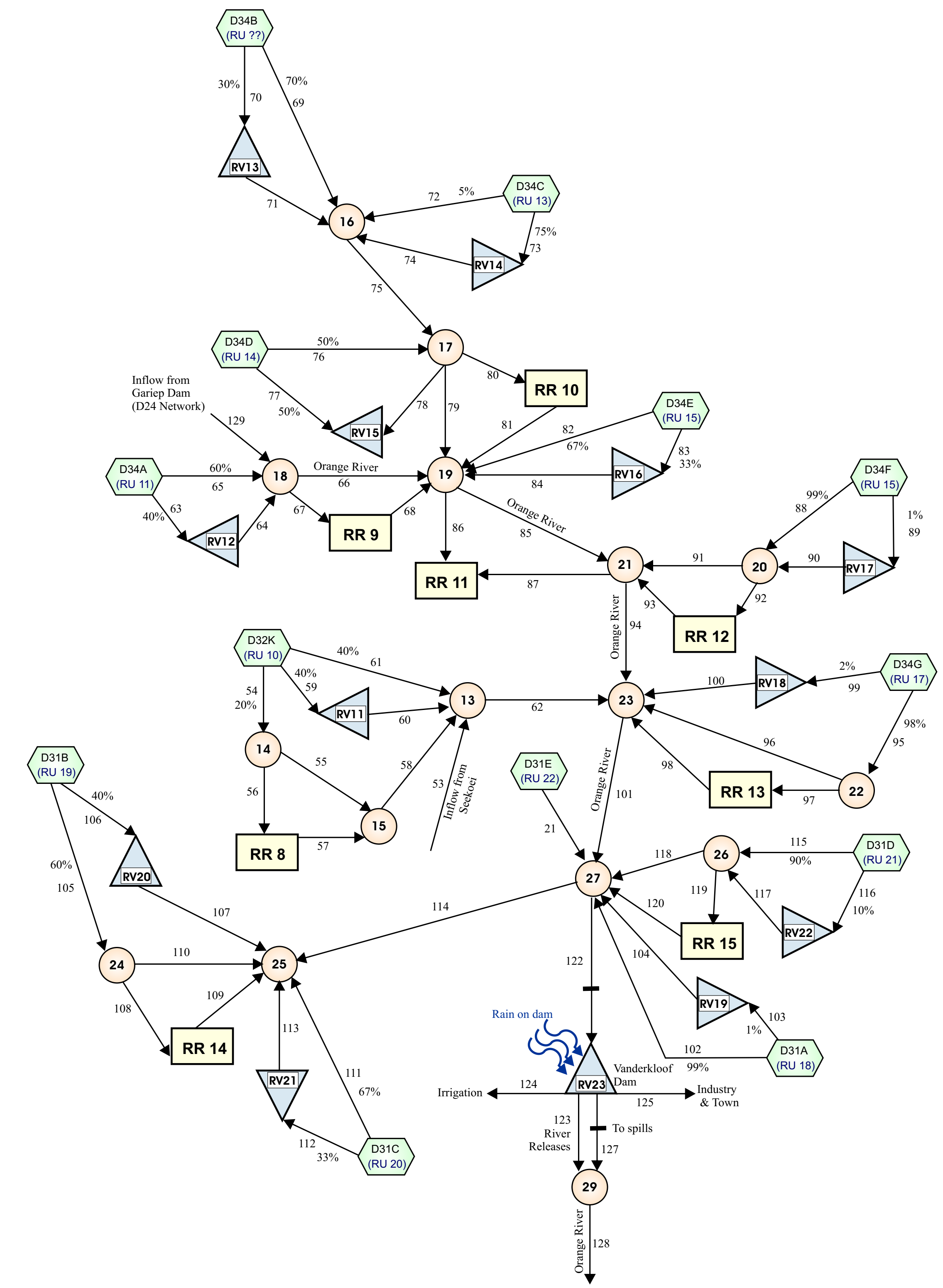
Seekoei (D32 Network)





VAN DER KLOOF INCREMENTAL WITHOUT SEEKOEI

PK le Roux (D32 Network)



WRP_P0237_ORASECOM_Graphics_Fig 67b.cdr
Last updated: 2011/05/05

SUPPORT TO PHASE II OF THE
BASIN-WIDE ORASECOM IWRM PLAN

WRSM2000 Network Diagram for the Upper Orange (OU) - Van der Kloof Incremental

A-9.3

APPENDIX B: TABLE B-1 - POINT RAINFALL GAUGES USED FOR CATCHMENT RAINFALL RECORD GENERATION

List of key rainfall gauges in Middle Vaal catchment

Count	Station	Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	263280	Westminster	29 10	27 10	1920	2004	C4A
2	294481	Erfenis Dam	28 31	26 47	1948	2004	C4A, C4C
3	294500	Verkeerdevkei	28 50	26 47	1923	2004	C4A, C4C
4	294847	Doornpoort	28 37	26 59	1929	2004	C4A
5	295001	Winburg	28 31	27 01	1910	2004	C4A, C4B
6	295116	Excelsior	28 56	27 04	1911	2004	C4A
7	295408	Moreson	28 48	27 14	1926	2004	C4A
8	295760	Marquard	28 40	27 26	1915	2004	C4A
9	295770	Belmont	28 50	27 26	1917	2004	C4A
10	326668	Geluk	28 08	25 53	1932	2004	C4E
11	327784	Nelsdrift	28 04	26 27	1908	2004	C4D. C4E
12	328384	Theunissen	28 24	26 43	1914	2004	C4C, C4D
13	328425	Adamsonvlei	28 05	26 45	1925	2004	C4D, C4E
14	328726	Olivine	28 06	26 55	1925	2004	C4D
15	329215	Ventersburg	28 05	27 08	1910	2004	C4D
16	330199	Senekal	28 19	27 37	1905	2004	C4B
17	330421	Roodepoort	28 01	27 45	1913	2004	C4B, C6A
18	330797	Paul Roux	28 17	27 57	1926	2004	C4B, C6A
19	363571	Hendrick Theron	27 31	26 20	1932	2004	C2F
20	363651	Wesselsbron	27 51	26 22	1924	2004	C2F, C4E
21	364322	Odendaalsrus	27 52	26 41	1906	2004	C2F, C4E
22	365444	Swartkoppie	27 54	27 15	1926	2004	C4D, C6A
23	366117	Steynsrus	27 57	27 34	1923	2004	C6A
24	366303	Edenville	27 33	27 41	1929	2004	C6A, C6B, C7A, C7B, C7C
25	366743	Lindley	27 53	27 55	1924	2004	C6A
26	367219	Petrus Steyn	27 39	28 08	1922	2004	C6B, C7A
27	398177	Zevenfontein	27 27	25 36	1911	2004	C2F
28	398409	Rietpan	27 19	25 44	1929	2004	C2F
29	400203	Bothaville	27 23	26 37	1912	2004	C2E, C6B
30	400647	Bovenlandsplaats	27 17	26 52	1930	2004	C2E, C6B
31	400792	Viljoenskroon	27 12	26 57	1934	2004	C6B, C7B, C7C
32	401383	Welvaart	27 23	27 13	1957	2004	C6A, C7B, C7C
33	402081	Morgenrood	27 21	27 33	1913	2004	C7C
34	402166	Doorndraai	27 16	27 36	1919	2004	C6B, C7A, C7B, C7C
35	402827	Heilbron	27 17	27 58	1921	2004	C6B, C7A
36	402866	Driefontein	27 26	27 59	1914	2004	C6B, C7A
37	434888	Ottosdal	26 48	26 00	1911	2004	C2F
38	435608	Mon Repos	26 38	26 21	1953	2004	C2D
39	435735	Hartbeesfontein	26 45	26 25	1916	2004	C2D, C2E
40	436297	Vaal Reefs West	26 57	26 40	1942	2004	C2E
41	436495	Beatrix	26 45	26 47	1920	2004	C2E
42	436747	Bushy Bend	26 57	26 55	1922	2004	C2C, C2E, C6B
43	436855	Brakspruit	26 45	26 59	1904	2004	C2C
44	437100	Potchefstroom	26 40	27 04	1918	2004	C2C
45	437452	Mimosa Park	26 32	27 16	1920	2004	C2C
46	437517	Klipdrift	26 37	27 18	1924	2004	C2C
47	437660	Vredefort	27 00	27 22	1906	2004	C2A, C7B, C7C
48	437834	Parys	26 54	27 28	1913	2004	C2A
49	438315	Barrage	26 45	27 41	1916	2004	C2A
50	474502	Welverdiend	26 22	27 17	1913	2004	C2B
51	474684	Blyvooruitsig	26 24	27 23	1941	2004	C2B
52	474899	Fochville	26 29	27 30	1927	2004	C2C
53	511120	Dwarsfontein	26 00	27 04	1911	2004	C2B, C2D
54	295539	Meqautlingsnek	28 59	27 18	1923	1996	C4A
55	327264	Kareepan	28 24	26 09	1919	2000	C4C,C4E
56	327883	Grootkuil	28 13	26 30	1911	2003	C4C
57	329001	Whites-Portland Cement	28 01	27 00	1915	2000	C4D
58	331271	Vaalbank	28 02	28 10	1913	1989	C6A
59	365731	Weltevrede	27 41	27 26	1913	1996	C6A,C7B,C7C
60	366735	Oatlands	27 45	27 53	1920	1998	C6A,C6B
61	398556	Hollowaysrust	27 16	25 49	1906	2003	C2F
62	398889	Makwassie	27 19	26 00	1909	2001	C2F
63	401798	Dunkeld	27 18	27 28	1915	1997	C7B,C7C
64	434599	Vogelstruiskruil	26 59	25 51	1925	2003	C2F
65	435442	Skietfontein	26 54	26 15	1953	2001	C2E,C2F
66	437555	Hartebeestpoort	26 45	27 18	1925	2002	C2A, C2C
67	474255	Klerkskraal	26 15	27 10	1903	2002	C2B
68	474270	Frederikstad-SAR	26 30	27 09	1910	2001	C2B

List of key rainfall gauges in Vaal Barrage catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	402788	OORSPRONG - OOS	27 8	27 57	1919	1996	B07
2	403062	Midden	27 02	28 02	1929	1976	B07
3	438315	Barrage-RWB	26 08	27 57	1916	2004	B05, B06,B07
4	438514	Rietspruit	26 34	27 46	1930	1977	B06
5	438533	Pietershoogte	26 53	27 48	1986	1988	B07
6	438550	VANDERBIJLPARK - YSKOR	26 40	27 49	1942	1991	B06, B07
7	438716	Rietfoentein	26 56	27 54	1915	1989	B07
8	438734	Viljoendrift-Pol	26 44	27 54	1905	2004	B03,B07
9	438744	Clydesdale Colliery	26 56	27 55	1972	1994	B07
10	438750	Schaapplaats	27 00	27 53	1933	1980	B07
11	439003	MEYERTON	26 33	28 1	1920	1994	B03
12	439203	Vaaldam-POL	26 53	28 07	1970	1994	B07
13	439396	Schikfontein	26 36	28 14	1920	2004	B01, B02, B03
14	439755	Kraal-SAR	26 34	28 24	1905	1965	B01, B02
15	439764	Vlakfontein	26 44	28 27	1904	1980	B01
16	439769	Beerlagte	26 49	28 26	1904	2004	B01
17	440129	Balfour-MAG	26 39	28 35	1904	2004	B01
18	440157	Rietbuilt	26 37	28 36	1913	1994	B01
19	440637	Rasrant	26 36	28 52	1934	1976	B01
20	475174	Kloof-GM	26 24	27 35	1966	1994	B06
21	475477	Eldorado	26 27	27 45	1929	1974	B06
22	475528	ZUURBEKOM - RWB	26 18	27 49	1899	1994	B05, B06
23	475611	DURBAN ROODEPOORT DEEP -	26 11	27 52	1904	1994	B05
24	475717	Doornkuil	26 27	27 54	1925	2002	B03
25	475717	Luipaardevlei-GM	26 07	27 48	1925	1994	B06
26	475736	KLIPSPRUIT - PUR	26 16	27 55	1907	1994	B05
27	476044	Johannesburg-Turffontein	26 14	28 02	1913	1994	B04
28	476111	ZWARTKOPJES - RWB	26 21	28 4	1906	1997	B05
29	476145	Kliprivier-Pol	26 25	28 05	1940	2004	B03, B04
30	476163	ROSHERVILLE - POW	26 13	28 6	1905	1994	B04
31	476283	Germiston-F J Payne PA	26 13	28 10	1908	1989	B04, B05
32	476386	Tamboekiesfontein	26 25	28 13	1963	1981	B04
33	476387	Diepkloof	26 28	28 14	1936	1977	B04
34	476403	East Rand-GM	26 13	28 14	1904	2004	B04
35	476563	Glenroy	26 23	28 19	1905	1946	B02, B04
36	476580	Benoni-Country	26 11	28 18	1965	1994	B02
37	476630	Heidelberg	26 30	28 21	1905	1994	B02
38	476644	Brakpan	26 14	28 22	1921	1985	B02
39	476666	PETIT - POL	26 6	28 22	1969	1989	B02
40	476766	Springs Olympia Park	26 16	28 26	1919	2004	B02
41	476802	Sub-Nigel_GM	26 22	28 27	1905	1977	B02
42	476835	Nigel Branwee	26 25	28 28	1989	1994	B02
43	477191	Droogefontein	26 11	28 36	1928	1987	B02
44	477501	DEVON - POL	26 21	28 47	1907	1989	B01

List of key rainfall gauges in Molopo catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	288528	Tweefontein			1920	2004	D42A, B, D42C, D42D, D42E
2	320696	Compass			1877	1999	D41J, D41K, D41L
3	322071	Danielskuil-Pol			1877	1999	D41J, D41K, D41L
4	355808	Hartebeeshoek			1932	1977	D42A, D42B, D42C, D42D, D42E
5	356285	Hopkins			1877	2004	D42A, D42B, D42C, D42D, D42E, D41J, D41K, D41L
6	356636	Deben-Pol			1877	2004	D41J, D41K, D41L
7	356712	Smythe			1877	2004	D41J, D41K, D41L
8	357592	Branksea			1877	1999	D41J, D41K, D41L
9	387240	Noenieput			1921	2004	D42A, D42B, D42C, D42D, D42E
10	391857	Dedeben			1912	2004	D42A, D42B, D42C, D42D, D42E
11	392148	Winton			1877	2004	D41J, D41K, D41L
12	392871	Gamodisa			1877	1999	D41G, D41H, D41M
13	393083	Kuruman			1877	2004	D41J, D41K, D41L
14	393126	Tsineng			1877	2004	D41J, D41K, D41L
15	393778	Kuruman			1882	1999	D41J, D41K, D41L
16	394574	Bothitho			1906	2004	D41G, D41H, D41M
17	394878	Boscobel			1906	2004	D41G, D41H, D41M
18	395141	Grootbultfontein			1884	1999	D41G, D41H, D41M
19	423044	Rietfontein			1920	2004	D42A, D42B, D42C, D42D, D42E, Z10G
20	424342	Bokspits	26 42	20 42	1974	2003	Z10E, Z10G
21	424354	Gemsbok-Pol			1920	2004	D42A, D42B, D42C, D42D, D42E, Z10G
22	424509	Askham			1920	1999	D42A, D42B, D42C, D42D, D42E, Z10G
23	426549	KHUIS	26 39	21 49	1981	2003	Z10E, Z10F
24	427377	Blakely			1925	1999	D42A, D42B, D42C, D42D, D42E, Z10E
25	427469	Onrust			1920	1999	D42A, D42B, D42C, D42D, D42E, Z10G
26	428635	Severn			1910	2004	D41G, D41H, D41M, Z10E
27	428838	Karlsruhe			1877	1999	D41G, D41H, D41M
28	428880	Elrida			1877	1999	D41G, D41H, D41M
29	430111	Longhurst			1906	1999	D41G, D41H, D41M
30	430888	Southey			1897	1999	D41G, D41H, D41J, D41K, D41L, D41M
31	431306	Genesa			1897	2004	D41C, D41D, D41E, D41F
32	431465	Mistake			1897	1999	D41C, D41D, D41E, D41F
33	432633	Stella			1920	1999	D41A, D41B, D41C, D41D, D41E, D41F
34	433512	Brandwag			1920	1999	D41A, D41B
35	464720	TSABONG	26 00	22 24	1949	2003	Z10E, Z10F
36	467818	Donegal			1897	1999	D41C, D41D, D41E, D41F
37	468244	Inverness			1897	1999	D41C, D41D, D41E, D41F, Z10F
38	468318	Palmyra			1897	2004	D41C, D41D, D41E, D41F
39	469459	Mosita			1920	1999	D41A, D41B
40	470196	Setlagodi			1920	1999	D41A, D41B
41	471490	Lusthof			1920	2004	D41A, D41B
42	495267	Koes	25 57	19 09	1912	2004	Z10G
43	495534	Grabstein	25 54	19 18	1936	2002	Z10G
44	497019	Gemsbokpark- Mata Mata			1920	2004	D42A, D42B, D42C, D42D, D42E, Z10E, Z10G
45	503200	Rochelle			1897	1999	D41C, D41D, D41E, D41F, D41G, D41H, D41M
46	504306	Python			1897	2004	D41C, D41D, D41E, D41F, Z10F
47	505493	Boshoek			1897	2004	D41C, D41D, D41E, D41F, Z10F
48	506386	Logaging			1920	1999	D41A, D41B
49	507716	Shopsite			1920	1999	D41A, D41B
50	508406	De-Wig			1920	1999	D41A, D41B
51	508428	Jagersfontein			1920	1999	D41A, D41B
52	508508	Spring Valley			1920	1999	D41A, D41B
53	508649	Slurry			1920	2004	D41A, D41B
54	531618	Persip	25 18	18 51	1928	1964	Z10A*
55	532173	Eindpaal	25 23	19 06	1931	2004	Z10A*, Z10G
56	535175	Gemsbokpark- Nossob			1920	2004	D42A, D42B, D42C, D42D, D42E, Z10B, Z10E, Z10G
57	540466	WERDA	25 16	23 16	1959	2001	Z10B, Z10F
58	540620	Rusthof			1897	1999	D41C, D41D, D41E, D41F, Z10B, Z10F
59	541297	Bray			189	2004	D41C, D41D, D41E, D41F, Z10B, Z10F
60	544778	GOOD Hope	25 28	25 26	1949	1998	Z10B
61	545048	DIGAWANA	25 18	25 32	1980	2002	Z10B
62	545839	Welbedacht			1920	2004	D41A, D41B, Z10B
63	568817	Mariental	24 37	17 58	1917	1998	Z10A*
64	570531	Gochas	24 51	18 48	1947	2004	Z10A*
65	571871	Vergenoeg	25 01	19 30	1986	2004	Z10A*
66	611630	Hardap	24 30	17 52	1982	2003	Z10A*
67	612710	Stampriet	24 20	18 24	1949	2004	Z10A*
68	612818	Rohrbeck	24 08	18 28	1958	2002	Z10A*
69	614188	Aranos	24 08	19 07	1947	2004	Z10A*
70	614406	Omrah	24 16	19 14	1951	2000	Z10A*
71	619661	TSHANE	24 01	21 53	1957	2001	Z10B, Z10E
72	654736	Mbela	23 46	17 55	1954	1994	Z10A*
73	655503	Gomchanas	23 53	18 17	1939	2004	Z10A*
74	656457	Reitz	23 37	18 46	1962	2004	Z10A*
75	656510	Leonardville	23 30	18 47	1928	2004	Z10A*
76	664435	KANG	23 45	22 45	1985	2003	Z10B
77	698865	Christirina	23 25	17 59	1981	2004	Z10A*
78	740154	Windhoek	22 34	17 06	1912	2004	Z10A*
79	740677	Binsenheim	22 47	17 23	1935	2004	Z10A*
80	740711	Rietfontein	22 51	17 24	1912	2004	Z10A*
81	740792	Hohenau	22 42	17 27	1913	2004	Z10A*
82	741219	Wolffsgrund	22 39	17 38	1930	1977	Z10A*
83	743117	Styria	22 57	18 34	1915	1996	Z10A*
84	743738	Spatzenfeld	22 48	18 55	1930	1977	Z10A*
85	744419	Rosendal	22 59	19 14	1956	2004	Z10A*
86	784720	Sonleitten	22 30	17 24	1925	2004	Z10A*
87	784826	Otjituezo	22 16	17 28	1913	1995	Z10A*
88	784839	Hosea	22 29	17 28	1965	2004	Z10A*
89	785147	Seeis	22 27	17 35	1912	1985	Z10A*
90	785183	Otjikundua	22 03	17 37	1930	2004	Z10A*
91	785326	Dordabis	22 26	17 41	1919	2004	Z10A*
92	785490	Okahua	22 10	17 47	1916	2004	Z10A*
93	786097	Kanonschoot	22 07	18 04	1950	2004	Z10A*
94	786283	Omateva	22 13	18 10	1917	2004	Z10A*
95	786865	Witvlei	22 25	18 29	1912	2004	Z10A*
96	787838	Gobabis	22 28	18 58	1913	2004	Z10A*
97	788241	Sandveld	22 01	19 09	1968	2004	Z10A*
98	830238	Otjisauna	21 58	17 38	1946	1979	Z10A*
99	831439	Steinhausen	21 49	18 15	1912	2004	Z10A*

List of key rainfall gauges in Senqu catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	204518	Spring Valley	30 08	27 18	1930	1977	Oranjedraai
2	204819	Mohaleshoek	30 09	27 28	1930	2004	Oranjedraai
3	205439	Fort Hartly (Hardley)	30 19	27 45	1965	2004	G03
4	205770	Tosing	30 19	27 45	1930	1955	G03
5	206077	Makoae	30 17	28 03	1978	2004	G03
6	233239	Ladysdale	29 59	27 08	1924	2004	Oranjedraai
7	234150	Mt Carmel	30 00	27 35	1930	1954	Oranjedraai
8	235110	Semonkong	29 50	28 04	1976	2004	G32
9	235243	Marakabei	29 33	28 09	1936	1985	G17, G32, G41
10	236677	Mokuinihi	29 47	28 53	1931	1950	G05, G07
11	237471	Bergview	29 51	29 16	1935	1987	G07
12	264715	Molimo (Molibo) Nthuse	29 25	27 54	1962	2004	G17
13	264836	Thaba Putsoa	29 26	27 58	1962	1995	G17, G32
14	265039	Moletsane	29 09	28 02	1977	2004	G41
15	266001	Rampai	29 01	28 30	1970	1995	G08, G41, G42, G45
16	266370	Meno	29 10	28 43	1932	1955	G06, G08, G36
17	266437	St Martins	29 17	28 45	1964	2004	G05, G42, G45
18	266631	Letseng-la-draai	29 01	28 51	1963	1991	G06, G08, G36, G42, G45
19	266646	Lelinggoana	29 16	28 52	1931	2003	G06, G08
20	267107	Mokhotlong	29 17	29 04	1930	2004	G06
21	267126	Mothebesoane	29 06	29 05	1932	1954	G36
22	298638	Matsoakeng	28 38	28 52	1920	1973	G45
23	0236492A	Sehong-hong	29 42	28 47	1935	1948	G05
24	0265875B	Pelaneng	-29° 5'	28°30'	1944	1979	G08
25	205385A	Quthing	30 25	27 43	1930	1977	G03
26	236521B	Mashai	29 41	28 48	1959	2004	G05
27	237113B	Sehlaba Thebe	29 53	29 04	1975	2004	G07

List of key rainfall gauges in Riet-Modder catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	0201361 W	Hamelfontein	30 02	25 43	1912	2004	C51G
2	0201373 W	Hamilton Manor	30 13	25 44	1922	1975	C51G
3	0228571 W	Adamshoop	29 31	24 50	1912	1980	C51K
4	0228783 W	Rietput	29 33	24 57	1932	1988	C51K
5	0229124 W	Taaiboslaagte	29 35	25 05	1919	1976	C51K
6	0229344 W	Sandymount Park	29 43	25 11	1925	1977	C51J
7	0229629 W	Spitskop	29 59	25 21	1931	1977	C51H
8	0229737 W	Jagersfontein - POL	29 47	25 26	1889	2004	C51H, C51J
9	0230027 W	Swartkoppies	29 57	25 30	1917	2004	C51H
10	0230073 W	Slangfontein	29 43	25°33'	1922	2004	C51H
11	0230764 W	Edenburg - POL	29 44	25 56	1905	1994	C51C
12	0230810 W	Lillydale	30 00	25 57	1906	2004	C51G
13	0230816 W	Bethany	29 36	25 58	1905	1979	C51C
14	0231114 W	Knelpoort	29 55	26 04	1912	1945	C51B
15	0231279 W	Reddersburg - POL	29 39	26 10	1905	2004	C51A, C51E
16	0231395 W	Bulsfontein	29 36	26 14	1912	1982	C51A
17	0231713 W	Donkerhoek	29 53	26 25	1923	1978	C51B
18	0231754 W	Blouboskop	29 32	26 27	1920	1973	C51D
19	0232018 W	Cyferfontein	29 48	26 31	1912	2004	C51B
20	0232123 W	Roodepoort	29 32	26 36	1910	2004	C51D, C52A
21	0232275 W	Dewetsdorp - POL	29 35	26 40	1905	2004	C52A
22	0256638 W	Wimbledon	29 08	23 53	1919	2000	C51M
23	0257391 W	Plooysburg	29 02	24 14	1928	1993	C51M
24	0257845 W	Eureka	29 05	24 29	1913	2004	C51L
25	0258164 W	Michville	29 14	24 36	1907	1977	C51K
26	0258182 W	Modderrivier - POL	29 02	24 38	1914	2004	C51L
27	0258458 W	Jacobsdal - POL	29 08	24 46	1888	2004	C51K
28	0258467 W	Gannahoek - IRR	29 16	24 46	1948	2004	C51K
29	0258812 W	De Kalk	29 02	24 58	1919	1987	C52L
30	0259278 W	Kroonplaas	29 09	25 10	1931	2002	C52L
31	0259348 W	Leyden	29 18	25 11	1927	2004	C51K
32	0259727 W	Petrusburg - POL	29 07	25 25	1905	2004	C52K
33	0259743 W	Kranshoek	29 23	25 25	1912	1975	C51F, C51J
34	0260030 W	Steunmekaar - POL	29 30	25 32	1918	2004	C51F
35	0260163 W	Koppiesdam	29 12	25 37	1924	2004	C52K
36	0260519 W	De Brug - POL	29 09	25 48	1907	1973	C52J
37	0260555 W	Northfield	29 15	25 48	1922	1971	C52J
38	0260660 W	Pakpoort	29 30	25 52	1910	1956	C51E
39	0260882 W	Salopia	29 12	25 58	1930	1985	C52J
40	0261146AW	Kafferrivier	29 26	26 05	1930	1969	C51E
41	0261183 W	Bainsvlei	29 03	26 07	1904	2004	C52H, C52J
42	0261312 W	Ferreira	29 12	26 10	1923	1985	C52J
43	0261368 W	Bloemfontein - Dieretuin	29 07	26 13	1910	2004	C52F
44	0261523 W	Grootvlei - TNK	29 14	26 18	1904	1998	C52F
45	0261597 W	Erasmusfontein	29 28	26 20	1912	1964	C51D
46	0261722 W	Mazelspoort Dam	29 02	26 24	1904	2004	C52D, C52E
47	0261733 W	Tussenvier	29 13	26 26	1928	2004	C52D, C52F, C52G
48	0261750 W	Niekerksvlei	29 30	26 25	1916	1970	C51D
49	0262129 W	Likatlong	29 10	26 35	1910	1980	C52B, C52D, C52G
50	0262314 W	Kromdraai	29 15	26 41	1925	1978	C52B, C52G
51	0262479 W	The Cliff	29 30	26 46	1904	2004	C52A, C52B, C52G
52	0262613AW	Thaba Nchu	29 13	26 51	1902	1943	C52B, C52C, C52G
53	0290560 W	Benfontein	28 50	24 50	1917	2004	C52L
54	0291148 W	Perdeberg - SAR	28 57	25 05	1907	2004	C52K, C52L
55	0291313 W	Waterpaslaagte	28 43	25 11	1955	2004	C52K
56	0291758 W	Content	28 38	25 26	1947	1979	C52K
57	0292461 W	Dealesville - MAG	28 41	25 46	1908	2004	C52H
58	0293007 W	Middelkop	28 37	26 01	1925	1989	C52H
59	0293106 W	Florisbad	28 46	26 04	1924	1994	C52H
60	0293204 W	Donkerhoek	28 55	26 08	1910	1971	C52D, C52G
61	0293514 W	Stillewoning	28 35	26 18	1922	1994	C52D, C52G
62	0293597 W	Glen College - AGR	28 57	26 20	1913	2003	C52D, C52G
63	0293622 W	Karee	28 53	26 21	1932	1967	C52D, C52G
64	0293792 W	Brandfort - MAG	28 42	26 27	1905	1994	C52D, C52G
65	0294233 W	Idomia	28 54	26 38	1913	2004	C52C, C52D, C52E

List of key rainfall gauges in Lower Orange catchment

Count	Station	Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	66304	Gunsfontein	32 34	20 41	1960	2004	D5B, D5C
2	87635	Bet-el	32 05	20 22	1933	2004	D5A, D5B
3	89693	Grootfontein	32 03	21 24	1930	2004	D5D
4	90196	Tafelberg	32 16	21 37	1914	2004	D5D, D5E
5	91763	Paardekraal	32 13	22 26	1935	2004	D5E
6	109835	Die Hoop	31 55	19 58	1920	2004	D5A
7	110512	Diepdrift	31 32	20 18	1934	2004	D5A
8	111373	Daniels Hope	31 43	20 43	1924	2004	D5B, D5C, D5D
9	112672	Rusoord	31 42	21 23	1957	2004	D5E, D5G
10	113025		31 55	21 31	1920	2004	D5D
11	113673	Saaifontein	31 43	21 53	1920	2004	D5E, D5F
12	136740	Williston - Skl	31 20	20 55	1936	2004	D5G
13	136741	Williston - SAR	31 21	20 55	1920	2004	D5A,D5B,D5C,D5D
14	138030	Springfontein	31 30	21 31	1920	2004	D5F, D5G
15	138041	Goraas	31 11	21 32	1920	2004	D5F, D5G
16	139658	Loxton	31 28	22 22	1923	2004	D5F
17	140020	Rietfontein	31 20	22 31	1933	2004	D6B
18	142153	Lekkervlei	31 03	23 36	1920	2004	D6A
19	142497	Oufontein	31 17	23 47	1926	2004	D6A
20	142805	Richmond	31 25	23 57	1920	2004	D6A
21	143345	Grootfontein	31 15	24 12	1920	2004	D6A, D6B
22	162366	Kans	30 36	20 13	1966	2004	D5H, D5K, D5M
23	166238	Carnarvon	30 58	22 08	1920	2004	D5F, D5J
24	166755	Oorlogshoek	30 55	22 26	1920	2004	D5J
25	167445	Roodewal	30 55	22 45	1973	2004	D6B
26	167665	Vosburg	30 35	22 53	1920	2004	D6B, D6C, D6D
27	169005	Britstown	30 35	23 31	1920	2004	D6C
28	170639	Roiwal	30 39	24 22	1900	2004	D6C
29	191526	Kraandraai	30 16	20 48	1947	2004	D5L
30	194454	Irene	30 04	22 16	1926	2004	D5L
31	224734	Uniteit	29 44	22 55	1934	2004	D6D, D7B
32	226327	Strydenburg	29 57	23 41	1920	2004	D6C, D6D
33	226771	Goedehoop	29 51	23 56	1932	2004	D6C
34	227054	Perdeput	29 54	24 02	1920	2004	D6C
35	244405	Steinkopf	29 15	17 44	1920	2004	D8C, D8D, D8G
36	249367	Droegrond	29 07	20 13	1957	2004	D5N
37	252005	Voordeelspan	29 05	21 31	1973	2004	D5N, D7D
38	254589	Niekerkshoop	29 19	22 50	1920	2004	D7A, D7B
39	254871	Witwater	29 01	23 00	1961	2004	D7A
40	255202	Nuwejaarskraal	29 22	23 07	1920	2004	D7A
41	256453	Douglas	29 03	23 46	1900	2004	D7A
42	275179	Lekkersing	28 59	17 06	1964	2004	D8D
43	276072	Vioolsdrift	28 42	17 33	1952	2004	D8D, D8G
44	277178	Henkriesfontein	28 58	18 06	1991	2004	D8F, D8G
45	279497	Onseepkans	28 47	19 17	1951	2004	D8F
46	280772	Bladgrond	28 52	19 56	1933	2004	D8B
47	281760	Augrabies	28 40	20 26	1945	2004	D8A
48	284008	Thornlea	28 38	21 31	1920	2004	D7D
49	284832	Groblershoop	28 52	21 58	1938	2004	D7C
50	288528	Tweefontein	28 48	23 48	1919	2004	D7A
51	314032	Namasvrede	28 02	19 32	1920	2004	D8E, D8F
52	314482	Ukamas	28 02	19 47	1953	2004	D8E
53	321110	Postmasburg	28 20	23 05	1920	2004	D7C
54	350113	Nabas	27 53	19 34	1952	2004	D8E
55	384852	Naos	27 12	18 59	1952	2004	D8E
56	385233	Hangas	27 23	18 59	1953	2004	D8E
57	385516	Warmfontein	27 06	19 18	1952	2004	D8E
58	387240	Noenieput	27 30	20 08	1922	2004	D8E
59	422538	Lousvlei	26 58	19 48	1927	2004	D8E

List of key rainfall gauges in Lower Vaal catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	0291392 W	Boshof - TNK	28 33	25 15	1879	2004	C91C
2	0322071 W	Danielskuil - POL	28 11	23 33	1913	1990	C92A
3	0322172 W	Silverstreams	28 20	23 35	1923	1993	C92A
4	0322329 W	Papkuil	28 29	23 40	1919	1996	C92B
5	0322648 W	Vaalpan	28 19	23 52	1936	2004	C92A
6	0323144 W	Potfontein	28 24	24 05	1924	2000	C92A
7	0323535 W	Delportshoop - POL	28 25	24 19	1966	2004	C91E
8	0324379 W	Windsorton - POL	28 20	24 43	1912	2004	C91D
9	0324607 W	Warrenton - MUN	28 07	24 51	1910	2004	C91D
10	0324725 W	Nazareth House Farm	28 07	24 55	1914	2001	C91B
11	0324888 W	Knapdaar	28 18	25 00	1910	1946	C91D
12	0324889 W	Lusthof	28 19	25 00	1944	1977	C91D
13	0325471 W	Bordeaux	28 22	25 17	1919	2004	C91C
14	0325877 W	Hertzogville - POL	28 08	25 30	1923	2004	C91B
15	0326298 W	Buitenverwag	28 29	25 39	1952	1994	C91C
16	0326344 W	Wolhuterskop	28 14	25 42	1923	1969	C91C
17	0358825 W	Balbriggen	27 45	23 58	1950	2004	C33B
18	0359304 W	Reivilo	27 34	24 11	1931	2000	C33B
19	0359458 W	Olyfenfontein	27 38	24 16	1929	2004	C33B
20	0359808 W	Boetsap - POL	27 58	24 27	1886	2004	C33B
21	0360432 W	Magogong - 2J11	27 40	24 46	1949	1988	C33A
22	0360512 W	Taung - POL	27 33	24 47	1899	2000	C31F, C33A
23	0360597 W	Vaalharts - AGR	27 57	24 51	1919	2004	C33A
24	0361220 W	Graspan	27 40	25 08	1912	1977	C91B
25	0361277 W	Welkom	27 37	25 10	1952	2004	C91B
26	0361295 W	Christiana - TNK	27 55	25 10	1903	2004	C91B
27	0361736 W	Moirton	27 45	25 22	1934	2001	C91A
28	0361760 W	Palmietfontein	27 40	25 26	1909	1973	C91A
29	0361832 W	Kalkpoort	27 53	25 28	1929	2004	C91B
30	0361846 W	S A Lombard Natuurreservaa	27 36	25 29	1951	2004	C91A
31	0362159 W	Bloemhof - POL	27 39	25 36	1930	2004	C91A
32	0395483 W	Geluk	27 03	24 17	1912	1968	C32D
33	0396284 W	Madrid	27 13	24 40	1918	2004	C32D
34	0396813 W	Leliefontein	27 04	25 00	1912	2004	C32C
35	0397114 W	Naauwpoort	27 24	25 04	1954	1997	C31F
36	0397581 W	Schweizer-Reneke - POL	27 11	25 20	1931	2004	C31F,C31E
37	0397784 W	Koppiesvlei	27 04	25 27	1933	2004	C31E
38	0398177 W	Zevenfontein	27 27	25 36	1910	2004	C91A
39	0431896 W	Biesiesvlakte - AGR	26 56	24 30	1924	1967	C32B
40	0432136 W	Welgeleven	26 46	24 35	1917	2004	C32B
41	0432309 W	Openside	26 39	24 41	1942	1990	C32B
42	0432633 W	Stella - POL	26 33	24 52	1919	1991	C32A
43	0433115 W	Rietpan	26 55	25 04	1925	2004	C32C
44	0433494 W	Delareyville-Kaalplaas	26 44	25 17	1932	1998	C32A, C32C
45	0433791 W	Delareyville - MUN	26 41	25 27	1921	2004	C31E
46	0433804 W	Poortjie	26 54	25 27	1903	1992	C31E
47	0434151 W	Leeuwpan	26 31	25 37	1939	1979	C31D
48	0434228 W	Doornbult	26 49	25 38	1913	2001	C31E
49	0434359 W	Brakpan	26 59	25 43	1922	2004	C31E
50	0434431 W	Klipdrift	26 41	25 46	1922	1974	C31C
51	0434619 W	Kareekuil	26 49	25 51	1948	2001	C31E
52	0434888 W	Ottosdal - POL	26 49	26 00	1911	2004	C31C
53	0435036 W	Uitschot	26 36	26 02	1936	2001	C31C
54	0435400 W	Werk - Met - Lust	26 40	26 14	1928	2004	C31C
55	0471259 W	Silverton	26 19	25 39	1928	2004	C31D
56	0471490 W	Lusthof	26 10	25 47	1937	2003	C31D
57	0471713 W	Biesiesvlei - POL	26 23	25 54	1928	2004	C31B
58	0472135 W	Rietfontein	26 15	26 05	1932	1987	C31B
59	0472175 W	Rooijantjiesfontein	26 25	26 06	1927	2001	C31B
60	0472281 W	Lichtenburg - MUN	26 09	26 10	1903	1977	C31A, C31B
61	0472455 W	Manana	26 06	26 13	1953	2004	C31A
62	0509796 W	Rietspruit	25 46	26 26	1906	1956	C31A, C31D
63	0509829 W	Bokkraal	25 49	26 28	1957	1988	C31A, C31B
64	0256453 W	Douglas - POL	29 03	23 46	1883	2004	C92C
65	0287885 W	Poplars	28 45	23 30	1935	2004	C92C
66	0288054 W	Koekama	28 54	23 32	1957	2004	C92C
67	0288416 W	Kalkdam	28 56	23 44	1927	1987	C92C
68	0288528 W	Tweefontein	28 48	23 48	1919	2004	C92B
69	0288610 W	Salmonsfontein	28 40	23 51	1920	1976	C92B
70	0289102 W	Schmidtsdrif	28 42	24 04	1923	1979	C92B
71	0289243 W	Muirton	28 33	24 10	1951	1979	C92A
72	0289302 W	Caerwinning	28 32	24 11	1926	1956	C92A
73	0290032 W	Barkly West - TNK	28 32	24 32	1885	2004	C91E
74	0290464AW	Kimberley - POL	28 44	24 46	1884	2004	C91E

List of key rainfall gauges in Upper Vaal catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	298512	Witsieshoek	28 32	28 48	1907	2004	FRANK
2	298871	BOSCHKLOOF	28 32	29 0	1924	1988	STERK
3	331271	VAALBANK	28 2	28 10	1912	1995	FRANK
4	331740	SPITSKRANS	28 20	28 25	1913	1981	FRANK
5	331828	Nil Desperandum	28 18	28 28	1940	2001	FRANK
6	333051	ROSEDALE	28 21	29 2	1912	1960	FRANK, STERK
7	333226	Harrismith	28 16	29 08	1915	2004	STERK
8	370486	Loskop	27 36	29 47	1924	2003	DELANG
9	403054	Schoongezicht	27 24	28 02	1925	2004	FRANK, VAAL
10	405295	VREDE - TNK	27 25	29 10	1944	2001	FRANK, DELANG, VAAL
11	406221	Paardekopplaas	27 11	29 38	1913	2004	DELANG, VAAL, GROOT
12	406607	Rietpoort	27 07	29 51	1906	2004	DELANG,GROOT
13	406639	Groot Rietvlei	27 09	30 09	1929	2003	GROOT
14	439389	Oranjeville	26 59	28 13	1922	2002	VAAL
15	440435	GREYLINGSTAD	26 45	28 45	1904	1997	VAAL
16	441777	BERRINGS	26 58	29 26	1906	1978	GROOT, VAAL
17	442660	Amersfoort	27 00	29 52	1905	2004	GROOT
18	443196	De Emigratie	26 46	30 07	1907	2004	GROOT
19	443451	Blaauwkop	26 31	30 16	1928	2004	GROOT
20	477772	Leslie	26 22	28 56	1910	2004	VAAL
21	479348	TEVREDEN	26 18	29 42	1913	1959	GROOT
22	369238	Buckland Downs	27 58	29 08	1952	1994	FRANK
23	442 068	Hendrikspan	26 38	29 33	1920	1976	GROOT
24	442 660	Amersfoort	27 00	29 52	1920	1994	GROOT
25	443 451	Blaauwkop	26 31	30 16	1928	1994	GROOT
26	479 348	Tevreden	26 18	29 42	1920	1959	GROOT
27	333 120	New Leeds	28 30	29 04	1920	1928	STERK

List of key rainfall gauges in Upper Orange catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	118395	ZOETVLEI	31 35	24 14	1906	1988	B09
2	143345	GROOTFONTEIN	31 15	24 12	1912	1989	B09
3	143784	HANOVER - POL	31 04	24 27	1879	1989	B09
4	144085	Bokfontein	31 25	24 33	1920	1975	B09
5	145310	GROENVLEI	31 10	25 12	1928	1997	B13
6	146453	EENBULT	31 03	25 46	1925	1997	B11
7	148517	Jamestown-Pol	31 07	26 48	1879	2004	B05
8	149082	Dardrecht-Tnk	31 22	27 03	1904	2004	B05
9	149490	Rossous-Pol	31 10	27 17	1944	2004	B05
10	150635	lisburn	31 06	27 52	1920	1971	B05
11	170639	Rooiwal	30 39	42 22	1900	2004	B09
12	170639	Rooiwal	30 38	24 22	1920	1988	B09
13	171117	Wolmada	30 57	24 33	1920	1986	B09
14	171756	Esperanza	30 37	24 56	1920	1988	B09
15	172163	Colesburg-Tnk	30 43	25 06	1976	2004	B09
16	172724	Tweefontein	30 34	25 25	1900	2004	B13
17	173134	MONTAGU	30 44	25 35	1901	1976	B11
18	174093	CLIFTON VALE	30 34	26 5	1927	1997	B11
19	174312	Hughender	30 42	26 11	1903	2004	B11
20	174753	GOEDEMOED - TNK	30 34	26 26	1915	1985	B11
21	175022	WELGEDACHT	30 51	26°31'	1924	1998	B11
22	176015	PAARDEFONTEIN	30 45	27 1	1926	2004	B01, B05
23	176038	Morgenson	30 37	27 00	1920	1979	B01
24	176372	LADY GREY - POL	30 43	27 13	1888	1989	B01, B05
25	176532	Motkop	30 52	27 18	1920	1956	B05
26	176631	STERKSPRUIT - TNK	30 32	27 22	1938	1986	B01
27	176735	Lower Orpendale	30 45	27 22	1920	1985	B05
28	177178	Barkly east-Tnk	30 58	27 36	1883	2004	B05
29	177552	Funny stone	30 42	27 49	1926	2004	B05
30	198836	PHILIPSTOWN - TNK	30 26	24 28	1920	1986	B13
31	199275	Petrusville-Pol	30 05	42 40	1900	2004	B13
32	200466	Philippolis-Pol	30 16	25 16	1900	2004	B13
33	201020	ORANJE	30 21	25 31	1920	1989	B13
34	201376	SPRINGFONTEIN - MUN	30 16	25 43	1923	1989	B11
35	202505	EBENHAEZER	30 25	26 18	1932	1989	B01,B11
36	203175	Rust-en-Vrede	30 26	26 36	1935	1987	B11
37	203483	Sonnelblom	30 03	26 48	1923	1979	B11
38	203657	Middelplaats	30 27	26 52	1920	2004	B01, B11, B13
39	203657	Middelplaats	30 27	26 53	1920	1987	B11
40	204050	Leeuwfontein	30 20	27 01	1921	1985	B11
41	204265	ZONDAGSFONTEIN	30 25	27 10	1933	1986	B01
42	204444	WELGEMOED	30 23	27 15	1931	1989	B01
43	228567	Teverdenheid	29 57	24 49	1920	2004	B13
44	232383	Mentzburg	29 54	26 44	1928	1985	B11
45	232823	Waterford	29 43	26 58	1914	1987	B07
46	232895	Sweetwater	29 55	27 00	1920	2004	B11
47	234111	Malealea	29 51	27 34	1955	1987	B07
48	262479	The Cliff	29 30	26 46	1905	1987	B07
49	263373	27 13	29 13	27 13	1916	1987	B07
50	263567	Convamore	29 27	27 18	1920	1987	B07
51	263792	Leilelhoek	29 12	27 29	1919	1987	B07
52	264022	Botsabelo	29 20	27 32	1936	1987	B07
53	264417	Roma	29 27	27 44	1936	1985	B07
54	295539	Mequatlingsnek	28 59	27 18	1923	1987	B07
55	296157	Sunny Hills	28 37	27 36	1931	1987	B07
56	296682	Fickburg-TNK	28 52	27 53	1920	1987	B07
57	297388				1937	1961	B07
58	297436	Butha-Buthe	28 46	28 15	1930	1985	B07
59	297721	Clarens-POL	28 31	28 25	1920	1987	B07
60	298244	Caledonia	28 34	28 38	1920	1981	B07
61	331058	Overdene	28 28	28 02	1920	1968	B07

List of key rainfall gauges in Caledon catchment

Count	Number	Station Name	Latitude Deg Min	Longitude Deg Min	Record starts	Record ends	Catchment(s)
1	232018	CYFERFONTEIN	29 48	26 31	1920	2004	D2G
2	232083	HELVETIA - POL	29 53	26 33	1920	1961	D2G
3	232123	ROODEPOORT	29 32	26 36	1920	1989	D2G
4	232383	MENTZBURG	29 54	26 44	1928	1985	D2G
5	232673	KROMDAM	29 44	26 51	1923	1986	D2G
6	232823	WATERFORD	29 43	26 58	1920	1989	D2G
7	232895	SWEETWATER	29 55	27 0	1920	2004	D2G
8	232898	QUILIMANE	29 58	27 0	1920	1989	D2G
9	233044	WEPENER	29 44	27 2	1950	1986	D2G
10	233078	WONDERBOOM	29 48	27 3	1920	2000	D2G
11	233103	MON REPOS	29 43	27 4	1920	1973	D2G
12	233154	ZAMENLOOP	29 34	27 6	1920	1958	D2F
13	233195	VANROOYENSHEK - POL	29 45	27 7	1965	2004	D2G
14	233239	LADYSDALE	30 0	27 8	1920	1989	D2G
15	233242	HOBHOUSE - POL	29 32	27 9	1920	2004	D2F
16	233267	VADERSGIFT	29 57	27 9	1920	2004	D2G
17	233439	MAFETENG	29 49	27 14	1920	1989	D2G
18	234008	MORIJA	29 38	27 31	1965	2001	caled44, D2F
19	262647	GROOTHOEK	29 17	26 52	1920	1926	D2F
20	263041	TWEESPRUIT	29 11	27 2	1920	2004	D2F
21	263047	SHEENSPOST	29 17	27 2	1920	1989	D2F
22	263057	ENGLAND	29 27	27 2	1920	1989	D2F
23	263255	BRAKFONTEIN	29 16	27 10	1920	1959	D2F
24	263280	WESTMINSTER ESTATE	29 11	27 9	1920	2004	D2F
25	263313	BROXTON	29 13	27 12	1920	1988	D2F
26	263316	WARGUNDY	29 15	27 11	1920	1979	D2F
27	263487	ZORGVLIET	29 7	27 17	1920	1963	D2F
28	263499	KOMMISSIEPOORT	29 19	27 17	1920	2004	caled44, D2F
29	263567	CONVAMORE	29 27	27 18	1920	1989	D2F
30	263888	MASERU RESEARCH	29.18	27.3	1920	1995	caled44
31	264417	ROMA	29.27	27.44	1922	1951	caled44
32	295539	MEQUATLINGSNEK	28.59	27.18	1923	1995	caled3_1
33	296682	FICKSBURG - TNK	28.52	27.53	1934	1989	caled2_2, caled3_1
34	296825	BERLIN	28.45	27.58	1956	2004	caled2_2, caled3_1
35	297388	PITSENG	28.58	28.13	1970	2001	caled1_5, cales2_2
36	297436	BUTHA-BUTHE	28.46	28.15	1930	2001	caled1_5, cales2_2
37	297721	CLARENS - POL	28.31	28.25	1920	2004	caled1_5
38	298244	CALEDONIA	28.34	28.39	1921	1989	caled1_5
39	331058	OVERDENE	28.28	28.02	1920	1968	caled2_2, caled3_1

APPENDIX B: TABLE B-2 – CALIBRATION FLOW GAUGING STATIONS USED

Tertiary Catchment	Gauge	River	Location	Lat	Long	Area	Used record	Comments
V_M	C2H001	Mooi	Witrand	26 38 53	27 05 22	3595	1920 - 1994	Flows affected by Boskop Dam (C2R001) since 1957, so use only for 1920 to 1956
	C2H018	Vaal	Schoemans-drift	26 58 13	27 12 40	49120	1938 - 1994	Good record
	C2H061	Vaal	Klipplaatdrift	27 23 15	26 27 45	79903	1972 - 1994	Good record
	C2H085	Mooi	Hoogekraal	26 52 49	26 57 54	5485	1986 - 1994	Affected by submergence from Vaal, DT should be extended by current metering
	C2R001	Mooi	Boskop Dam	26 33 40	27 06 42	3287	1957 - 1993	No d/s weir, so low flows inaccurate
	C2R002	Schoon	Johan Neser Dam	26 50 00	26 36 56	5635	1922 - 1950	Poor accuracy on low flows but gaugings should be extended
	C2R003	Mooi	Klerkskraal Dam	26 15 09	27 09 38	1335	1969 - 1994	No d/s weir, so low flows inaccurate
	C2R008	Vaal	Vaal Barrage	26 46 54	27 41 05	47118	1924 - 1994	Overestimates flows by a few percent
	C4H002	Vet	Floorsdrift	27 50 45	25 54 32	17599	1950 - 1971	Overestimates high flows
	C4H004	Vet	Nooitge-dacht	27 56 06	26 07 36	16153	1968 - 1994	High flows suspect
	C4R001	Sand	Allemans-kraal Dam	28 17 16	27 08 45	3665	1959 - 1994	Good record
	C4R002	Vet	Erfenis Dam	28 30 27	26 46 42	4750	1959 - 1994	Good record
	C6H001	Vals	Roodewal	27 26 29	26 58 11	5674	1955 - 1994	Accuracy of high flows could be improved by more data on submergence
	C6H003	Vals	Mooifontein	27 24 00	26 37 29	7765	1967 - 1994	Wide, broad crest gives rise to inaccurate low flows - stepped sharp-crested weir would improve accuracy
	C7H003	Heuning	Dankbaar	27 21 24	27 17 11	914	1947 - 1994	Should be upgraded or abandoned
	C7H006	Renoster	Arriesrust	27 02 40	27 00 18	5758	1978 - 1994	Wide, broad crest gives rise to inaccurate low flows - stepped sharp-crested weir would improve accuracy
	C7R001	Renoster	Koppies Dam	27 15 29	27 40 27	2147	1969 - 1994	Problems with gauging before autographic recorder installed in 1969
	C9R002	Vaal	Bloemhof Dam	27 40 09	25 37 05	107911	1968 - 1994	Good record
V_L	C3H003	Harts	Taung	27 34 25	24 44 46	7975	1935 - 1994	Good record, many missing values after 1963.
	C3R002	Harts	Spitskop Dam	28 07 28	24 30 04	9249	1975 - 1994	Good record.
	C9H009	Vaal	De Hoop	28 30 58	24 36 03	3201	1971 - 1994	Good record, many missing values prior to 1990.
	C5R001	Tierpoort	Tierpoort Dam	29 25 20	26 08 10	922	1923 - 1976	Good record, many missing values after 1986.
	C9R001	Vaal	Vaalharts Weir	28 06 57	24 55 32	2509	1971 - 1994	Good record.
V_U	C1H001	Vaal	Langwerwyl	26 56 30	29 15 51	7995	1920-1977	Good. From 1978 reflects Grootdraai releases
	C1H002	Klip	Sterkfontein	26 16 39	29 14 02	4158	1920-2004	Many unreliable values due to submergence during high flows. Use in combination with C1H015 for high flows.
	C2H003	Vaal	Elandsfontein	26 49 10	28 03 48	38638	1923-1936	Good. From 1936 reflects Vaal Dam releases
	C8H001	Wilge	Frankfort	27 16 26	28 29 23	15693	1920-2004	Many unreliable values due to submergence during high flows. Use in combination with C8H022 for high flows.
	C1R001	Vaal	Vaal Dam	26 53 44	29 19 55	38638	1936-2004	Good
	C1R002	Vaal	Grootdraai Dam	26 33 02	28 08 16	7995	1978-2004	Good
	C8R003	Nuwejaarspruit	Sterkfontein Dam	28 25 37	29 00 58	195	1974-2004	Good
V_B	B10	Blesbokspruit	Heidelberg	26 31 00	28 21 00	1350	Unavailable	Assessment unavailable
	C2H070	Suikerbos	Platkoppie	26 38 24	28 13 49	3124	1975 - 2004	Assessment unavailable
	C2H004 (S2)	Suikerbos	Uitvlugt	26 40 15	28 01 51	3474	1977- 2004	Assessment unavailable
	N8	Natalspruit	Heidelberg - Klip River road bridge	26 25 30	28 10 00	392	1990 - 2004	Assessment unavailable
	R 6	Small Rietspruit	Waterval Sewage Works	26 27 00	28 07 00	465	1975 - 1988	Assessment unavailable
	K21	Klip	Alberton Road Bridge	26 24 00	28 05 00	779	1991 - 2004	Assessment unavailable
	C2H141 and C2H021	Klip	Heidelberg	26 27 13	28 05 09	1726	1993 - 2004	Assessment unavailable
	2C2H071 (K19)	Klip	Kookfontein Train Bridge	26 37 10	27 58 51	2205	Unavailable	Assessment unavailable
	C2H005 (RV2)	Greater Rietspruit	Kaalplaats	26 43 47	27 43 04	1121	1982 - 2004	Assessment unavailable
	C2H014 (T1)	Taaibosspruit	Verdun	26 49 26	27 55 33	825	1990 - 2004	Assessment unavailable
	C2R008	Vaal	Luciana Barrage	26 46 54	27 41 05	47118	1990 - 2004	Assessment unavailable
	C2H003	Vaal	Engelbrechtsdrift	26 49 11	28 03 49	38564	1923 - 2004	Assessment unavailable
	C2H122	Vaal	Annie's Rust	26 51 15	28 07 15	38523	1923 - 1981	Assessment unavailable
RM	C5H016	Riet	Aucampshoop	28 57 37	24 14 32	1 847	1960 - 1994	Fair record, many missing values.
	C5H018	Modder	Twee River	29 02 37	24 38 26	2 236	1971 - 1994	Good record and good location – should be reopened.
	C5R002	Riet	Kalkfontein Dam	29 29 46	25 13 19	8 085	1937 - 1972	Good record.
	C5R003	Modder	Rustfontein Dam	29 16 14	26 36 54	937	1954 - 1994	Good record.
	C5R004	Modder	Krugersdrift Dam	28 53 01	25 57 19	5 391	1971 - 1994	Good record.
CA	D2H001	Caledon	Jammerdrift	29 72 00	26 98 00	13421	1920-1976	Good record. Original patched record used
	D2H012	Little Caledon	The Po	28 30 00	28 24 00	518	1968-2004	Good record
	D2H037	Caledon	Wilgedraai	29 36 34	27 03 52	12850	1993- 2004	Good but short record
	D2R002	Leeu	Armenia	29 35 00	27 13 00	858	1954-2004	Good record from 1973 onwards
	D2R004	Caledon	Welbedacht	29 88 00	26 87 00	15245	1973-2004	Good record but changing capacity makes calibration difficult
	CG25	Unknown	Unknown	Unknown	Unknown	Unknown	1966 - 2004	Suspect record but used to verify
	CG50	Unknown	Unknown	Unknown	Unknown	Unknown	1966 - 2004	Suspect record but used to verify
	CG55	Unknown	Unknown	Unknown	Unknown	Unknown	1966 - 2004	Suspect record but used to verify
	D2R006	Rietspruit	Knellpoort	29 78 00	26 89 00	798	1988-2004	Good but short record
SE	G03	Senqu	Seaka	30 27 47	29 34 29	5243	1966-2004	WR2005 data mostly used for 1967 - 1987 and then latest data for 1993 to 2004 from Lesotho DWA
	G06	Senqu	Mokhotlong	29 17 00	28 58 59	2059	1966-2004	
	G07	Senqu	Tsoelike	30 01 29	28 43 23	820	1966-2004	
	G17	Senqu	Marakabei	29 33 35	28 09.4	1087	1966-2004	
	G32	Senqu	Nkaus	29 57 29	28 15 24	2460	1966-2004	
	G36	Khubule	Tlokoeng	29 14 17	28 53 06	846	1966-2004	
	G42	Motsuko	Sehotse	29 16 54	28 34 00	821	1966-2004	
	D1H006	Kornet SP	Maghalee	30 09 36	27 24 36	Unknown	1948-2004	Good but patchy record
Ou	D1H009	Orange	Oranjedraai	30 33 35	27 35 53	4544	1960-2004	Good long record
	D1H001	Wonderboom	Diep	32 00 00	26 35 00	2065	1920-2004	Bad record highly patched
	D1H003	Orange	Aliwal-North	30 68 00	26 71 00	3645	1920-2004	Good Record
	D1H004	Stomberg	Molte	31 04 00	26 37 00	324	1924-1980	Good record
	D1H011	Kraai	Roodewaal	30 83 00	26 92 00	8676	1965-2004	Good record but patched
	D3H015	Seekoei	De Eerstep	30 53 00	24 96 00	8257	1980-2002	Good record
	D3R002	Orange	Gariep	30 69 00	25 71 00	13171	1971-2004	Good record
	D3R003	Orange	Van de Kloof	30 15 00	24 15 00	9416	1976-2004	Good but patched
Ol	D5H011	Renoster	Bonekraal	31 48 55	20 34 43	1658	1982 - 2004	First 3 years omitted as 1981 had huge flood (Laingsburg)
	D5H017	Renoster	Leeuwenkuil	31 26 13	20 28 29	8938	1987 - 2004	OK
	D5R001	Hartbees	Rooiberg	29 24 00	21 12 22	72335	1933 - 1973	Should be re-instated
	D6R002	Ongers	Huisfontein	30 36 42	23 18 00	13394	1965 - 2004	Earlier record (1921 - 1945) rejected as unreliable
	TSAMAB	Ham	Tsamab			2470	1969 - 2004	Calibration problem with extreme wet year (1975)
Molopo/Nossob	D4H002	Mareetsane	Neverse	26 05 13	25 17 07	Unknown	1905-1965	Assessment unavailable
	D4H013	Molopo	Rietvallei	25 51 15	25 52 09	Unknown	1905-2004	Assessment unavailable
	D4H037	Molopo River	Lotlamoreng	25 52 40	25 36 01	Unknown	1995-2004	Assessment unavailable
	3112MO2	White Nossob	Amasib	Unknown	Unknown	Unknown	1973-2004	Assessment unavailable
	3111M01	Black Nossob	Henopsrus	Unknown	Unknown	Unknown	1969-2004	Assessment unavailable
	3111R01	Black Nossob	Daan Viljoen Dam	Unknown	Unknown	Unknown	1969-2004	Assessment unavailable
	3111M02	Black Nossob	Mentz	Unknown	Unknown	Unknown	1973-2004	Assessment unavailable
	3124M02	Aoub	Stampriet	Unknown	Unknown	Unknown	1977-2004	Assessment unavailable
	3124M01	Auob	Gochas	Unknown	Unknown	Unknown	1973-2004	Assessment unavailable

APPENDIX B: TABLE B-3 – DETAILED NATURAL RUNOFF COMPARISON TABLES: VAAL SECONDARY CATCHMENT

Teriary Catchment	Ref#	Description	Incremental File Name	Calibration Flow Gauging Station #	Catchment Area (km^2)		MAP (Area Weighted)	MAE (Area Weighted)	VRSAU (1920 -1994) Incremental Natural Runoff			ORASECOM (1920 - 2004) Incremental Natural Runoff			% Diff (MAR)	Quaternaries
					Gross	Nett			$10^6m^3/a$	mm/a	%MAP	$10^6m^3/a$	mm/a	%MAP		
V_U	1	Frankfort (Wilge River)	fran9.inc	C8H001	15498	15498	712	1407	733.3	47	6.6%	760.0	49	6.9%	4%	C81A-C,E-M, C82A-H, C83A-J
	2	Delangesdrift (Sandspruit)	dela9.inc	C1H002	4158	4158	679	1407	249.5	60	8.8%	261.1	63	9.2%	5%	C13A-F
	3	Grootdraai Dam	grootd9.inc	C1H001/C1R001	7995	7995	690	1444	457.7	57	8.3%	462.0	58	8.4%	1%	C11A-L
	4	Sterkfontein	sterk9.inc	C8R003	195	195	735	1310	18.1	93	12.6%	19.5	100	13.6%	8%	C81D
	5	Vaal Dam	vaal9.inc	C2H003/C1R001	10792	10792	657	1540	518.7	48	7.3%	570.6	53	8.0%	10%	C11M, C12A-L, C13G-H, C83K-M
Sub-Total (V_U)					**38638**	**38638**	**689**	**1451**	**1977.3**	**51**	**7.4%**	**2073.2**	**54**	**7.8%**	**5%**	
V_B	1	Vaal Barrage	barr9.inc	C2R008	2828	2828	637	1650	68.5	24	3.8%	72.2	26	4.0%	5%	C22F-K
	2	Klip River	klipr9.inc	C2H071/K19	2282	2282	670	1650	96.2	42	6.3%	102.7	45	6.7%	7%	C22A-E
	3	Suikerbosrant River	suik9.inc	C2H004/S2	3541	3541	668	1650	92.3	26	3.9%	99.9	28	4.2%	8%	C21A-G
Sub-Total (V_B)					**8651**	**8651**	**658**	**1650**	**257.0**	**30**	**4.5%**	**274.8**	**32**	**4.8%**	**7%**	
V_M	1	Taaibos & Monamaledi tributaries to Schoonspruit	c24f.inc	C2R002	2020	1180	577	1830	19.5	10	1.7%	19.6	10	1.7%	0%	C24F
	2	Flow from Schoonspruit Eye	c24c.inc	C2H064 & C2H109	1350	1585	582	1750	60.6	45	7.7%	58.2	43	7.4%	-4%	C24C * - See note below Table
	3	Klerkskraal Dam	klerk9.inc	C2R003	1324	1001	605	1700	37.7	28	4.7%	39.7	30	5.0%	5%	C23F
	4	Upper Schoonspruit	c24e.inc	C2R002	925	664	560	1800	9.8	11	1.9%	9.8	11	1.9%	0%	C24E
	5	Rietssruit Dam	c24d.inc	C2R002	364	364	584	1725	7.3	20	3.4%	7.4	20	3.5%	1%	C24D
	6	Boskop Dam	bosk9.inc	C2R001	1973	1756	629	1675	35.8	18	2.9%	37.5	19	3.0%	5%	C23D, E & G
	7	Johan Neser Dam incremental	c24g.inc	C2R002	985	985	581	1820	16.9	17	2.9%	16.9	17	3.0%	0%	C24G
	8	Lakeside Dam	lakesn3.inc	C2H085	451	451	604	1700	9.4	21	3.4%	9.7	21	3.6%	3%	C23H
	9	Klipdrif Dam	klipdn3	C2R005	890	890	620	1670	20.3	23	3.7%	21.2	24	3.8%	5%	C23J
	10	Lower Schoonspruit	c24h.inc	C2H061	840	840	576	1820	8.8	11	1.8%	8.5	10	1.8%	-4%	C24H
	11	Kromdraai	kromn3.inc	C2H018	2028	2028	613	1625	40.9	20	3.3%	42.0	21	3.4%	3%	C23A, B & C
	12	Bloemhof Dam	bloemn3.inc	C9R002	14007	12555	534	1800	129.3	9	1.7%	138.9	10	1.9%	7%	C23K & L; C24A, B & K; C25A - F
	13	Renoster River (C70K)	c70k.inc	C7H006	891	392	565	1690	10.9	12	2.2%	10.3	12	2.0%	-6%	C70K
	14	Renoster River (C70J)	c70j.inc	C7H006	521	521	575	1670	8.6	16	2.9%	8.6	16	2.9%	0%	C70J
	15	Renoster River (C70E)	c70e.inc	C7H006	693	693	578	1630	12.0	17	3.0%	12.0	17	3.0%	0%	C70E
	16	Renoster River (C70H)	c70h.inc	C7H006	251	251	568	1650	4.0	16	2.8%	4.0	16	2.8%	0%	C70H
	17	Renoster River (C70F)	c70f.inc	C7H006	564	564	574	1620	9.5	17	2.9%	9.5	17	2.9%	0%	C70F
	18	Renoster River (C70G)	c70g.inc	C7H003	901	901	577	1600	14.0	15	2.7%	16.9	19	3.3%	21%	C70G
	19	Renoster River (C70D)	c70d.inc	C7H006	675	675	586	1600	12.6	19	3.2%	12.6	19	3.2%	0%	C70D
	20	Koppies Dam	kop9.inc	C7R001	2160	2160	617	1550	59.1	27	4.4%	61.1	28	4.6%	3%	C70A, B & C
	21	Klipbank	klipbn3.inc	C6H003	7871	6351	563	1575	150.8	19	3.4%	153.3	19	3.5%	2%	C60A - J
	22	Lower Sand-Vet	sandn3.inc	C4H004	10800	8962	504	1700	156.7	15	2.9%	160.2	15	2.9%	2%	C41F - J; C42F - L;C43A - D
	23	Allemanskraal Dam	allem9.inc	C4R001	3628	3628	593	1465	96.1	26	4.5%	94.9	26	4.4%	-1%	C42A - E
	24	Erfenis Dam	erf9.inc	C4R002	4724	4724	579	1525	167.5	35	6.1%	163.6	35	6.0%	-2%	C41A - E
Sub-Total (V_M)					**60836**	**54121**	**559**	**1676**	**1097.7**	**18**	**3.2%**	**1116.2**	**18**	**3.3%**	**2%**	
V_L	1	Barberspan	Barbers.inc	-	1494	434	530	1925	3.2	2	0.4%	2.9	2	0.4%	-7%	C31D
	2	Wentzel Dam	Uswentzd.inc	C3R001	7740	5785	544	1904	42.7	6	1.0%	39.5	5	0.9%	-7%	C31A, B, C & E
	3	Spitskop Dam	Spits.inc	C3R002	15899	9249	438	2039	77.5	5	1.1%	81.3	5	1.2%	5%	C32A - D, C33A & B
	4	Taung Dam	Dswentzd.inc	C3H003	1789	1756	477	1960	13.1	7	1.5%	12.1	7	1.4%	-7%	C31F
	5	Vaalharts Weir	Vharts.inc	C9R001	7225	2509	444	1946	11.2	2	0.3%	10.0	1	0.3%	-11%	C91A & B
	6	Lower Harts	Lowharts.inc	-	4149	1691	397	2150	11.7	3	0.7%	11.7	3	0.7%	0%	C33C
	7	De Hoop	Dehoop.inc	C9H009	6587	3201	406	1963	12.9	2	0.5%	15.3	2	0.6%	18%	C91C, D & Prtn C91E
	8	Douglas Weir	Douglas.inc	C9R003	10136	4405	350	2221	18.6	2	0.5%	18.6	2	0.5%	0%	Prtn C91E, C92A - C, C51M
Sub-Total (V_L)					**55019**	**29030**	**444**	**2023**	**190.8**	**3**	**0.8%**	**191.5**	**3**	**0.8%**	**0%**	
RM	1	Aucampshoop	Auch.inc	C5H016	5664	1847	350	2050	6.4	1	0.3%	5.8	1	0.3%	-9%	C51K & L
	2	Tweerivier	Twee.inc	C5H018	11035	2236	422	1871	14.4	1	0.3%	15.7	1	0.3%	9%	C52H - L
	3	Krugersdrift Dam	Krug.inc	C5R004	5394	5391	508	1639	114.4	21	4.2%	118.1	22	4.3%	3%	C52B - G
	4	Kalkfontein Dam	Kalkf.inc	C5R002	9342	8781	412	1740	215.9	23	5.6%	185.9	20	4.8%	-14%	C51A - C & C51E - J
	5	Tierpoort Dam	Tier.inc	C5R001	922	922	491	1640	23.8	26	5.2%	23.2	25	5.1%	-2%	C51D
	6	Rustfontein Dam	Rustf.inc	C5R003	937	937	543	1600	30.7	33	6.0%	31.0	33	6.1%	1%	C52A
Sub-Total (RM)					**33294**	**20114**	**443**	**1745**	**405.5**	**12**	**2.8%**	**379.6**	**11**	**2.6%**	**-6%**	
Total Secondary Catchment: Vaal					**196438**	**150554**	**537**	**1740**	**3928.38**	**20**	**3.7%**	**4035.246**	**21**	**3.8%**	**3%**	

APPENDIX B: TABLE B-4 – DETAILED NATURAL RUNOFF COMPARISON TABLES: UPPER ORANGE SECONDARY CATCHMENT

Teriary Catchment	Ref#	Description	Incremental File Name	Calibration Flow Gauging Station #	Catchment Area (km^2)		MAP (Area Weighted)		MAE (Area Weighted)		VRSAU (1920 -1995)			ORASECOM (1920 - 2004)			% Diff (MAR)	Quatenaries
											Incremental Natural Runoff							
					Gross	Nett					$10^6m^3/a$	mm/a	%MAP	$10^6m^3/a$	mm/a	%MAP		
	1	Katze	kat9.inc	D1R002	1867	1867	922	1721374	1299	2425233	546.0	292	31.7%	559.4	300	32.5%	2%	D11A-F
	2	Matsoku	mat9.inc	SG42	652	652	721	470092	1299	846948	94.0	144	20.0%	98.1	150	20.9%	4%	D11G&H
	3	Mashai	mas9.inc	SG36, SG08, SG06, SG05	5458	5458	786	4289988	1332	7267676.37	775.2	142	18.1%	792.9	145	18.5%	2%	D11J-K,D16A-M
	4	Mohale	moh9.inc	D1R003, SG17	938	938	944	885472	1299	1218462	301.8	322	34.1%	303.2	323	34.2%	0%	D17A&B (partly)
SE	5	Malatsi	mal9.inc	SG32	2628	2628	694	1823832	1323	3478122.08	284.4	108	15.6%	291.7	111	16.0%	3%	D17B(partly) - D17F
	6	Tsoelike	tso9.inc	SG07	2394	2394	785	1879290	1390	3328281.42	353.8	148	18.8%	362.6	151	19.3%	2%	D17G-L(partly)
	7	Ntoahae	nto9.inc	-	1130	1130	796	899480	1401	1583130	150.9	134	16.8%	154.5	137	17.2%	2%	D17L(partly) - M
	8	Oranjedraai	oran9.inc	SG03, D1H006, D1H009	9613	9613	742	7133090.86	1432	13771053.33	1542.7	160	21.6%	1557.7	162	21.8%	1%	D18A-L, D15A-L
	9	Aliwal Noord	aliwal.inc	D1H003	2967	2967	607	1800969	1590	4717530	166.8	77	12.7%	155.5	52	8.6%	-7%	D12A-F
Sub-Total (SE)					**27647**	**27647**	**756**	20903587.86	**1397**	38636436.2	**4215.5**	**152**	**20.2%**	**4275.6**	**155**	**20.5%**	**1%**	
											VAPS (1920 - 1987)			**ORASECOM (1920 - 2004)**				
	1	Klein Caledon (D21D&E)	D21ED.inc	D2H012	520	520	811	421540	1299	675480				47.0	90	11.1%		D21D&E
	2	D21A	D21A.inc	CG55	309	309	978	302202	1276	394284				56.9	184	18.8%		D21A
	3	D21B	D21B.inc	CG26	394	394	1021	402274	1276	502744				78.3	199	19.5%		D21B
	4	D21K	D21K.inc	CG50	326	326	960	312960	1299	423474				91.8	282	29.3%		D21K
	5	D21JL	D21JL.inc	CG25	663	663	931	617209	1311	869141	1216.8	84	10.4%	158.2	239	25.6%	-1%	D21J&L
CA	6	D21 Incremental	D21.inc	D2H035	1351	1351	763	1031316	1318	1780323				128.1	95	12.4%		D21C,F,G,H
	7	D22 Incremental	D22.inc	-	6200	6200	733	4544600	1420	8804000				446.2	72	9.8%		D22A-L
	8	Armenia Dam (D23C)	D23C.inc	D2R002	861	861	638	549318	1499	1290639				30.1	35	5.5%		D23C
	9	Welbedacht Dam (D23 Incremental)	D23.inc	D2H001, D2R004	3870	3870	632	2445840	1513	5855310				171.6	44	7.0%		D23A-G&J
	10	Knelpoort Dam (D23H)	D23H.inc	D2R006	776	776	670	519920	1600	1241600	20.8	27	4.0%	17.6	23	3.4%	-15%	D23H
	11	Egmond Dam (D24A)	D24A.inc	D2R001	310	310	627	194370	1548	479880	6.8	25	4.0%	10.9	35	5.6%	61%	D24A
	12	Lower Caledon (Downstream from Welbedacht Da	D24.inc	-	6304	6304	487	3070048	1621	10218784	138.4	25	5.1%	129.7	21	4.2%	-6%	D24B-L
Sub-Total (CA)					**21884**	**21884**	**659**	**14411597**	**1487**	**32535659**	**1382.8**	**63**	**9.6%**	**1366.4**	**62**	**9.5%**	**-1%**	
	1	Kraai River (D13)	D13.inc	D1H011	9354	9354	646	6042684	1583	14807382	731.1	72	11.2%	650.5	70	10.8%	-11%	D13A-M
	2	Burgersdorp/Molento	D14B-E.inc	D1H001/D1H004	2389	2389	460	1098940	1701	4063689	52.5	6	1.2%	42.6	18	3.9%	-19%	D14B-E
O_U	3	Gariep Incremental	gariep.inc	D3R002 (D3H002)	9394	9394	424	3983056	1706	16026164	206.3	25	6.2%	131.5	14	3.3%	-36%	D14A,F-K, D35A-K
	4	Seekoei	D32A-J.inc	D3H015	8257	8257	312	2576184	1912	15787384	63.8	8	2.7%	36.9	4	1.4%	-42%	D32A-K
	5	Van Der Kloof Incremental	vdkloof.inc	D3R003	10754	10240	356	3828424	1848	19873392	83.2	76	21.4%	79.1	7	2.1%	-5%	D31A-E, D34A-G
	6	Orange-Vaal Incremental (D/S Vd Kloof)	orvaal.inc		9598	3404	307	2946586	2201	21125198	14.3	1	0.5%	14.3	1	0.5%	0%	D33A-K
Sub-Total (O_U)					**49746**	**43038**	**412**	**20475874**	**1843**	**91683209**	**1151.1**	**23**	**5.6%**	**954.9**	**19**	**4.7%**	**-17%**	
Total Secondary Catchment: Upper Orange					**99277**	**92569**	**562**	**55791059**	**1640**	**162855304**	**6749.5**	**68**	**12.1%**	**6596.8**	**66**	**11.8%**	**-2%**	

APPENDIX B: TABLE B-5 – DETAILED NATURAL RUNOFF COMPARISON TABLES: LOWER ORANGE SECONDARY CATCHMENT

Teriary Catchment	Ref#	Description	Incremental File Name	Calibration Flow Gauging Station #	Catchment Area (km^2)		MAP (Area Weighted)	MAE (Area Weighted)	WR2005 (1920 - 2004) Incremental Natural Runoff			ORASECOM (1920 - 2004) Incremental Natural Runoff			% Diff MAR	Quatenaries
					Gross	Nett			$10^6m^3/a$	mm/a	%MAP	$10^6m^3/a$	mm/a	%MAP		
BO	1	Ongers at Smartt Syndicate Dam	GROUP1.INC	D6R002	13405	12426	241	2190	24.7	2	0.8%	22.1	2	0.7%	-10%	D61A - D61M
	2	Ongers between Smartt Syndicate Dam and Orange R. conf.	GROUP2.INC		20328	12178	255	2220	32.5	2	0.6%	30.2	1	0.6%	-7%	D62A - D62J
Sub-Total (BO)					**33733**	**24604**	**248**	**2205**	**57.2**	**2**	**0.7%**	**52.3**	**2**	**0.6%**	**-9%**	
O_M	1	Orange R. between Vaal and Ongers confluences	GROUP3.INC		7390	4792	280	2350	19.5	3	0.9%	17.5	2	0.8%	-10%	D71A - D71D
	2	Orange R. between Ongers confluence and Buchuberg Dam	GROUP4.INC		6742	5714	208	2450	17.1	3	1.2%	11.6	2	0.8%	-32%	D72A - D72C
	3	Orange R. between Buchuberg Dam and Hartbees confluence	GROUP5.INC		25968	11080	218	2550	37.1	1	0.7%	21.1	1	0.4%	-43%	D73A - D73F
Sub-Total (O_M)					**40100**	**21586**	**229**	**2479**	**73.7**	**2**	**0.8%**	**50.1**	**1**	**0.5%**	**-32%**	
SH	1	Fish R. (main tributary of Sak R.)	GROUP6.INC	D5H017	16806	15153	200	1990	22.4	1	0.7%	46.4	3	1.4%	107%	D51, D52, D56 & D58
	2	Sak R. to confluence with Fish R.	GROUP7.INC	D5R001	19398	19225	175	2240	42.5	2	1.3%	22.1	1	0.7%	-48%	D55A - D55M
	3	Fish-Sak confluence to Sak-Hartbees confluence	GROUP8.INC	D5R001	10165	6197	140	2360	2.6	0	0.2%	3.9	0	0.3%	48%	D57A - D57E
	4	Hartbees R. to Van Wyks Vlei	GROUP9.INC	D5R001	5571	4724	187	2325	6.9	1	0.7%	9.6	2	0.9%	40%	D54A - D54B
	5	Catchment of Van Wyks Vlei	GROUP10.INC	D5R001	1342	1342	155	2325	1.0	1	0.5%	1.4	1	0.7%	40%	D54C
	6	Remainder of Sak-Hartbees to Rooiberg Dam	GROUP11.INC	D5R001	18648	11513	166	2430	9.3	0	0.3%	16.0	1	0.5%	72%	D53A & D54D - D54G
	7	Rooiberg Dam to confluence with Orange R.	GROUP12.INC		21111	18588	113	2370	19.5	1	0.8%	10.9	1	0.5%	-44%	D53B - D53J
Sub-Total (SH)					**93041**	**76742**	**161**	**2267**	**104.1**	**1**	**0.7%**	**110.2**	**1**	**0.7%**	**6%**	
O_L	1	Orange R. between Hartbees confluence and Namibian border	GROUP13.INC		5844	4010	122	2730	4.3	1	0.6%	4.5	1	0.6%	4%	D81A - D81C
	2	Remainder of Tertiary D81 (RSA)	GROUP14.INC		6965	6965	102	2720	2.5	0	0.4%	3.1	0	0.4%	25%	D81D - D81G
	3	Remainder of Tertiary D81 (Namibia)	GROUP15.INC	TSAMAB	20870	20870	144	2600		0	0.0%	53.1	3	1.8%	N/A	D81H - D81K
	4	Tertiary D82 to Vioolsdrift RSA)	GROUP16.INC		14701	12809	88	2640	3.0	0	0.2%	4.6	0	0.4%	56%	D82A - D82E
	5	Tertiary D82 to Vioolsdrift (Namibia)	GROUP17.INC		8553	8553	118	2600		0	0.0%	13.0	2	1.3%	N/A	D82M
	6	Vioolsdrift to sea (RSA)	GROUP18.INC		5511	5376	56	2350	1.5	0	0.5%	1.6	0	0.5%	6%	D82F - D82L
	7	Vioolsdrift to sea (Namibia)	GROUP19.INC		13995	13995	80	2555		0	0.0%	4.5	0	0.4%	N/A	D82N - D82P
Sub-Total (O_L)					**76439**	**72578**	**107**	**2599**	**11.3**	**0**	**0.1%**	**84.4**	**1**	**1.0%**	**648%**	
Total Secondary Cactment: Lower Orange					**243313**	**195510**	**167**	**2398**	**246.4**	**1**	**0.6%**	**297.0**	**1**	**0.7%**	**21%**	

APPENDIX B: TABLE B-6 – DETAILED NATURAL RUNOFF COMPARISON TABLES: MOLOPO NOSSOB SECONDARY CATCHMENT

Teriary Catchment	Ref#	Description	Incremental File Name	Calibration Flow Gauging Station #	Catchment Area (km²)		MAP (Area Weighted)²	MAE (Area Weighted)²	ORASECOM (1920 - 2004) Natural Incremental¹&²			Quatenaries
					Gross	Nett			$10^6m^3/a$	mm/a	%MAP	
M_U	1	Sb1Ru1 - D41A	D41A.inc	D4H013 & D4H037	4 301	2 778	521	1951	9.9	2	0.4%	D41A
	2	Sb1Ru2 - D41B	D41B.inc	D4H002	6 239	5 193	476	1951	4.7	1	0.2%	D41B
	3	Sb1Ru3 - D41C	D41C.inc		3 915	2 995	416	2050	2.8	1	0.2%	D41C
	4	Sb1Ru4 - D41D	D41D.inc		4 371	2 744	380	2050	1.2	0	0.1%	D41D
	5	Sb2Ru1 - D41E	D41E.inc		4 535	467	346	2250	0.0	0	0.0%	D41E
	6	Sb2Ru2 - D41F	D41F.inc		6 002	1 498	338	2250	0.0	0	0.0%	D41F
	7	Sb2Ru3 - D41H1 - D41G	D41G.inc		3 277	850	307	2250	0.0	0	0.0%	D41G
	8	B5Ru1 - Z10C - D41N Botswana	D41N.inc		3 357	1 372	476	1951	3.2	1	0.2%	D41N
	9	B4Ru1 - Z10D - D41M Botswana	D41M.inc		1 701	936	371	2250	1.1	1	0.2%	D41M
	10	B3Ru1 - Z10F - D41K Botswana	D41K.inc		10 718	750	288	2250	0.0	0	0.0%	D41K
	11	Sb3Ru1 -D42C1 - D41J	D41J.inc		2 685	190	225	2700	0.0	0	0.0%	D41J
	12	D41L&H	D41J.inc	Modelled as Endoreic	91 605	0	N/A	N/A	N/A	N/A	N/A	D41L&H
Sub-Total (MU)					**142 706**	**19 773**	**372**	**2160**	**22.9**	**0**	**0.1%**	
KU	1	S1Ru1 - D41H2 - D42A	D42A.inc		5 371	1 388	316	1951	0.2	0	0.0%	D42A
	2	S1Ru2 - D41G - D42B	D42B.inc		4 305	2 408	361	2199	1.4	0	0.1%	D42B
	3	S2Ru3 - D41L - D42D	D42D.inc		5 375	2 946	403	2250	6.4	1	0.3%	D42D
	4	S2Ru1 - D41J - D42F	D42F.inc		3 874	1 360	323	2351	0.7	0	0.1%	D42F
	5	S2Ru2 - D41K - D42E	D42E.inc		4 213	1 552	330	2351	1.1	0	0.1%	D42E
	6	S2Ru4 - D41M - D42C	D42C.inc		2 626	471	322	2399	0.0	0	0.0%	D42C
	7	S3Ru1 - D42C2 - D42G	D42G.inc		15 431	1 075	258	2700	0.0	0	0.0%	D42G
Sub-Total (KU)					**41 195**	**11 200**	**313**	**2404**	**9.8**	**0**	**0.1%**	
M_L	1	Sn1Ru1 - D42D - D45C	D45C.inc		16 210	138	182	2750	0.0	0	0.0%	D45C
	2	S4Ru1 - D42E - D45D	D45D.inc		4 208	1 044	188	2750	0.0	0	0.0%	D45D
	3	D45A&B	-	Modelled as Endoreic	17 923	0	N/A	N/A	N/A	N/A	N/A	D45A&B
Sub-Total (ML)					**38 341**	**1 182**	**183**	**2750**	**0.0**	**0**	**0.0%**	
NO	1	N1Ru2 - Z10A2 - D43A2 - Daan Viljoen (Black Nossop)	Dvilj.inc	3111R01 Daan Viljoen & 3111M02 Mentz & 3111M01 Henopsrus	7 992	966	268	1691	1.2	0	0.1%	Part of D43A, upstream of Daan Viljoen Dam
	2	N1Ru1 - Z10A1 - D43A1 - Otjivero (White Nossob)	Otjv.inc	3112M02 Amasib & 3111M02 Mentz	9 207	966	268	1691	1.2	0	0.0%	Part of D43A, upstream of confluence with Black Nossob
	3	N2Ru1 - Z10A3 - D43B - Middle Nossob	D43B.inc		46 499	5 041	270	1691	4.1	0	0.0%	D43B
	4	Snb2Ru1 - D42A1 - D43C Botswana	D43C.inc		4 749	342	222	2900	0.0	0	0.0%	D43C
	5	Snb1Ru1 - D42B - D44D Botswana	D44D.inc		3 203	101	165	2951	0.0	0	0.0%	D44D
Sub-Total (NO)					**71 650**	**7 415**	**262**	**1827**	**6.5**	**0**	**0.0%**	
AU	1	N3Ru1 - Z10A5 - D44A1 - Seeis River	Seeis.inc		2 843	146	331	1691	0.2	0	0.0%	Part of D44A, upstream of confluence with Olifants
	2	N3Ru2 - Z10A4 - D44A2 - Upper Olifants River	Uolif.inc		1 105	218	331	1691	0.2	0	0.1%	Part of D44A, upstream of confluence with Seeis
	3	N4Ru2 - Z10A7 - D44B1 - Lower Olifants River	Lolif.inc		12 106	2 032	195	1691	0.7	0	0.0%	Part of D44B, upstream of confluence with Auob
	4	N4RU1 - Z10A6 - D44B2 - Upper Auob River	UAub.inc	3124M02 Stampriet & 3124M01 Cochas	19 383	1 356	195	1691	3.3	0	0.1%	Part of D44B, Auob River
	5	Sn2Ru1 -D42A2 - D44C - Lower Auob River Botswana	D44C.inc		5 592	401	120	2900.0	0.0	0	0.0%	D44C
	6	Nauaspoort Dam, Oanob Dam and remainder of Skaap - Not modelled in Molopo-Nossob Study	-		16 633	N/A	N/A	N/A	N/A	N/A	N/A	D44E-G
Sub-Total (AU)					**57 661**	**4 153**	**198**	**1856**	**4.4**	**0**	**0.1%**	
Total Secondary Cactment: Molopo-Nossob					**351 553**	**43 723**	**277**	**2097**	**43.7**	**0**	**0.1%**	

Notes: (1) Natural Runoff includes estimates of losses

(2) Values only reflect non-endoreic areas where there are data available.

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