



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



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Prepared by









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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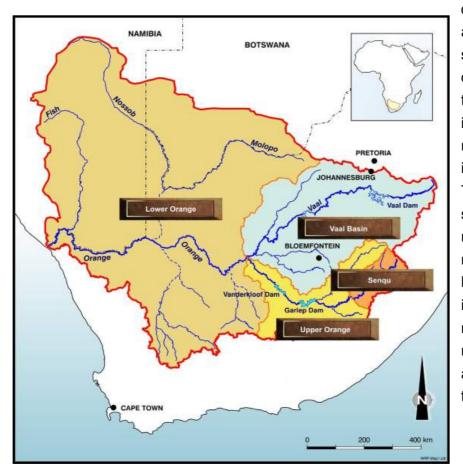
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1 INTRODUCTION

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 850,000km² 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 Mm³, 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-Sengu system is regulated by more than thirty-one major dams and is a highly complex and integrated water resource systems, with numerous large interand 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.

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-Sengu 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.

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

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

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.

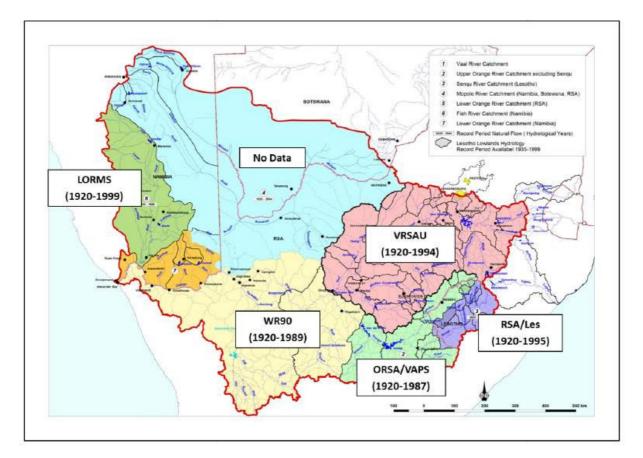


Figure 2-1: Source Studies for Original Orange-Senqu Hydrological Database

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 Sengu

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 subcatchments 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.

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

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

 Database

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 thisReport.

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.

Secondary Catchment	Tertiary Catchment	Quaternary Catchments	Gross Tertiary Catchment Area (km ²) ⁽¹⁾	Gross Secondary Catchment Area (km ²)	
	Upper Vaal (V _U)	C11A-M, C12A-L, C13A-H, C81A- M, C82A-H, C83A-M	38 638		
	Vaal Barrage (V _B)	C21A-G, C22A-K	8 651		
1. Vaal	Middle Vaal (V_M)	C23A-L, C24A-J, C25A-F, C41A-J, C42A-L, C43A-D, C60A-J, C70A-K	60 836	196 438	
	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		
	Caledon (CA)	D21A-L, D22A-L, D23A- J, D24A-L	21 884		
2. Upper Orange	Senqu (SE)	D11A-K, D12A-F, D15A-H, D16A-M, D17A-M,D18A-L	27 647	99 277	
	Upper Orange (O _U)	D13A-M, D14A-K, D31A-E, D32A-K, D33A-K, D34A-G, D35A-K	49 746		
	Brak/Ongers (BO)	D61A-M, D62A-J	33 733		
	Sak/Harts (SH)	D51A-C, D52A-F, D53A-J, D54A-G, D55A-M, D56A-J, D57A-D, D58A-C	93 041	243 313	
3. Lower Orange	Middle Orange (O _M)	D71A-D ,D72A-C ,D73A-F	40 100		
	Lower Orange (O_L)	D81A-K, D82A-P	76 439		
	Kuruman (KU)	D42A-G	41 195		
4. Molopo/Nossob	Upper Molopo (M _U)	D41A-J	148 167	356 788	
	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					

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.

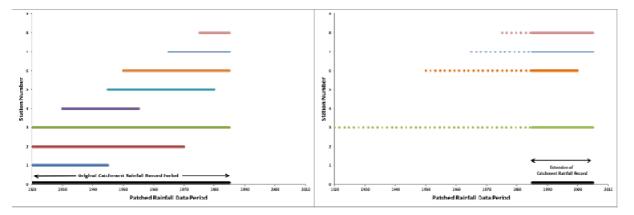


Figure 2-2: Schematic Representation of the process of Extending Catchment Rainfall Time Series

- 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.

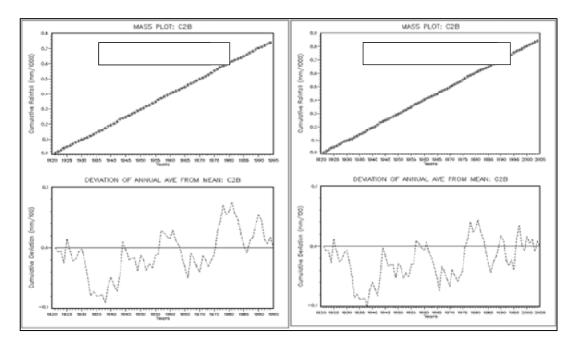


Figure 2-3: Example of Stationarity Tests, pre- and post-extension of the catchment Rainfall Record Period

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 Hyd	rological
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.

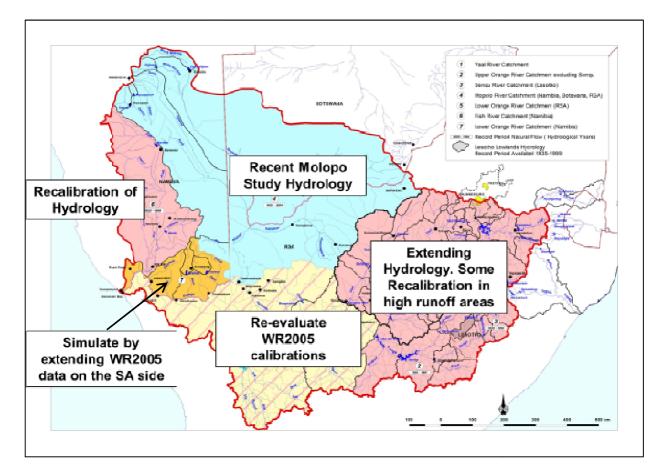


Figure 2-4: Spatial Distributions of Action Taken to Improve/Extend the Hydrological Database

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.

Secondary Catchment	Tertiary Catchment	Gross Tertiary Area (km²)	Secondary Area (km²)	Flow Gauges Used	Gauges still open and useful	% Still Open
	Upper Vaal (V_U)	38 638		7	5	71%
1) Vaal	Vaal Barrage (V _B)	8 651		13	9	69%
	Middle Vaal (V_M)	60 836	196 438	18	14	78%
	Lower Vaal (V_L)	55.019		5	4	80%
	Riet-Modder (RM)	33 294		5	4	80%
	Caledon (CA)	21 884		9	8	89%
2) Upper Orange	Senqu (SE)	27 647	99 277	8	8	100%
	Upper Orange (O _U)	49 746	00277	8	8	100%
3) Lower Orange	Brak/Ongers (BO), (SH), Lower Orang	243 313	5	4	80%	
4) Molopo/Nossob	Kuruman (KU), Up Lower Molopo (M _L) Auob (AU)	356 788	8	6	75%	
5) Namibian Fish Fish (FI)			81 630			
Total (Excluding FI)			895 816	86	70	81%

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

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	v of Rainfall Ga	uaes used for A	Analysis of the	Senqu-Orange Basin
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Secondary	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)	
Catchment							Used	Still Open
1) Vaal	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
	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
2) Upper Orange	Caledon (CA)	21 884	99 277	39	10	26%	4.5	1.1
	Senqu (SE)	27 647		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	- 243 313	59	59	100%		
3) Lower	Sak/Harts (SH)	93041					0.6	0.6
Orange	Middle Orange (O_M)	40 100						
	Lower Orange (O _L)	76 439						
4) Molopo /Nossob	Kuruman (KU)	41 195	356 788	99	49	49%		
	Upper Molopo (M _U)	148 167					0.7	0.3
	Lower Molopo (M _L)	38078						
	Nossob (NO)	71 650						
	Auob (AU)	57 698						
5) Namibian Fish	Fish (FI)	81 630	81630					
Total (Excludi	Total (Excluding FI)			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.

Tertiary Catchment	Catchment	Area (km²)	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%			

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

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 km²; in the Middle Orange catchment there are no gauges in area of 40 000 km²; in the Sak/Hartbees catchment there are 3 gauges in 100 000 km²; and in the Lower Orange there is only 1 gauge in 30 000 km².

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 subcatchments 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 km².

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 km². 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.

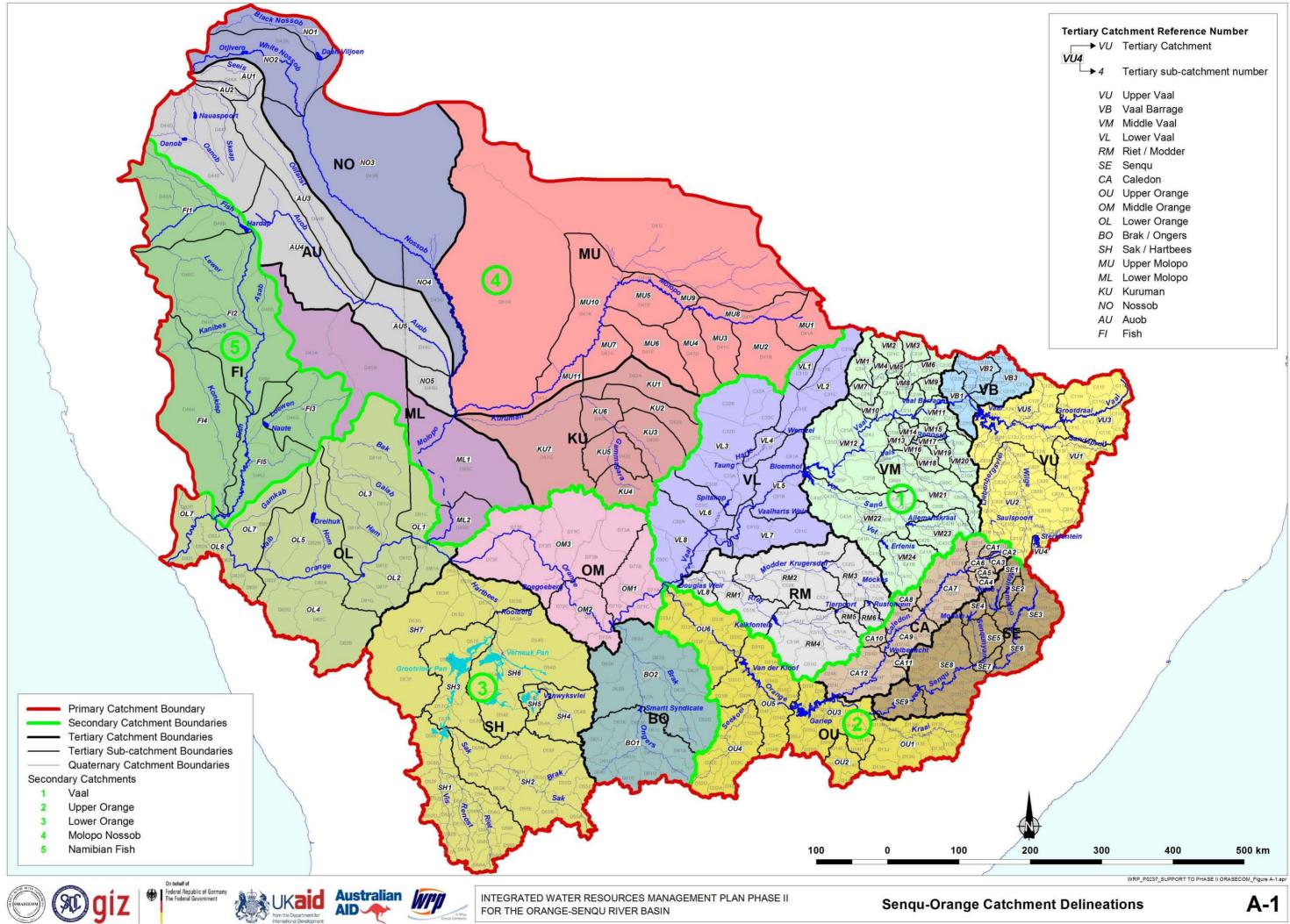
5 APPENDICES

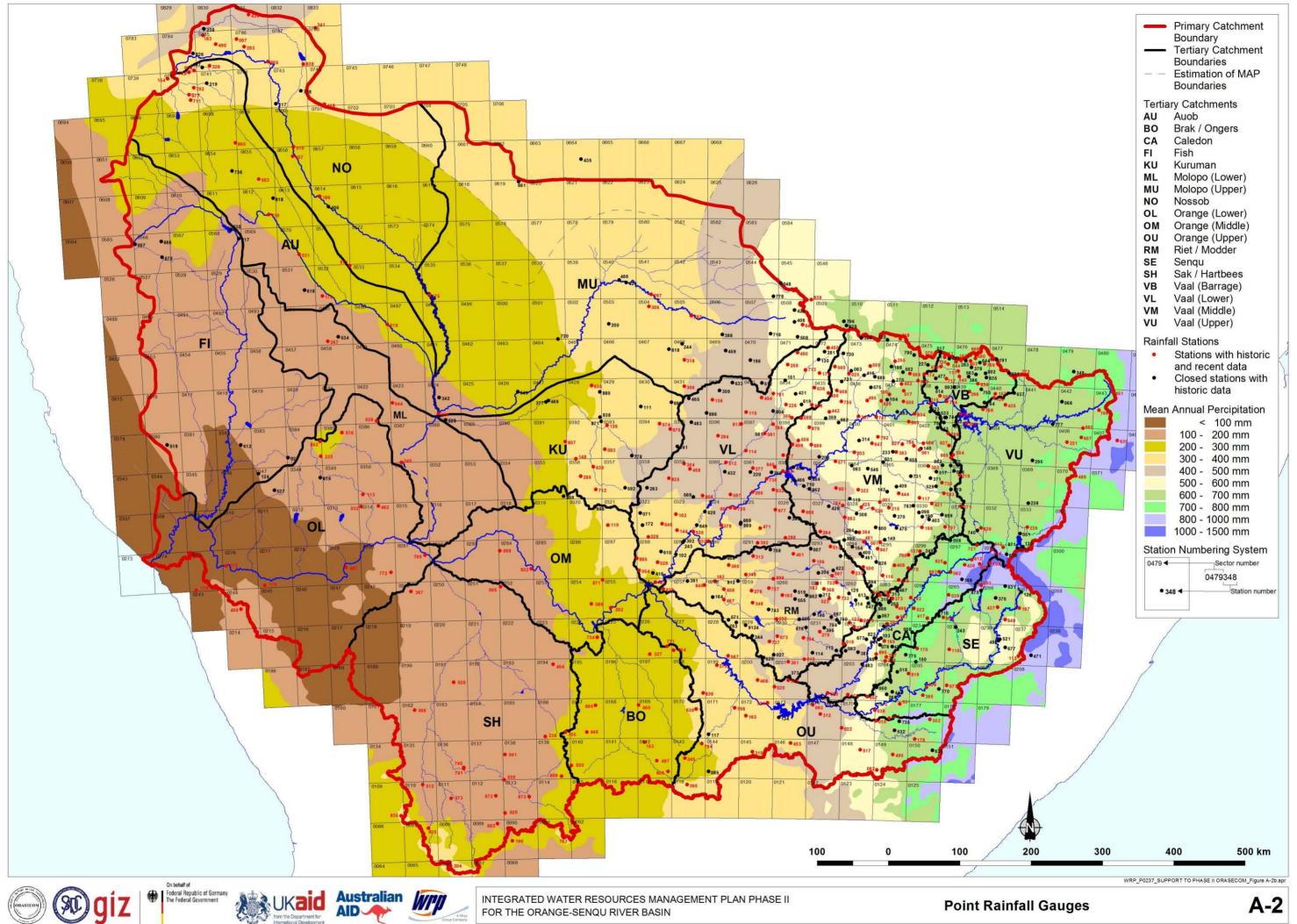
APPENDIX A: MAPS AND FIGURES

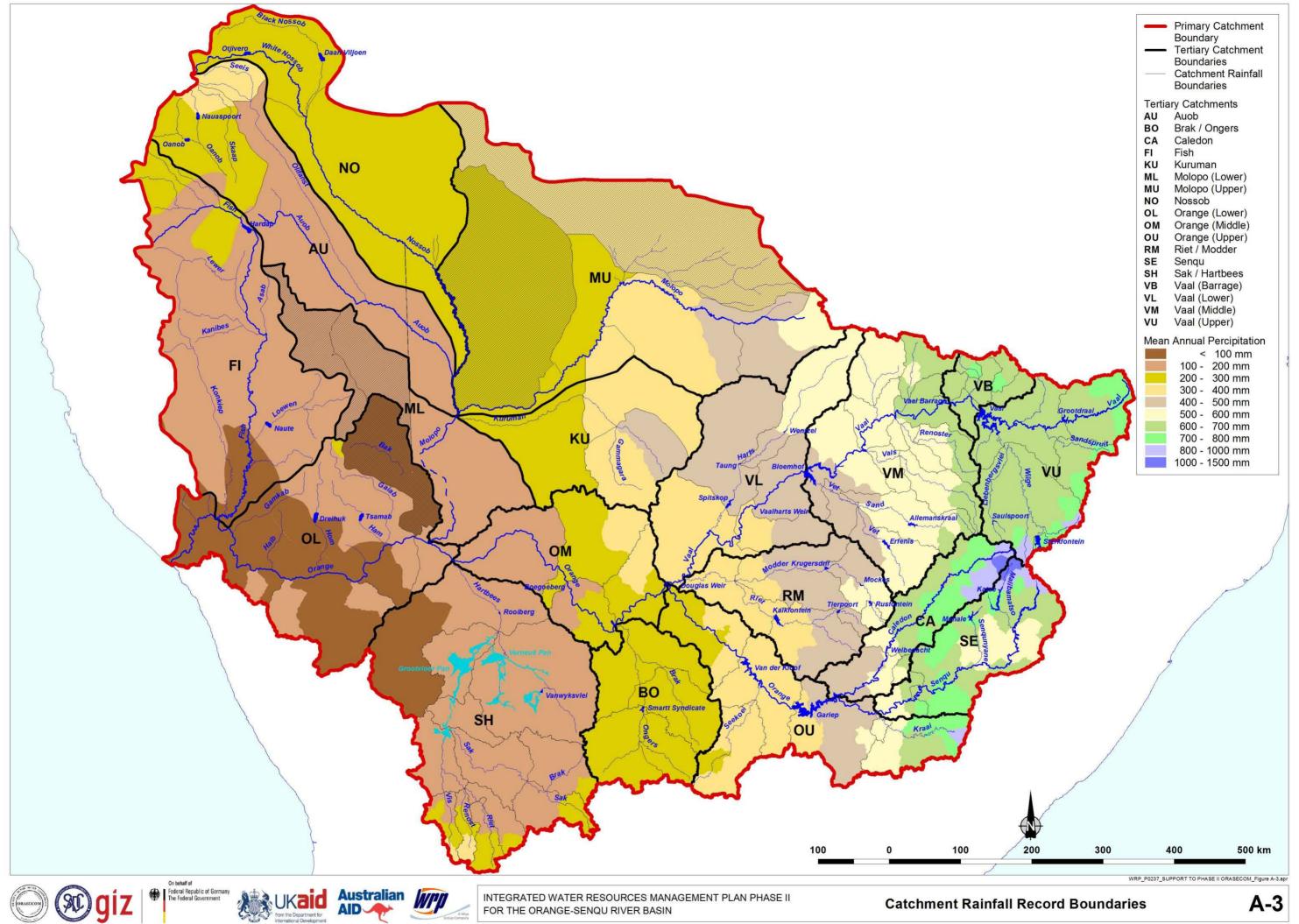
- Figure A-1: Senqu-Orange Catchment Delineations
- Figure A-2: Point Rainfall Gauges
- Figure A-3: Catchment Rainfall Record Boundaries
- Figure A-4: Calibration Flow Gauging Stations Catchment Boundaries
- Figure A-5: Natural Incremental Runoff
- Figure A-6: WRSM2000 Network Diagram for the Senqu (SE) up to Oranjedraai.
- Figure A-7: WRSM2000 Network Diagram for the Caledon River (CA) up to Welbedacht Dam.
- Figure A-8: WRSM2000 Network Diagram for the Caledon River (CA) downstream from Welbedacht Dam
- Figure A-9.1: WRSM2000 Network Diagram for the Upper Orange (OU) Kraai and Aliwal.
- Figure A-9.2: WRSM2000 Network Diagram for the Upper Orange (OU) D14 and D35.
- Figure A-9.3: WRSM2000 Network Diagram for the Upper Orange (OU) Van der Kloof Incremental.

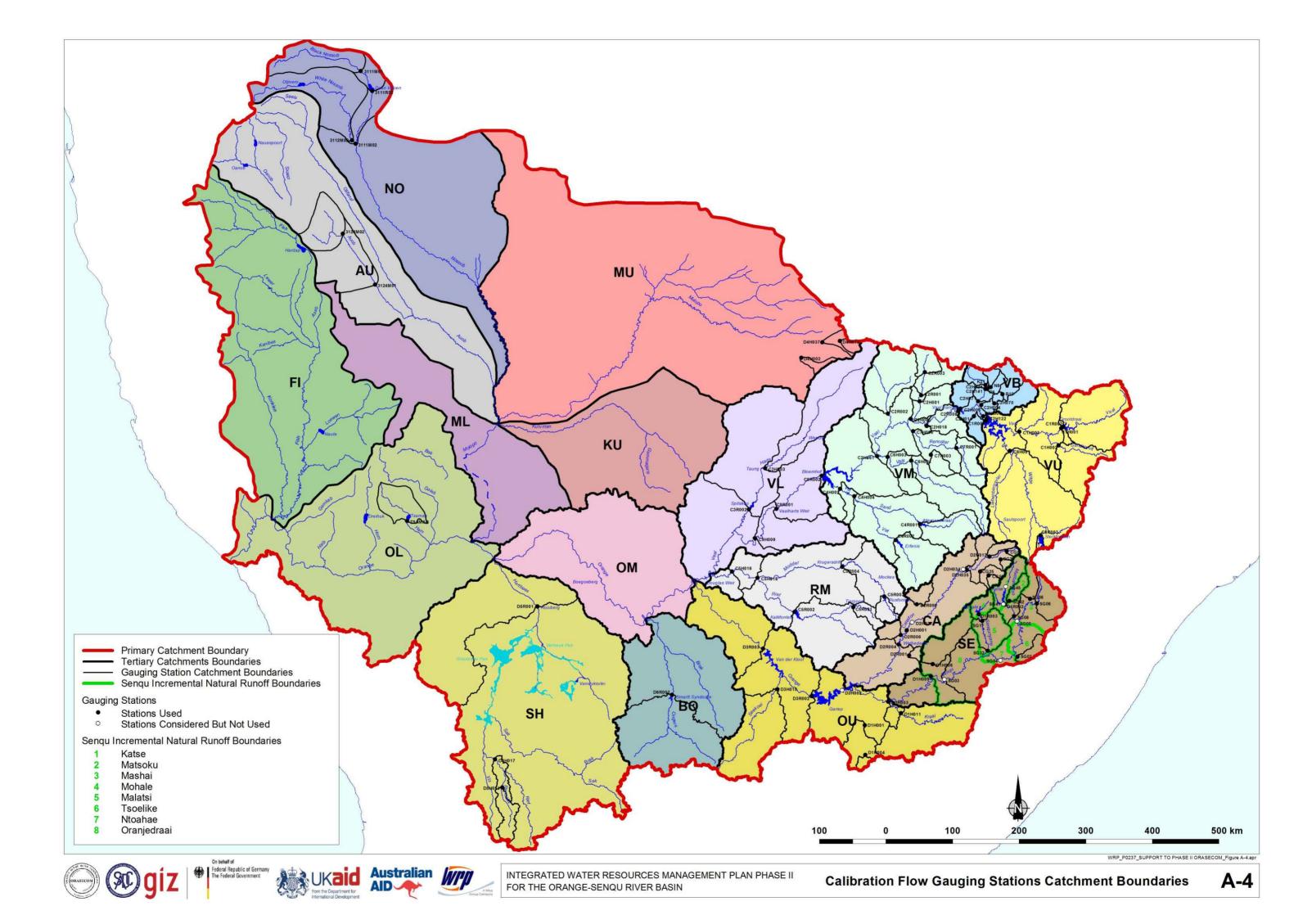
APPENDIX B: DATA SHEETS

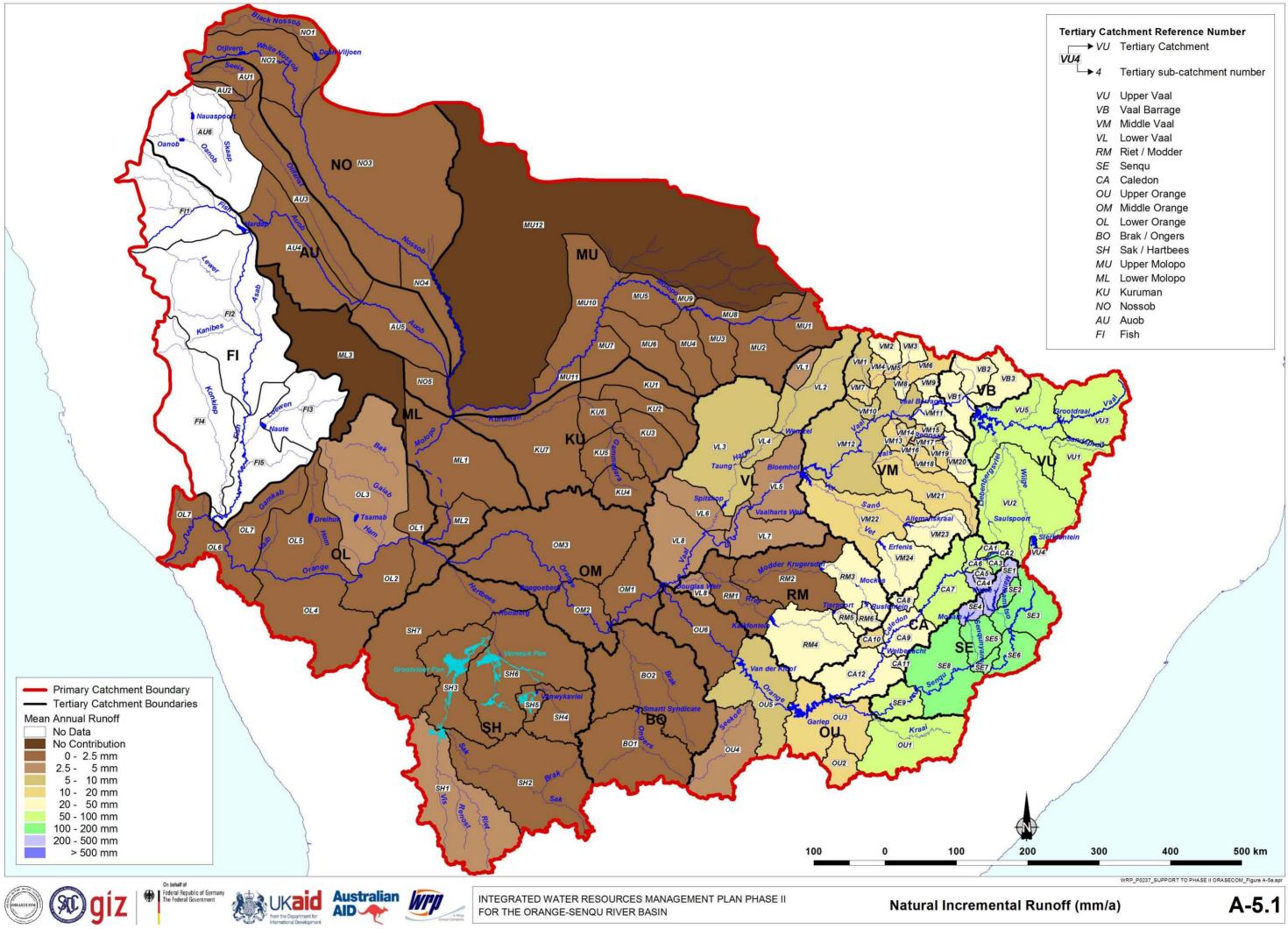
- Table B-1: Point rainfall stations used for catchment rainfall records
- Table B-2: Calibration flow gauging stations used
- Table B-3: Detailed natural runoff comparison tables: Vaal Secondary Catchment
- Table B-4: Detailed natural runoff comparison tables: Upper Orange Secondary Catchment
- Table B-5: Detailed natural runoff comparison tables: Lower Orange Secondary Catchment
- Table B-6: Detailed natural runoff comparison tables: Molopo-Nossob Secondary Catchment

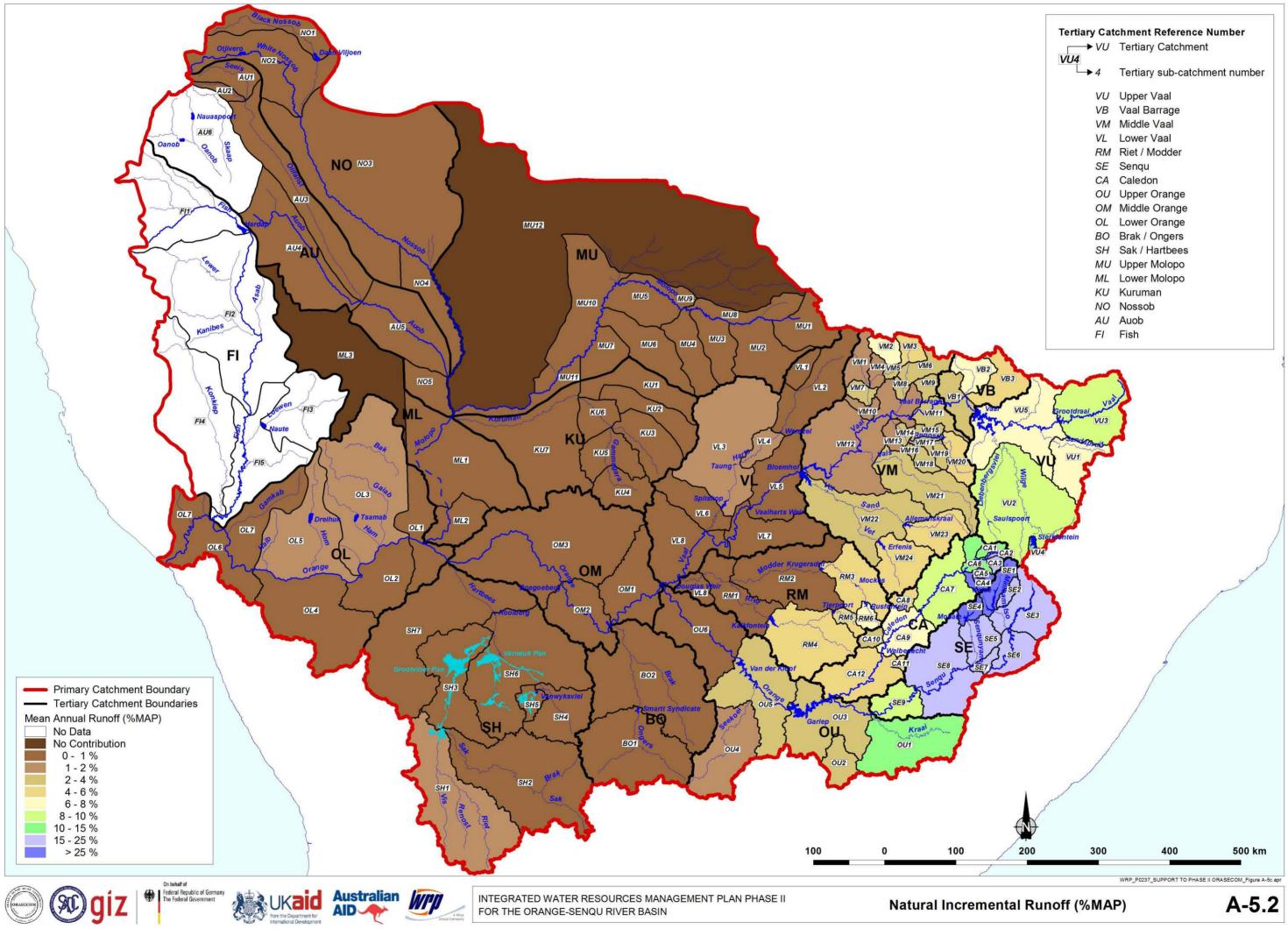


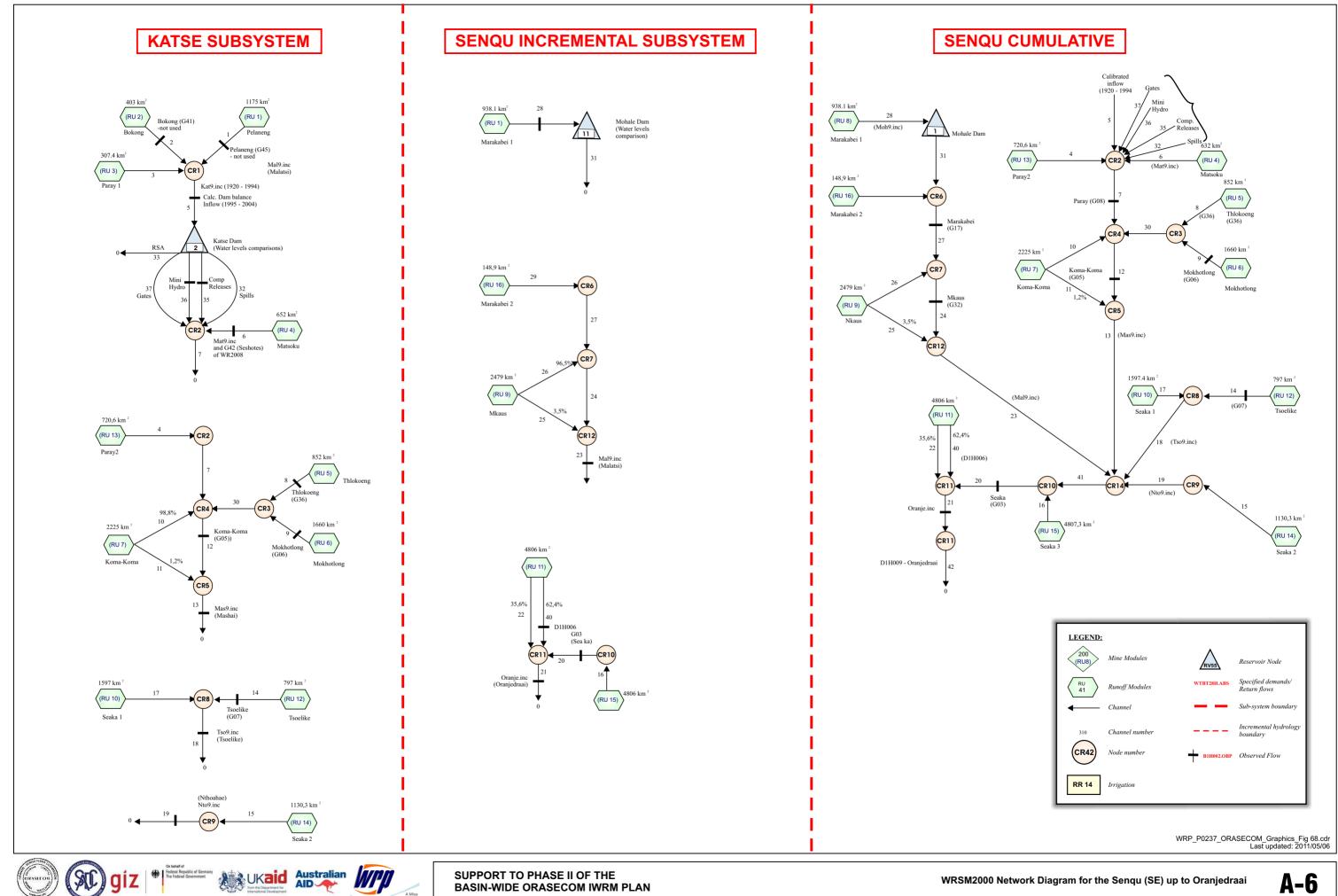


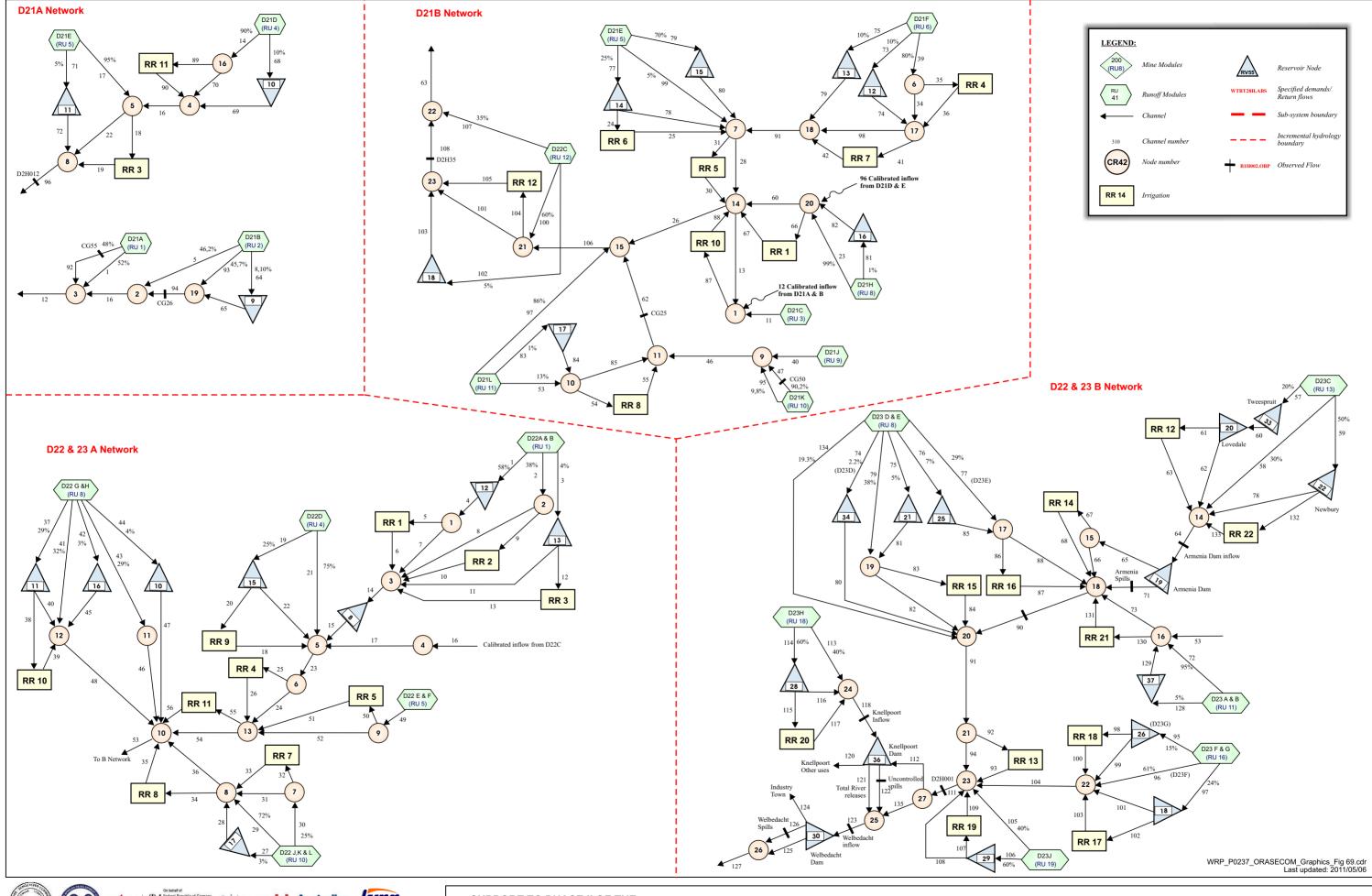








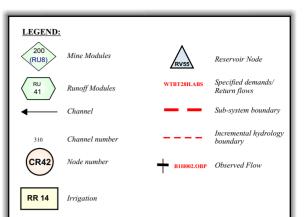




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SUPPORT TO PHASE II OF THE BASIN-WIDE ORASECOM IWRM PLAN

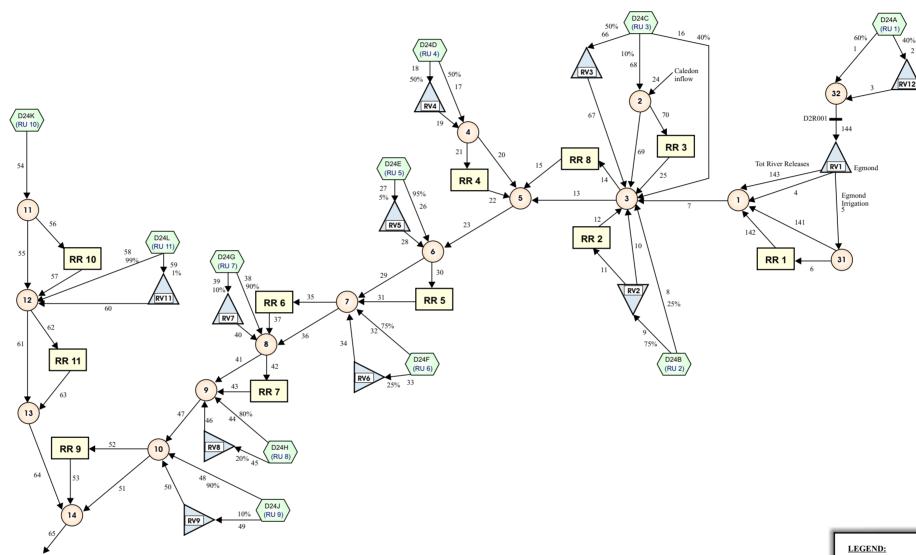
WRSM2000 Network Diagram for the Caledon River (CA) up to Welbedacht Dam



A-7

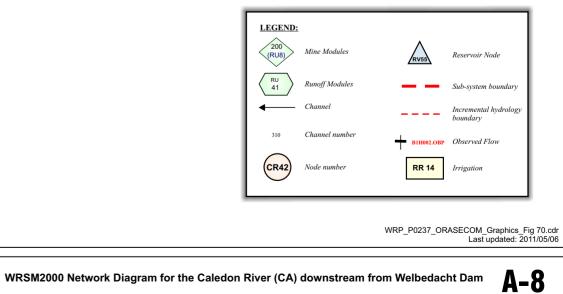


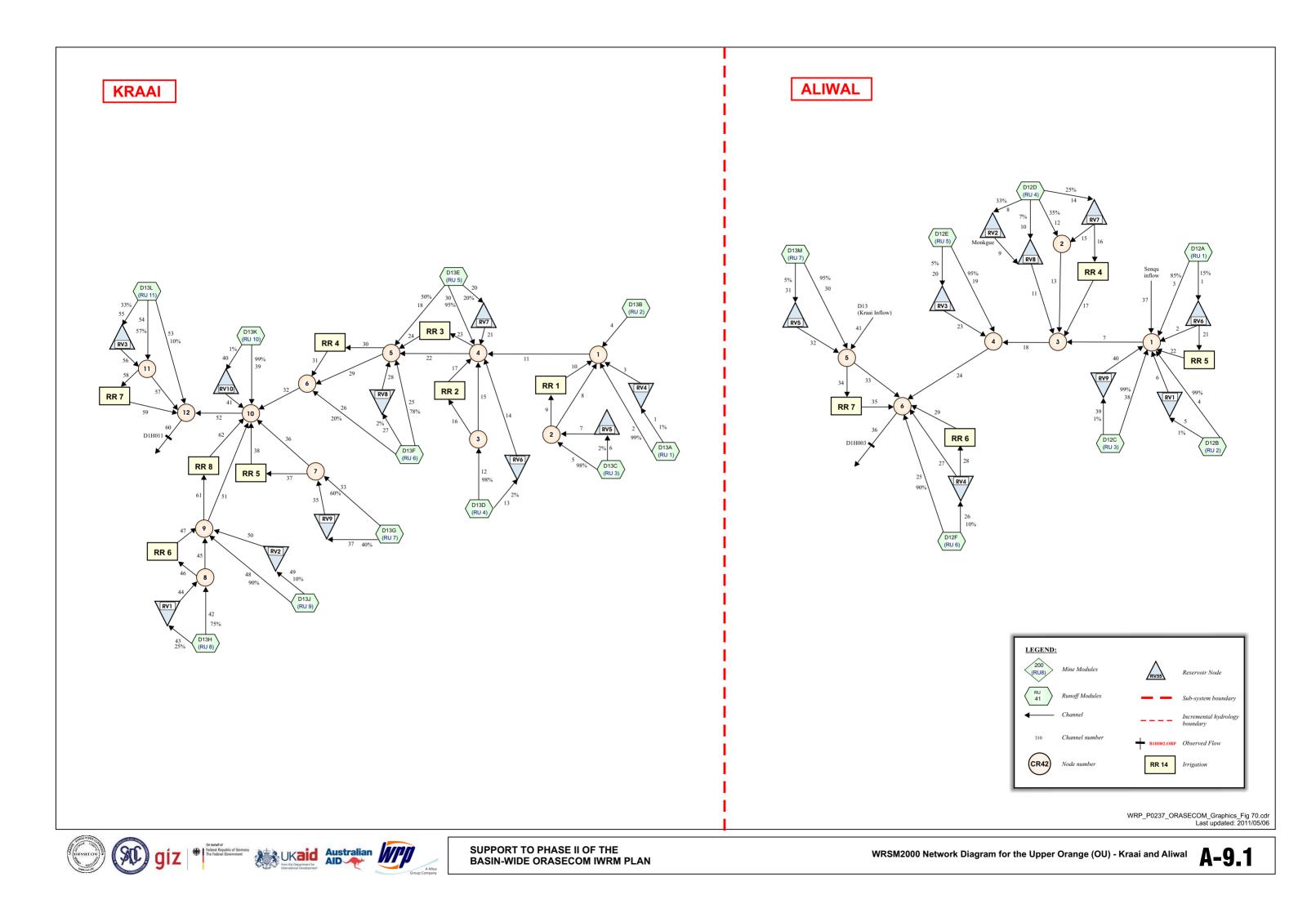
D24 (D24 Network)

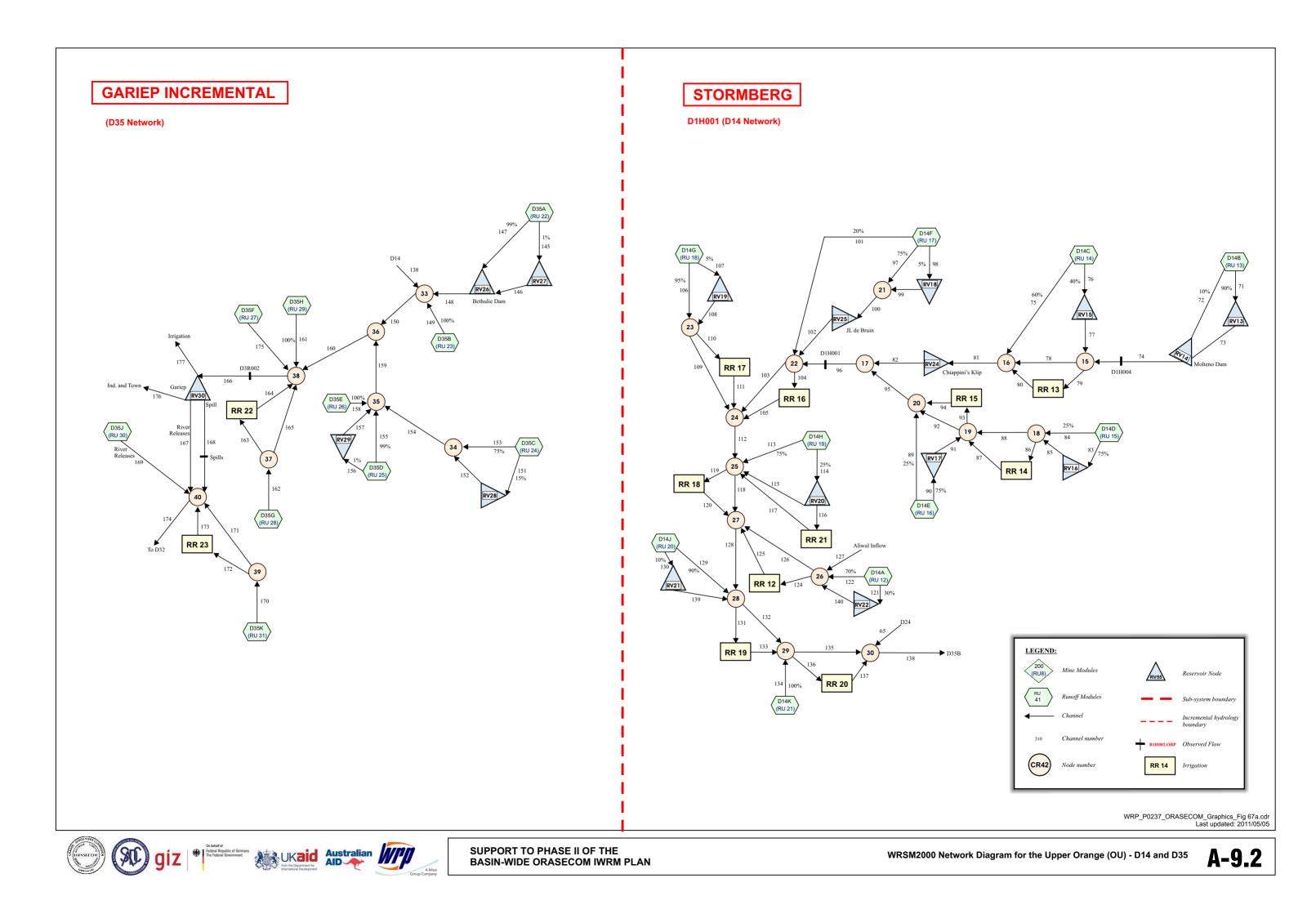


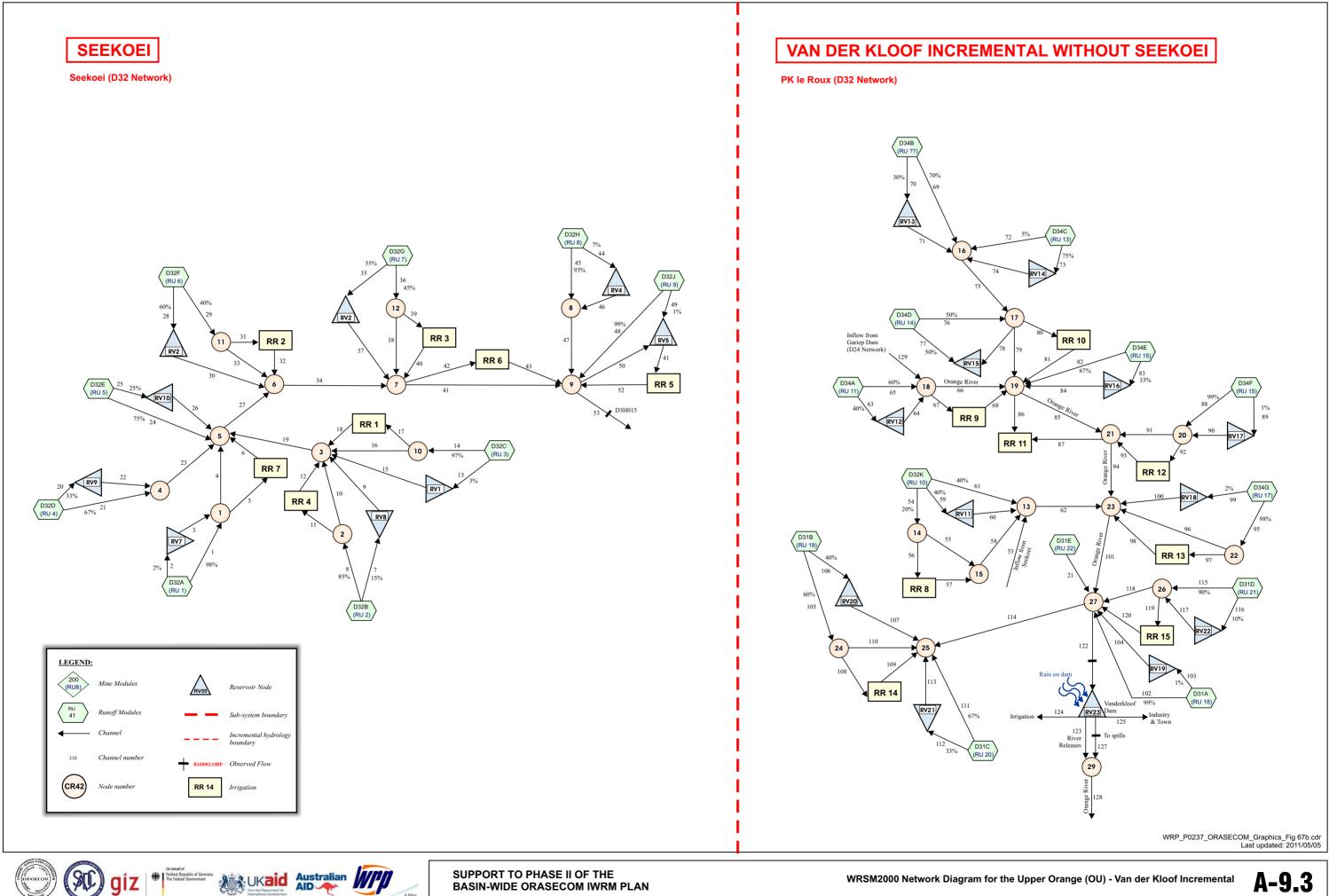


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APPENDIX B: TABLE B-1 - POINT RAINFALL GAUGES USED FOR CATCHMENT RAINFALL RECORD GENERATION

| | e Vaal catchme
Latitude | Longitude | |

 | List of key rainfall gauges in Molopo

 | Latitude Longitude

 | | |

 | List of
 | .f key rainfall ga | gauges in Riet-Modder c
L
 | | ongitude
 | | | | List of key rainfall gauges in Lower Vaa
 | Latitude Longitude | Je | | | | List of key rainfall gauges in Upper Oran |
 | Longitude | | |
|--|--|---|--
--
--

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--
--
--
--
---|--|--
--

--|--
--
---|---|--|--
--|--|--
---|--|--|--|--|---
---|---|--|--|
| ion Name | Deg Min | Deg Min | ecord starts Record |

 | Number Station Name

 |

 | | |

 | Count Numbe
 | | Name E
 | Deg Min | Deg Min Re
 | cord starts R | cord ends | atchment(s) Co | ount Number Station Name
 | Deg Min Deg Min | in Record starts | | Catchment(s) | Count | Number Station Name | Deg Min
 | Deg Min | Record starts | Record ends Catch |
| 53280 Westminster
94481 Erfenis Dam | 29 10
28 31 | 27 10
26 47 | 1920 200
1948 200 |

 | 1 288528 Tweefontein
2 320696 Compass

 |

 | 1920 | | D42A, B, D42C, D42D, D42E
D41J, D41K, D41L

 |
 | 361 W Hamelfor
373 W Hamilton |
 | 30 02
30 13 | 25 43
25 44
 | 1912
1922 | 2004 C | 51G
51G | 1 0291392 W Boshof - TNK
2 0322071 W Danielskuil - POL
 | 28 33 25 15
28 11 23 33 | 1879 | 2004 1990 | C91C
C92A | 1 | 1 118395 ZOETVLEI
2 143345 GROOTFONTEIN | 31 35
31 15
 | 24 14
24 12 | 1906
1912 | 1988 809
1989 809 |
| 94481 Errenis Dam
94500 Verkeerdevkei | 28 50 | 26 47 | 1948 200 |

 | 3 322071 Danielskuil-Pol

 |

 | 1877 | | D41J, D41K, D41L
D41J, D41K, D41L

 | 3 02285
 | 571 W Adamsho | hoop
 | 29 31 | 24 50
 | 1912 | | 51K | 3 0322172 W Silverstreams
 | 28 20 23 35 | 1923 | 1993 | C92A | 3 | 3 143784 HANOVER - POL | 31 04
 | 24 12 24 27 | 1879 | 1989 809 |
| 94847 Deornpoort | 28 37 | 26 59 | 1929 200 | 14 C4A

 | 4 355808 Hartebeeshoek

 |

 | 1932 | 1977 | D42A, D428, D42C, D42D, D42E

 | 4 022878
 | 783 W Rietput |
 | 29 33 | 24 57
 | 1932 | 1988 0 | 51K | 4 0322329 W Papkuil
s 0322648 W Vaalpan
 | 28 29 23 40
28 19 23 52 | | 1996
2004 | C92B
C92A | 4 | 4 144085 Bokfontein | 31 25
 | 24 33 | 1920 | 1975 B09 |
| 95001 Winburg
95116 Excelsior | 28 31
28 56 | 27 01 27 04 | 1910 200
1911 200 |

 | 5 356285 Hopkins
6 356636 Deben-Pol

 |

 | 1877 | 2004 | D42A, D42B, D42C, D42D, D42E, D41J, D41K, D41L
D41J, D41K, D41L

 | 5 02291
6 02293
 | 124 W Taaibosla
344 W Sandymo | iount Park
 | 29 35
29 43 | 25 05
25 11
 | 1919 | 1976 C | 51K
51J | 5 0322648 W Vaalpan
6 0323144 W Potfontein
 | 28 19 23 52
28 24 24 05 | | 2004 | C92A
C92A | 5 | 5 145310 GRDENVLEI
6 146453 EENBULT | 31 10
31 03
 | 25 12
25 46 | 1928
1925 | 1997 B13
1997 B11 |
| 95408 Moreson | 28 48 | 27 14 | 1926 200 |

 | 7 356712 Smythe

 |

 | 1877 | | D41J, D41K, D41L

 | 7 022963
 | 629 W Spitskop | p
 | 29 59 | 25 21
 | 1931 | | 51H | 7 0323535 W Delportshoop - POL
 | 28 25 24 19 | | 2004 | C91E | 7 | 7 148517 Jamestown-Pol | 31 07
 | 26 48 | 1879 | 2004 805 |
| 95760 Marquard | 28 40 | 27 26 | 1915 200 | 4 C4A

 | 8 357592 Branksea
9 387240 Noenieput

 |

 | 1877 | 1999
2004 | D41J, D41K, D41L

 |
 | 737 W Jagersfon
027 W Swartkop |
 | 29 47
29 57 | 25 26
25 30
 | 1889 | | 51H, C51J
51H | 8 0324379 W Windsorton - POL
0 0324607 W Warrenton - MUN
 | 28 20 24 43
28 07 24 51 | | 2004 | C91D
C91D | 8 | 8 149082 Dardrecht-Tnk
9 149490 Rossous-Pol | 31 22
 | 27 03 | 1904 | 2004 805 |
| 95770 Belmont
26668 Geluk | 28 50
28 08 | 27 26
25 53 | 1917 200
1932 200 |

 | 9 387240 Noenieput
10 391857 Dedeben

 |

 | 1921 | 2004 | D42A, D42B, D42C, D42D, D42E
D42A, D42B, D42C, D42D, D42E

 |
 | 027 W Swartkop
073 W Slangfont |
 | 29 57 | 25'33'
 | 1917 | 2004 0 | 51H | 10 0324725 W Nazareth House Farm
 | 28 07 24 55 | | 2004 | C91B | 9 | 9 149490 Rossous-Pol
10 150635 lisburn | 31 10
31 06
 | 27 17 27 52 | 1944 1920 | 2004 805
1971 805 |
| 27784 Nelsdrift | 28 04 | 26 27 | 1908 200 | 14 C4D. C4E 1

 | 11 392148 Winton

 |

 | 1877 | 2004 | D41J, D41K, D41L

 | 11 023076
 | 764 W Edenburg | rg - POL
 | 29 44 | 25 56
 | 1905 | | 51C | 11 0324888 W Knapdaar
 | 28 18 25 00 | | 1946 | C91D | 11 | 1 170639 Rooiwal | 30 39
 | 42 22 | 1900 | 2004 809 |
| 28384 Theunissen | 28 24 | 26 43 | 1914 200 |

 | 12 392871 Gamodisa

 |

 | 1877 | 1999 | D41G, D41H, D41M

 |
 | 810 W Lillydale
816 W Bethany |
 | 30 00
29 36 | 25 57
25 58
 | 1906 | 2004 C | 51G | 12 0324889 W Lusthof
13 0325471 W Bordeaux
 | 28 19 25 00
28 22 25 17 | 1944 | 1977 2004 | C91D
C91C | 12 | 12 170639 Rooiwal
13 171117 Wolmada | 30 38
 | 24 22 | 1920 | 1988 B09 |
| 28425 Adamsonvlei
28726 Olivine | 28 05
28 06 | 26 45
26 55 | 1925 200
1925 200 | 14 C4D, C4E 1

 | 13 393083 Kuruman
14 393126 Tsineng

 |

 | 1877 | 2004 | D41J, D41K, D41L
D41J, D41K, D41L

 |
 | 114 W Knelpoor |
 | 29 55 | 25 58
 | 1905 | | 518 | 14 0325877 W Hertzogville - POL
 | 28 08 25 30 | | 2004 | C91B | 13 | 4 171756 Esperanza | 30 57
30 37
 | 24 33
24 56 | 1920
1920 | 1986 B09
1988 B09 |
| 29215 Ventersburg | 28 05 | 27 08 | 1910 200 | 4 C4D

 | 15 393778 Kuruman

 |

 | 1882 | 1999 | D41J, D41K, D41L

 |
 | 279 W Reddersb |
 | 29 39 | 26 10
 | 1905 | | 51A, C51E | 15 0326298 W Buitenverwag
 | 28 29 25 39 | | 1994 | C91C | 15 | 5 172163 Colesburg-Tnk | 30 43
 | 25 06 | 1976 | 2004 809 |
| 30199 Senekal | 28 19 | 27 37 | 1905 200 |

 | 16 394574 Bothitho

 |

 | 1906 | 2004 | D41G, D41H, D41M

 |
 | 395 W Bulsfonte
713 W Donkerho |
 | 29 36
29 53 | 26 14
26 25
 | 1912 | 1982 C | 51A | 16 0326344 W Wolhuterskop
17 0358825 W Balbriggen
 | 28 14 25 42
27 45 23 58 | | 1969
2004 | C91C
C33B | 16 | 15 172724 Tweefontein | 30 34
 | 25 25 | 1900 | 2004 813 |
| 30421 Roodepoort
30797 Paul Roux | 28 01
28 17 | 27 45 27 57 | 1913 200
1926 200 |

 | 17 394878 Boscobel
18 395141 Grootbultfontein

 |

 | 1906 | 1999 | D41G, D41H, D41M
D41G, D41H, D41M

 |
 | 754 W Bloubosk |
 | 29 33 | 26 27
 | 1920 | | 51D | 18 0359304 W Renilo
 | 27 34 24 11 | | | C33B | 17 | 7 173134 MONTAGU
18 174093 CLIFTON VALE | 30 44
30 34
 | 25 35 26 5 | 1901 | 1976 B11
1997 B11 |
| 53571 Hendrick Theron | 27 31 | 26 20 | 1932 200 | 14 C2F 1

 | 19 423044 Rietfontein

 |

 | 1920 | 2004 | D42A, D428, D42C, D42D, D42E, Z10G

 |
 | 018 W Cyferfont |
 | | 26 31
 | 1912 | | 518 | 19 0359458 W Olyfenfontein
 | 27 38 24 16 | | 2004 | C33B | 19 | 9 174312 Hughender | 30 42
 | 26 11 | 1903 | 2004 811 |
| 53651 Wesselsbron
54322 Odendaalsrus | 27 51 | 26 22 | 1924 200 |

 | 20 424342 Bokspits
21 424354 Gemsbok-Pol

 | 26 42 20 42

 | 1974 | 2003 | Z10E, Z10G
D42A, D428, D42C, D42D, D42E, Z10G

 |
 | 123 W Roodepoo
275 W Dewetsdo |
 | 29 32
29 35 | 26 36 26 40
 | 1910 | | 51D, C52A
52A | 20 0359808 W Boetsap - POL
21 0360432 W Magogong - 2J11
 | 27 58 24 27
27 40 24 46 | 1886 | 2004 | C33B
C33A | 20 | 20 174753 GOEDEMOED - TNK
11 175022 WELGEDACHT | 30 34
 | 26 26 | 1915 | 1985 811 |
| 54322 Odendaalsrus
55444 Swartkoppie | 27 52 27 54 | 26 41
27 15 | 1906 200
1926 200 |

 | 21 424354 Gemsbok-Pol
22 424509 Askham

 |

 | 1920 | 2004 | D42A, D42B, D42C, D42D, D42E, Z10G
D42A, D42B, D42C, D42D, D42E, Z10G

 |
 | 638 W Wimbled |
 | 29 08 | 23 53
 | 1905 | | 51M | 22 0360512 W Taung - POL
 | 27 33 24 47 | 1899 | 2000 | C31F, C33A | 21 | 11 175022 WELGEDACHT
12 176015 PAARDEFONTEIN | 30 51
30 45
 | 26*31'
27 1 | 1924
1926 | 1998 811
2004 801, 8 |
| 96117 Steynsrus | 27 57 | 27 34 | 1923 200 | 14 C6A 2

 | 23 426549 KHUIS

 | 26 39 21 49

 | 1981 | | Z10E, Z10F

 |
 | 391 W Plooysbu |
 | | 24 14
 | 1928 | | 51M | 23 0360597 W Vaalharts - AGR
 | 27 57 24 51 | 1919 | 2004 | C33A | 23 | 176038 Morgenson | 30 37
 | 27 00 | 1920 | 1979 B01 |
| 56303 Edenville
56743 Lindley | 27 33 27 53 | 27 41 27 55 | 1929 200
1924 200 |

 | 24 427377 Blakely
25 427469 Onrust

 |

 | 1925 | 1999 | D42A, D42B, D42C, D42D, D42E, Z10E
D42A, D42B, D42C, D42D, D42E, Z10G

 |
 | 845 W Eureka
164 W Michville |
 | 29 05
29 14 | 24 29
24 36
 | 1913 | 2004 C | 51L
51K | 24 0361220 W Graspan
25 0361277 W Welkom
 | 27 40 25 08
27 37 25 10 | | 1977 2004 | C91B
C91B | 24 | 14 176372 LADY GREY - POL
176532 Motkep | 30 43
30 52
 | 27 13 27 18 | 1888 1920 | 1989 801,
1956 B05 |
| 57219 Petrus Steyn | 27 39 | 28 08 | 1924 200 |

 | 26 428635 Severn

 |

 | 1920 | 2004 | D426, D428, D420, D420, D422, 2105
D416, D41H, D41M, Z10E

 |
 | 182 W Modderri | rrivier - POL
 | 29 02 | 24 38
 | 1914 | 2004 0 | | 26 0361295 W Christiana - TNK
 | 27 55 25 10 | 1903 | 2004 | C91B | 25 | 176532 MOROP
16 176631 STERKSPRUIT - TNK | 30 32
 | 27 22 | 1920 | 1986 801 |
| 98177 Zevenfontein | 27 27 | 25 36 | 1911 200 |

 | 27 428838 Karlsruhe

 |

 | 1877 | | D41G, D41H, D41M

 |
 | 458 W Jacobsda |
 | 29 08 | 24 46
 | 1888 | | 51K | 27 0361736 W Mairton
 | 27 45 25 22 | 1934 | 2001 | C91A | 27 | 7 176735 Lower Orpendale | 30 45
 | 27 22 | 1920 | 1985 B05 |
| 38409 Rietpan
30203 Bothaville | 27 19 | 25 44
26 37 | 1929 200
1912 200 |

 | 28 428880 Elrida

 |

 | 1877 | 1999 | D41G, D41H, D41M
D41G, D41H, D41M

 |
 | 467 W Gannaho
812 W De Kalk |
 | 29 16
29 02 | 24 46
24 58
 | 1948 | 2004 C | 51K | 28 0361760 W Palmietfontein
29 0361832 W Kalkpoort
 | 27 40 25 26
27 53 25 28 | 1909 | 1973
2004 | C91A
C91B | 28 | 8 177178 Barkly east-Tnk
19 177552 Funny stone | 30 58
 | 27 36 27 49 | 1883 | 2004 805 |
| 0203 Bothaville
00647 Bovenlandsplaats | 27 23 | 26 37 | 1912 200
1930 200 |

 | 29 430111 Longhurst
30 430888 Southey

 |

 | 1906 | 1999 | D416, D41H, D41M
D416, D41H, D41J, D41K, D41L D41M

 |
 | 278 W Kroonpla |
 | 29 09 | 25 10
 | 1931 | 2002 0 | 521 | 30 0361846 W S A Lombard Natuurreservaar
 | 27 36 25 29 | 1951 | 2004 | C91A | 29 | 9 177552 Funny stone
198836 PHILIPSTOWN - TNK | 30 42
30 26
 | 2749 | 1926
1920 | 2004 805
1986 813 |
| 00792 Viljoenskroon | 27 12 | 26 57 | 1934 200 |

 | 31 431306 Genesa

 |

 | 1897 | | D41C, D41D, D41E, D41F

 | 31 025934
 | 348 W Leyden |
 | 29 18 | 25 11
 | 1927 | 2004 0 | 51K | 31 0362159 W Bloemhof - POL
 | 27 39 25 36 | 1930 | 2004 | C91A | 31 | 11 199275 Petrusville-Pol | 30 05
 | 42 40 | 1900 | 2004 813 |
| 01383 Welvaart | 27 23 | 27 13 | 1957 200 |

 | 32 431465 Mistake

 |

 | 1897 | | D41C, D41D, D41E, D41F

 | 32 02597
 | 727 W Petrusbu | arg - POL
 | 29 07 | 25 25
 | 1905 | | 52K | 32 0395483 W Geluk
 | 27 03 24 17 | 1912 | 1968 | C32D | 32 | 2 200466 Philippolis-Pol | 30 16
 | 25 16 | 1900 | 2004 813 |
| 02081 Morgenrood
02166 Doorndraai | 27 21 27 16 | 27 33
27 36 | 1913 200
1919 200 |

 | 33 432633 Stella
34 433512 Brandwag

 |

 | 1920 | | D41A, D418, D41C, D41D, D41E, D41F
D41A, D418

 | 33 025974
 | 743 W Kranshoe
030 W Steunmek | ekaar - POL
 | 29 23
29 30 | 25 25
25 32
 | 1912 | | 51F, C51J
51F | 33 0396284 W Madrid
34 0396813 W Leliefontein
 | 27 13 24 40
27 04 25 00 | 1918
1912 | 2004 | C32D
C32C | 33 | 201020 ORANJE 201376 SPRINGFONTEIN - MUN | 30 21
30 16
 | 25 31
25 43 | 1920
1923 | 1989 B13
1989 B11 |
| 02827 Heilbron | 27 16 | 27 36 | 1919 200
1921 200 |

 | 34 433512 Brandwag
35 464720 TSABONG

 | 26 00 22 24

 | 1949 | | D41A, D418
Z10E, Z10F

 | 35 02601
 | 163 W Koppiesd | sdam
 | 29 12 | 25 37
 | 1924 | 2004 0 | 52K | 35 0397114 W Naauwpoort
 | 27 24 25 04 | 1954 | 1997 | C31F | 34 | 5 202505 EBENHAEZER | 30 25
 | 25 43 | 1923 | 1989 801, |
| 02866 Driefontein | 27 26 | 27 59 | 1914 200 | 14 C6B, C7A 3

 | 36 467818 Donegal

 |

 | 1897 | 1999 | D41C, D41D, D41E, D41F

 | 36 02605
 | 519 W De Brug - | - POL
 | 29 09 | 25 48
 | 1907 | 1973 0 | 521 | 36 0397581 W Schweizer-Reneke - POL
 | 27 11 25 20 | 1931 | 2004 | C31F,C31E | 36 | as 203175 Rust-en-Vrede | 30 26
 | 26 36 | 1935 | 1987 B11 |
| 34888 Ottosdal
35608 Mon Repos | 26 48
26 38 | 26 00
26 21 | 1911 200
1953 200 |

 | 37 468244 Inverness
38 468318 Palmyra

 |

 | 1897 | | D41C, D41D, D41E, D41F, Z10F
D41C, D41D, D41E, D41F

 | 37 02605
 | 555 W Northfield
660 W Pakpoort | .a
et
 | 29 15
29 30 | 25 48
25 52
 | 1922 | 1971 C
1956 C | 523
51E | 37 0397784 W Koppiesvlei
38 0398177 W Zevenfontein
 | 27 04 25 27
27 27 25 36 | 1933
1910 | 2004 2004 | C31E
C91A | 37 | 7 203483 Sonnelblom
8 203657 Middelplaats | 30 03
30 27
 | 26 48
26 52 | 1923
1920 | 1979 B1
2004 B0 |
| 5608 Mon Repos
5735 Hartbeesfontein | 26 38 | 26 21 26 25 | 1953 200
1916 200 |

 | 38 468318 Palmyra
39 469459 Mosita

 |

 | 1920 | | D41C, D41D, D41E, D41F
D41A, D41B

 | 39 02608
 | 882 W Salopia | · · · · ·
 | 29 12 | 25 58
 | 1930 | 1985 0 | 521 | 39 0431896 W Biesiesvlakte - AGR
 | 26 56 24 30 | 1924 | 1967 | C32B | 38 | 98 203657 Middelplaats
19 203657 Middelplaats | 30 27
 | 26 53 | 1920 | 2004 B0
1987 B1 |
| 5297 Vaal Reefs West | 26 57 | 26 40 | 1942 200 | 14 C2E 4

 | 40 470196 Setlagodi

 |

 | 1920 | 1999 | D41A, D418

 | 40 026114
 | 146AW Kafferrivi | ivier
 | 29 26 | 26 05
 | 1930 | | 51E | 40 0432136 W Welgeleven
 | 26 46 24 35 | 1917 | 2004 | C32B | 40 | 0 204050 Leeuwfontein | 30 20
 | 27 01 | 1921 | 1985 B |
| 5495 Beatrix | 26 45 | 26 47 | 1920 200 |

 | 41 471490 Lusthof

 | 25 57 19 09

 | 1920 | | D41A, D418

 | 41 02611/
 | 183 W Bainsvlei
312 W Ferreira | 4
 | 29 03
29 12 | 26 07
26 10
 | 1904 | | 52H, C52J
52J | 41 0432309 W Openside
42 0432633 W Stella - POL
 | 26 39 24 41
26 33 24 52 | 1942
1919 | 1990
1991 | C32B
C32A | 41 | 204265 ZONDAGSFONTEIN | 30 25
 | 27 10 | 1933 | 1986 B |
| 747 Bushy Bend
855 Brakspruit | 26 57
26 45 | 26 55
26 59 | 1922 200
1904 200 |

 | 42 495267 Koes
43 495534 Grabstein

 | 25 57 19 09
25 54 19 18

 | 1912 | | Z10G
Z10G

 | 42 02613
 | 312 W Ferreira
368 W Bloemfon | ontein - Dieretuin
 | 29 12
29 07 | 26 10 26 13
 | 1910 | 2004 0 | 52F | 42 0432633 W Stella - POL
43 0433115 W Rietpan
 | 26 33 24 52 26 55 25 04 | | 2004 | C32A
C32C | 42 | 2 204444 WELGEMOED
3 228567 Teverdenheid | 30 23
29 57
 | 27 15
24 49 | 1931 1920 | 1989 BC
2004 B1 |
| 100 Potchefstroom | 26 40 | 27 04 | 1918 200 |

 | 44 497019 Gemsbokpark- Mata Mata

 | 12.10

 | 1920 | 2004 | D42A, D42B, D42C, D42D, D42E, Z10E, Z10G

 | 44 026153
 | 523 W Grootvlei | lei - TNK
 | 29 14 | 26 18
 | 1904 | 1998 0 | 52# | 44 0433494 W Delareyville-Kaalplaas
 | 26 44 25 17 | 1932 | 1998 | C32A, C32C | 43 | 4 232383 Mentzburg | 29 54
 | 26 44 | 1928 | 1985 B |
| 152 Mimosa Park | 26 32 | 27 16 | 1920 200 | 14 C2C 4

 | 45 503200 Rochelle

 |

 | 1897 | 1999 | D41C, D41D, D41E, D41F, D41G, D41H, D41M

 | 45 026159
 | 597 W Erasmusf | isfontein
 | 29 28 | 26 20
 | 1912 | 1964 0 | 51D | 45 0433791 W Delareyville - MUN
 | 26 41 25 27 | 1921 | 2004 | C31E | 45 | 15 232823 Waterford | 29 43
 | 26 58 | 1914 | 1987 B |
| 517 Klipdrift
560 Vredefort | 26 37
27 00 | 27 18 | 1924 200
1906 200 |

 | 46 504306 Python
47 505493 Boshoek

 |

 | 1897 | 2004 | D41C, D41D, D41E, D41F, Z10F
D41C, D41D, D41E, D41F, Z10F

 | 46 02617
 | 722 W Mazelspo
733 W Tussenvie | oort Dam
 | 29 02
29 13 | 26 24
26 26
 | 1904 | | 52D, C52E
52D, C52F, C52G | 46 0433804 W Poortjie
47 0434151 W Leeuwpan
 | 26 54 25 27
26 31 25 37 | 1903
1939 | 1992
1979 | C31E
C31D | 46 | 16 232895 Sweetwater
17 234111 Malealea | 29 55
29 51
 | 27 00 27 34 | 1920 | 2004 B |
| 60 Vredefort
34 Parys | 27 00 26 54 | 27 22 27 28 | 1905 200
1913 200 |

 | 4/ 505493 Boshoek
48 506386 Logaging

 |

 | 1920 | 2004 | D41C, D41D, D41E, D41F, Z10F
D41A, D418

 | 48 02617
 | 750 W Niekerksv | svlei
 | 29 30 | 26 25
 | 1928 | 1970 0 | 51D | 48 0434228 W Doornbuit
 | 26 49 25 38 | 1913 | 2001 | C31E | 47 | 1/ 234111 Malealea
18 262479 The Cliff | 29.51
 | 27 34 26 46 | 1955 | 1987 1 |
| 15 Barrage | 26 45 | 27 41 | 1916 200 | 14 C2A 4

 | 49 507716 Shopsite

 |

 | 1920 | 1999 | D41A, D418

 | 49 02621
 | 129 W Likatlong | ng
 | 29 10 | 26 35
 | 1910 | 1980 0 | 528, C52D, C52G | 49 0434359 W Brakpan
 | 26 59 25 43 | | 2004 | C31E | 49 | 9 263373 27 13 | 29 13
 | 27 13 | 1916 | 1987 |
| 02 Welverdiend | 26 22 | 27 17 | 1913 200 | 4 C28 /

 | 50 508406 De-Wig

 |

 | 1920 | 1999 | D41A, D418

 |
 | 314 W Kromdraa
479 W The Cliff |
 | 29 15
29 30 | 26 41
 | 1925 | | 528, C52G
52A, C528, C52G | 50 0434431 W Klipdrift
51 0434619 W Kareekuil
 | 26 41 25 46
26 49 25 51 | | 1974 | C31C
C31E | 50 | 0 263567 Convamore | 29 27
 | 27 18 | 1920 | 1987 E |
| 84 Blyvooruitsig
99 Fochville | 26 24
26 29 | 27 23 27 30 | 1941 200
1927 200 | 4 C28 5

 | 51 508428 Jagersfontein
52 508508 Spring Valley

 |

 | 1920 | 1999
1999 | D41A, D418
D41A, D418

 |
 | 613AW Thaba No |
 | 29 30 | 26 51
 | 1904 | | 528, C526, C526 | 52 0434888 W Ottosdal - POL
 | 26 49 26 00 | | | C31C | 51 | 1 263792 Leileihoek
2 264022 Botsabelo | 29 12
29 20
 | 27 29
27 32 | 1919
1936 | 1987 1 |
| 20 Dwarsfontein | 26 00 | 27 04 | 1911 200 |

 | 53 508649 Slurry

 |

 | 1920 | 2004 | D41A, D418

 | 53 029056
 | 560 W Benfontei | tein
 | 28 50 | 24 50
 | 1917 | 2004 0 | 52L | 53 0435036 W Uitschot
 | 26 36 26 02 | | 2001 | C31C | 53 | 3 264417 Roma | 29 27
 | 27 44 | 1936 | 1985 E |
| 19 Meqautlingsnek | 28 59 | 27 18 | 1923 195 |

 | 54 531618 Persip

 | 25 18 18 51

 | 1928 | | Z10A*

 |
 | 148 W Perdeberg |
 | 28 57 | 25 05
 | 1907 | | 52K, C52L | 54 0435400 W Werk - Met - Lust
 | 26 40 26 14 | | | C31C | 54 | 4 295539 Meguatlingsnek | 28 59
 | 27 18 | 1923 | 1987 8 |
| 54 Kareepan | 28 24 | 26 09 | 1919 200 |

 | 55 532173 Eindpaal

 | 25 23 19 06

 | 1931 | | Z10A*, Z10G

 |
 | 313 W Waterpas
758 W Content |
 | 28 43
28 38 | 25 11
25 26
 | 1955 | | 52K
52K | 55 0471259 W Silverton
56 0471490 W Lusthof
 | 26 19 25 39
26 10 25 47 | | 2004 2003 | C31D
C31D | 55 | 5 296157 Sunny Hills | 28 37
 | 27 36 | 1931 | 1987 B
1987 B |
| 183 Grootkuil
101 Whites-Portland Cement | 28 13
28 01 | 26 30
27 00 | 1911 200
1915 200 |

 | 56 535175 Gemsbokpark-Nossob
57 540466 WERDA

 | 25 16 23 16

 | 1920 | | D42A, D42B, D42C, D42D, D42E, Z10B, Z10E, Z10G
Z10B, Z10F

 |
 | 461 W Dealesvil |
 | 28 41 | 25 46
 | 1908 | | 52H | 57 0471713 W Biesiesviei - POL
 | 26 23 25 54 | | 2003 | C31B | 56 | is 296682 Fickburg-TNK
297388 | 28 52
 | 27 53 | 1920 | 1967 E |
| 71 Vaalbank | 28 02 | 28 10 | 1913 198 |

 | 58 540620 Rusthof

 | 25 10 25 10

 | 1959 | | D41C, D41D, D41E, D41F, Z10B, Z10F

 |
 | 007 W Middelko |
 | 28 37 | 26 01
 | 1925 | | 52H | 58 0472135 W Rietfontein
 | 26 15 26 05 | | 1987 | C31B | 58 | 8 297436 Butha-Buthe | 28 46
 | 28 15 | 1930 | 1985 B |
| 31 Weltevrede | | 27 26 | 1913 195 |

 | 59 541297 Bray

 |

 | 189 | 2004 | D41C, D41D, D41E, D41F, Z10B, Z10F

 |
 | 106 W Florisbad |
 | 28 46 | 26 04
 | 1924 | 1994 0 | 52H | 59 0472175 W Rooijantjiesfontein
 | 26 25 26 06 | | 2001 | C31B | 59 | 9 297721 Clarens-POL | 28 31
 | 28 25 | 1920 | 1987 E |
| 735 Oatlands | | 27 53 | 1920 195 |

 | 60 544778 GOOD Hope

 | 25 28 25 26

 | 1949 | | Z108

 |
 | 204 W Donkerho |
 | 28 55 | 26 08
 | 1910 | | 52D, C52G | 60 0472281 W Lichtenburg - MUN
 | 26 09 26 10 | | 1977 | C31A, C31B | 60 | 298244 Caledonia | 28 34
 | 28 38 | 1920 | 1981 B |
| 8556 Hollowaysrust | 27 16 | 25 49 | 1906 200 | J C2F F

 | 61 545048 DIGAWANA

 | 25 18 25 32

 | 1980 | | 2108

 |
 | 514 W Stillewon
597 W Glen Coll |
 | 28 35
28 57 | 26 18
26 20
 | 1922 | | 52D, C52G
52D, C52G | 61 0472455 W Manana
62 0509796 W Rietspruit
 | 26 06 26 13
25 46 26 26 | | | C31A
C31A, C31D | 61 | 331058 Overdene | 28 28
 | 28 02 | 1920 | 1968 B |
| 8889 Makwassie
1798 Dunkeld | 27 19
27 18 | 26 00
27 28 | 1909 200
1915 195 | 11 C2P 6

 | 62 545839 Welbedacht
63 568817 Mariental

 | 24 37 17 58

 | 1920 | 2004 | D41A, D418, Z108
Z10A*

 |
 | 622 W Karee | selle - wak
 | 28 53 | 26 20
 | 1915 | | 52D, C52G | 63 0509829 W Bokkraal
 | 25 49 26 28 | | | C31A, C31B | | List of key rainfall gauges in Caledon ca | ratchmont
 | | | |
| 4599 Vogelstruiskruil | 26 59 | 25 51 | 1925 200 |

 | 64 570531 Gochas

 | 24 51 18 48

 | 1917 | 2004 | Z10A*

 | 64 02937
 | 792 W Brandfort | urt - MAG
 | 28 42 | 26 27
 | 1905 | 1994 0 | 52D, C52G | 64 0256453 W Douglas - POL
 | 29 03 23 46 | 1883 | 2004 | C92C | | List of key familian gauges in caleaon ct |
 | Longitude | | |
| 5442 Skietfontein | 26 54 | 26 15 | 1953 200 |

 | 65 571871 Vergenoeg

 | 25 01 19 30

 | 1986 | 2004 | Z10A ⁸

 | 65 02942
 | 233 W Idomia |
 | 28 54 | 26 38
 | 1913 | 2004 0 | 52C, C52D, C52E | 65 0287885 W Poplars
 | 28 45 23 30 | | 2004 | C92C | Count | Number Station Name |
 | Deg Min | Record starts | Record ends Ca |
| 37555 Hartebeestpoort
74255 Klerkskraal | 26 45
26 15 | 27 18 | 1925 200
1903 200 |

 | 66 611630 Hardap
67 612710 Stampriet

 | 24 30 17 52
24 20 18 24

 | 1982 | 2003 | Z10A*
Z10A*

 | Liete
 | of kov rainfall o | gauges in Lower Orange
 | o catchmont |
 | | | | 66 0288054 W Koekama
67 0288416 W Kalkdam
 | 28 54 23 32
28 56 23 44 | | 2004 | C92C
C92C | 1 | 1 232018 CYFERFONTEIN
2 232083 HELVETIA - POL | 29 48
29 53
 | 26 31
26 33 | 1920 | 2004 D2/
1961 D2/ |
| 4270 Frederikstad-SAR | 26 30 | 27 09 | 1910 200 |

 | 68 612818 Rohrbeck

 | 24 08 18 28

 | 1958 | 2004 | Z10A*

 | List of
 | i key tainan ga |
 | | ongitude
 | | | | 68 0288528 W Tweefontein
 | 28 48 23 48 | 1919 | 2004 | C92B | 3 | 3 232123 ROODEPOORT | 29 32
 | 26 36 | 1920 | 1989 D2 |
| | | | |

 | 69 614188 Aranos

 | 24 08 19 07

 | 1947 | | Z10A*

 | Count Statio
 | |
 | |
 | ecord starts R | cord ends | | 69 0288610 W Salmonsfontein
 | 28 40 23 51 | | | C92B | 4 | 4 232383 MENTZBURG | 29 54
 | 26 44 | 1928 | 1985 D |
| of key rainfall gauges in Vaal Ba | Barrage catchn
Latitude | Longitude | |

 | 70 614406 Omrah
71 619661 TSHANE

 | 24 16 19 14
24 01 21 53

 | 1951 | 2000 | 210A*
2108, 210E

 |
 | 66304 Gunsfont
87635 Bet-el |
 | 32 34
32 05 | 20 41 20 22
 | 1960 | | 58, D5C
5A, D5B | 70 0289102 W Schmidtsdrif
71 0289243 W Muirton
 | 28 42 24 04
28 33 24 10 | | 1979
1979 | C92B
C92A | 5 | 5 232673 KROMDAM
6 232823 WATERFORD | 29 44
29 43
 | 26 51
26 58 | 1923 | 1986 D2
1989 D2 |
| er Station Name | Deg Min | | ecord starts Record | ends Catchment(s)

 | 72 654736 Mbela

 | 23 46 17 55

 | 1954 | 1994 | Z10A*

 |
 | 89693 Grootfont | ntein
 | 32 03 | 21 24
 | 1930 | | 50 | 72 0289302 W Caerwinning
 | 28 32 24 11 | 1926 | 1956 | C92A | 7 | 7 232895 SWEETWATER | 29 55
 | 27 0 | 1920 | 2004 Di |
| 2788 OORSPRONG - OOS | 27 8 | 27 57 | 1919 199 | 6 807 7

 | 73 655503 Gomchanas

 | 23 53 18 17

 | 1939 | 2004 | Z10A*

 |
 | 90196 Tafelberg | rg
 | 32 16 | 21 37
 | 1914 | | SD, DSE | 73 0290032 W Barkly West - TNK
74 0290464AW Kimberley - POL
 | 28 32 24 32
28 44 24 46 | | | C91E
C91E | 8 | 8 232898 QUILIMANE | 29 58
 | 27 0 | 1920 | 1989 D: |
| 1062 Midden
1315 Barrage-RWB | 27 02
26 08 | 28 02
27 57 | 1929 197
1916 200 |

 | 74 656457 Reitz
75 656510 Leonardville

 | 23 37 18 46
23 30 18 47

 | 1962
1928 | 2004 2004 | Z10A*
Z10A*

 | 5
 | 91763 Paardekr
109835 Die Hoop | raal
 | 32 13
31 55 | 22 26
19 58
 | 1935 | 2004 D | SE SA | 74 0290464AVV Kimberley - POL
 | 28 44 24 46 | 1884 | 2004 | C91E | 9 | 9 233044 WEPENER
0 233078 WONDERBOOM | 29 44
29 48
 | 27 2 27 3 | 1950
1920 | 1986 D
2000 D |
| IS14 Rietspruit | 26 34 | 27 46 | 1930 197 | 7 806

 | 76 664435 KANG

 | 23 45 22 45

 | 1985 | 2003 | 2108

 |
 | 110512 Diepdrift |
 | 31 32 | 20 18
 | 1934 | 2004 0 | SA | List of key rainfall gauges in Upper Vaal
 | i catchment | | | | 11 | 1 233103 MON REPOS | 29 43
 | 27.4 | 1920 | 1973 D |
| 533 Pietershoogte | 26 53 | 27 48 | 1986 198 |

 | 77 698865 Christirina

 | 23 25 17 59

 | 1981 | 2004 | Z10A*

 |
 | 111373 Daniels H |
 | 31 43 | 20.43
 | 1924 | | 58, D5C, D5D |
 | Latitude Longitude | | | | 12 | 2 233154 ZAMENLOOP | 29 34
 | 27 6 | 1920 | 1958 0 |
| 550 VANDERBIJLPARK - YSKOR
716 Rietfoentein | 26 40
26 56 | 27 49 27 54 | 1942 195
1915 198 | 1 806, 807 7

 | 78 740154 Windhoek
79 740677 Binsenheim

 | 22 34 17 06
22 47 17 23

 | 1912 | 2004 | Z10A*
Z10A*

 |
 | 112672 Rusoord
113025 | ·
 | 31 42
31 55 | 21 23
21 31
 | 1957 | 2004 0 | SE, DSG Cou | 1 298512 Witsieshoek
 | Deg Min Deg Min
28 32 28 48 | | Record ends
2004 | Catchment(s) | 13 | 233195 VANROOYENSHEK - POL 233239 LADYSDALE | 29 45
30 0
 | 27 7 27 8 | 1965 | 2004 C |
| | | 27 54 | 1905 200 |

 | 80 740711 Rietfontein

 |

 | 1933 | 2004 | Z10A*

 |
 | 113673 Saaifonte | tein
 | 31 43 | 21 53
 | 1920 | | 56, D5F | 2 298871 BOSCHKLOOF
 | 28 32 29 0 | 1924 | 1988 | STERK | 15 | 15 233242 HOBHOUSE - POL | 29 32
 | 27.9 | 1920 | 2004 D |
| 734 Viljoendrift-Pol | 26 44 | 27 55 | 1972 199 | 4 807

 |

 |

 | | | Z10A*

 | 12
 | 136740 Williston | on - Skl
 | 31 20 | 20 55
 | 1936 | 2004 0 | |
 | 28 2 28 10 | 1912 | 1995 | FRANK | 16 | 6 233267 VADERSGIFT | 29 57
 | 27 9 | 1920 | 2004 D |
| 734 Viljoendrift-Pol
744 Clydesdale Colliery | 26 56 | | |

 | 81 740792 Hohenau

 | 22 51 17 24
22 42 17 27

 | 1913 | |

 |
 | |
 | |
 | | | 5G | 3 331271 VAALBANK
 | | 1913 | 1981 | FRANK | 17 | 7 233439 MAFETENG
234008 MORIJA | 29 49
29 38
 | 27 14 | 1920 | 1989 D
2001 C |
| 34 Viljoendrift-Pol
44 Clydesdale Colliery
50 Schaapplaats | 26 56
27 00 | 27 53 | 1933 198 | 0 807

 | 81 740792 Hohenau
82 741219 Wolffsgrund

 | 22 42 17 27
22 39 17 38

 | 1913
1930 | 1977 | Z10A*

 | 13 1
 | 136741 Williston | n - SAR
 | 31 21 | 20 55
 | 1920 | | 5G
5A,D5B,D5C,D5D
5E,D5G | 4 331740 SPITSKRANS
 | 28 20 28 25 | | | EDANK | 18 | 204000 MORUM |
 | | 1965 | |
| 34 Viljoendrift-Pol
44 Clydesdale Colliery
50 Schaapplaats
03 MEYERTON | 26 56 | | 1933 198
1920 199
1970 199 | 0 807
4 803
807

 | 81 740792 Hohenau 82 741219 Wolffsgrund 83 743117 Styria

 | 22 42 17 27
22 39 17 38
22 57 18 34

 | 1913
1930
1915
1930 | 1977 |

 | 13 1
14 1
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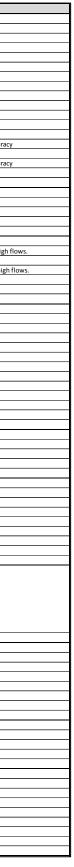
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APPENDIX B: TABLE B-2 – CALIBRATION FLOW GAUGING STATIONS USED

ertiary Catchment	Gauge	River	Location	Lat	Long	Area	Used record	Comments
	C2H001	Мооі	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
V _M	C4H002 C4H004	Vet Vet	Floorsdrift Nooitge-dacht	27 50 45 27 56 06	25 54 32 26 07 36	17599 16153	1950 - 1971 1968 - 1994	Overestimates high flows High flows suspect
	C4R001	Sand	Allemans-kraal Dam	27 56 06	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 accurate
	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 accurate
	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
	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.
VL	C9H009	Vaal	De Hoop	28 30 58	24 36 03	3201	1971 - 1994	Good record, many missing values prior to 1990.
	C5R001 C9R001	Tierpoort Vaal	Tierpoort Dam Vaalharts Weir	29 25 20 28 06 57	26 08 10 24 55 32	922 2509	1923 - 1976 1971 - 1994	Good record, many missing values after 1986. Good record.
	C1H001	Vaal		26 56 30	29 15 51	7995	1971 - 1994	Good. From 1978 reflects Grootdraai releases
	C1H001	Klip	Langwerwyl Sterkfontein	26 36 30	29 13 31	4158	1920-2004	Many unreliable values due to submergence during high flows. Use in combination with C1H015 for high
	C2H003	Vaal	Elandsfontein	26 49 10	28 03 48	38638	1923-1936	Good. From 1936 reflects Vaal Dam releases
Vu	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
- 0	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
	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 K21	Small Rietspruit	Waterval Sewage Works	26 27 00	28 07 00	465	1975 - 1988	Assessment unavailable
v	C2H141 and C2H02	Klip	Alberton Road Bridge Heidelberg	26 24 00 26 27 13	28 05 00 28 05 09	779 1726	1991 - 2004 1993 - 2004	Assessment unavailable
V _B	2C2H071 (K19)	Klip	Kookfontein Train Bridge	26 27 13	27 58 51	2205	Unavailable	Assessment unavailable Assessment unavailable
	C2H005 (RV2)	Greater Rietspruit	Kaalplaats	26 43 47	27 38 31	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
	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.
RM	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.
	D2H001	Caledon	Jammerdrift	29 72 00	26 98 00	13421	1920-1976	Good record. Original patched record used
	D2H012 D2H037	Little Caledon	The Po	28 30 00	28 24 00	518	1968-2004	Good record
	D2R002	Caledon Leeu	Wilgedraai Armenia	29 36 34 29 35 00	27 03 52 27 13 00	12850 858	1993- 2004 1954-2004	Good but short record Good record from 1973 onwards
CA	D2R002	Caledon	Welbedacht	29 33 00	26 87 00	15245	1973-2004	Good record but changing capacity makes calibration difficult
CA	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
	G03	Senqu	Seaka	30 27 47	29 34 29	5243	1966-2004	
	G06	Senqu	Mokhotlong	29 17 00	28 58 59	2059	1966-2004	
	G07	Senqu	Tsoelike	30 01 29	28 43 23	820	1966-2004	
SE	G17	Senqu	Marakabei	29 33 35	28 09.4	1087	1966-2004	WR2005 data mostly used for 1967 - 1987 and then latest data for 1993 to 2004 from Lesotho DWA
JL	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
	D1H009	Orange	Oranjedraai	30 33 35	27 35 53	4544	1960-2004	Good long record
	D1H001 D1H003	Wonderboom Orange	Diep Aliwal-North	32 00 00 30 68 00	26 35 00 26 71 00	2065 3645	1920-2004 1920-2004	Bad record highly patched Good Record
	D1H003	Stomberg	Molte	31 04 00	26 71 00	324	1920-2004	Good record
Ou	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
	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	ОК
OI	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)
	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 3111M01	White Nossob	Amasib	Unknown	Unknown	Unknown	1973-2004	Assessment unavailable
Jone /Nesset		Black Nossob	Henopsrus	Unknown	Unknown Unknown	Unknown	1969-2004 1969-2004	Assessment unavailable Assessment unavailable
olopo/Nossob		Plack Noscob	Doon Vilioon Dom					
olopo/Nossob	3111R01	Black Nossob Black Nossob	Daan Viljoen Dam Mentz	Unknown Unknown		Unknown		
olopo/Nossob	3111R01 3111M02	Black Nossob	Mentz	Unknown	Unknown	Unknown	1973-2004	Assessment unavailable
1olopo/Nossob	3111R01							



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

Teriary			Incremental File		Catchment	t Area (km²)	MAP (Area	MAE (Area	VRS	AU (1920 - 1994)			OM (1920 - 2	2004)	% Diff
Catchment	Ref#	Description	Name	Gauging Station #	Gross	Nett	Weighted)	Weighted)	10 ⁶ m³/a		nental Na %MAP	tural Runoff 10 ⁶ m ³ /a	mm/a	%MAP	(MAR) Quatenaries
		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
Vu		3 Grootdraai Dam	grootd9.inc	C1H001/C1R001	7995	7995	690	1407	457.7	57	8.3%	462.0	58	8.4%	1% C11A-L
0		4 Sterkfontein	sterk9.inc	C8R003	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 ₁₁)				,	38638			1451	1977.3	51	7.4%	2073.2	54	7.8%	5%
		1 Vaal Barrage	barr9.inc	C2R008	2828	2828	637	1650	68.5	24	3.8%	72.2	26	4.0%	5% C22F-K
V _B		2 Klip River	klipr9.inc	C2H071/K19	2282	2282	670	1650	96.2	42	6.3%	102.7	45	6.7%	7% C22A-E
Б		3 Suikerbosrant River	suik9.inc	C2H004/S2	3541	3541	668	1650	92.3	26	3.9%	99.9	28	4.2%	8% C21A-G
ub-Total (V _B)			bandshire	0211001/02	8651	8651	658	1650	257.0	30	4.5%	274.8	32	4.8%	7%
		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	C2H062	1350	1180	582	1750	60.6	45	7.7%	58.2	43	7.4%	-4% C24C * - See note below Table
		3 Klerkskraal Dam	klerk9.inc	C2R003	1330	1001	605	1750	37.7	28	4.7%	39.7	30	5.0%	5% C23F
		4 Upper Schoonspruit	c24e.inc	C2R003	925		560	1700	9.8	28	4.7%		30	5.0% 1.9%	0% C24E
		Rietssruit Dam	c24e.inc	C2R002	364	364	584	1800	9.8 7.3	20	3.4%	9.8 7.4	20	1.9% 3.5%	1% C24D
		Boskop Dam	bosk9.inc	C2R002	1973	1756	629	1725	35.8	18	2.9%	37.5	19	3.0%	5% C23D, E & G
		7 Johan Neser Dam incremental	c24g.inc	C2R001	985	985	581	1820	16.9	18	2.9%	16.9	13	3.0%	0% C24G
		BLakeside Dam	lakesn3.inc	C2H085	451	451	604	1700	9.4	21	3.4%	9.7	21	3.6%	3% C23H
		P Klipdrif Dam	klipdn3	C2R005	890			1670	20.3	23	3.7%	21.2	24	3.8%	5% C23J
		Lower Schoonspruit	c24h.inc	C2H061	840			1820	8.8	11	1.8%	8.5	10	1.8%	-4% C24H
		1 Kromdraai	kromn3.inc	C2H018	2028	2028	613	1625	40.9	20	3.3%	42.0	21	3.4%	3% C23A, B & C
		2 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
V _M		3 Renoster River (C70K)	c70k.inc	C7H006	891	392	565	1690	10.9	12	2.2%	10.3	12	2.0%	-6% C70K
		4 Renoster River (C70J)	c70j.inc	C7H006	521	521	575	1670	8.6	16	2.9%	8.6	16	2.9%	0% C70J
		5 Renoster River (C70E)	c70e.inc	C7H006	693	693	578	1630	12.0	17	3.0%	12.0	17	3.0%	0% C70E
	16	6 Renoster River (C70H)	c70h.inc	C7H006	251	251	568	1650	4.0	16	2.8%	4.0	16	2.8%	0% C70H
	17	7 Renoster River (C70F)	c70f.inc	C7H006	564	564	574	1620	9.5	17	2.9%	9.5	17	2.9%	0% C70F
	18	8 Renoster River (C70G)	c70g.inc	C7H003	901	901	577	1600	14.0	15	2.7%	16.9	19	3.3%	21% C70G
	19	9 Renoster River (C70D)	c70d.inc	C7H006	675	675	586	1600	12.6	19	3.2%	12.6	19	3.2%	0% C70D
) Koppies Dam	kop9.inc	C7R001	2160	2160	617	1550	59.1	27	4.4%	61.1	28	4.6%	3% C70A, B & C
	22	1 Klipbank	klipbn3.inc	C6H003	7871	6351	563	1575	150.8	19	3.4%	153.3	19	3.5%	2% C60A - J
		2 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
		3 Allemanskraal Dam	allem9.inc	C4R001	3628	3628	593	1465	96.1	26	4.5%	94.9	26	4.4%	-1% C42A - E
	24	4 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%
	:	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
VL	4	4 Taung Dam	Dswentzd.inc	C3H003	1789			1960	13.1	7	1.5%	12.1	7	1.4%	-7% C31F
۷L	Į.	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		397	2150	11.7	3	0.7%	11.7	3	0.7%	0% C33C
		7 De Ноор	Dehoop.inc	С9Н009	6587	3201	406	1963	12.9	2	0.5%	15.3	2	0.6%	18% C91C, D & Prtn C91E
	8	B Douglas Weir	Douglas.inc	C9R003	10136			2221	18.6	2	0.5%	18.6	2	0.5%	0% Prtn C91E, C92A - C, C51M
ub-Total (V _L)					55019			2023	190.8	3	0.8%	191.5	3	0.8%	0%
		1 Aucampshoop		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		1871	14.4	1	0.3%	15.7	1	0.3%	9% C52H - L
RM		3 Krugersdrift Dam	Krug.inc	C5R004	5394		508	1639	114.4	21	4.2%	118.1	22	4.3%	3% C52B - G
11141		4 Kalkfontein Dam	Kalkf.inc	C5R002	9342		412	1740	215.9	23	5.6%	185.9	20	4.8%	-14% C51A - C & C51E - J
		5 Tierpoort Dam	Tier.inc	C5R001	922			1640	23.8	26	5.2%	23.2	25	5.1%	-2% C51D
	6	5 Rustfontein Dam	Rustf.inc	C5R003	937			1600	30.7	33	6.0%	31.0	33	6.1%	1% C52A
ub-Total (RM)					33294			1745	405.5	12	2.8%	379.6	11	2.6%	-6%
otal Secondary	Catchme	ent: 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

					Catchmer	nt Area	_		-		VRSAU (1	1920 - 19	995)	ORASECON	1 (1920 -	- 2004)	
Teriary	Ref#	Description	Incremental File	Calibration Flow Gauging	(km	²)	MAP (Area		MAE (Area			Incre	emental N	latural Runoff			% Diff Quatenaries
Catchment		•	Name	Station #	Gross	Nett	Weighted)		Weighted)		10 ⁶ m³/a n	nm/a	%MAP	10 ⁶ m ³ /a I	mm/a	%MAP	(MAR)
	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 (19	920 - 19	87)	ORASECON	1 (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
CA	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 D	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
0	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
Ο _U	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)	-Total (O _U)				49746	43038	412	20475874	1843	91683209	1151.1	23	5.6%	954.9	19	4.7%	-17%
Total Secondary	Catchmen	t: 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		Incremental File	Calibration Flow	Catchment	$\Delta rec (low2)$	MAP (Area	MAE (Area	WR2005	i (1920 - 2	2004)	ORASECO	M (1920 - 2004)	% Diff	
Catchment	Ref# Description	Name	Gauging Station #	Catchment	Area (KIII)	Weighted)	Weighted)		Incre	emental Na	atural Runoff		MAR	Quatenaries
Catchinent		Name	Gauging Station #	Gross	Nett	weighted)	weighted)	10 ⁶ m³/a	mm/a	%MAP	10 ⁶ m ³ /a	mm/a %MAP	WIAN	
во	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
ЬО	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%	
	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
O _M	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%	
	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
SH	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%	
	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
OL	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)	ıb-Total (O _L)					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

					Catchment	Area (km ²)	MAP (Area	MAE (Area	ORASE	COM (1920 - 20	04)	
Teriary Catchment	Ref#	Description	Incremental File Name	Calibration Flow Gauging Station #	Catchment	Area (Km.)	•	•		al Incremental ¹	.&2	Quatenaries
Catchinent			File Name		Gross	Nett	Weighted) ²	Weighted) ²	10 ⁶ m ³ /a	mm/a	%MAP	
		1 Sb1Ru1 - D41A	D41A.inc	D4H013 & D4H037	4 301	2 778	521		9.9	2	0.4%	5 D41A
		2 Sb1Ru2 - D41B	D41B.inc	D4H002	6 239	5 193	476		4.7	1	0.2%	5 D41B
		3 Sb1Ru3 - D41C	D41C.inc		3 915	2 995	416	2050	2.8	1		5 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%	5 D41E
		6 Sb2Ru2 - D41F	D41F.inc		6 002	1 498	338	2250	0.0	0	0.0%	5 D41F
M _U		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%	5 D41N
		9 B4Ru1 - Z10D - D41M Botswana	D41M.inc		1 701	936	371	2250	1.1	1	0.2%	5 D41M
	1	0 B3Ru1 - Z10F - D41K Botswana	D41K.inc		10 718	750	288	2250	0.0	0	0.0%	5 D41K
	1	1 Sb3Ru1 -D42C1 - D41J	D41J.inc		2 685	190	225		0.0	0		5 D41J
	1	2 D41L&H	D41J.inc	Modelled as Endoreic	91 605	0	N/A	N/A	N/A	N/A	N/A	D41L&H
Sub-Total (M					142 706	19 773	372		22.9	0	0.1%	
	- - -	1 S1Ru1 - D41H2 - D42A	D42A.inc		5 371	1 388	316		0.2	0		D42A
		2 S1Ru2 - D41G - D42B	D42B.inc		4 305	2 408	361	2199	1.4	0		D42B
		3 S2Ru3 - D41L - D42D	D42D.inc		5 375	2 946	403		6.4	1		D42D
КU		4 S2Ru1 - D41J - D42F	D42F.inc		3 874	1 360	323		0.7	0	0.1%	6 D42F
		5 S2Ru2 - D41K - D42E	D42E.inc		4 213	1 552	330	2351	1.1	0		6 D42E
		6 S2Ru4 - D41M - D42C	D42C.inc		2 626	471	322	2399	0.0	0		D42C
		7 S3Ru1 - D42C2 - D42G	D42G.inc		15 431	1 075	258		0.0	0	0.0%	D42G
Sub-Total (K	U)				41 195	11 200	313		9.8	0	0.1%	
•		1 Sn1Ru1 - D42D - D45C	D45C.inc		16 210	138	182		0.0	0		6 D45C
M		2 S4Ru1 - D42E - D45D	D45D.inc		4 208	1 044	188	2750	0.0	0		6 D45D
-		3 D45A&B	-	Modelled as Endoreic	17 923	0	N/A	N/A	N/A	N/A	N/A	D45A&B
Sub-Total (M	IL)		•	1	38 341	1 182	183	2750	0.0	0	0.0%	
•		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%	۶ Part of D43A, upstream of Daan Viljoen Dam
NO		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		5 D43B
		4 Snb2Ru1 - D42A1 - D43C Botswana	D43C.inc		4 749	342	222	2900	0.0	0		D43C
		5 Snb1Ru1 - D42B - D44D Botswana	D44D.inc		3 203	101	165	2951	0.0	0	0.0%	D44D
Sub-Total (N	0)				71 650	7 415	262	1827	6.5	0	0.0%	/ 0
		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		Part of D44A, upstream of confluence with Seeis
		3 N4Ru2 - Z10A7 - D44B1 - Lower Olifants River	Lolif.inc		12 106	2 032	195		0.7	0	0.0%	Part of D44B, upstream of confluence with Auob
AU		4 N4RU1 - Z10A6 - D44B2 - Upper Auob River	UAub.inc	3124M02 Stampriet & 3124M01 Cochas	19 383	1 356	195		3.3	0		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%	5 D44C
		Nauaspoort Dam, Oanob Dam and remainder of Skaap – Not modelled in Molopo-Nossob 6 Study	-		16 633	N/A	N/A	N/A	N/A	N/A	N/A	D44E-G
Sub-Total (A	U)		•		57 661	4 153	198	1856	4.4	0	0.1%	6
		actment: Molopo-Nossob			351 553	43 723	277		43.7		0.1%	

Notes: (1) Natural Runoff includes estimates of losses

(2)

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

