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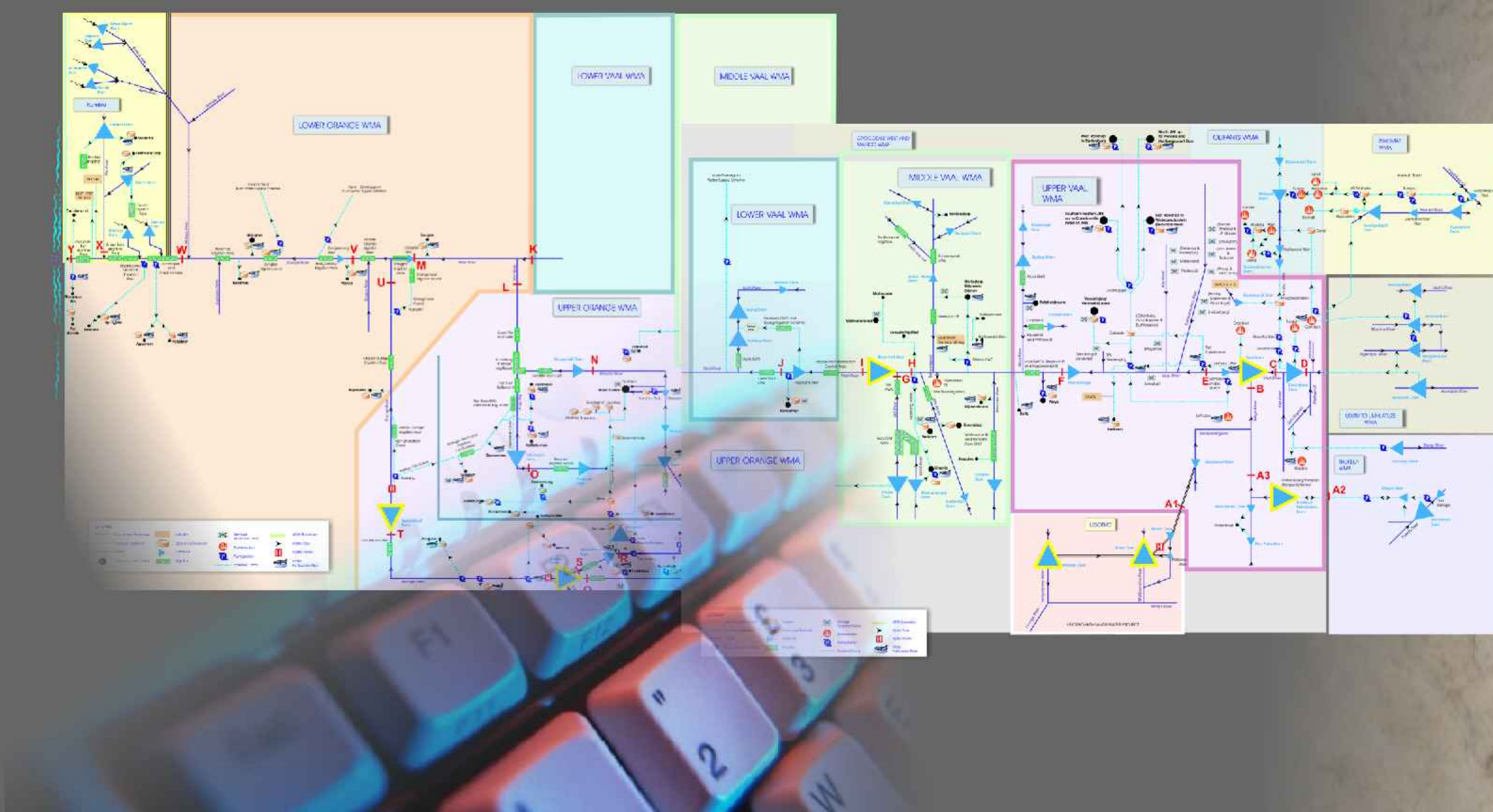
ORANGE - SENQU RIVER COMMISSION
BOTSWANA LESOTHO
ORASECOM
NAMIBIA SOUTH AFRICA
Established 2000

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

Work Package 1:
Water Resources Modelling of the Orange-Senqu Basin

Setting up and Testing of the Final Extended and Expanded Models; Changes in Catchment Yields and Review of Water Balance



April 2011

ORASECOM

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

Prepared by

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Study Name	Support to Phase 2 of the ORASECOM Basin-wide Integrated Water resources Management Plan
Report Title:	***Setting up and Testing of the Final Extended and Expanded Models, Changes in Catchment Yields and Review of Water Balanc***e
Submitted by:	WRP Consulting Engineers in association with Golder Associates, DMM, PIK, RAMBOLL and WCE

REPORTS, WPS AND OTHER DELIVERABLES SUBMITTED	TYPE	No.
Overall Study		
Inception Report	Report	004/2010
Final Report	Report	013/2011
Work Package 1: WATER RESOURCES MODELLING OF THE ORANGE-SENQU BASIN		
Strengths and Weaknesses of Existing Models	WP	005/2010
Setting up and Testing of the Final Extended and Expanded Models; Changes in Catchment Yields and Review of Water Balance	***Report & WP***	***001/2011***
Modelling software and datasets	Software	None
Capacity Building and Setting up the Models in each Country; Process of Continuous Review	WP	003/2011
Work Package 2: EXTENSION AND EXPANSION OF HYDROLOGY OF ORANGE-SENQU BASIN		
Improvements to Gauging Network and Review of Existing Data Acquisition Systems	WP	005/2011
Extension of Hydrological Records	Report	006/2011
Hydrological Database	Database	None
Work Package 3: INTEGRATED WATER RESOURCES QUALITY MANAGEMENT PLAN		
Development of Water Quality Monitoring programme and Data Management Framework	Report	007/2011
Development of Specifications for the Water Quality Model	WP	006/2010
Work Package 4: CLIMATE CHANGE IN THE ORANGE-SENQU RIVER BASIN		
Downscaling Methodology and Ongoing Climate Modelling Initiatives	WP	007/2010
GCC Downscaling for the Orange-Senqu River Basin	Report	008/2011
Projection of impacts and Guidelines on Climate Change Adaptation Strategies	WP	009/2011
Work Package 5: ASSESSMENT OF ENVIRONMENTAL FLOW REQUIREMENTS		
Literature survey and Gap Analysis	WP	008/2010
Delineation of Management Resource Units	WP	009/2010
Desktop EcoClassification Assessment	Report	016/2010
Goods and Services Report	WP	010/2010
Environmental Flow Requirements	Report	010/2011
Work Package 6: WATER CONSERVATION AND WATER DEMAND IN THE IRRIGATION SECTOR		
The Promotion of WC WDM in the Irrigation Sector	Report	011/2011
Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools	WP	012/2011
Irrigation GIS Database and Interactive Classification Tool	Software	None
Irrigation Scenario Generation Tool	Software	None

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1 INTRODUCTION AND OBJECTIVES

1.1 General

The Orange - Senqu River originates in the highlands of Lesotho, some 3 300m above mean sea level and it runs for over 2300km to its mouth at the Atlantic Ocean. The river system is one of the largest river basins in Southern Africa, with a total catchment area of more than 850,000km^2 and includes the whole of Lesotho as well as portions of Botswana, Namibia and South Africa. The natural mean annual runoff at the mouth is estimated to be in the order of 11 500 million m^3. This runoff has been significantly reduced by extensive water utilization for domestic, industrial and agricultural purposes to such an extent that the current flow reaching the river mouth is now in the order of half the natural flow. The basin is shown in **Figure 1-1**. The Orange-Senqu system is regulated by more than thirty-one major dams and is a highly complex and integrated water resource system with numerous large inter- and intra-basin transfers.

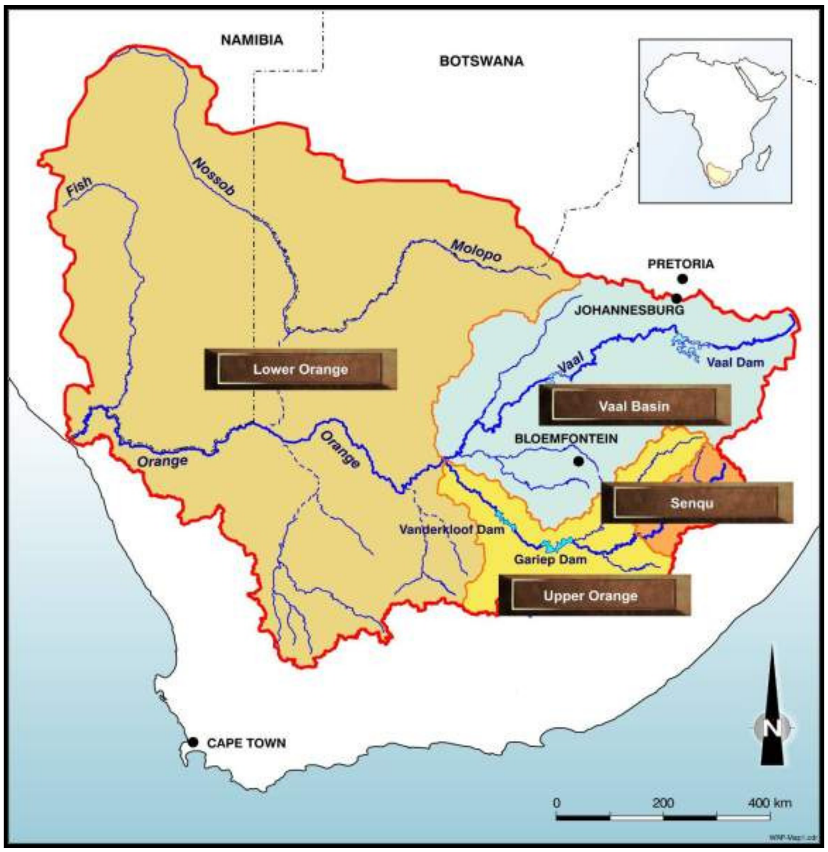

Figure 1-1: Orange – Senqu River Basin

1.2 Management and Environmental Context

1.2.1 General

Management issues, including environmental protection, conservation and sustainable development, have to deal with problems relating to water quantity and water 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 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 of both 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 demands) further downstream, is a challenge for planners, 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, 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), a further positive step has been the initiative towards the establishment of river basin commissions. 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 partiers 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 organizations (RBO); and
- Capacity development of local water governance and transboundary 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 **Table 1-1**.

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

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.

The Six Work Packages

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

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

Work Package	Main Objectives	Main Activities
WP 1: Development of Integrated Orange-Senqu River Basin Model	To enlarge and improve existing models so that they incorporate all essential components in all four States and are accepted by each State	• Extension and expansion of existing models • Capacity building for experts and decision-makers • Review of water balance and yields • Design/initiation of continuous review process
WP 2: Updating and Extension of Orange-Senqu Hydrology	Updating of hydrological data, hands-on capacity building in each basin state for generation of reliable hydrological data including the evaluation of national databases,	• Assessment of Required Improvements to the Existing Gauging Networks. • Capacity Development • Extension of Naturalized Flow Data • Review of Existing Data Acquisition Systems, proposals on basin-wide data acquisition and display system.
WP 3: Preparation and development of integrated water resources quality management plan	Build on Phase 1 initial assessment to propose water quality management plan, based on monitoring of agreed water quality variables at selected key points	• Establishment of protocols, institutional requirements for a water quality monitoring programme, data management and reporting. • Development of specifications for a water quality model that interfaces with the systems models. • Capacity building to operate the water quality monitoring system and implement the water quality management plan.
WP 4: Assessment of global climate change	Several objectives leading to assessment of adaptation needs	• Identification of all possible sources of reliable climate data and Global Climate Model downscaling for the Orange-Senqu Basin • Scenario assessment of impacts on soil erosion, evapotranspiration, soil erosion, and livelihoods • Identification of water management adaptation requirements with respect 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 demand management in the key irrigation sector (WP6).

1.4 Background to Work Package 1 and this Report

1.4.1 Work Package Objectives

The main objectives for this Work Package are to enlarge and improve the existing models to cover the total Orange River Basin and to capacitate representatives of each of the basin states to set up and use the models effectively. The improvement of the existing models included a number of aspects, namely:

- Updated demands and return flows: All demands and return flows were updated to 2010 development level using latest available information: Vaal & Orange River Annual Operating Analyses, Small Towns Studies;
- Extended hydrology included: All hydrology extended till 2004-05 (carried out in WP2);
- New catchments configured into the model including the Molopo River and the Lower Orange tributaries; and
- Finer level of details included on existing catchments including selected Vaal sub-catchments and the Lesotho Lowlands area.

1.4.2 Work Package Activities

- Assessment of the strengths and weaknesses of the existing models.
- Extension and expansion of the existing models.
- Provision of a clear assessment of any anticipated changes in the yield of each catchment, in a probabilistic manner.
- Review the water balance for the Basin, (recording both the demand and supply components).
- Design and initiation of a suitable technical process for a continuous review (at least annually) of the water balance to identify and pre-empt potential future problems.
- Assist representatives from each of the four Basin States to set up the models in each country and ensure that ORASECOM staff in each basin state are able to use the models effectively.

1.5 Structure of Report

While the initial intention was for this Work Package to produce a Report on the extension and expansion of the existing models followed by a Working Paper on the updated yields and water balance, this has been changed and the Report and Paper have been amalgamated into one report presenting both.

This report is divided into a number of different sections in order to make it simpler and easier for the user to read. The section following the introduction presents an overview of water resources modelling and describes the various models used in the process. **Section 3** presents a summary of the hydrology used in the systems analyses models. This is followed by **Section 4,** which presents a summary of the demands and return flows used (details of which can be found in **Appendix C**) and **Section 5,** which summarises the physical system components. **Section 6** presents an overview of the configuration of the WRYM and **Section 7** presents the results from the yield analyses and updated water balance carried out with the WRYM. **Section 8** is only a very brief introduction to the WRPM. A detailed report will be compiled only once the proposed "additional work" has been completed. The last section of the report presents conclusions and specific recommendations resulting from this activity. The report also includes Appendices in which the reader will locate the geographical maps and schematic network diagrams for the WRYM configuration as well as further details referred to under the specific chapters in the report.

2 SYSTEMS ANALYSES MODELS

Water resources modelling can be divided into three main modelling processes namely:

- **Rainfall-runoff modelling:** objective to produce naturalized hydrology that covers the entire historical record period based on observed streamflow and rainfall data for input into yield and planning models;
- **Yield modelling:** objective to determine yields of individual sub-catchments for input into planning model; and
- **Planning and operations modelling:** objective to operate and manage catchments in an integrated manner using individual sub-catchment yield characteristics.

The models used for the systems analyses for this study are as follows:

- **WRSM2000 and NAMRON**: Used to prepare hydrology, Namron only used for Namibian Fish River hydrology
- **WRYM**: Used to determine sub-catchment yields;
- **WRPM**: Configured for future management of the Integrated Orange-Senqu River catchment.

The remainder of this section provides a brief description of the models used. References are provided for other reports should the reader wish to obtain more details of the models.

2.1 Water Resources Simulation Model 2000 (WRSM2000)

WRSM2000 is a mathematical model to simulate the movement of water through an interlinked system of catchments, river reaches, reservoirs, irrigation areas and mines. WRSM2000 is of a modular construction (running under Windows), with five different types of modules (runoff, reservoir, irrigation, channel and mine) linked by means of routes. The routes represent lines along which water flows, such as river reaches.

The model was first developed in 1969 and has been subject to numerous enhancements over the years. WRSM2000 has been used to analyse the hydrology on a monthly time scale for a number of diverse applications ranging from very small to very large catchments varying in complexity from being totally undeveloped to highly developed. It has been used throughout South Africa, SADC countries and even in certain overseas countries.

Some common uses of the model are:

- to calibrate streamflow records taking land-use changes over time into account by comparing the observed flows against those simulated by the model;
- for broad regional assessment of water resources;
- to produce naturalised flow records i.e. take out man-made land-use effects;

- to estimate flows in ungauged catchments by transferring parameters.;
    - when the density of flow gauges is insufficient to cover all catchments, when record periods are too short and/or when records show changes in land-use over time;
- simple reservoir yield analysis;
- input to complex system models of water resources (eg. WRYM, WRPM and WSAM);
- input to water quality studies and
- input to Ecological Water Requirement models.

The model is not appropriate for flood design and for determining yields of dams in a complex system of competing water users. Each of the 5 Modules contains one (or offers a choice between more than one) hydrological Models that simulate a particular hydrological aspect. The Modules are linked to one another by means of Routes. Multiple instances of the different Modules, together with the Routes, form a Network. By choosing and linking several modules judiciously, virtually any real-world hydrological system can be represented.

The first step in simulating any hydrological system is to set up the Network of Modules and Routes to represent this system. The Windows version of WRSM2000 allows for much larger networks than ever before and offers interactive creation and editing of all Modules, Routes and Networks. The program supports the user by means of extensive error checking and does away with the error prone and time consuming chore of creating data files in an editor, external to the program. Where files of older versions of the program are supplied, WRSM2000 will automatically update these files to be compatible to this latest version. WRSM2000 simulates flows in a catchment and by comparing against observed flows, the user can analyse statistics and graphs of various water resource parameters and manipulate calibration parameters to achieve a good 'fit' between observed and simulated flows. Once this has been achieved for the network, naturalised flows can be determined i.e. flows without any man made effects of reservoirs, industry, towns, irrigation schemes, mines etc.

The original version of the NAMRON rainfall/runoff model was developed within the Hydrology Division of the Namibian Department of Water Affairs in 1981. It can be run on a monthly or annual timestep. In the case of the Fish River it has been run using a monthly time step. One of the main differences between NAMRON and models used in South Africa and elsewhere, is that it allows for "negative serial correlation". It has been observed in many of the more arid parts of Namibia that higher than average antecedent previous rainfall years tend to generate above average vegetation coverage in the catchment and that this has a runoff inhibiting effect. NAMRON allows the user to take into account the effects of the previous three years of rainfall.

2.2 Water Resources Yield Model (WRYM)

The WRYM is a monthly stochastic yield reliability model used to determine the system yield capability at present day development levels. The model allows for scenario-based historical firm and stochastic long-term yield reliability analysis. In addition, short term reservoir yield reliability can be determined, given current starting conditions.

The WRYM was developed by the South African Department of Water Affairs (SA-DWA) for the purpose of modelling complex water resource systems and is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating the country's water resources.

The WRYM uses a sophisticated network solver in order to analyse complex multi-reservoir water resource systems for a variety of operating policies and is designed for the purpose of assessing a system's long- and short-term resource capability (or yield). Analyses are undertaken based on a monthly time-step and for constant development levels, i.e. the system configuration and modelled demands remain unchanged over the simulation period. The major strength of the model lies in the fact that it enables the user to configure most water resource system networks using basic building blocks, which means that the configuration of a system network and the relationships between its elements are defined by means of input data, rather than by fixed algorithms embedded in the complex source code of the model.

Recently, SA-DWA has developed a software system for the structured storage and utilisation of hydrological and water resource system network model information. The system, referred to as the WRYM Information Management System (IMS), serves as a user friendly interface with the Fortran-based WRYM and substantially improves the performance and ease of use of the model. It incorporates the WRYM data storage structure in a database and provides users with an interface which allows for system configuration and run result interpretation within a Microsoft Windows environment.

SA-DWA recently made available WRYM Release 7.5.6.7 which incorporates a number of new sub-models designed to support the explicit modelling of water resource system components in various studies. Detailed information in this regard may be obtained from the Water Resources Yield Model (WRYM) User Guide – Release 7.4 (WRP, 2007).

2.3 Water Resources Planning Model (WRPM)

The WRPM is similar to the WRYM, but uses short term yield reliability relationships of systems to determine for a specific planning horizon what the likely water supply volumes will be, given starting storages, operating rules, user allocation and curtailment rules. The model is used for operational planning of reservoirs and inter-dependant systems, and provides insight into infrastructure scheduling, probable curtailment interventions and salt blending options.

A unique feature of the analysis methodology is the capability of the WRPM to simulate drought curtailments for water users with different risk requirements (profiles) receiving water from the same resource (see **Basson et. Al, 1994** for a technical description). This methodology makes it possible to evaluate and implement adaptive operating rules (transfer rules and drought curtailments) that can accommodate changing water requirements (growth in water use) as well as future changes in infrastructure (new transfers, dams and/or dam raisings) in a single simulation model. By combining these simulation features in one model gives the WRPM the ability to undertake risk based projection analysis for **operation** and **development** planning of water resource systems. The WRPM therefore simulates all the interdependencies of the aforementioned variables and allow management decisions (operational and/or developmental) to be informed by results where all these factors are properly taken into consideration.

3 HYDROLOGY

Hydro-meteorological data provide the foundation of any assessment aimed at determining the capability of a water resource system and the level of confidence that can be placed on the results of such assessments is largely dependent on the quality of the data available. The updated hydro-meteorological data used in the yield analysis of the integrated Orange-Senqu-Vaal system were obtained from the hydrological analysis undertaken as part of this Study and a detailed description of this process may be found in Report ORASECOM006/2011, “Extension of Hydrological Records”. The following sections provide details on the various hydro-meteorological data sets applied in the yield analysis of the integrated Orange-Senqu-Vaal system, including a breakdown of how they were derived as well as a summary of their application in the WRYM. These data sets cover the Study period of 85 years from the 1920 to the 2004 hydrological year (i.e. October 1920 to September 2005) and include the following:

- Rainfall (see **Section 3.1**);
- Evaporation (see **Section 3.2**);
- Streamflow (see **Section 3.3**).

3.1 Rainfall

Rainfall data are used in the WRYM and WRPM to calculate:

- The impact of rainfall on irrigation water requirements (see **Section 4.1.3**);
- Rainfall directly on the surface area of impoundments in the catchment, including major dams, small storage dams, weirs and gravel pits (as described in **Section 5**).

Rainfall data are defined for a WRYM and WRPM analysis by means of a set of data files that contain monthly historical rainfall in units of mm, referred to as *RAN -files. In the case of this Study, one such file was generated for each of the updated catchments in the integrated Orange-Senqu-Vaal system for a period of 85 years from 1920 to 2004 (hydrological years). **Table** 3-1 presents the details of the rainfall files used in the WRYM and WRPM analysis.

Table 3-1: Rainfall File Details

Figure [(1)]	Catchment	Rainfall file name	Mean Annual Precipitation (mm/a)	Standard Deviation	Coefficient of Variation
A-3	Thukela	TM0194.RAN	1026.82	211.05	0.21
A-3	Thukela	TM0294.RAN	1042.18	213.17	0.2
A-3	Thukela	TM0394.RAN	829.75	199.04	0.24
A-3	Thukela	TM0494.RAN	1010.51	216.83	0.21

Figure [1]	Catchment	Rainfall file name	Mean Annual Precipitation (mm/a)	Standard Deviation	Coefficient of Variation
A-4	Wilge	FRAN4.RAN	682.27	137.15	0.2
A-4	Wilge	STERK4.RAN	749.09	179.05	0.24
A-4	Grootdraai	GROOTD4.RAN	677.24	108.28	0.16
A-5	Vaal	C12D4.RAN	641.02	161.04	0.25
A-5	Vaal	DELA4.RAN	717.56	125.84	0.18
A-5	Vaal	VAAL4.RAN	648.02	109.6	0.17
A-6	Klipbank & Barrage	BARR4.RAN	646.97	121.56	0.19
A-6	Klipbank & Barrage	KLIPR4.RAN	782.62	152.32	0.19
A-6	Krom	KROMN4.RAN	608.04	140.22	0.23
A-6	Suikerbos	SUIK4.RAN	681.97	133.33	0.2
A-7	Schoonspruit	C24D4.RAN	577.85	140.34	0.24
A-7	Schoonspruit	C24E4.RAN	584.27	125.97	0.22
A-7	Schoonspruit	C24F4.RAN	581.64	125.48	0.22
A-7	Schoonspruit	C24G4.RAN	581.64	125.48	0.22
A-7	Schoonspruit	C24H4.RAN	581.64	125.48	0.22
A-8	Renoster	C70ABC4.RAN	605.46	124.84	0.21
A-8	Renoster	C70D4.RAN	581.66	126.55	0.22
A-8	Renoster	C70E4.RAN	574.7	125.33	0.22
A-8	Renoster	C70F4.RAN	571.22	124.75	0.22
A-8	Renoster	C70G4.RAN	573.83	125.19	0.22
A-8	Renoster	C70H4.RAN	566	123.9	0.22
A-8	Renoster	C70J4.RAN	572.09	124.89	0.22
A-8	Renoster	C70K4.RAN	561.52	132.88	0.24
A-9	Sand - Vet	ALLEM4.RAN	595.85	129.37	0.22
A-9	Sand - Vet	ERF4.RAN	574.74	136.06	0.24
A-9	Sand - Vet	SANDN4.RAN	461.21	124.97	0.27
A-9	Bloemhof	BLOEMN3D4.RAN	494.86	136.37	0.28
A-9	Mooi	BOSK4.RAN	603.03	117.48	0.19
A-9	Mooi	KLERK4.RAN	611.11	119.05	0.19
A-9	Mooi	LAKESN4.RAN	622.5	129.92	0.21
A-9	Vals	KLIPBN4.RAN	543.35	139.29	0.26
A-9	Klipdrift	KLIPDN4.RAN	618.13	146.2	0.24
A-10	Lower Vaal	BARBERS4.RAN	529.99	136.54	0.26
A-10	Lower Vaal	C3H0134.RAN	397.01	138.7	0.35
A-10	Lower Vaal	C9H0074.RAN	350.02	123.35	0.35
A-10	Lower Vaal	DEHOOP4.RAN	406.06	117.02	0.29
A-10	Lower Vaal	DSWENTZD4.RAN	476.99	133.4	0.28
A-10	Lower Vaal	SPITS4.RAN	437.93	125.6	0.29
A-10	Lower Vaal	USWENTZD4.RAN	544.38	129.01	0.24
A-10	Lower Vaal	VHARTS4.RAN	444.12	121.56	0.27

Figure [1]	Catchment	Rainfall file name	Mean Annual Precipitation (mm/a)	Standard Deviation	Coefficient of Variation
B-3	Senqu	KAT10.RAN	951.86	155.13	0.16
B-3	Senqu	MAKABS.RAN	788.28	171.55	0.22
B-3	Senqu	MAKDAM.RAN	788.28	171.55	0.22
B-3	Senqu	MAL10.RAN	850.57	131.12	0.15
B-3	Senqu	MAS10.RAN	789.51	134.12	0.17
B-3	Senqu	MAT10.RAN	761.27	123.49	0.16
B-3	Senqu	MOH10.RAN	997.84	157.55	0.16
B-3	Senqu	NTO10.RAN	735.57	149.96	0.2
B-3	Senqu	ORAN10.RAN	788.28	171.55	0.22
B-3	Senqu	TSO10.RAN	801.66	130.61	0.16
B-4	Caledon	ARMEN.RAN	632.89	135.64	0.21
B-4	Caledon	HLOABS.RAN	1020.57	207.85	0.2
B-4	Caledon	HLODAM.RAN	1020.57	207.85	0.2
B-4	Caledon	HOLABS.RAN	1020.57	207.85	0.2
B-4	Caledon	HOLDAM.RAN	1020.57	207.85	0.2
B-4	Caledon	KATJREST.RAN	783.67	159.6	0.2
B-4	Caledon	KNELL.RAN	516.93	122.66	0.24
B-4	Caledon	METO.RAN	538.84	127.86	0.24
B-4	Caledon	WATER.RAN	838.65	170.8	0.2
B-4	Caledon	WELINC.RAN	538.84	127.86	0.24
B-5	Riet - Modder	AUCH4.RAN	349.99	136.41	0.39
B-5	Riet - Modder	KALKF4.RAN	411.55	116.14	0.28
B-5	Riet - Modder	KRUG4.RAN	507.66	117.81	0.23
B-5	Riet - Modder	RUSTF4.RAN	542.99	136.42	0.25
B-5	Riet - Modder	TIER4.RAN	490.99	144.63	0.29
B-5	Riet - Modder	TWEE4.RAN	422.15	116.38	0.28
B-6	Upper Orange	ALIW4.RAN	573.12	162.53	0.28
B-6	Upper Orange	PKDU4.RAN	353.09	116.4	0.33
B-6	Upper Orange	ROOD4.RAN	657.55	149.72	0.23
B-6	Upper Orange	VERW4.RAN	403.53	129.79	0.32
B-6	Upper Orange	HFDU4.RAN	449.26	128.5	0.29
B-7,8	Molopo	COM1113.RAN	512.18	130.86	0.26
B-7,8	Molopo	COM2124.RAN	512.18	130.86	0.26
B-7,8	Molopo	COM22.RAN	512.18	130.86	0.26
B-7,8	Molopo	COM2327.RAN	512.18	130.86	0.26
B-7,8	Molopo	D41ARED.RAN	512.18	130.86	0.26
B-7,8	Molopo	D41B.RAN	467.94	119.56	0.26
B-7,8	Molopo	D41C.RAN	420.21	138.91	0.33
B-7,8	Molopo	D41D.RAN	383.85	126.89	0.33
B-7,8	Molopo	D41E.RAN	349.51	115.53	0.33

Figure [1]	Catchment	Rainfall file name	Mean Annual Precipitation (mm/a)	Standard Deviation	Coefficient of Variation
B-7,8	Molopo	D41F.RAN	341.43	112.86	0.33
B-7,8	Molopo	D41G.RAN	305.43	109.5	0.36
B-7,8	Molopo	D41J.RAN	224.83	100.41	0.45
B-7,8	Molopo	D41K.RAN	306.56	106.3	0.35
B-7,8	Molopo	D41M.RAN	376.05	168.97	0.45
B-7,8	Molopo	D41N.RAN	482.47	216.79	0.45
B-7,8	Molopo	D42A.RAN	314.39	112.71	0.36
B-7,8	Molopo	D42B.RAN	359.16	128.77	0.36
B-7,8	Molopo	D42C.RAN	320.36	114.85	0.36
B-7,8	Molopo	D42D.RAN	401.98	159.53	0.4
B-7,8	Molopo	D42E.RAN	329.16	130.63	0.4
B-7,8	Molopo	D42F.RAN	322.18	127.86	0.4
B-7,8	Molopo	D42G.RAN	257.8	115.13	0.45
B-7,8	Molopo	D43B.RAN	274.7	124.03	0.45
B-7,8	Molopo	D43C.RAN	221.83	99.07	0.45
B-7,8	Molopo	D44C.RAN	119.91	53.55	0.45
B-7,8	Molopo	D44D.RAN	164.87	73.63	0.45
B-7,8	Molopo	D45C.RAN	181.86	81.22	0.45
B-7,8	Molopo	D45D.RAN	187.86	83.89	0.45
B-7,8	Molopo	DVILJ.RAN	266.83	98.42	0.37
B-7,8	Molopo	GRO.RAN	512.18	130.86	0.26
B-7,8	Molopo	LOLIF.RAN	194.92	97.96	0.5
B-7,8	Molopo	OTJV.RAN	266.83	98.42	0.37
B-7,8	Molopo	SEEIS.RAN	330.3	134.52	0.41
B-7,8	Molopo	UAUB.RAN	194.92	97.96	0.5
B-7,8	Molopo	UOLIF.RAN	330.3	134.52	0.41
B-9	Lower Tributaries	LOGR1.RAN	248.18	100.55	0.41
B-9	Lower Tributaries	LOGR10.RAN	172.14	84.71	0.49
B-9	Lower Tributaries	LOGR11.RAN	142.95	75.08	0.53
B-9	Lower Tributaries	LOGR12.RAN	142.95	75.08	0.53
B-9	Lower Tributaries	LOGR2.RAN	157.54	55.13	0.35
B-9	Lower Tributaries	LOGR6.RAN	151.29	60.63	0.4
B-9	Lower Tributaries	LOGR7.RAN	206.63	78.55	0.38
B-9	Lower Tributaries	LOGR8.RAN	206.63	78.55	0.38
B-9	Lower Tributaries	LOGR9.RAN	172.14	84.71	0.49
B-10	Fish	HARDP4.RAN	176.15	125.81	0.71
B-10	Fish	KONKP4.RAN	92.27	57.17	0.62
B-10	Fish	LOWF4.RAN	93.36	56.61	0.61
B-10	Fish	NAUT4.RAN	137.21	91.82	0.67
B-10	Fish	SEEH4.RAN	137.21	91.82	0.67

Figure [1]	Catchment	Rainfall file name	Mean Annual Precipitation (mm/a)	Standard Deviation	Coefficient of Variation
B-11	Lower Main	LOGR13.RAN	142.95	75.08	0.53
B-11	Lower Main	LOGR14.RAN	142.95	75.08	0.53
B-11	Lower Main	LOGR15.RAN	142.95	75.08	0.53
B-11	Lower Main	LOGR16.RAN	142.95	75.08	0.53
B-11	Lower Main	LOGR17.RAN	142.95	75.08	0.53
B-11	Lower Main	LOGR18.RAN	142.95	75.08	0.53
B-11	Lower Main	LOGR19.RAN	142.95	75.08	0.53
B-11	Lower Main	LOGR3.RAN	157.54	55.13	0.35
B-11	Lower Main	LOGR4.RAN	157.54	55.13	0.35
B-11	Lower Main	LOGR5.RAN	157.13	72.53	0.46

Note 1: Refers to figure in Appendices where catchment is located

3.2 Evaporation

While rainfall and streamflow data are generally modelled in yield and planning analyses as monthly time series, which incorporate the variability of these data on a monthly and annual basis, this is not the case with evaporation data. The latter is known to not vary significantly from one year to next (i.e. evaporation in, for example, one October-month is similar to evaporation in the next October-month). Therefore, it is generally considered to be acceptable to model evaporation data simply by applying 12 average monthly evaporation values over the standard hydrological year, from October to September, for the particular area in question. Evaporation data are used in the WRYM and WRPM to calculate:

- Evapo-transpiration from irrigated crops (see **Section 4.1.3**);
- Evaporation losses from the surface area of impoundments in the catchment, including large reservoirs, small storage dams, weirs and gravel pits (as described in **Section 5**).

Evaporation losses from water bodies are defined in the WRYM and WRPM by means of 12 monthly *lake evaporation* values which were calculated for each of the hydrological units in the integrated Orange-Senqu-Vaal catchment based on *Symons pan* (or S-pan) data and a set of S-pan-to-lake evaporation conversion factors (which is common to all catchment areas in Southern Africa). These were obtained, respectively, from Report ORASECOM006/2011, "Extension of Hydrological Records" and the WR90 publications (WRC, 1994). The lake evaporation data values used are shown in **Table 3-2**. All units are in millimetres.

Table 3-2: Lake Evaporation Data (mm) for each Catchment

No	Reservoir Name	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
519	UP THUK WOODSTOCK DUMMY DAM	1104	109	101	107	106	92	92	81	78	63	71	96	108
552	UP THUK WOODSTOCK DAM	1397	130	148	164	161	143	126	103	83	63	69	90	117
553	UP THUK DRIEL BARRAGE	1134	112	104	110	108	95	94	84	81	65	72	99	110
532	VAAL GROOTDRAAI DUMMY DAM	1291	134	137	149	146	127	119	90	72	58	61	86	112
533	VAAL GROOTDRAAI DAM	1571	156	157	175	179	156	146	117	95	75	80	102	133
534	VAAL BALMORAL DAM	1176	117	117	128	128	116	110	85	71	57	61	82	104
537	VAAL DUMMY DAM	1293	134	137	149	146	127	119	90	72	58	61	86	114
538	VAAL SAULSPOORT DAM	1171	122	125	135	133	115	107	81	65	52	55	77	104
540	VAAL FRANKFORD DUMMY DAM	1181	124	125	137	134	116	108	82	66	52	55	78	104
143	VAAL FRANKFORT DUMMY DAM	1181	124	125	137	134	116	108	82	66	52	55	78	104
5	VAAL SERFONTEIN DAM	1345	143	149	164	164	139	126	92	69	52	56	79	112
114	VAAL BLOEM UPPER DUMMY DAM	1552	167	184	193	185	148	132	100	78	63	71	97	134
133	VAAL GROOTDRAAI DUMMY DAM2	1291	134	137	149	146	127	119	90	72	58	61	86	112
183	VAAL DELA DUMMY DAM	1408	146	144	155	153	132	126	97	82	68	74	102	129
191	VAAL DUMMY DAM 1	1293	134	137	149	146	127	119	90	72	58	61	86	114
155	VAAL UWATERVAL DUMMY DAM	1311	137	139	152	149	129	121	91	73	58	61	87	116
169	VAAL LWATERVAL DUMMY DAM	1311	137	139	152	149	129	121	91	73	58	61	87	116
165	VAAL WATERVAL DUMMY DAM	1311	137	139	152	149	129	121	91	73	58	61	87	116
542	VAAL DAM	1453	146	151	166	165	149	139	103	85	67	62	93	127
544	VAAL STERKFONTEIN DAM	1541	151	157	168	170	143	138	107	94	85	87	105	136
548	VAAL BARRAGE	1217	127	134	149	145	126	115	85	64	48	51	72	101
551	VAAL KLIPRIVER DUMMY DAM	1387	147	154	169	170	143	130	95	70	53	58	82	115
557	VAAL BARRAGE DUMMY DAM	1366	144	152	167	167	141	128	93	70	52	57	81	113
561	VAAL KROMDRAAI DAM	1388	147	154	169	171	143	130	95	71	53	58	82	115
565	VAAL BLOEMHOF DAM	1802	187	208	226	221	173	162	119	97	72	78	109	150
567	VAAL KLERKSKRAAL DAM	1515	153	166	175	160	146	137	110	91	69	74	100	134
568	VAAL BOSKOP DAM	1489	151	161	173	172	146	133	103	84	66	71	98	131
569	VAAL KLIPDRIFT DAM	1489	151	161	173	172	146	133	103	84	66	71	98	131
577	VAAL KLIPBANK DAM	1388	147	154	169	171	143	130	95	71	53	58	82	115
579	VAAL ALLEMANSKRAAL DAM	1539	154	171	198	194	160	144	102	78	58	64	89	127
580	VAAL ERFINIS DAM	1700	176	195	220	213	172	157	109	85	63	70	99	141
581	VAAL KLIPBANK DUMMY DAM	1345	143	149	164	164	139	126	92	69	52	56	79	112
582	VAAL ALLEMANSKRAAL DUMMY DAM	1240	128	146	169	167	132	114	77	56	40	46	66	99
583	VAAL SAND DUMMY DAM	1531	165	181	190	182	147	130	99	77	62	70	96	131
584	VAAL ERFENIS DUMMY DAM	1282	132	151	175	173	136	118	80	58	41	47	68	102
586	VAAL BOSKOP DUMMY DAM	1406	151	157	165	161	133	120	93	77	60	68	94	126
587	VAAL KLIPDRIFT DUMMY DAM	1406	151	157	165	161	133	120	93	77	60	68	94	126
588	VAAL BLOEMHOF DUMMY DAM	1552	167	184	193	185	148	132	100	78	63	71	97	134
591	VAAL KROMDRAAI DUMMY DAM	1387	147	154	169	170	143	130	95	71	53	58	82	115
592	VAAL SUIKER DUMMY DAM	1365	143	145	158	155	134	125	95	76	60	64	90	121
2	VAAL POTCHEFSTROOM DAM	1427	153	160	168	164	135	121	95	78	60	69	96	128
244	VAAL KLIPRIVER D/S DUM DAM	1387	147	154	169	170	143	130	95	70	53	58	82	115
249	VAAL BARRAGE U/S DUM DAM	1366	144	152	167	167	141	128	93	70	52	57	81	113
219	VAAL SUIKER D/S DUM DAM	1365	143	145	158	155	134	125	95	76	60	64	90	121
234	VAAL BLESBOK DUMMY DAM	1365	143	145	158	155	134	125	95	76	60	64	90	121
229	VAAL BLESBOK DUMMY DAM	1365	143	145	158	155	134	125	95	76	60	64	90	121
224	VAAL BLESBOK DUMMY DAM	1365	143	145	158	155	134	125	95	76	60	64	90	121

No	Reservoir Name	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
226	VAAL BLESBOK DUMMY DAM	1365	143	145	158	155	134	125	95	76	60	64	90	121
578	RENOST KOPPIES DUMMY DAM	1304	138	145	159	160	135	122	90	67	50	54	77	108
305	RENOST C70D DUMMY DAM	1345	143	149	164	165	139	126	92	69	51	56	79	112
308	RENOST C70E DUMMY DAM	1365	144	152	167	167	141	128	94	70	53	56	80	113
307	RENOST C70F DUMMY DAM	1365	144	152	167	167	141	128	94	70	53	56	80	113
312	RENOST C70G DUMMY DAM	1345	143	149	164	165	139	126	92	69	51	56	79	112
314	RENOST C70H DUMMY DAM	1395	147	154	169	170	143	139	95	70	53	58	82	115
574	RENOST C70J DUMMY DAM	1409	149	157	172	172	145	132	97	72	54	59	83	117
318	RENOST C70K DUMMY DAM	1428	151	159	174	175	148	134	98	73	54	60	84	118
571	RENOST KOPPIES DAM	1621	164	171	192	182	162	147	114	90	71	79	106	143
572	RENOST RIETFONTEIN DAM	1403	148	156	172	171	145	132	96	71	54	58	83	117
920	SCHOON KALK DAM	1510	162	170	178	174	142	128	100	83	64	73	101	136
575	SCHOON RIETSPRUIT DAM	1727	173	185	191	190	159	160	125	108	82	85	117	152
576	SCHOON JOHAN NESER DAM	1532	164	172	180	176	144	130	102	84	65	75	103	138
935	SCHOON ELANDSKUIL DAM	1510	162	170	178	174	142	128	100	83	64	73	101	136
950	SCHOON C24D DUMMY DAM	1727	173	185	191	190	159	160	125	108	82	85	117	152
970	SCHOON C24E DUMMY DAM	1510	162	170	178	174	142	128	100	83	64	73	101	136
975	SCHOON C24F DUMMY DAM	1532	164	172	180	176	144	130	102	84	65	75	103	138
985	SCHOON C24G DUMMY DAM	1532	164	172	180	176	144	130	102	84	65	75	103	138
912	SCHOON C24H DUMMY DAM	1511	162	169	178	174	143	128	100	83	64	73	101	136
272	TAUNG WENTZEL DUMMY DAM	1601	177	189	198	189	150	138	103	81	63	71	102	140
277	TAUNG BARBERSPAN	1614	179	191	200	190	151	139	104	82	63	72	102	141
278	TAUNG WENTZEL DAM	1752	174	200	207	213	166	160	123	99	73	81	110	146
280	TAUNG DAM	1643	178	200	199	197	119	150	112	86	80	77	104	141
281	TAUNG DUMMY DAM	1644	182	194	204	194	154	142	106	83	64	73	104	144
283	TAUNG SPITSKOP DUMMY DAM	1644	182	194	204	194	154	142	106	83	64	73	104	144
287	TAUNG SPITSKOP DAM	1896	162	230	249	220	199	160	144	113	99	84	104	132
264	TAUNG VAALHARTS WEIR	1635	173	192	213	209	169	145	104	79	59	68	92	132
1020	LES HIGH 20 POLIHALI DAM	1195	132	130	123	139	105	104	75	75	52	60	91	109
1021	LES HIGH 21 KATSE DAM	1162	128	126	122	135	103	104	73	72	49	58	88	105
1023	LES HIGH 23 TAUNG DAM	1195	132	130	123	139	105	104	75	75	52	60	91	109
1024	LES HIGH 24 MASHAI DAM	1193	132	130	123	139	105	104	75	75	52	60	91	109
1025	LES HIGH 25 TSOELIKE DAM	1231	138	134	124	143	108	105	77	78	55	62	94	114
1026	LES HIGH 26 NTOAHAE DAM	1257	141	137	125	146	110	105	78	81	57	64	96	117
1027	LES HIGH 27 MOHALE DAM	1151	126	125	122	134	102	103	73	71	48	57	87	104
1029	LES HIGH 29 MALATSI DAM	1253	141	137	125	146	110	105	78	81	56	64	96	117
1032	UP ORAN 32 BOSBERG DAM	1430	138	163	188	187	173	129	88	68	50	56	81	107
1038	CALEDON 38 DUMMY3 DAM RSA	1217	129	143	157	146	115	102	77	63	49	48	82	106
2699	CALEDON ARMENIA DAM	1217	129	143	157	146	115	102	77	63	49	48	82	106
1044	CALEDON 44 KNELLPOORT DAM	1636	142	221	234	219	161	149	105	79	65	60	84	117
1047	CALEDON 47 WELBEDACHT DAM	1636	142	221	234	219	161	149	105	79	65	60	84	117
1052	VAAL 52 RUSTFONTEIN DAM	1556	142	195	220	211	157	141	98	78	62	57	81	114
1054	VAAL 54 GROOTHOEK DAM	1556	142	195	220	211	157	141	98	78	62	57	81	114
1055	VAAL 55 MOCKES DAM	1540	138	195	224	224	168	144	98	72	51	48	72	106
1056	VAAL 56 KRUGERSDRIFT DAM	1774	187	210	251	225	174	154	114	90	68	76	79	146
1057	VAAL 57 TIERPOORT DAM	1629	144	205	234	222	174	154	108	79	61	56	81	111
1058	VAAL 58 KALKFONTEIN DAM	1813	158	234	268	265	200	166	118	85	63	56	82	118
1062	UP ORAN 62 DUMMY2 DAM	1949	195	228	259	255	226	168	115	90	68	78	115	152

No	Reservoir Name	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1063	UP ORAN 63 GARIEP DAM	2007	202	236	275	277	226	169	116	90	71	82	108	155
1064	UP ORAN 64 DUMMY1 DAM	2100	212	246	285	280	229	179	122	97	76	88	120	166
1066	UP ORAN 66 VANDERKLOOF DAM	2281	230	269	313	315	256	191	132	102	81	93	123	176
1071	FISH 71 HARDAP DAM	2212	234	263	283	268	181	156	144	125	108	119	146	185
1075	FISH 75 NAUTE DAM	2538	245	275	301	328	248	215	178	149	130	124	151	194
1078	FISH 78 LOW FISH DAM	2400	232	260	285	310	235	203	168	141	123	117	143	183
1081	VAAL 81 RUSTFONT DUMMY DAM	1346	138	158	183	182	143	125	84	61	43	50	72	107
1084	VAAL 84 MOCKES DUMMY DAM	1335	138	157	182	181	142	123	83	60	43	49	71	106
1088	VAAL 88 DOUGLAS WEIR	1608	173	193	219	212	140	109	94	94	70	75	95	134
1091	VAAL 91 KRUGERSDRIFT DUMMY DAM	1749	180	206	239	236	186	161	109	79	56	65	93	139
1093	VAAL 93 TWEERIVIER DUMMY DAM	1942	192	222	252	248	204	176	130	98	78	83	109	150
1094	VAAL 94 TWEERIVIER WEIR	2600	272	322	365	354	272	224	158	112	85	94	138	204
1096	VAAL 96 TIERPOORT DUMMY DAM	1378	141	160	184	177	145	129	90	64	48	55	77	108
1098	VAAL 98 KNOFFELFONTEIN DAM	2600	272	322	365	354	272	224	158	112	85	94	138	204
1104	UP ORAN 104 TORQUAY DAM	1629	172	194	229	226	155	117	93	73	70	74	92	134
1105	LOW MAIN 105 BOEGOEBERG WEIR	1904	190	226	265	264	197	160	112	90	70	78	105	147
1106	VAAL 106 KALKFONTEIN DUMMY DAM	1466	150	171	196	188	154	137	95	68	52	58	82	115
1127	LOW MAIN 127 VIOOLSDRIFT DAM ADJ	2007	188	228	263	275	237	216	148	93	64	63	93	139
1129	LOW MAIN 129 KABIES DAM	1998	178	213	249	260	211	202	141	104	85	83	97	175
2591	CALEDON 1591 HLOTSE DAM	1092	114	125	145	139	113	98	68	52	39	44	63	92
2596	CALEDON 1596 HOLOLO DAM	1071	112	122	143	136	111	96	67	52	38	43	62	90
2601	LES HIGH 1601 MAKHALENG DAM	1637	181	194	203	193	153	141	106	83	64	73	104	143
2606	CALEDON 1606 METALONG DAM	1176	123	134	157	150	122	106	73	57	42	48	68	99
2517	MOLOPO 1517 LOTLAMORENG DAM	1637	181	194	203	193	153	141	106	83	64	73	104	143
2518	MOLOPO 1518 SETUMO DAM	1637	181	194	203	193	153	141	106	83	64	73	104	143
2511	MOLOPO 1511 D41A DUMMY DAM	1637	181	194	203	193	153	141	106	83	64	73	104	143
2520	MOLOPO 1520 DISANENG DAM	1637	181	194	203	193	153	141	106	83	64	73	104	143
2528	MOLOPO 1528 D41B DUMMY DAM	1720	190	203	213	202	161	149	111	87	67	76	109	151
2521	MOLOPO 1521 D41D DUMMY DAM	1720	190	203	213	202	161	149	111	87	67	76	109	151
2525	MOLOPO 1525 D41C DUMMY DAM	1888	209	223	234	223	177	163	121	96	74	84	119	165
2539	MOLOPO 1539 D41E DUMMY DAM	1888	209	223	234	223	177	163	121	96	74	84	119	165
2537	MOLOPO 1537 D41F DUMMY DAM	1888	209	223	234	223	177	163	121	96	74	84	119	165
2549	MOLOPO 1549 D42D DUMMY DAM	1218	127	139	162	155	126	109	76	59	43	49	70	102
2553	MOLOPO 1553 D42B DUMMY DAM	1845	204	218	229	218	172	159	119	93	72	82	117	161
2555	MOLOPO 1555 D42A DUMMY DAM	1637	181	194	203	193	153	141	106	83	64	73	104	143
2543	MOLOPO 1543 D42F DUMMY DAM	1972	219	233	244	233	185	170	127	100	77	88	125	173
2558	MOLOPO 1558 D42G DUMMY DAM	2271	220	256	288	287	235	212	157	123	98	105	125	166
2590	MOLOPO 1590 D42D DUMMY DAM	2313	224	261	294	292	239	216	160	125	99	107	127	168
2561	MOLOPO 1561 OTJV DUMMY DAM	1539	168	155	178	159	126	116	110	97	80	91	117	141
2564	MOLOPO 1564 OTJIVERO DAM	1539	168	155	178	159	126	116	110	97	80	91	117	141
2566	MOLOPO 1566 DVILJ DUMMY DAM	1418	155	143	164	146	116	107	101	90	73	84	109	130
2570	MOLOPO 1570 DAAN VILJOEN DAM	1418	155	143	164	146	116	107	101	90	73	84	109	130
2571	MOLOPO 1571 TILDA VILJOEN DAM	1418	155	143	164	146	116	107	101	90	73	84	109	130
2578	MOLOPO 1578 SEEIS DUMMY DAM	1418	155	143	164	146	116	107	101	90	73	84	109	130
2575	MOLOPO 1575 OLIFANTS FARM DAM	1418	155	143	164	146	116	107	101	90	73	84	109	130
2644	LOW TRIB 1644 VICTORIA WES DAM	1893	188	221	259	264	222	184	121	84	57	66	92	137
2643	LOW TRIB 1643 GROUP 1 DUMMY	1893	188	221	259	264	222	184	121	84	57	66	92	137
2641	LOW TRIB 1641 SMART SYNDICATE DAM	1893	188	221	259	264	222	184	121	84	57	66	92	137

No	Reservoir Name	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2639	LOW TRIB 1639 GROUP 2 DUMMY	1887	177	219	261	260	202	168	191	77	54	61	88	127
2638	LOW TRIB 1638 MODDERPOORT DAM	1811	172	213	252	260	208	181	118	79	57	62	85	123
2628	LOW TRIB 1628 LOXTON DAM	1811	172	213	252	260	208	181	118	79	57	62	85	123
2627	LOW TRIB 1627 GROUP 7 DUMMY	1936	183	228	270	278	222	194	126	85	61	66	91	132
2637	LOW TRIB 1637 GROUP 6 DUMMY RIET	1645	146	193	234	244	206	178	107	70	47	51	70	99
2636	LOW TRIB 1636 GROUP 6 DUMMY RENOS	1645	146	193	234	244	206	178	107	70	47	51	70	99
2633	LOW TRIB 1633 GROUP 6 DUMMY FISH 2	1602	142	188	228	239	201	173	105	68	45	50	68	96
2631	LOW TRIB 1631 GROUP 6 DUMMY FISH 1	1769	156	196	233	251	212	192	123	84	62	63	81	115
2623	LOW TRIB 1623 VAN WYKSVLEI DAM	1958	185	230	273	281	224	195	128	86	61	67	92	134
2622	LOW TRIB 1622 GROUP 9 DUMMY	1958	185	230	273	281	224	195	128	86	61	67	92	134
2619	LOW TRIB 1619 ROOIBERG DAM	2004	185	229	270	275	228	194	136	99	74	78	100	135
2646	LOW MAIN 1646 GROUP 5 DUMMY	2228	216	258	301	302	244	210	147	104	77	88	117	162

3.3 Streamflow

Streamflow data are used in yield and planning analyses as a basis for determining the historical sequence of inflows to reservoirs and other nodal points within the water resources system under consideration and thereby allow for the behaviour of the system to be simulated. In the case of the WRYM and WRPM, streamflows entering the system are defined by means of a set of data files, each of which contains a time-series of monthly historical natural incremental runoff (in units of million m^3) for defined sub-catchments located within the modelled system. Such a data file, which is referred to as a *.INC-file, was developed for each of the integrated Orange-Senqu-Vaal sub-catchments, for a period of 85 years from 1920 to 2004 (hydrological years), as part of the hydrological analysis of the Study. For this purpose, the *Water Resources Simulation Model 2000* (WRSM2000) rainfall-runoff model was used for the majority of the system and the NAMRON model for the Namibian Fish River. At the time of writing this report, the Fish River hydrology had not yet been updated or extended between 2000 and 2004. Dummy variables were used for those years and will be replaced once the hydrology has been extended. More information in this regard is provided in Report ORASECOM006/2011, "Extension of Hydrological Records".

The characteristics of each catchment are shown in **Table 3-3,** including the mean annual runoff (MAR), standard deviation (SD), coefficient of variance (CV) as well as the name of the associated WRYM and WRPM data input file.

Table 3-3: Summary of Hydrology Data

Figure [(1)]	Catchment	Streamflow file name	Mean Annual Runoff (mill m^3/month)	Standard Deviation	Coefficient of Variation
A-3	Thukela	TM0194.INC	76.3	31.81	0.42
A-3	Thukela	TM0294.INC	372.5	155.31	0.42

Figure (1)	Catchment	Streamflow file name	Mean Annual Runoff (mill m^3/month)	Standard Deviation	Coefficient of Variation
A-3	Thukela	TM0394.INC	20.24	10.02	0.5
A-3	Thukela	TM0494.INC	227.95	88.05	0.39
A-4	Wilge	FRAN4.INC	760.01	648.97	0.85
A-4	Wilge	STERK4.INC	19.53	14.92	0.76
A-4	Grootdraai	GROOTD4.INC	462.02	377.43	0.82
A-5	Vaal	C12D4.INC	77.38	49.46	0.64
A-5	Vaal	DELA4.INC	261.14	217.84	0.83
A-5	Vaal	VAAL4.INC	493.19	466.2	0.95
A-6	Klipbank & Barrage	BARR4.INC	72.24	55.99	0.78
A-6	Klipbank & Barrage	KLIPR4.INC	102.66	79.69	0.78
A-6	Krom	KROMN4.INC	42.04	40.47	0.96
A-6	Suikerbos	SUIK4.INC	99.87	98.78	0.99
A-7	Schoonspruit	C24D4.INC	7.35	10.41	1.42
A-7	Schoonspruit	C24E4.INC	9.81	14.87	1.52
A-7	Schoonspruit	C24F4.INC	19.55	28.94	1.48
A-7	Schoonspruit	C24G4.INC	16.91	24.82	1.47
A-7	Schoonspruit	C24H4.INC	8.5	13.48	1.59
A-8	Renoster	C70ABC4.INC	61.11	53.23	0.87
A-8	Renoster	C70D4.INC	12.6	11.59	0.92
A-8	Renoster	C70E4.INC	11.97	10.95	0.92
A-8	Renoster	C70F4.INC	9.46	8.65	0.92
A-8	Renoster	C70G4.INC	14.16	12.71	0.9
A-8	Renoster	C70H4.INC	3.98	3.64	0.91
A-8	Renoster	C70J4.INC	8.58	7.81	0.91
A-8	Renoster	C70K4.INC	10.25	11.15	1.09
A-9	Sand - Vet	ALLEM4.INC	94.9	85.71	0.9
A-9	Sand - Vet	ERF4.INC	163.59	152.38	0.93
A-9	Sand - Vet	SANDN4.INC	160.21	163.63	1.02
A-9	Bloemhof	BLOEMN3D4.INC	130.6	148.94	1.14
A-9	Mooi	BOSK4.INC	37.54	17.34	0.46
A-9	Mooi	KLERK4.INC	39.73	29.35	0.74
A-9	Mooi	LAKESN4.INC	9.68	7.36	0.76
A-9	Vals	KLIPBN4.INC	153.29	147.92	0.97
A-9	Klipdrift	KLIPDN4.INC	21.19	23.24	1.1
A-10	Lower Vaal	BARBERS4.INC	2.94	4.47	1.52
A-10	Lower Vaal	C3H0134.INC	11.71	39.31	3.36
A-10	Lower Vaal	C9H0074.INC	18.63	62.51	3.36
A-10	Lower Vaal	DEHOOP4.INC	15.32	25.22	1.65
A-10	Lower Vaal	DSWENTZD4.INC	12.11	18.38	1.52
A-10	Lower Vaal	SPITS4.INC	81.29	142.07	1.75

Figure (1)	Catchment	Streamflow file name	Mean Annual Runoff (mill m^3/month)	Standard Deviation	Coefficient of Variation
A-10	Lower Vaal	USWENTZD4.INC	39.49	59.94	1.52
A-10	Lower Vaal	VHARTS4.INC	9.97	18.4	1.85
B-3	Senqu	KAT10.INC	559.44	232.65	0.42
B-3	Senqu	MAKABS.INC	354.83	183.09	0.52
B-3	Senqu	MAKDAM.INC	169.7	87.57	0.52
B-3	Senqu	MAL10.INC	291.72	147.02	0.5
B-3	Senqu	MAS10.INC	792.91	443.11	0.56
B-3	Senqu	MAT10.INC	98.11	51.67	0.53
B-3	Senqu	MOH10.INC	303.24	125.98	0.42
B-3	Senqu	NTO10.INC	154.55	87.52	0.57
B-3	Senqu	ORAN10.INC	1018.2	525.41	0.52
B-3	Senqu	TSO10.INC	362.64	181.99	0.5
B-4	Caledon	ARMEN.INC	30.08	27.79	0.92
B-4	Caledon	HLOABS.INC	103.94	43.98	0.42
B-4	Caledon	HLODAM.INC	99.48	43.65	0.44
B-4	Caledon	HOLABS.INC	43.1	24.81	0.58
B-4	Caledon	HOLDAM.INC	36.34	16.69	0.46
B-4	Caledon	KATJREST.INC	206.83	139.3	0.67
B-4	Caledon	KNELL.INC	17.57	23.34	1.33
B-4	Caledon	METO.INC	61.83	48.16	0.78
B-4	Caledon	WATER.INC	63.64	60.2	0.95
B-4	Caledon	WELINC.INC	556.42	433.47	0.78
B-5	Riet - Modder	AUCH4.INC	5.8	18.23	3.14
B-5	Riet - Modder	KALKF4.INC	185.85	271.94	1.46
B-5	Riet - Modder	KRUG4.INC	118.06	130.61	1.11
B-5	Riet - Modder	RUSTF4.INC	30.96	42.05	1.36
B-5	Riet - Modder	TIER4.INC	23.23	29.61	1.27
B-5	Riet - Modder	TWEE4.INC	15.67	24.51	1.56
B-6	Upper Orange	ALIW4.INC	218.16	188.26	0.86
B-6	Upper Orange	PKDU4.INC	143.99	236.6	1.64
B-6	Upper Orange	ROOD4.INC	682.49	475.15	0.7
B-6	Upper Orange	VERW4.INC	189.48	265.68	1.4
B-6	Upper Orange	HFDU4.INC	188.93	260.37	1.38
B-7,8	Molopo	COM1113.INC	0.27	0.89	3.32
B-7,8	Molopo	COM2124.INC	10.82	4.98	0.46
B-7,8	Molopo	COM22.INC	2.78	1.22	0.44
B-7,8	Molopo	COM2327.INC	0.02	0.14	6.93
B-7,8	Molopo	D41ARED.INC	5.06	8.17	1.61
B-7,8	Molopo	D41B.INC	12.76	18.6	1.46
B-7,8	Molopo	D41C.INC	9.65	17.13	1.78

Figure (1)	Catchment	Streamflow file name	Mean Annual Runoff (mill m^3/month)	Standard Deviation	Coefficient of Variation
B-7,8	Molopo	D41D.INC	5.99	11.12	1.86
B-7,8	Molopo	D41E.INC	0.67	1.31	1.95
B-7,8	Molopo	D41F.INC	1.94	3.84	1.98
B-7,8	Molopo	D41G.INC	0.85	1.88	2.22
B-7,8	Molopo	D41J.INC	0.1	0.4	3.98
B-7,8	Molopo	D41K.INC	0.64	1.52	2.38
B-7,8	Molopo	D41M.INC	3.57	11.45	3.21
B-7,8	Molopo	D41N.INC	16.84	57.07	3.39
B-7,8	Molopo	D42A.INC	1.58	3.45	2.19
B-7,8	Molopo	D42B.INC	7.13	12.74	1.79
B-7,8	Molopo	D42C.INC	0.89	1.65	1.86
B-7,8	Molopo	D42D.INC	18.02	45.72	2.54
B-7,8	Molopo	D42E.INC	4.53	12.44	2.75
B-7,8	Molopo	D42F.INC	3.66	10.13	2.77
B-7,8	Molopo	D42G.INC	1.05	3.91	3.71
B-7,8	Molopo	D43B.INC	15.83	38.6	2.44
B-7,8	Molopo	D43C.INC	0.22	0.89	4
B-7,8	Molopo	D44C.INC	0.01	0.05	5.54
B-7,8	Molopo	D44D.INC	0.01	0.06	4.83
B-7,8	Molopo	D45C.INC	0.03	0.12	4.45
B-7,8	Molopo	D45D.INC	0.24	1.04	4.31
B-7,8	Molopo	DVILJ.INC	1.15	2.55	2.21
B-7,8	Molopo	GRO.INC	0.12	0.75	6.26
B-7,8	Molopo	LOLIF.INC	2.1	7.78	3.7
B-7,8	Molopo	OTJV.INC	1.15	2.55	2.21
B-7,8	Molopo	SEEIS.INC	0.88	2.5	2.84
B-7,8	Molopo	UAUB.INC	4.17	15.1	3.62
B-7,8	Molopo	UOLIF.INC	0.59	1.67	2.84
B-9	Lower Orange Tributaries	LOGR1.INC	22.12	51.3	2.32
B-9	Lower Orange Tributaries	LOGR10.INC	1.37	3.67	2.69
B-9	Lower Orange Tributaries	LOGR11.INC	15.95	42.35	2.65
B-9	Lower Orange Tributaries	LOGR12.INC	10.88	31.52	2.9
B-9	Lower Orange Tributaries	LOGR2.INC	30.2	65.36	2.16
B-9	Lower Orange Tributaries	LOGR6.INC	46.36	99.68	2.15
B-9	Lower Orange Tributaries	LOGR7.INC	22.11	45.79	2.07

Figure (1)	Catchment	Streamflow file name	Mean Annual Runoff (mill m^3/month)	Standard Deviation	Coefficient of Variation
B-9	Lower Orange Tributaries	LOGR8.INC	3.89	8.94	2.3
B-9	Lower Orange Tributaries	LOGR9.INC	9.58	25.69	2.68
B-10	Fish	HARDP4.INC	183.22	240.83	1.31
B-10	Fish	KONKP4.INC	45.33	84.09	1.86
B-10	Fish	LOWF4.INC	82.83	153.67	1.86
B-10	Fish	NAUT4.INC	57.62	85.86	1.49
B-10	Fish	SEEH4.INC	326.11	605	1.86
B-11	Lower Main	LOGR13.INC	4.48	9.89	2.21
B-11	Lower Main	LOGR14.INC	3.14	5.88	1.87
B-11	Lower Main	LOGR15.INC	53.08	124.37	2.34
B-11	Lower Main	LOGR16.INC	4.59	9.48	2.06
B-11	Lower Main	LOGR17.INC	13.02	31.94	2.45
B-11	Lower Main	LOGR18.INC	1.6	5.75	3.6
B-11	Lower Main	LOGR19.INC	4.49	11.09	2.47
B-11	Lower Main	LOGR3.INC	17.45	42.14	2.41
B-11	Lower Main	LOGR4.INC	11.6	28.55	2.46
B-11	Lower Main	LOGR5.INC	21.07	48.26	2.29
	TOTAL		12538.09		

Note 1: Refers to figure in Appendices where catchment is located

4 WATER REQUIREMENTS, RETURN FLOWS AND CATCHMENT TRANSFERS

This section provides detailed information on the water requirements and return flows in the integrated Orange-Senqu-Vaal system and how these were modelled in the WRYM for the purpose of undertaking the yield analysis. In all cases, the information provided is representative of the 2010-development level (i.e. roughly corresponding with the 2010 hydrological year, which covers the period from October 2010 to September 2011). The purpose of modelling water requirements and return flows in the yield analysis of the integrated Orange-Senqu-Vaal system is to estimate the impact of such developments on the water resource capability (yield) of the system at the development level in question.

4.1 Demands

4.1.1 Streamflow Reduction Activities

As a result of recent developments in the WRYM, most diffuse irrigation previously simulated as streamflow reduction activities via the *.irr files is now simulated as time series irrigation blocks further explained in **Section 4.1.3**. A few catchments do, however, still make use of *.irr files to simulate irrigation and *.aff files to simulate afforestation. Only these catchments are summarised in **Table 4-1.**

Table 4-1: Summary of Streamflow Reduction Activity Data Files

Figure (1)	Catchment	SFR file name	SFR Type	Average (mill m^3/a)
A-3	Thukela	TM0494.AFF	afforestation	2.84
A-4	Grootdraai	GROOTD4.IRR	irrigation	0.336
A-5	Vaal	DELA4.IRR	irrigation	2.78
A-9	Sand - Vet	ALLEM4.IRR	irrigation	1.18
A-9	Sand - Vet	ERF4.IRR	irrigation	1.27
A-9	Sand - Vet	SANDN4.IRR	irrigation	1.28
A-9	Klipdrift	KLIPDN4.IRR	irrigation	0.44
A-10	Lower Vaal	SPITS4.AFF	afforestation	0.04
B-6	Upper Orange	ALIW4.IRR	irrigation	17.51
B-6	Upper Orange	ROOD4.IRR	irrigation	43.6

Note 1: Refers to figure in Appendices where catchment is located

4.1.2 Point Demands

All demands in the integrated Orange-Senqu-Vaal system were updated as part of this study to represent the 2010 development level. A summary of the point abstraction demands included in the integrated Orange-Senqu-Vaal system are presented per sub-catchment in **Table 4-2.** Details of each individual demand including its channel number, name and average supply. supply over the simulation period are presented in **Appendix C**, **Table C-1**.

Table 4-2: Summary of Point Demands Simulated

Figure [(1)]	Sub catchment	Total Average Supply (mill m^3/a)
A-3	Thukela	8.10
A-4	Wilge	48.25
A-4	Grootdraai	106.93
A-5	Vaal	1220.83
A-6	Klipbank & Barrage	10.42
A-6	Krom	15.49
A-6	Suikerbos	22.33
A-7	Schoonspruit	25.30
A-8	Renoster	9.58
A-9	Sand - Vet	48.35
A-9	Bloemhof	241.92
A-9	Mooi	43.95
A-9	Vals	8.86
A-9	Klipdrift	6.41
A-10	Lower Vaal	312.9
B-3	Senqu	28.57
B-4	Caledon	133.27
B-5	Riet - Modder	161.91
B-6	Upper Orange	1440.54
B-7,8	Molopo	150.28
B-9	Lower Tributaries	0.00
B-10	Fish	217.82
B-11	Lower Main	1642.02
	TOTAL	5903.9

Note 1: Refers to figure in Appendices where catchment is located

4.1.3 Irrigation time series

A relatively new feature that has been added to the WRYM offers the advantage that irrigation demands can now be simulated as a time series as opposed to the previous method which only offered the user the ability to simulate constant demands. This is advantageous as it more correctly represents reality whereby irrigators modify their requirements as a result of rainfall. Irrigation is now modelled by means of "blocks" which represent a number of users obtaining their water from a similar source. Input data to these blocks include evaporation, crop factors, soil properties, return flow factors, irrigated areas and irrigation system efficiencies. The irrigation block algorithm included in the WRYM uses these input data to calculate a monthly demand and return flow for each irrigation block. A summary of the irrigation included in the integrated Orange-Senqu-Vaal system model by catchment is included in **Table 4-3.** Further details of individual irrigation blocks are presented in **Table C-3** of **Appendix C**.

Table 4-3: Total Irrigation Summary

Figure (1)	Sub catchment	Total irrigated area (km^2)	Total Average Demand (mill m^3/a)	Total Average Return flow (mill m^3/a)	Total Average Net Demand (mill m^3/a)
A-3	Thukela	0.00	0.00	0.00	0.00
A-4	Wilge	172.66	84.23	11.94	72.29
A-4	Grootdraai	36.65	19.31	2.88	16.43
A-5	Vaal	171.91	127.70	55.14	72.55
A-6	Klipbank & Barrage	51.03	59.47	8.72	50.75
A-6	Krom	6.26	5.83	1.13	4.69
A-6	Suikerbos	13.69	16.70	2.77	13.92
A-7	Schoonspruit	43.43	29.05	5.10	23.96
A-8	Renoster	20.11	14.84	1.60	13.24
A-9	Sand - Vet	92.30	55.76	10.73	45.03
A-9	Bloemhof	36.64	54.34	8.14	46.20
A-9	Mooi	35.50	27.71	1.51	26.20
A-9	Vals	28.76	17.42	2.58	14.84
A-9	Klipdrift	1.45	0.61	0.08	0.53
A-10	Lower Vaal	285.11	427.25	93.77	333.48
B-3	Senqu	0.00	0.00	0.00	0.00
B-4	Caledon	0.00	0.00	0.00	0.00
B-5	Riet - Modder	401.35	442.85	26.64	416.21
B-6	Upper Orange	0.00	0.00	10.07	-10.07(2)
B-7,8	Molopo	40.02	1.88	0.62	1.26
B-9	Lower Orange Tributaries	56.80	20.00	0.61	20.00

Figure [(1)]	Sub catchment	Total irrigated area (km^2)	Total Average Demand (mill m^3/a)	Total Average Return flow (mill m^3/a)	Total Average Net Demand (mill m^3/a)
B-10	Fish	0.00	0.00	0.00	0.00
B-11	Lower Main	0.00	0.00	0.00	0.00
	TOTAL	1493.67	1404.95	244.03	1161.53

Note 1: Refers to figure in Appendices where catchment is located

Note 2: This value refers to an irrigation block whose demand is situated in the Lower Vaal system however the return flow enters the Upper Orange system

4.2 Return Flows

All return flows in the integrated Orange-Senqu-Vaal system were updated as part of this study to represent the 2010 development level. A summary of the point return flows included in the integrated Orange-Senqu-Vaal system are presented per sub-catchment in **Table 4-2.** Details of each individual return flow including its channel number, name and average supply over the simulation period are presented in **Appendix C**, **Table C-2**.

Table 4-4: Details of Point Return Flows Simulated

Figure [(1)]	Sub catchment	Total Average Return flow (mill m^3/a)
A-3	Thukela	0.00
A-4	Wilge	0.00
A-4	Grootdraai	6.17
A-5	Vaal	29.42
A-6	Klipbank & Barrage	389.87
A-6	Krom	0.00
A-6	Suikerbos	105.45
A-7	Schoonspruit	14.12
A-8	Renoster	0.35
A-9	Sand - Vet	13.98
A-9	Bloemhof	19.55
A-9	Mooi	68.46
A-9	Vals	5.93
A-9	Klipdrift	4.54
A-10	Lower Vaal	0.00
B-3	Senqu	0.00
B-4	Caledon	0.00
B-5	Riet - Modder	0.00

Figure (1)	Sub catchment	Total Average Return flow (mill m^3/a)
B-6	Upper Orange	0.00
B-7,8	Molopo	15.43
B-9	Lower Tributaries	0.00
B-10	Fish	0.00
B-11	Lower Main	0.00
	TOTAL	673.27

Note 1: Refers to figure in Appendices where catchment is located

4.3 Catchment Transfers

Two main catchment transfers are simulated in the integrated Orange-Senqu-Vaal WRYM configuration for the purposes of determining catchment yields. These are described as follows:

- Thukela – Sterkfontein Dam: The operating rule of this transfer is that water is transferred from the Upper Thukela to Sterkfontein Dam up to a limit of 606 mill m^3/a in order to keep Sterkfontein Dam full. The transfer stops when Sterkfontein Dam is full. This is simulated through channel 262. Sterkfontein Dam forms a significant part of the storage created for the Upper Thukela yield and therefore need to be taken into account in the calculation of the yield. This transfer is thus included in the yield characteristics of the Vaal system used in the WRPM.
- Senqu – Vaal transfer: This transfer is simulated through channel 1139. A transfer volume of 780 mill m^3/a was removed as a demand on Katse Dam out of the system. While this water in reality enters Vaal Dam, this is not simulated as such because the Vaal catchment yield is determined without this transfer volume. The volume should however be removed in order to determine the Orange yield as it would be incorrect to include it in such a yield determination.

Additional transfers that are simulated are as follows:

- Caledon-Modder transfer: Bloemfontein and surrounding areas pull water from the Caledon system (Welbedacht and Knellpoort Dams) when there is insufficient water in the Modder system. The transfer differs according to the required demand and availability in the Modder system.
- Eastern Cape Transfer: This is modelled as a single constant abstraction (via channel number 130) as the detailed Eastern Cape system has not been configured into the WRYM.

- Orange-Riet Transfer: Irrigation demands in the Riet area pull water from the Orange system as and when required.
- Orange-Vaal Transfer: Douglas irrigation demands in the Lower Vaal pull water from the Orange system as and when required. The Vaal spills are also able to support these irrigation demands.

5 PHYSICAL SYSTEM COMPONENTS

5.1 Impoundments

There are 56 existing major dams modelled implicitly in the integrated Orange-Senqu-Vaal configuration and a further 19 possible dams. Details of these major existing dams are provided in **Section 5.1.1** while the possible dams are in **Section 5.1.3**

A number of other smaller farms dams exist, and these have been lumped together to create larger "dummy" dams. Details of the 80 simulated dummy dams are provided in **Section 5.1.2**.

5.1.1 Major Dams

Table 5-1 presents the details of the major dams simulated in the systems analyses.

Table 5-1: Details of Major Dams

Figure (1)	Dam no.	Name	FSA (km^2)	FSV (mill m^3)	FSL (m)	DSL (m)	BL (m)
A-3	552	UP THUK WOODSTOCK DAM	29.1	373.3	1175.6	1150.0	1135.5
A-3	553	UP THUK DRIEL BARRAGE	3.1	10.4	1134.0	1125.0	1124.0
A-4	533	VAAL GROOTDRAAI DAM	38.8	356.0	1549.0	1533.0	1514.0
A-4	538	VAAL SAULSPOORT DAM	4.0	16.9	1627.3	1616.8	1616.8
A-4	544	VAAL STERKFONTEIN DAM	67.3	2617.0	1702.0	1646.0	1617.0
A-5	542	VAAL DAM	322.8	2609.8	1484.6	1462.9	1444.5
A-6	548	VAAL BARRAGE	13.5	55.4	1421.1	1413.5	1410.5
A-7	920	SCHOON KALK DAM	1.0	2.2	1327.3	1325.0	1325.0
A-7	575	SCHOON RIETSPRUIT DAM	2.3	7.3	1410.3	1403.0	1403.0
A-7	576	SCHOON JOHAN NESER DAM	2.7	5.7	1317.7	1311.6	1311.0
A-7	935	SCHOON ELANDSKUIL DAM	0.5	1.2	1438.6	1432.3	1432.0
A-8	571	RENOST KOPPIES DAM	13.8	42.3	1412.4	1408.0	1406.5
A-9	5	VAAL SERFONTEIN DAM	1.8	5.3	1303.0	1300.0	1300.0
A-9	565	VAAL BLOEMHOF DAM	233.5	1264.4	1228.5	1213.6	1210.8
A-9	567	VAAL KLERKSKRAAL DAM	3.8	8.2	1461.1	1456.2	1454.5
A-9	568	VAAL BOSKOP DAM	3.8	20.9	1386.9	1374.8	1372.0
A-9	569	VAAL KLIPDRIFT DAM	4.7	13.6	1368.4	1363.5	1363.5
A-9	579	VAAL ALLEMANSKRAAL DAM	26.5	179.3	1368.7	1355.9	1353.0
A-9	580	VAAL ERFINIS DAM	32.9	212.2	1331.9	1318.2	1313.0
A-9	2	VAAL POTCHEFSTROOM DAM	0.8	2.0	1346.1	1340.0	1340.0
A-10	277	TAUNG BARBERSPAN	16.0	30.4	1492.5	1490.0	1490.0
A-10	278	TAUNG WENTZEL DAM	3.0	6.6	1297.7	1291.3	1291.3
A-10	280	TAUNG DAM	4.6	65.2	1155.0	1129.0	1120.0
A-10	287	TAUNG SPITSKOP DAM	25.3	57.9	1042.6	1037.1	1037.0
A-10	264	TAUNG VAALHARTS WEIR	21.2	48.7	1190.2	1182.9	1182.9

Figure (1)	Dam no.	Name	FSA (km^2)	FSV (mill m^3)	FSL (m)	DSL (m)	BL (m)
B-3	1021	LES HIGH 21 KATSE DAM	35.8	1950.0	2053.0	1989.0	1895.0
B-3	1027	LES HIGH 27 MOHALE DAM	22.1	938.0	2075.0	2005.0	1940.0
B-4	2699	CALEDON ARMENIA DAM	3.9	13.8	1514.9	1503.0	1503.0
B-4	1044	CALEDON 44 KNELLPOORT DAM	9.8	137.0	1452.1	1428.6	1412.0
B-4	1047	CALEDON 47 WELBEDACHT DAM	11.8	15.5	1402.9	1385.2	1383.2
B-5	1052	VAAL 52 RUSTFONTEIN DAM	11.6	72.6	1373.0	1356.3	1354.0
B-5	1054	VAAL 54 GROOTHOEK DAM	2.9	15.0	1495.0	1484.8	1470.0
B-5	1055	VAAL 55 MOCKES DAM	3.4	4.6	1303.6	1301.9	1299.5
B-5	1056	VAAL 56 KRUGERSDRIFT DAM	18.8	68.9	1248.1	1229.9	1229.9
B-5	1057	VAAL 57 TIERPOORT DAM	9.1	34.5	1382.8	1374.5	1374.5
B-5	1058	VAAL 58 KALKFONTEIN DAM	45.3	319.6	1229.0	1210.1	1210.1
B-5	1088	VAAL 88 DOUGLAS WEIR	7.8	16.1	990.5	988.6	987.8
B-5	1094	VAAL 94 TWEERIVIER WEIR	7.5	12.6	1490.5	1488.0	1488.0
B-5	1098	VAAL 98 KNOFFELFONTEIN DAM	2.3	22.0	1493.0	1490.0	1490.0
B-6	1063	UP ORAN 63 GARIEP DAM	352.2	5348.1	1258.7	1233.1	1202.9
B-6	1066	UP ORAN 66 VANDERKLOOF DAM	133.4	3188.6	1170.5	1151.0	1109.8
B-7,8	2517	MOLOPO 1517 LOTLAMORENG DAM	0.3	0.4	1700.0	1671.0	1671.0
B-7,8	2518	MOLOPO 1518 SETUMO DAM	4.4	19.6	1226.3	1213.4	1213.0
B-7,8	2520	MOLOPO 1520 DISANENG DAM	4.4	16.0	1700.0	1671.0	1671.0
B-7,8	2564	MOLOPO 1564 OTJIVERO DAM	1.5	9.8	1700.0	1671.0	1671.0
B-7,8	2570	MOLOPO 1570 DAAN VILJOEN DAM	0.2	0.4	1700.0	1671.0	1671.0
B-7,8	2571	MOLOPO 1571 TILDA VILJOEN DAM	0.2	1.2	1700.0	1671.0	1671.0
B-9	2644	LOW TRIB 1644 VICTORIA WES DAM	2.2	3.7	1700.0	1671.0	1671.0
B-9	2641	LOW TRIB 1641 SMART SYNDICATE DAM	31.4	101.1	1700.0	1671.0	1671.0
B-9	2638	LOW TRIB 1638 MODDERPOORT DAM	2.2	12.3	1700.0	1671.0	1671.0
B-9	2628	LOW TRIB 1628 LOXTON DAM	0.3	3.4	1700.0	1671.0	1671.0
B-9	2623	LOW TRIB 1623 VAN WYKSVLEI DAM	49.6	143.1	1700.0	1671.0	1671.0
B-9	2619	LOW TRIB 1619 ROOIBERG DAM	3.1	3.7	1700.0	1671.0	1671.0
B-10	1071	FISH 71 HARDAP DAM	28.7	294.6	1135.0	1114.8	1109.9
B-10	1075	FISH 75 NAUTE DAM	11.5	83.6	732.0	711.3	703.5
B-11	1105	LOW MAIN 105 BOEGOEBERG WEIR	6.9	20.7	884.6	875.3	874.9

Note 1: Refers to figure in Appendices where dam is located

Abbreviations: FSA: Full supply area, FSV: full supply volume, FSL: Full supply level, DSL: Dead storage level, BL: Bottom level

5.1.2 Dummy Dams

Because dummy dams are a single dam which represent a number of smaller farm dams, their elevations are merely dummy values selected in order for a point of reference for the model to use in the simulations. For this reason, only the full supply areas and capacities of the dummy dams are presented in **Table 5-2.**

Table 5-2: Details of Dummy Dams

Figure (1)	Dam no.	Name	FSA (km^2)	FSV (mill m^3)	Figure (1)	Dam no.	Name	FSA (km^2)	FSV (mill m^3)
A-3	519	UP THUK WOODSTOCK DUMMY DAM	3.82	14.14	A-9	586	VAAL BOSKOP DUMMY DAM	4.075	8.15
A-4	532	VAAL GROOTDRAAI DUMMY DAM	24.802	35.517	A-9	587	VAAL KLIPDRIFT DUMMY DAM	1.71	3.42
A-4	540	VAAL FRANKFORD DUMMY DAM	30.66	48.438	A-9	588	VAAL BLOEMHOF DUMMY DAM	8.57	17.14
A-4	143	VAAL FRANKFORT DUMMY DAM	1.61	2.549	A-10	272	TAUNG WENTZEL DUMMY DAM	4.493	7.537
A-4	133	VAAL GROOTDRAAI DUMMY DAM2	5.768	8.26	A-10	281	TAUNG DUMMY DAM	1	1.376
A-5	537	VAAL DUMMY DAM	7.382	8.36	A-10	283	TAUNG SPITSKOP DUMMY DAM	5.56	6.119
A-5	183	VAAL DELA DUMMY DAM	8.581	10.496	B-4	1038	CALEDON 38 DUMMY3 DAM RSA	20.3	46.43
A-5	191	VAAL DUMMY DAM 1	12.293	13.921	B-5	1081	VAAL 81 RUSTFONT DUMMY DAM	2.05	3.1
A-5	155	VAAL UWATERVAL DUMMY DAM	4.49	8.25	B-5	1084	VAAL 84 MOCKES DUMMY DAM	1.581	2.31
A-5	169	VAAL LWATERVAL DUMMY DAM	2.75	5.06	B-5	1091	VAAL 91 KRUGERSDRIFT DUMMY DAM	0.913	1.24
A-5	165	VAAL WATERVAL DUMMY DAM	3.59	6.59	B-5	1093	VAAL 93 TWEERIVIER DUMMY DAM	4.445	7.447
A-6	551	VAAL KLIPRIVER DUMMY DAM	4.186	9.66	B-5	1096	VAAL 96 TIERPOORT DUMMY DAM	3.341	5.39
A-6	557	VAAL BARRAGE DUMMY DAM	2.47	5.69	B-5	1106	VAAL 106 KALKFONTEIN DUMMY DAM	26.478	56.21
A-6	591	VAAL KROMDRAAI DUMMY DAM	3.765	7.53	B-6	1062	UP ORAN 62 DUMMY2 DAM	85	150
A-6	592	VAAL SUIKER DUMMY DAM	7.406	16.366	B-6	1064	UP ORAN 64 DUMMY1 DAM	65	80
A-6	244	VAAL KLIPRIVER D/S DUM DAM	2.314	5.34	B-7,8	2511	MOLOPO 1511 D41A DUMMY DAM	2.07	1.94
A-6	249	VAAL BARRAGE U/S DUM DAM	3.13	7.21	B-7,8	2528	MOLOPO 1528 D41B DUMMY DAM	10.24	16.45
A-6	219	VAAL SUIKER D/S DUM DAM	2.122	5.331	B-7,8	2521	MOLOPO 1521 D41D DUMMY DAM	0.44	0.27
A-6	234	VAAL BLESBOK DUMMY DAM	0.592	1.306	B-7,8	2525	MOLOPO 1525 D41C DUMMY DAM	1.42	2.56
A-6	229	VAAL BLESBOK DUMMY DAM	0.329	0.823	B-7,8	2539	MOLOPO 1539 D41E DUMMY DAM	0.03	0.01
A-6	224	VAAL BLESBOK DUMMY DAM	1.005	2.499	B-7,8	2537	MOLOPO 1537 D41F DUMMY DAM	0.07	0.04
A-6	226	VAAL BLESBOK DUMMY DAM	0.855	4.815	B-7,8	2549	MOLOPO 1549 D42D DUMMY DAM	1.03	1.85
A-7	950	SCHOON C24D DUMMY DAM	0.19	0.38	B-7,8	2553	MOLOPO 1553 D42B DUMMY DAM	0.37	0.29
A-7	970	SCHOON C24E DUMMY DAM	1.01	2.01	B-7,8	2555	MOLOPO 1555 D42A DUMMY DAM	0.28	0.22
A-7	975	SCHOON C24F DUMMY DAM	2.25	4.51	B-7,8	2543	MOLOPO 1543 D42F DUMMY DAM	0.38	0.32
A-7	985	SCHOON C24G DUMMY DAM	1.07	3.51	B-7,8	2558	MOLOPO 1558 D42G DUMMY DAM	0.77	0.49
A-7	912	SCHOON C24H DUMMY DAM	2.06	4.29	B-7,8	2590	MOLOPO 1590 D42D DUMMY DAM	1.76	1.99
A-8	578	RENOST KOPPIES DUMMY DAM	3.89	7.79	B-7,8	2561	MOLOPO 1561 OTJV DUMMY DAM	4.55	3.26
A-8	305	RENOST C70D DUMMY DAM	0.71	1.47	B-7,8	2566	MOLOPO 1566 DVILJ DUMMY DAM	4.55	3.26
A-8	308	RENOST C70E DUMMY DAM	0.82	3.14	B-7,8	2578	MOLOPO 1578 SEEIS DUMMY DAM	1.05	1.71
A-8	307	RENOST C70F DUMMY DAM	3.74	6.68	B-7,8	2575	MOLOPO 1575 OLIFANTS FARM DAM	1.05	1.71

Figure (1)	Dam no.	Name	FSA (km²)	FSV (mill m³)	Figure (1)	Dam no.	Name	FSA (km²)	FSV (mill m³)
A-8	312	RENOST C70G DUMMY DAM	3.17	6.33	B-9	2643	LOW TRIB 1643 GROUP 1 DUMMY	1.7	3.6
A-8	314	RENOST C70H DUMMY DAM	1.07	2.14	B-9	2639	LOW TRIB 1639 GROUP 2 DUMMY	0.13	0.52
A-8	574	RENOST C70J DUMMY DAM	0.79	1.57	B-9	2627	LOW TRIB 1627 GROUP 7 DUMMY	4.49	13.73
A-8	318	RENOST C70K DUMMY DAM	2.63	5.25	B-9	2637	LOW TRIB 1637 GROUP 6 DUMMY RIET	1.34	2.23
A-9	114	VAAL BLOEM UPPER DUMMY DAM	8.217	15.953	B-9	2636	LOW TRIB 1636 GROUP 6 DUMMY RENOS	0.11	0.32
A-9	581	VAAL KLIPBANK DUMMY DAM	23.01	46.29	B-9	2633	LOW TRIB 1633 GROUP 6 DUMMY FISH 2	0.36	1
A-9	582	VAAL ALLEMANSKRAAL DUMMY DAM	8.45	16.93	B-9	2631	LOW TRIB 1631 GROUP 6 DUMMY FISH 1	2.1	7.09
A-9	583	VAAL SAND DUMMY DAM	15.085	30.17	B-9	2622	LOW TRIB 1622 GROUP 9 DUMMY	0.49	0.9
A-9	584	VAAL ERFENIS DUMMY DAM	15.94	31.87	B-11	2646	LOW MAIN 1646 GROUP 5 DUMMY	1.11	1.84

Note 1: Refers to figure in Appendices where dam is located

Abbreviations: FSA: Full supply area, FSV: full supply volume

5.1.3 Possible Dams

Over the years, the yield model has been used to assess the impacts of future possible dams in the integrated Orange-Senqu-Vaal catchment. Some of these dams are more likely to be developed than others. A possible dam can either be switched on or off for a simulation, depending on whether the user would like to include it or not. For the purposes of determining the yields for this study, no possible dams were switched on for the analyses. They are however configured into the model should they be required in the future. The possible dams are summarised in **Table 5-3.**

Table 5-3: Details of Possible Dams.

Figure (1)	Dam no.	Name	FSA (km²)	FSV (mill m³)	FSL (m)	DSL (m)	BL (m)
A-4	534	VAAL BALMORAL DAM	93.6	1864.4	1680.0	1603.0	1603.0
A-6	561	VAAL KROMDRAAI DAM	90.0	900.0	1339.0	1313.0	1313.0
A-8	572	RENOST RIETFONTEIN DAM	13.6	61.5	1317.5	1298.0	1298.0
A-9	577	VAAL KLIPBANK DAM	36.0	186.0	1287.7	1271.0	1271.0
B-3	1020	LES HIGH 20 POLIHALI DAM	50.4	2322.2	2075.0	2009.0	1925.0
B-3	1023	LES HIGH 23 TAUNG DAM	48.0	2000.0	1885.0	1820.0	1760.0
B-3	1024	LES HIGH 24 MASHAI DAM	67.0	3357.4	1885.0	1834.0	1730.0
B-3	1025	LES HIGH 25 TSOELIKE DAM	48.8	2037.5	1758.0	1725.0	1640.0
B-3	1026	LES HIGH 26 NTOAHAE DAM	32.0	1465.7	1636.0	1610.0	1520.0
B-3	1029	LES HIGH 29 MALATSI DAM	21.0	1075.0	1660.0	1640.0	1520.0
B-3	2601	LES HIGH 1601 MAKHALENG DAM	1.5	28.4	1700.0	1656.7	1656.7
B-4	2591	CALEDON 1591 HLOTSE DAM	2.3	26.3	1600.0	1579.7	1579.7

Figure (1)	Dam no.	Name	FSA (km^2)	FSV (mill m^3)	FSL (m)	DSL (m)	BL (m)
B-4	2596	CALEDON 1596 HOLOLO DAM	2.8	54.0	1680.0	1624.7	1624.7
B-4	2606	CALEDON 1606 METALONG DAM	2.9	63.6	1671.0	1644.8	1605.0
B-6	1032	UP ORAN 32 BOSBERG DAM	40.1	1213.6	1343.0	1332.8	1297.0
B-6	1104	UP ORAN 104 TORQUAY DAM	35.2	560.0	1041.0	1015.0	991.5
B-10	1078	FISH 78 LOW FISH DAM	11.0	170.0	752.0	710.0	700.0
B-11	1127	LOW MAIN 127 VIOOLSDRIFT DAM ADJ	134.5	3120.3	221.4	213.5	176.4
B-11	1129	LOW MAIN 129 KABIES DAM	132.6	3662.8	140.0	68.1	68.1

Note 1: Refers to figure in Appendices where dam is located

Abbreviations: FSA: Full supply area, FSV: full supply volume, FSL: Full supply level, DSL: Dead storage level, BL: Bottom level.

5.2 Water Reticulation Infrastructure

Though the main purpose of the yield model is not for operations modelling but rather to determine subsystem yields, a number of capacity limitations are included where these are likely to affect the yield of a subsystem in one way or another. These infrastructure capacities are sometimes modelled by means of “min-max” channels where a maximum limit is placed on a channel that represents a pipeline capacity. Diversions are also simulated which refer to either dam or river levels or flows.

5.2.1 Infrastructure Capacities

Table 5-4 presents the capacities of the described channels as configured into the model.

Table 5-4: Channels with Capacity Limitations

Figure (1)	Channel No	Name	Maximum Channel capacity (mill m^3/a)
A-7	933	933 - SCHOONSPRUIT CANAL 2	13.16
A-7	934	934 - SCHOONSPRUIT CANAL 3	26.29
A-7	948	948 - SCHOONSPRUIT SPLIT TO ELANDSKUIL DAM	6.94
B-3	1021	LES HIGH 1021 - MOHALE/KATSE TFER TUN	807.56
B-6	1049	UP ORAN 1049 - O/V CANAL MAX KAP.	252.46
B-6	1128	UP ORAN 1128 - ORANGE RIET CANAL CAP	795.25
B-4	1232	CALEDON 1232 - KNELLPOORT TO RUSTFONTEIN	75.74
B-5	1076	VAAL 1076 - BLOEMFONTEIN LIMIT	45.29
B-11	1154	LOW MAIN 1154 - BOEG CANAL CAPACITY	308.00
B-11	1166	LOW MAIN 1166 - UPING IRR CANAL CAP	312.77

5.2.2 Diversions

Table 5-5 presents a summary of the channels in the integrated Orange-Senqu-Vaal system where various system flows or reservoir levels impact the flow determined for the channel.

Table 5-5: Diversion Flow Details

Figure	Chan no	Channel Name	Diversion Description	Diversion details	
A-11	270	270 - TAUNG CONTROLLED SPITSK REL	The level of Spitskop Dam dictates the release through channel 270	**Spitskop level**	**Channel 270 flow**
				1037.5	0
				1037.75	1.75
				1038.01	2.48
				1038.77	3.92
				1039.52	4.96
				1040.03	5.55
				1041.04	6.56
				1041.55	7.01
				1042.05	7.44
				1042.56	7.84
B-3	120	LES HIGH 1021 - MOHALE/KATSE TFER TUN	The difference in elevations between Katse and Mohale dictates the flow through channel 1021	**Difference in elevation**	**Channel 120 flow**
				0	0
				2.4	4.74
				4.8	6.7
				7.2	8.21
				9.6	9.47
				12	10.59
				14.4	11.6
				36.77	18.54
				59.13	23.51
				81.5	27.61
B-4	1061	CALEDON 1061 - TIENF. TO KNELLPOORT	The inflow to upstream node 1042 dictates the flow through channel 1061	**Inflow to node 1042**	**Channel 1061 flow**
				0	0
				1.03	0.47
				7.3	2.08
				12.64	2.32
				17.3	2.52
				22.79	2.61
				27.14	2.69
				34.77	2.74

Figure	Chan no	Channel Name	Diversion Description	Diversion details	
				45.01	2.79
				59.67	2.87
				82.26	2.97
				999	3
B-4	1600	CALEDON 1600 - WELBEDACHT COMP	The inflow to upstream node 1041 dictates the flow through channel 1061	**Inflow to node 1041**	**Channel 1600 flow**
				0	0
				0.5	0.5
				1	1
				1.5	1.5
				2	2
				10	2
				20	2
				30	2
				40	2
				50	2
				80.01	2
				99	2
B-4	3571	LOW TRIB 3571 VAN WYKS DIVERS	The inflow to upstream node 2621 dictates the flow through channel 3571	**Inflow to node 2621**	**Channel 3571 flow**
				0	0
				0.01	0.01
				0.5	0.5
				1	1
				2	2
				3	3
				4	4
				5	5
				10	5
				20	5
				50	5
				999	5
A-7	932	932 - SCHOON DIVERSION CANAL 1	The inflow to upstream node 900 dictates the flow through channel 932	**Inflow to node 900**	**Channel 932 flow**
				0	0
				0.79	0.79
				1.11	0.99
				1.43	1.07
				1.74	1.13
				2.06	1.19
				2.38	1.23

Figure	Chan no	Channel Name	Diversion Description	Diversion details	
				2.7	1.27
				3.01	1.31
				3.33	1.33
				3.4	1.33
				999	1.33
A-3	701	701 - UP THUK CLIFFORD CHAMBERS TRSF	The natural hydrology inflow to node 518 dictates the flow through channel 701 differently per month	**Month**	**Proportion of natural inflow diverted**
				Oct	0.6
				Nov	0.6
				Dec	0.63
				Jan	0.46
				Feb	0.47
				Mar	0.6
				Apr	0.57
				May	0.6
				Jun	0.54
				Jul	0.43
				Aug	0.54
				Sep	0.55
A-3	709	709 - UP THUK DIVERSION TO DRIEL	The natural hydrology inflow to node 529 and the reservoir level of Driel Barrage dictate the flow through channel 709	See Table 5-6	

Table 5-6: Channel 709 Diversion Details

	Reservoir storage levels						
	1124	1125	1127	1129	1132	1134	1124
Reference flow values	**Proportion of flow diverted**						
0	1	1	1	1	1	1	1
10	1	1	1	1	1	0.9	1
20	0.9	0.9	0.9	0.9	0.8	0.7	0.9
30	0.6	0.6	0.6	0.6	0.6	0.5	0.6
40	0.5	0.5	0.5	0.5	0.45	0.4	0.5
60	0.35	0.35	0.35	0.35	0.33	0.3	0.35
0	1	1	1	1	1	1	1

6 CONFIGURATION OF WRYM

6.1 Overview

The Water Resources Yield Model (WRYM) was selected for use in this study to be updated and used to determine the individual system yields required as input to the Water Resources Planning Model (WRPM). The integrated Orange-Senqu-Vaal yield model used two separate system configurations which were then combined in order to make the final integrated system model. The next two subsections describe the procedure that took place in order to configure the WRYM.

6.1.1 Vaal

The most recent version of the Vaal WRYM configuration was used as a basis for the Vaal part of the integrated model. This includes sub-catchment configurations obtained the following indicated studies:

- Grootdraai & Bloemhof: Vaal River System Analyses Update Study (VRSAU);
- Schoonspruit: Vaal River Continuous Investigations: Schoonspruit Sub-system Analysis Study;
- Renoster: Vaal River Continuous Investigations (ph 2): Assessment of the Assurance of Supply of Bulk Water from the Koppies Dam to Voorspoed Diamond Mine; and
- Lower Vaal: Feasibility Study for Utilisation of Taung Dam.

Over the years, very few updates have been carried out on the Vaal WRYM configuration, and more focus has been placed on updating the WRPM as this is the tool used on an annual basis for planning and operational purposes of the integrated system. As a result, the WRPM configuration includes a much greater level of detail and was therefore used as a basis to update the WRYM configuration. A large portion of the effort of this task was spent as follows:

- updating the Vaal WRYM network configuration to match the WRPM configuration;
- updating all the demands and return flows to 2010 development level;
- including irrigation time series information (i.e. Irrigation blocks) instead of the previously simulated constant demand over the full record period; and
- connecting the updated Vaal WRYM to the updated Orange WRYM to produce a final integrated model configuration.

6.1.2 Orange

The most recent version of the Orange WRYM configuration was used as a basis for the Orange-Senqu part of the integrated model. This includes sub-catchment configurations obtained the following indicated studies:

- Senqu, Caledon, Riet/Modder, Upper Orange, Lower Orange Main Stem and Fish: Lower Orange River Management Study (LORMS)

The other subsystems were included in the network for the first time based on hydrological study networks as described below:

- Molopo subsystem: Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse: Hydrology Report
- Lower Orange tributaries: hydrology updated as part of this study based on WR2005 network configurations.

6.1.3 Development of a Representative System Network Model

Developing a representative network model for a water resource system involves a process whereby the modeller creates a synthetic representation of reality, in the form of a schematic diagram. This is achieved by indicating the connectivity between and nature of the various components that make up the system in question. This process of synthesis, however, always implies a trade-off between the need to simulate the behaviour of individual system components at a sufficient level of detail, on the one hand, and practical modelling limitations on the other. The process of developing a representative system network model therefore includes three main aspects, (a) the identification of physical system features, (b) assessing the appropriate spatial resolution and (c) the lumping and aggregation of system components until the appropriate spatial resolution is achieved.

The system network schematic diagrams are presented in **Appendix A** and **B** for the Vaal and Orange systems respectively. The model is integrated and does run as one combined system, and the schematic diagrams have merely been separated for ease of reference. **Figures A-1** and **B-1** present the geographical layouts of the catchments, and show where each catchment is located on the map. **Figures A-2** and **B-2** represent how the various schematic diagrams fit together. The maps and schematic diagrams have been colour coded in order to make it simpler for the reader to follow. The following table presents a summary of the figure on which each catchment can be located, and its associated colour code. The table also represents any channels that either flow in to or out of the sub-catchment and their details.

Table 6-1 Catchment Location Details

Figure (1)	Catchment	Colour code	Inflow channels	Outflow channels
A-3	Thukela	Light pink	-	18, 294: to remaining Thukela 262: to Wilge
A-4	Wilge	Purple	262: from Thukela	562: to Vaal
	Grootdraai		-	215: to Vaal
A-5	Vaal	Brown	562, 215 from Wilge, Grootdraai	561: to Barrage
A-6	Klipbank & Barrage	Dark pink	561: from Vaal	-
	Krom		-	591: to Bloemhof
	Suikerbos		-	-
A-7	Schoonspruit	Blue	-	622: to Bloemhof
A-8	Renoster	Orange	-	349 to Bloemhof
A-9	Sand - Vet	Green		
	Bloemhof		591: from Krom 349: from Renoster 622: from Schoonspruit	220: to Lower Vaal
	Mooi			
	Vals			
	Klipdrift			
A-10	Lower Vaal	Yellow	220: from Bloemhof	289: to Riet Modder
B-3	Senqu	Light pink	-	1030: to Upper Orange
B-4	Caledon	Purple	-	1071: to Upper Orange 1068, 1147: to Riet Modder
B-5	Riet - Modder	Blue	289: from Lower Vaal 1068,1 147: from Caledon 1128, 1049: from upper Orange	1124, 1173: to Upper Orange 1095: to Lower Main
B-6	Upper Orange	Light green	1030: from Senqu 1124, 1173: from Riet – Modder 1071: from Caledon	1049, 1128 :to Riet – Modder 1041: to Lower Main
B-7	Molopo	Orange	-	3431, 3404: to Nossob
B-8	Nossob	Dark pink	3431, 3404: from Molopo	3468: to Lower Main
B-9	Lower Tributaries	Brown	-	3597, 3572: to Lower Main
B-10	Fish	Dark green	-	3221: to Lower Main
B-11	Lower Main	Yellow	1095: from Riet-Modder 3468: from Nossob 1141: from Upper Orange 3597, 3572: from Lower Tributaries	

6.1.4 WRYM System Configuration Testing

Great care was taken to ensure that the network configuration definition input into the WRYM was correct and accurately represented the intended configuration. This included four main processes which are discussed below:

- Extensive checking was undertaken to verify that the sub-catchment hydrology data was applied correctly in the WRYM system. This involved comparing simulated node inflows with the net runoffs contained in the associated sub-catchment hydrology data sets.
- Simulated model results were checked against the known physical characteristics of system components, such as the full supply, dead storage and bottom levels of reservoirs.
- The system network connectivity was checked by undertaking mass balances at selected nodes in the system to ensure that the defined linkages in the system definition are correct.
- Simulated model results were checked to ensure that the behaviour of the system does reflect the intended operating rules, including the following situations:
  - When reservoirs / dummy dams are full;
  - When reservoirs / dummy dams are empty;
  - During drawdown events;
  - When supply priorities control the flow of water.

6.2 Model Description

6.2.1 General

The Water Resources Yield Model (WRYM) system of the integrated Orange-Senqu-Vaal catchments was configured and simulated using Version 7.5.6.7 of the WRYM-IMS (version 3.8.2). System schematic diagrams of the WRYM configurations for the integrated system are presented in **Figures A-3** to **A-10** of **Appendix A** and **Figures B-3** to **B-11** of **Appendix B**. It should be noted that these diagrams are representative of the base scenarios, and would change if and when the user implements changes to undertake scenario analyses.

The following sections provide more detail on the configuration of the WRYM for the integrated Orange-Senqu-Vaal system, particularly with regard to the selected basic run control settings, modelled sub-catchment areas, incremental runoffs, irrigation areas, operating rule definitions, as well as the determination of the system yield.

6.2.2 Run Control Settings

Run control settings in the WRYM are used to define general information on how the system will be analysed for a particular model run. For the yield analysis of the integrated Orange-Senqu-Vaal system, this includes, most importantly, the following:

- An analysis period of 85 years from the 1920 to the 2004 hydrological year (i.e. October 1920 to September 2005) was used. This corresponds with the selected Study period as well as with the updated and extended hydro-meteorological data sets developed during the hydrological analysis of the Study

6.2.3 Sub-Catchment Areas and Incremental Runoffs

Information on the modelling of sub-catchment areas and incremental runoffs within the context of the WRYM representative network model is provided in **Table 6-2** below and is based on the updated and extended hydro-meteorological data sets developed during the hydrological analysis of the Study. The information includes a description of the network element, node number associated with the sub-catchment in question, as well as the reference number (i.e. the catchment number), in sequence as listed in the PARAM.DAT-file and routing percentage of the associated hydrological data file set.

It should be noted that such a data file set is defined for each catchment in the system and includes four time-series data files that cover the Study period of 85 years from 1920 to 2004 (hydrological years). These are:

- The *.INC-file, which contains monthly historical natural incremental runoff volumes (in units of million m^3);
- The *.IRR-file, which contains monthly historical diffuse irrigation water requirements (in units of million m^3) (all zeros for this study);
- The *.AFF-file, which contains monthly historical reductions in runoff due to in-catchment alien vegetation (in units of million m^3);
- The *.RAN-file, which contains monthly historical rainfall (in units of mm).

Table 6-2: Summary of Simulated Incremental Runoffs

Figure (1)	Catchment	Streamflow file name	Param. dat no.	Perc-entage inflow	Inflow node	Figure (1)	Catchment	Stream-flow file name	Para m.dat no.	Perc-entage inflow	Inflow node
A-3	Thukela	TM0194	79	100	518	B-4	Caledon	KATJREST	71	69	1039
A-3	Thukela	TM0294	80	100	519	B-4	Caledon	KATJREST	71	31	1040
A-3	Thukela	TM0394	81	100	553	B-4	Caledon	KNELL	72	100	1044
A-3	Thukela	TM0494	82	100	529	B-4	Caledon	WATER	77	100	1018
A-4	Wilge	FRAN4	7	20.1	540	B-4	Caledon	WELINC	78	28	1038
A-4	Wilge	FRAN4	7	5.5	143	B-4	Caledon	WELINC	78	72	1037
A-4	Wilge	FRAN4	7	42.1	543	B-4	Caledon	METO	239	100	2606

Figure (1)	Catchment	Streamflow file name	Param. dat no.	Perc-entage inflow	Inflow node	Figure (1)	Catchment	Stream-flow file name	Para m.dat no.	Perc-entage inflow	Inflow node
A-4	Wilge	FRAN4	7	11.6	141	B-4	Caledon	HLOABS	240	100	2593
A-4	Wilge	FRAN4	7	16.8	150	B-4	Caledon	HOLDAM	241	100	2596
A-4	Wilge	FRAN4	7	3.9	538	B-4	Caledon	HOLABS	242	100	2598
A-4	Grootdraai	GROOTD4	8	5.7	534	B-4	Caledon	ARMEN	243	100	2699
A-4	Grootdraai	GROOTD4	8	23.5	532	B-5	Riet - Modder	AUCH4	40	100	1088
A-4	Grootdraai	GROOTD4	8	13.8	133	B-5	Riet - Modder	KALKF4	41	10	1106
A-4	Grootdraai	GROOTD4	8	33.9	531	B-5	Riet - Modder	KALKF4	41	90	1108
A-4	Grootdraai	GROOTD4	8	23.1	132	B-5	Riet - Modder	KRUG4	42	4.6	1054
A-4	Wilge	STERK4	19	100	544	B-5	Riet - Modder	KRUG4	42	20.75	1084
A-5	Vaal	DELA4	5	16.3	183	B-5	Riet - Modder	KRUG4	42	10.95	1091
A-5	Vaal	DELA4	5	61.8	188	B-5	Riet - Modder	KRUG4	42	20.75	1085
A-5	Vaal	DELA4	5	21.9	186	B-5	Riet - Modder	KRUG4	42	42.95	1089
A-5	Vaal	VAAL4	21	17.7	537	B-5	Riet - Modder	RUSTF4	43	51	1081
A-5	Vaal	VAAL4	21	13.1	191	B-5	Riet - Modder	RUSTF4	43	49	1082
A-5	Vaal	VAAL4	21	3.8	169	B-5	Riet - Modder	TIER4	44	10	1096
A-5	Vaal	VAAL4	21	26.5	535	B-5	Riet - Modder	TIER4	44	90	1097
A-5	Vaal	VAAL4	21	19.7	536	B-5	Riet - Modder	TWEE4	45	30	1093
A-5	Vaal	VAAL4	21	8.7	162	B-5	Riet - Modder	TWEE4	45	70	1059
A-5	Vaal	VAAL4	21	3.2	172	B-6	Upper Orange	ALIW4	67	73	1032
A-5	Vaal	VAAL4	21	7.3	165	B-6	Upper Orange	ALIW4	67	27	1035
A-5	Vaal	C12D4	205	54	156	B-6	Upper Orange	PKDU4	73	100	1064
A-5	Vaal	C12D4	205	46	155	B-6	Upper Orange	ROOD4	74	100	1033
A-6	Klip & Barrage	BARR4	2	16.6	557	B-6	Upper Orange	VERW4	75	100	1063
A-6	Klip & Barrage	BARR4	2	10.5	249	B-7,8	Molopo	D41ARED	17	100	2511
A-6	Klip & Barrage	BARR4	2	44.6	547	B-7,8	Molopo	UAUB	24	70	2584
A-6	Klip & Barrage	BARR4	2	28.3	556	B-7,8	Molopo	UAUB	24	10	2585
A-6	Klip & Barrage	KLIPR4	12	10.7	551	B-7,8	Molopo	UAUB	24	20	2586
A-6	Klip & Barrage	KLIPR4	12	5.3	244	B-7,8	Molopo	LOLIF	36	100	2583
A-6	Klip & Barrage	KLIPR4	12	58.3	239	B-7,8	Molopo	D41N	38	100	2533
A-6	Klip & Barrage	KLIPR4	12	25.7	242	B-7,8	Molopo	D41M	46	100	2535
A-6	Krom	KROMN4	14	75	561	B-7,8	Molopo	D41K	47	100	2541
A-6	Krom	KROMN4	14	25	591	B-7,8	Molopo	D41B	48	58	2527
A-6	Suikerbos	SUIK4	20	1	234	B-7,8	Molopo	D41B	48	32	2530
A-6	Suikerbos	SUIK4	20	3	229	B-7,8	Molopo	D41B	48	10	2528
A-6	Suikerbos	SUIK4	20	7	224	B-7,8	Molopo	D41C	49	50	2526
A-6	Suikerbos	SUIK4	20	5	226	B-7,8	Molopo	D41C	49	50	2525
A-6	Suikerbos	SUIK4	20	18	546	B-7,8	Molopo	D41D	50	75	2523
A-6	Suikerbos	SUIK4	20	5	235	B-7,8	Molopo	D41D	50	25	2521
A-6	Suikerbos	SUIK4	20	21	221	B-7,8	Molopo	D41E	51	75	2540
A-6	Suikerbos	SUIK4	20	6	228	B-7,8	Molopo	D41E	51	25	2539
A-6	Suikerbos	SUIK4	20	13	225	B-7,8	Molopo	D41F	52	75	2538
A-6	Suikerbos	SUIK4	20	13	592	B-7,8	Molopo	D41F	52	25	2537
A-6	Suikerbos	SUIK4	20	8	219	B-7,8	Molopo	D42B	53	75	2554
A-7	Schoonspruit	C24D4	128	11	950	B-7,8	Molopo	D42B	53	25	2553
A-7	Schoonspruit	C24D4	128	89	945	B-7,8	Molopo	UOLIF	55	75	2577
A-7	Schoonspruit	C24E4	129	20	970	B-7,8	Molopo	UOLIF	55	25	2575
A-7	Schoonspruit	C24E4	129	5	935	B-7,8	Molopo	SEEIS	56	20	2580

Figure (1)	Catchment	Streamflow file name	Param. dat no.	Perc-entage inflow	Inflow node	Figure (1)	Catchment	Stream-flow file name	Para m.dat no.	Perc-entage inflow	Inflow node
A-7	Schoonspruit	C24E4	129	75	965	B-7,8	Molopo	SEEIS	56	60	2581
A-7	Schoonspruit	C24F4	130	68	975	B-7,8	Molopo	SEEIS	56	20	2578
A-7	Schoonspruit	C24F4	130	32	980	B-7,8	Molopo	D41G	60	100	2536
A-7	Schoonspruit	C24G4	131	45	985	B-7,8	Molopo	D42A	61	75	2557
A-7	Schoonspruit	C24G4	131	55	990	B-7,8	Molopo	D42A	61	25	2555
A-7	Schoonspruit	C24H4	132	70	912	B-7,8	Molopo	D42F	62	75	2545
A-7	Schoonspruit	C24H4	132	30	908	B-7,8	Molopo	D42F	62	25	2543
A-8	Renoster	C70ABC4	13	16	578	B-7,8	Molopo	D42E	63	100	2546
A-8	Renoster	C70ABC4	13	84	301	B-7,8	Molopo	D42D	64	75	2551
A-8	Renoster	C70K4	127	90	318	B-7,8	Molopo	D42D	64	25	2549
A-8	Renoster	C70K4	127	10	320	B-7,8	Molopo	D42C	65	100	2552
A-8	Renoster	C70D4	191	60	305	B-7,8	Molopo	D43C	136	100	2574
A-8	Renoster	C70D4	191	40	304	B-7,8	Molopo	D44C	137	100	2587
A-8	Renoster	C70E4	192	10	308	B-7,8	Molopo	D44D	138	100	2588
A-8	Renoster	C70E4	192	90	309	B-7,8	Molopo	D41J	139	100	2542
A-8	Renoster	C70F4	193	47	307	B-7,8	Molopo	D42G	140	75	2559
A-8	Renoster	C70F4	193	53	306	B-7,8	Molopo	D42G	140	25	2558
A-8	Renoster	C70G4	194	41	312	B-7,8	Molopo	D45C	141	100	2560
A-8	Renoster	C70G4	194	59	313	B-7,8	Molopo	D45D	142	75	2589
A-8	Renoster	C70H4	195	36	314	B-7,8	Molopo	D45D	142	25	2590
A-8	Renoster	C70H4	195	64	315	B-7,8	Molopo	OTJV	143	25	2563
A-8	Renoster	C70J4	196	28	574	B-7,8	Molopo	OTJV	143	50	2565
A-8	Renoster	C70J4	196	72	572	B-7,8	Molopo	OTJV	143	25	2561
A-9	Sand - Vet	ALLEM4	1	75	579	B-7,8	Molopo	DVILJ	144	10	2567
A-9	Sand - Vet	ALLEM4	1	25	582	B-7,8	Molopo	DVILJ	144	80	2568
A-9	Bloemhof	BLOEMN3D4	3	14.4	114	B-7,8	Molopo	DVILJ	144	10	2566
A-9	Bloemhof	BLOEMN3D4	3	9.7	588	B-7,8	Molopo	D43B	150	100	2573
A-9	Bloemhof	BLOEMN3D4	3	17.8	560	B-7,8	Molopo	COM2124	217	100	2514
A-9	Bloemhof	BLOEMN3D4	3	6.8	573	B-7,8	Molopo	COM1113	218	100	2515
A-9	Bloemhof	BLOEMN3D4	3	34.2	564	B-7,8	Molopo	GRO	219	100	2516
A-9	Bloemhof	BLOEMN3D4	3	17.1	119	B-7,8	Molopo	COM2327	220	100	2513
A-9	Mooi	BOSK4	4	67	586	B-7,8	Molopo	COM22	221	100	2611
A-9	Mooi	BOSK4	4	33	1	B-9	Lower Trib	LOGR1	68	3	2644
A-9	Sand - Vet	ERF4	6	80	580	B-9	Lower Trib	LOGR1	68	3	2643
A-9	Sand - Vet	ERF4	6	20	584	B-9	Lower Trib	LOGR1	68	69	2641
A-9	Mooi	KLERK4	9	100	567	B-9	Lower Trib	LOGR1	68	25	2642
A-9	Vals	KLIPBN4	10	19	581	B-9	Lower Trib	LOGR2	76	7	2639
A-9	Vals	KLIPBN4	10	3.4	207	B-9	Lower Trib	LOGR2	76	93	2640
A-9	Vals	KLIPBN4	10	11.5	7	B-9	Lower Trib	LOGR6	225	1	2637
A-9	Vals	KLIPBN4	10	66.1	5	B-9	Lower Trib	LOGR6	225	0.5	2636
A-9	Klipdrift	KLIPDN4	11	55	89	B-9	Lower Trib	LOGR6	225	0.5	2633
A-9	Klipdrift	KLIPDN4	11	45	98	B-9	Lower Trib	LOGR6	225	1	2631
A-9	Sand - Vet	SANDN4	18	73.4	585	B-9	Lower Trib	LOGR6	225	31	2635
A-9	Sand - Vet	SANDN4	18	4.6	86	B-9	Lower Trib	LOGR6	225	27	2634
A-9	Sand - Vet	SANDN4	18	22	583	B-9	Lower Trib	LOGR6	225	37	2632
A-9	Mooi	LAKESN4	197	100	110	B-9	Lower Trib	LOGR6	225	2	2630
A-10	Lower Vaal	DEHOOP4	35	100	267	B-9	Lower Trib	LOGR7	226	4	2638

Figure (1)	Catchment	Streamflow file name	Param. dat no.	Perc-entage inflow	Inflow node	Figure (1)	Catchment	Stream-flow file name	Para m.dat no.	Perc-entage inflow	Inflow node
A-10	Lower Vaal	SPITS4	37	63	285	B-9	Lower Trib	LOGR7	226	8	2628
A-10	Lower Vaal	SPITS4	37	12	286	B-9	Lower Trib	LOGR7	226	25	2627
A-10	Lower Vaal	SPITS4	37	25	283	B-9	Lower Trib	LOGR7	226	32	2629
A-10	Lower Vaal	VHARTS4	39	100	264	B-9	Lower Trib	LOGR7	226	31	2626
A-10	Lower Vaal	BARBERS4	180	100	277	B-9	Lower Trib	LOGR8	227	34	2625
A-10	Lower Vaal	USWENTZD4	181	46	274	B-9	Lower Trib	LOGR8	227	66	2624
A-10	Lower Vaal	USWENTZD4	181	24	272	B-9	Lower Trib	LOGR9	228	50	2622
A-10	Lower Vaal	USWENTZD4	181	30	278	B-9	Lower Trib	LOGR9	228	50	2621
A-10	Lower Vaal	DSWENTZD4	182	79	280	B-9	Lower Trib	LOGR10	229	100	2623
A-10	Lower Vaal	DSWENTZD4	182	21	281	B-9	Lower Trib	LOGR11	230	100	2620
A-10	Lower Vaal	C3H0134	183	100	292	B-9	Lower Trib	LOGR12	231	100	2618
A-10	Lower Vaal	C9H0074	184	85	296	B-10	Fish	HARDP4	186	100	1071
A-10	Lower Vaal	C9H0074	184	15	299	B-10	Fish	KONKP4	187	100	1080
B-3	Senqu	KAT10	27	100	1021	B-10	Fish	LOWF4	188	20	1078
B-3	Senqu	MAL10	28	100	1029	B-10	Fish	LOWF4	188	80	1079
B-3	Senqu	MAS10	29	66	1020	B-10	Fish	NAUT4	189	100	1075
B-3	Senqu	MAS10	29	32.8	1023	B-10	Fish	SEEH4	190	100	1073
B-3	Senqu	MAS10	29	1.2	1024	B-11	Lower Main	LOGR3	222	100	1164
B-3	Senqu	MAT10	30	91.8	1019	B-11	Lower Main	LOGR4	223	100	1162
B-3	Senqu	MAT10	30	8.2	1022	B-11	Lower Main	LOGR5	224	25	2646
B-3	Senqu	MOH10	31	100	1027	B-11	Lower Main	LOGR5	224	75	2647
B-3	Senqu	NTO10	32	100	1026	B-11	Lower Main	LOGR13	232	100	2649
B-3	Senqu	ORAN10	33	100	1031	B-11	Lower Main	LOGR14	233	100	2650
B-3	Senqu	TSO10	34	100	1025	B-11	Lower Main	LOGR16	234	100	2653
B-3	Senqu	MAKABS	245	100	2603	B-11	Lower Main	LOGR17	235	100	2652
B-3	Senqu	MAKDAM	246	100	2601	B-11	Lower Main	LOGR18	236	100	2654
B-6	Upper Orange	HFDU4	69	100	1062	B-11	Lower Main	LOGR19	237	100	1161
B-4	Caledon	HLODAM	70	100	2591	B-11	Lower Main	LOGR15	238	100	2651

6.3 Installed Model Configuration

One of the objectives of this Work Package was to install the final versions of the WRYM configuration onto computers that are available for each basin state to use for future scenario analyses. It is the aim that each country has access to exactly the same information and data sets. The WRYM-IMS version 3.8.2 has been installed on a laptop to be handed over to each country, which includes the latest data sets. Three data sets have been imported into the IMS, a stand alone Vaal configuration, a stand alone Orange configuration and an integrated Orange and Vaal configuration. Should future updates to the models be required, the users can simply download the updates from the study website and import them into the WRYM-IMS. A step-by-step procedure of how this is done is included in **Appendix E**.

The installed model configuration for the WRYM represents the existing system at 2010 development level which means that the full phase 1 of the Lesotho Highlands project is in place. The Usutu, Komati, Zaaihoek and Assesegaai (Heyeshope Dam) sub-systems do not form part of the WRYM data sets as it was not part of the Phase 2 TOR. The transfer from the Upper Tugela to Sterkfontein Dam in the Upper Vaal catchment however need to be included as Sterkfontein Dam in the Upper Vaal forms the main storage of the Tugela transfer system.

The installed model configuration therefore includes all the sub-systems in the entire Orange Senqu basin as well as the Upper Thukela transfer system as mentioned in the previous paragraph. The Eastern Cape system receiving water from Gariep Dam via the Orange Fish tunnel is not modelled in detail as it was not requested in the TOR. The total demand imposed on Gariep Dam as result of this transfer was however included in the given data sets as a demand imposed on Gariep Dam.

The Bloemhof sub-system forms the core of the Integrated Vaal River System and includes Grootdraai Dam, Vaal Dam, Vaal Barrage, Bloemhof Dam and Sterkfontein Dam as the main storage dams as well as Woodstock and Driel Barrage in the Upper Thukela, that forms part of the Thukela transfer system. The operating rules used for the analysis of the Bloemhof sub-system include the following:

- Grootdraai Dam do not support Vaal Dam
- Transfers from Tugela continue until Sterkfontein Dam is full
- Sterkfontein Dam start to support Vaal Dam only when Vaal Dam is at 15% or lower storage
- Vaal Dam release water to support the abstractions at Sedibeng and Midvaal if local runoff and spills are insufficient.
- Vaal Dam only start to support Bloemhof Dam when Bloemhof reaches its minimum operating level.

In **Section 7** details of the yield determined for the Bloemhof sub-system are given. The demands imposed on the Bloemhof sub-system is in the yield model replaced by yield channels as shown in **Figure 7.1** to be able to determine the yield available from this entire sub-system. Three different yield scenarios were carried out for the Bloemhof sub-system (see **Section 7.1.1**). The model configuration installed represents that of Scenario B3. Several other smaller sub-systems located on the tributaries of the Vaal River are included in the data sets. The 2010 demands were imposed on these sub-systems. These sub-systems do not support the Bloemhof sub-system and only spills from these sub-systems enter the Bloemhof sub-system and can contribute to the Bloemhof sub-system yield. These sub-systems include:

- Schoonspruit sub-system with Rietspruit, Elandskuil and Johan Neser dams
- Renoster sub-system with Koppies Dam
- Sand-Vet sub-system including Allemanskraal and Erfenis dams
- Mooi River sub-system that includes the Mooi River Government Scheme comprising of Klerkskraal, Boskop and Lakeside dams as well as the Klipdrift

Irrigation scheme using Klipdrift Dam in the Loopspruit River a tributary of the Mooi River.

Operating rules and related penalties for these sub-systems where selected to allow them to be operated as individual systems without supporting the main Vaal system. These sub-systems will supply the demand imposed on them until the dam reaches the defined minimum operating level where after only the water available will be supplied.

For the Lower Vaal sub-system Bloemhof Dam was allowed to support the various demands downstream of the dam which are currently supplied from the dam. The largest of these demands is that of the Vaalharts Irrigation scheme, which also generates a considerable volume of return flows. This setup is in line with that required for Scenario B3, see **Section 7.1.1**. This scenario will provide the most realistic spills from the Vaal to be used when simulating the Orange River system. The different sub-systems in the Lower Vaal were treated in the same manner as those located in the Middle and Upper Vaal. These sub-systems include:

- Wentzel Dam sub-system on the Upper Harts River;
- Taung Dam sub-system on the Middle Harts River;
- Spitskop Dam sub-system on the Lower Harts River receiving return flows from Vaalharts scheme;
- Krugersdrift Dam on Modder River;
- Groothoek Dam tributary of the Modder River;
- Mockes and Rustfontein dams upper Modder River;
- Tierpoort Dam Upper Riet River tributary; and
- Kalkfontein Dam on the Riet River.

The Orange River System is set up so that the Vaal River system is not used to support any of the demands in the Orange River. Spills from the Vaal can also not be utilized by Lower Orange demands as in practice the total demand for the Lower Orange is released from Vanderkloof Dam without taking into account inflows from the Vaal. To be able to model this, channels parallel to the main Orange were included in the model setup so that Orange River demands can't utilize these spills (see **Figure B-11**). Inflows from tributaries along the Lower Orange were also routed through these parallel channels.

Penalties were set up in such a manner that Katse and Mohale dams as well as dams in the Caledon (Welbedacht and Knellpoort dams) are not able to support Gariep and Vanderkloof dams. Only spills and environmental releases from these dams can flow into Gariep Dam. The 2010 transfer rate applicable to the Lesotho Highlands project was imposed on Katse and Mohale dams. The 2010 demands for Bloemfontein, Botshabelo and small towns were imposed on the Caledon Modder sub-system and transfers were allowed from the Caledon to the Modder as part of this sub-system.

All the demands imposed on the Orange River Project (ORP) comprising of Gariep and Vanderkloof dams were included in the model setup. The surplus yield available after all the demands were supplied was then determined (See **Section 7.2**). The environmental demand imposed on Gariep and Vanderkloof dams represents that for the River mouth as determine in the Orange River Replanning study. This is the environmental demand that is currently released in practice from the dams.

Several smaller sub-systems are also found in the Middle and Lower Orange which is operated as individual systems that is not used to support any of the ORP demands. These typically include:

- Ongers sub-system including Smartt Syndicate and Victoria Wes dams;
- Hartbees River sub-system including Modderpoort, Loxton, Van Wyksvlei and Rooiberg dams;
- Molopo sub-system RSA including Lotlamoreng, Setumo and Disaneng dams;
- Molopo sub-system Namibia including Daan & Tilda Viljoen and Otjivero dams; and
- Fish River sub-system (Namibia) Hardap and Naute dams.

Operating rules and related penalties for these sub-systems where selected to allow them to be operated as individual systems without supporting the demands related to the ORP. These sub-systems will supply the demand imposed on them until the dam reaches the defined minimum operating level when only the water available will be supplied.

The Namibia Fish River sub-system includes the total system, Hardap, and Naute dams as well as all the sub-catchments representing the entire Fish River catchment. The hydrology for this sub-system is still in the process to be updated and the hydrology as used in the LORMS was used to populate the current installed model.

7 YIELDS

The main objective of this work package in the study was to assemble, update and integrate the WRYM for future use. Yield scenario analyses were not carried out as part of this study. In order to confirm that the model was configured and operated correctly, historic firm yields for the Bloemhof system and the Orange system were obtained separately. The reason for this was to compare these yields with yields obtained in previous studies where separate Orange and Vaal system configurations were used. For this reason, this section is divided into two subsections, one presenting the approach to determine the yield for the Vaal sub-system and one for the Orange sub-system. The same integrated model configuration was used for both yield determinations, with the only difference being the position of the yield channel.

7.1 Vaal Subsystem

7.1.1 Yield Determination Methodology

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

Abstractions from the Vaal River system take place at two main points in the river. In order to account for this, channels representing these abstractions are configured at their respective points, and are linked to the yield node. An "open" channel that represents all additional yield over and above the 2010 development level abstractions already removed is then placed on Vaal Dam and linked to the yield node. This is represented by **Figure 7.1**. Three different scenarios were carried out to assess Bloemhof's yield as described below.

- B1: Total yield of Bloemhof system without Lesotho transfer and no support to downstream Lower Vaal demands: carried out to determine yield comparable to VRSAU study;
- B2: Scenario B1 including full Lesotho transfer (777 mill m^3/a) into Vaal dam;
- B3: Surplus yield of Bloemhof system after downstream Lower Vaal demands supplied: carried out to determine yield to be removed from Bloemhof in order to obtain correct spills into Orange system for Orange yield analyses.

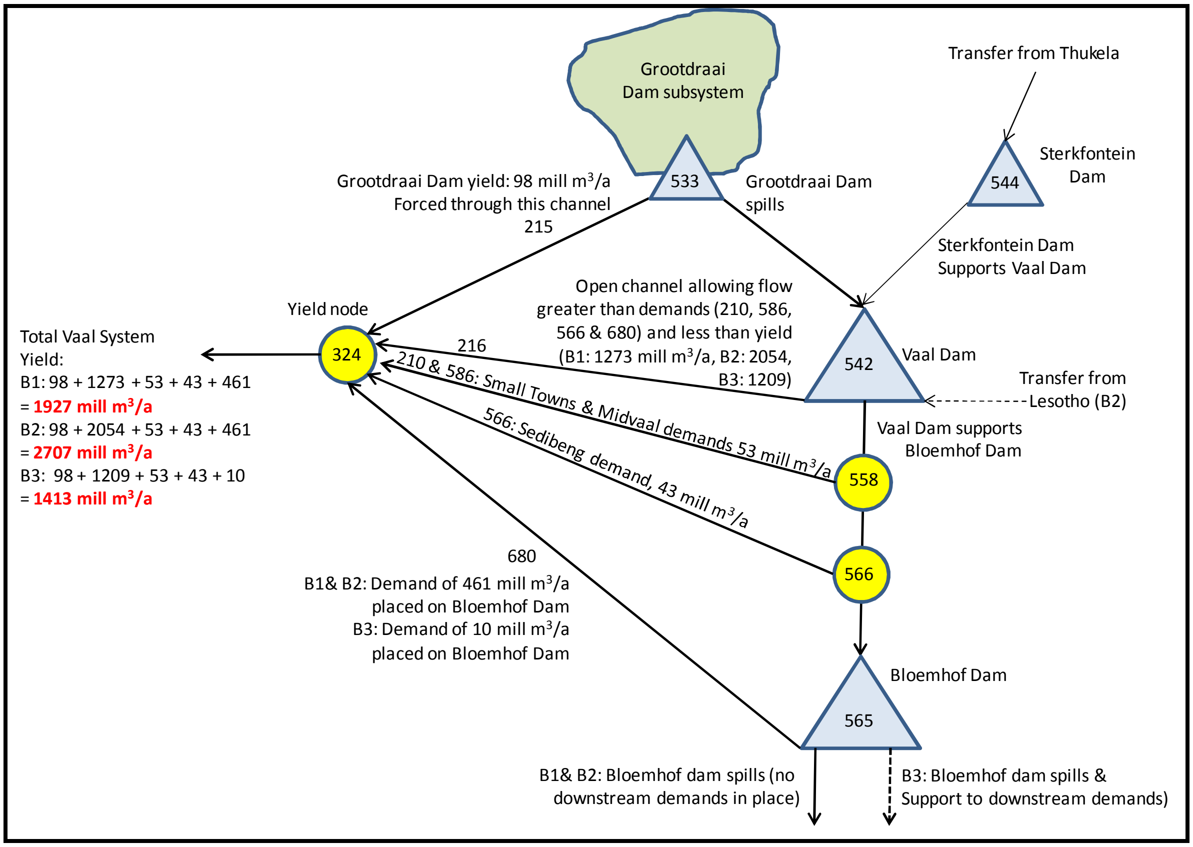

Figure 7.1: Diagram Representing Vaal Yield Determination Approach (Scenario B1, B2 and B3)

7.1.2 Historic Firm Yields

Historic firm yields for selected systems were determined and compared to the yields obtained in previous studies. These are summarised in **Table 7-1.**

Table 7-1: Historic Firm Yields for Selected Subsystems

Scen no.(1)	Sub catchment	Yield (mill m^3/a)
	Grootdraai	98
	Taung Dam	7.85
	Koppies Dam (Renoster)	13.0
B1	Bloemhof total yield, obtained by cutting off Lower Vaal system (no Lesotho transfer)	1927
B2	Bloemhof total yield, obtained by cutting off Lower Vaal system (including full Lesotho transfer)	2707
B3	Bloemhof yield after supply to Lower Vaal demands, determined for use in Orange yield analysis	1413

Note 1: Represents the number indicated in **Figure 7.1**

7.1.3 Comparisons with Previous Studies

In order to confirm that the model was operating correctly, detailed checks were carried out using the data sets from previous studies that were used as a basis for updating and integrating in this study. Explanations for the differences are included in the following Tables. The Taung and Koppies Dam yields remained identical and no explanation is therefore required regarding these yields.

Table 7-2: Grootdraai Yield Comparison

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

Table 7-3: Bloemhof Yield Comparison

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

7.2 Orange Subsystem

7.2.1 Yield Determination Methodology

Similar to the Vaal, the approach to determine the yield for the Orange sub-system is carried out in two steps. To be able to obtain the correct spills from the Vaal to the Orange River it is important to allow Bloemhof Dam to supply various users in the Lower Vaal of the Vaalharts Irrigation scheme is the largest user. Significant return flows are generated from this irrigation scheme and it is therefore important to include this effect on the flows from the Lower Vaal that will eventually spill into the Orange River. The setup for Scenario B1 (**Section 7.1.1**) will therefore supply incorrect Vaal spills to be used in the Orange System. For this reason the yield of Bloemhof dam, under the condition that the Lower Vaal demands are met before the yield channel, is then first determined (Scenario B3). A yield of 1413 mill m^3/a was obtained as presented in **Table 7-1.** This yield is then placed on Bloemhof Dam as a demand channel as storage in Bloemhof Dam is not allowed to support any of the Orange River demands. This is how the system is operated in reality as a large portion of the water available in the Vaal System is expensive water that was transferred from neighbouring catchments. Only the spills from the Lower Vaal sub-system enter the Orange part of the integrated model, with these only being allowed to support the Douglas irrigation demands. All other demands in the Orange River downstream of Gariep and Vanderkloof Dams are supplied by these two dams only, and the Vaal spills cannot be used to support these demands. To be able to accommodate this operating rule, a channel parallel to the main Orange River was built into the WRYM setup, into which the Vaal spills were directed. In addition to the Vaal spills, the Molopo, Ongers, Hartbeest and all other Lower Orange tributaries enter this parallel channel and can therefore not contribute to the supply of the Lower Orange demands. This is the situation which best represents reality as these demands are all met via releases from Gariep and Vanderkloof dams.

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

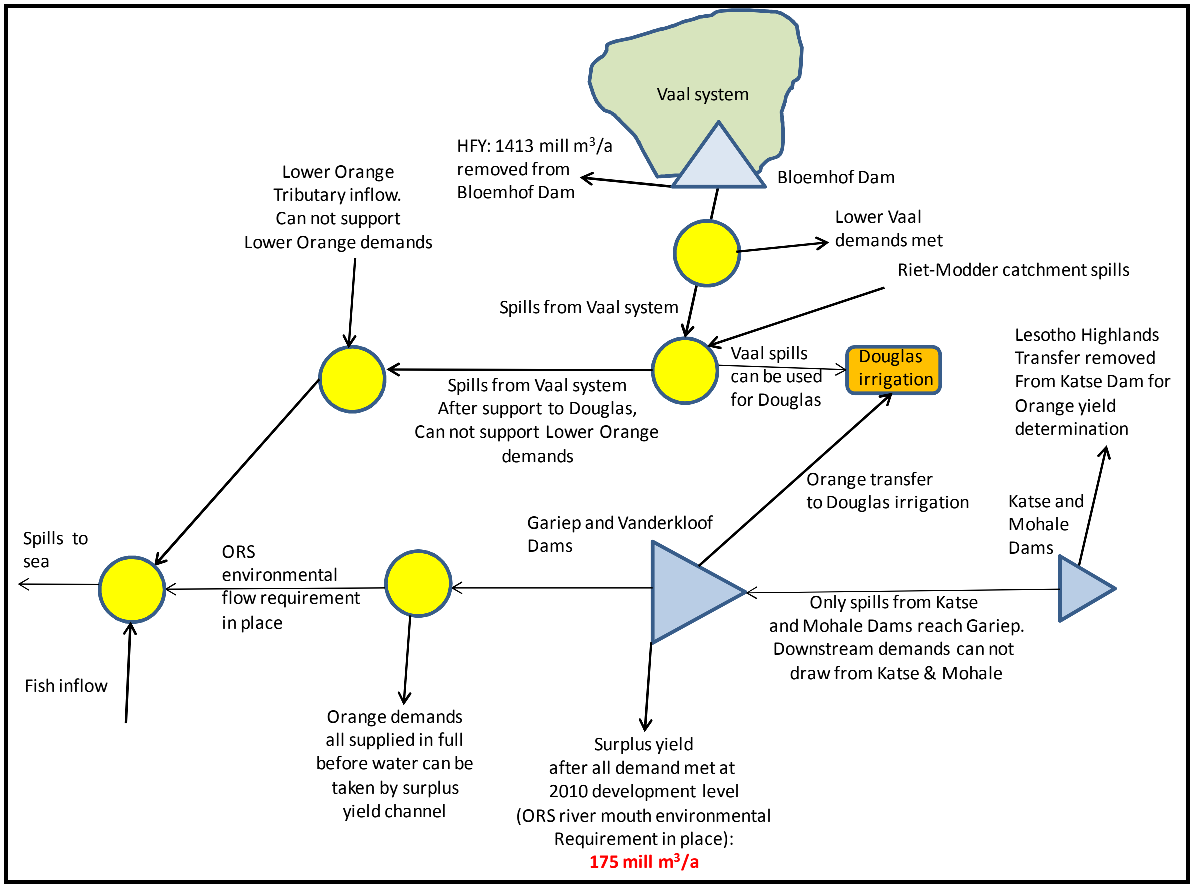

Figure 7.2: Diagram Representing Orange Yield Determination Approach

7.2.2 Orange River Project Surplus Yield

The surplus yield obtained for the Orange River project (Gariep and Vanderkloof Dams) once all demands on the dams have been met is 175 mill m^3/a. This is in comparison with 120 mill m^3/a obtained in the LORMS study. The main reason for the slight increase is a result of improved hydrology in the Caledon River which produced higher inflows, reduction in the operational losses in the ORP, and the introduction of the latest Katse and Mohale environmental flow requirements which were not in place in the LORMS which produce higher inflows to Gariep Dam. The total demands supplied at a 2010 development level by the Orange River Project before the surplus yield is taken off amounts to 3143 mill m^3/a. The total yield is therefore 3318 mill m^3/a.

7.3 Total Combined System Balance

A summary of the total combined system balance is presented in **Table 7-4.** Individual sub-catchment balances are presented in **Table D-1** and **Table D-2** of **Appendix D**.

Table 7-4: Total Orange System Yield

Contribution	Volume (mill m^3/a)	Details
+	3609	Natural Hydrology Vaal
+	8220	Natural Hydrology Orange
+	478	Thukela transfer inflow
-	2205	Net Demands Vaal
-	4022	Demands Orange
-	1724	Evaporation & Dam storage adjustment
-	4182	Spills to sea
=	175	TOTAL ORANGE RIVER SURPLUS YIELD

8 INTEGRATED WRPM

During the Inception Phase of this study, an additional task was proposed in order to carry out the verification and validation of stochastic generated flows. The stochastic flows are based on the characteristics of the historical hydrological record and it is of utmost importance to ensure that the stochastic flows generated do in fact mimic the historic flow sequences well. The stochastic hydrology is required to first determine the short-term stochastic yield characteristics which forms part of the operating rule in the WRPM and is therefore part of the input to the WRPM. Secondly the stochastic stream flow sequences are used to carry out planning and operations analyses using enabling the WRPM to provide results in terms or risk and assurance of supply. As this additional task did not form part of the phase 2 study task descriptions, it can only commence once the phase 2 work was completed. This additional work has already been approved to be carried out after the completion of the phase 2 work.

A complete description of the integrated WRPM setup will be compiled as part of the Additional Work Report as the WRPM is highly depended on the stochastic flows and short-term stochastic yield results.

9 CONCLUSIONS AND RECOMMENDATIONS

To be completed after WRPM analysis was carried out.

- The system data sets for the first time now cover the entire Orange Senqu River Basin. This enables basin states to also carry out simulations and determine water balances on the smaller sub-systems that are not used to support the main Orange and Vaal systems.
- Flows from the Lower Orange tributaries is for the first time modelled in detail which will improve the accuracy of incremental yield calculations on dams in the Lower Orange such as Vioolsdrift Dam as well as for dams on these tributaries.
- Details on possible future dams in the Lesotho Lowlands are included for the first time. It is now relative easy to carry out analysis to improve operating rules on these dams, to determine short and long-term stochastic yield results, and to determine the effect of these dams on downstream users.
- Improved hydrology for the Caledon and Upper Orange will result in improved yield and operating analysis of the Orange and Caledon sub-systems.
- The in general improved and extended hydrology (between 10 to 17 years extension) covering the same record period (1920 to 2004) hydrological years of the entire basin will result in improved yield analysis and improved stochastic flow generation.
- The extended record period did not include a more severe drought and a decrease in sub-systems yields are in general not expected. Results from yield analysis carried out for some of the main sub-systems also confirmed this.
- Verification and Validation of Stochastic flow sequences need to be carried out before any stochastic yield analysis can be carried out.
- Results from the analysis showed that almost no flow from the Molopo downstream of the confluence of the Molopo and Nossob is experienced. Due to the lack of observed flow information in this area it is not possible to confirm the accuracy of this. It is however expected that these flows will not reach the Orange River as it disappears into the Kalahari sand dunes.
- Results from the yield analysis showed a slight increase in historic firm yield of about 2.1% for the Orange River Project (Gariep and Vanderkloof dams). This is as result of improved hydrology upstream of Gariep Dam and higher environmental flow releases from Katse and Mohale dams.
- The historic firm yield for the Bloemhof sub-system increased by almost 13% as result of return flows that was not included in the previous yield estimation.

- The historic firm yield for Grootdraai Dam decreased significantly as result of compensation releases that was supplied first in the recent estimation, before the available yield was determined.
- Historic firm yield for Koppies and Taung dams remained unchanged.

10 REFERENCES

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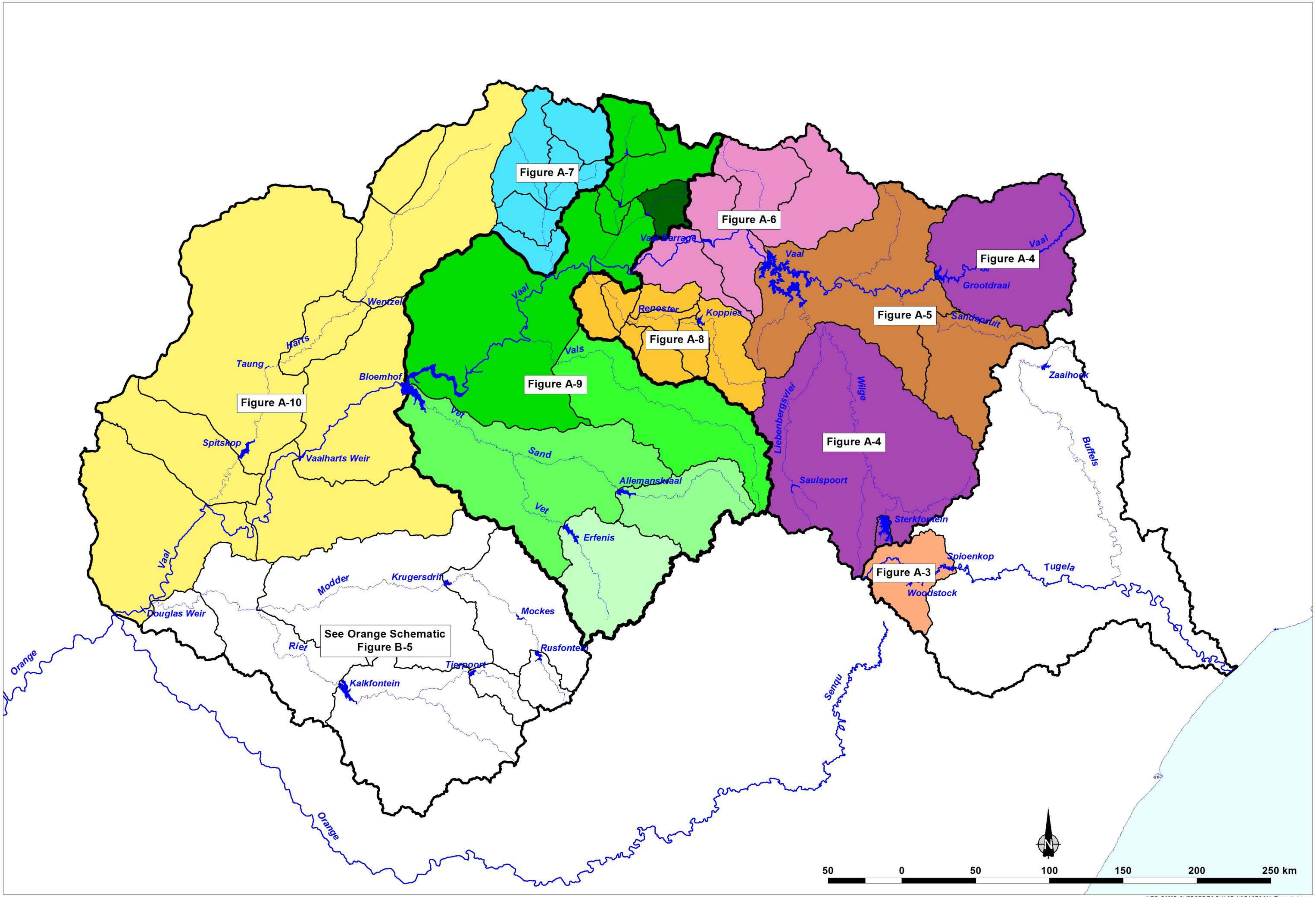
APPENDIX A

MAPS AND NETWORK DIAGRAMS:

VAAL



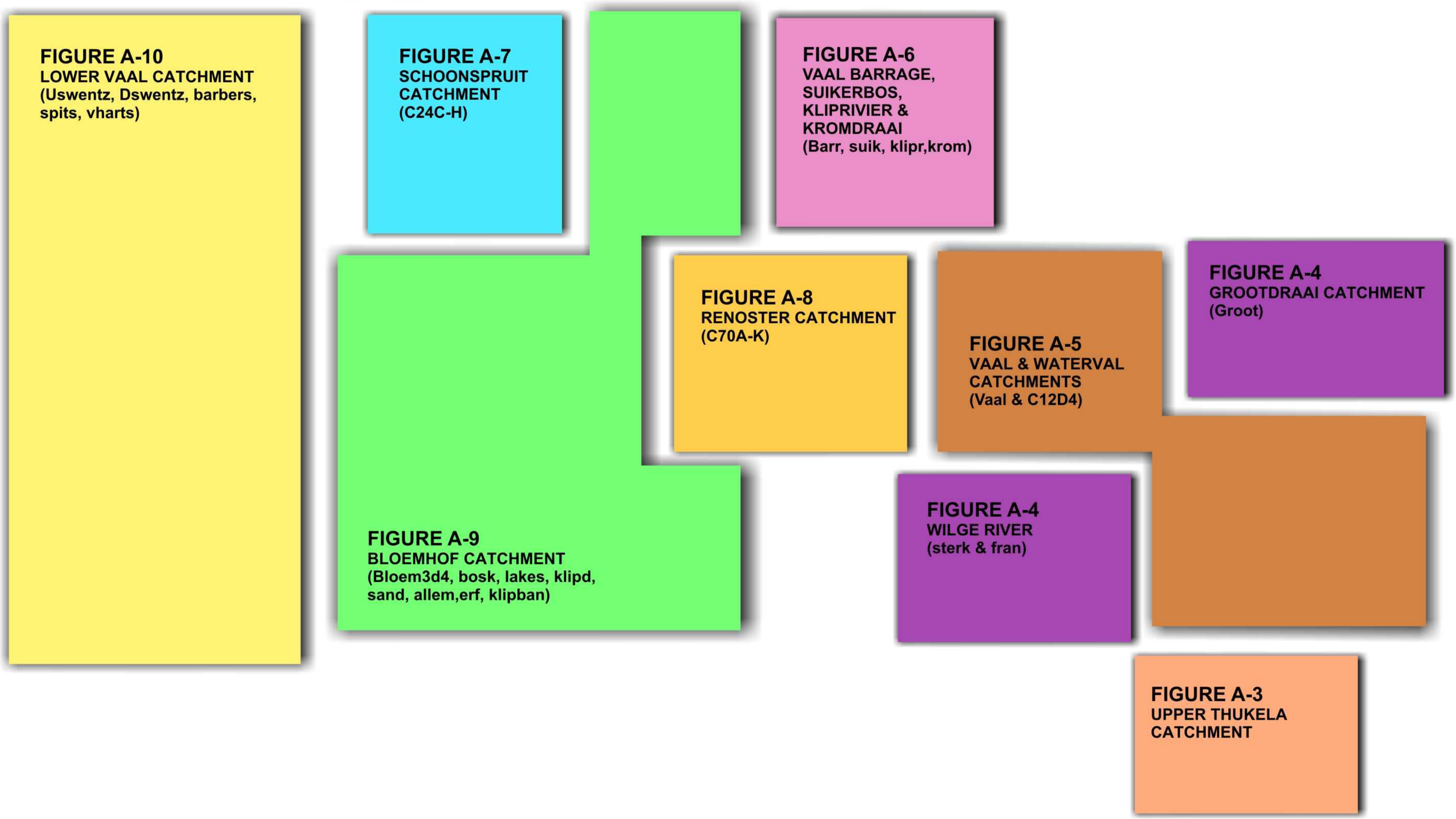
WRP_P0237_SUPPORT TO PHASE II ORASECOM_Figure A-1.apr

On behalf of Federal Republic of Germany The Federal Government

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

Vaal River Catchment

Fig A-1

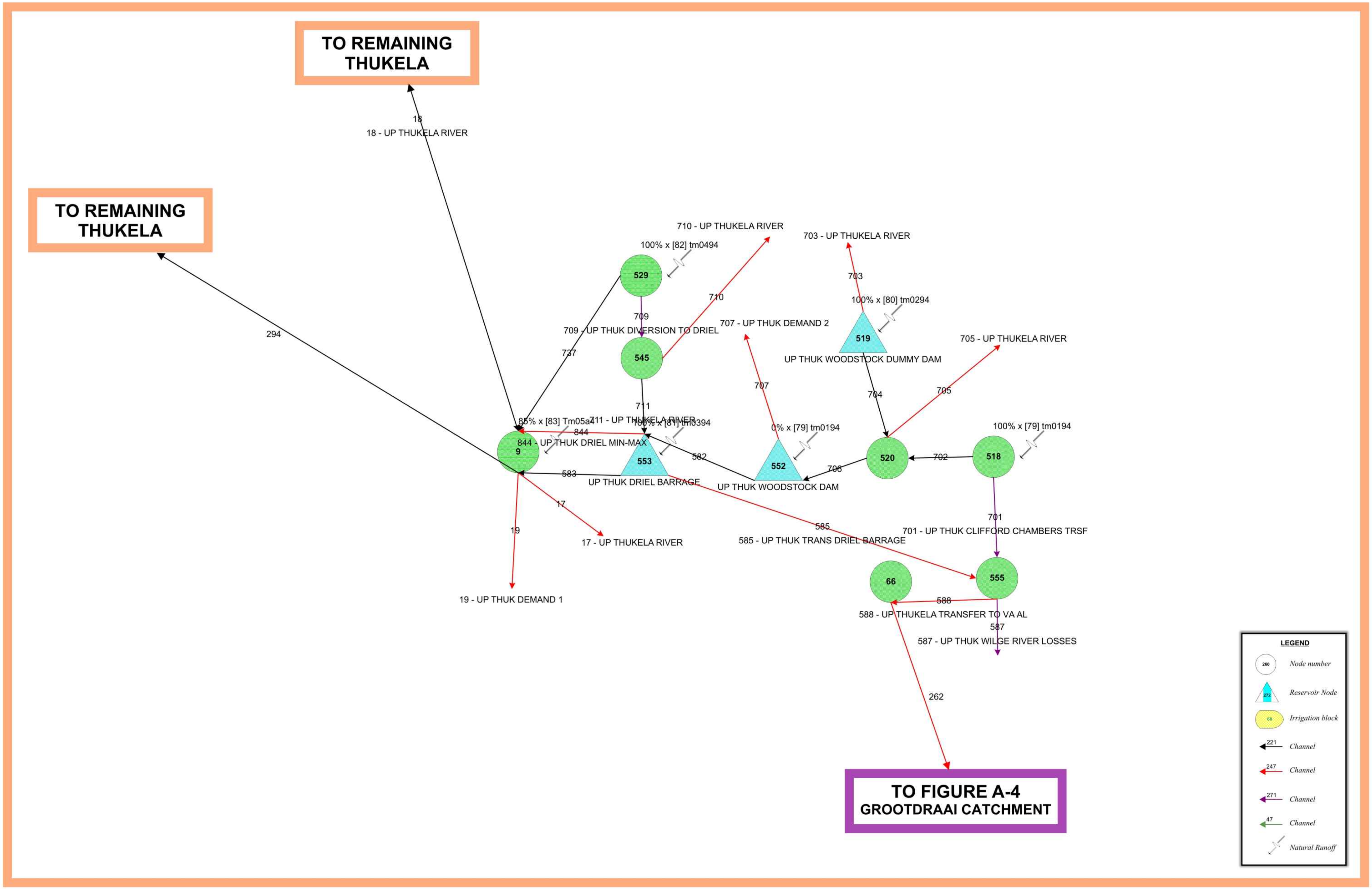


WRP_P0237_ORASECOM_Graphics_Fig 58.cdr
Last updated: 2011/04/20

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

Layout of Schematics

Fig A-2



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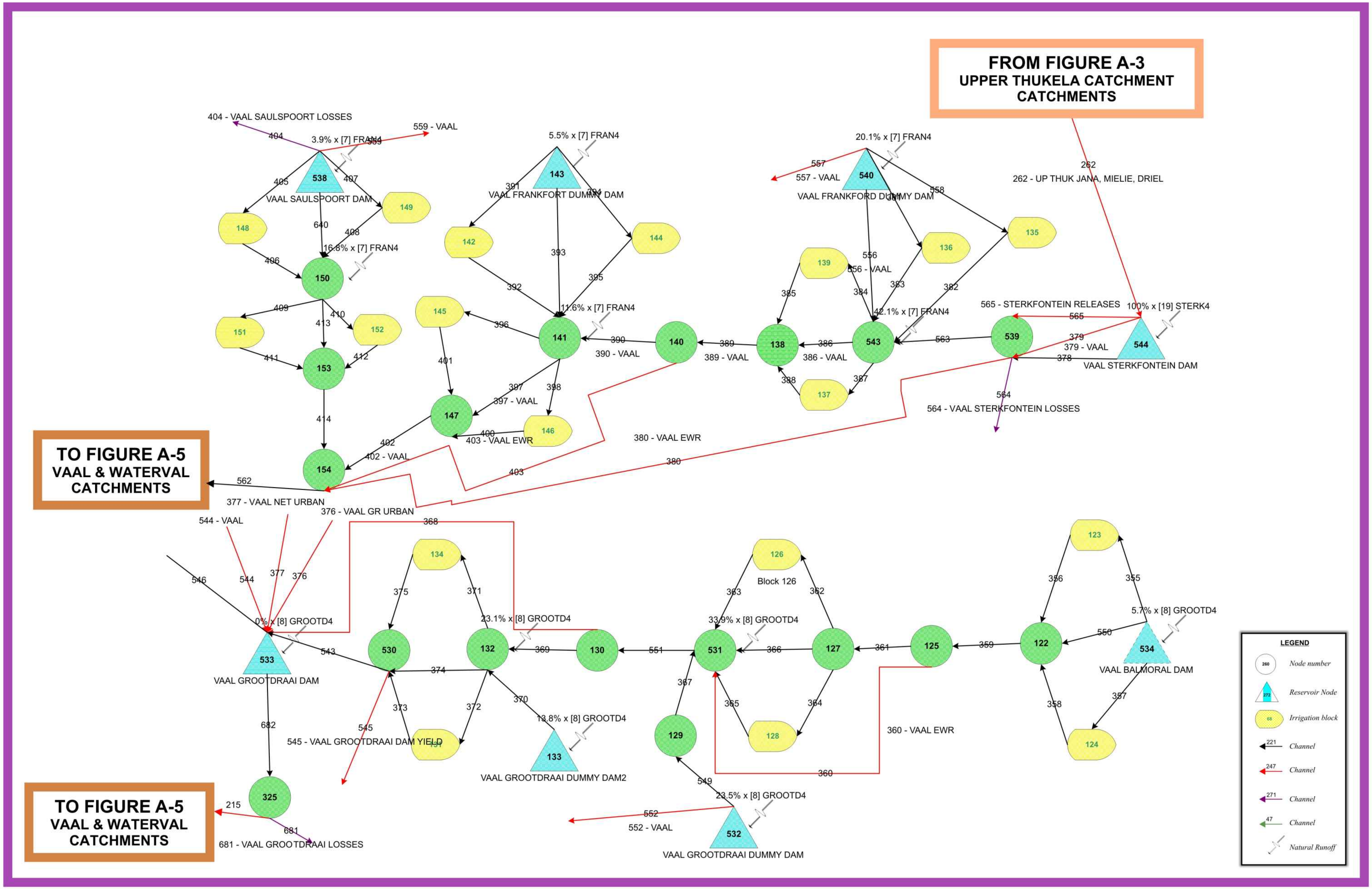
Last updated: 2011/04/20



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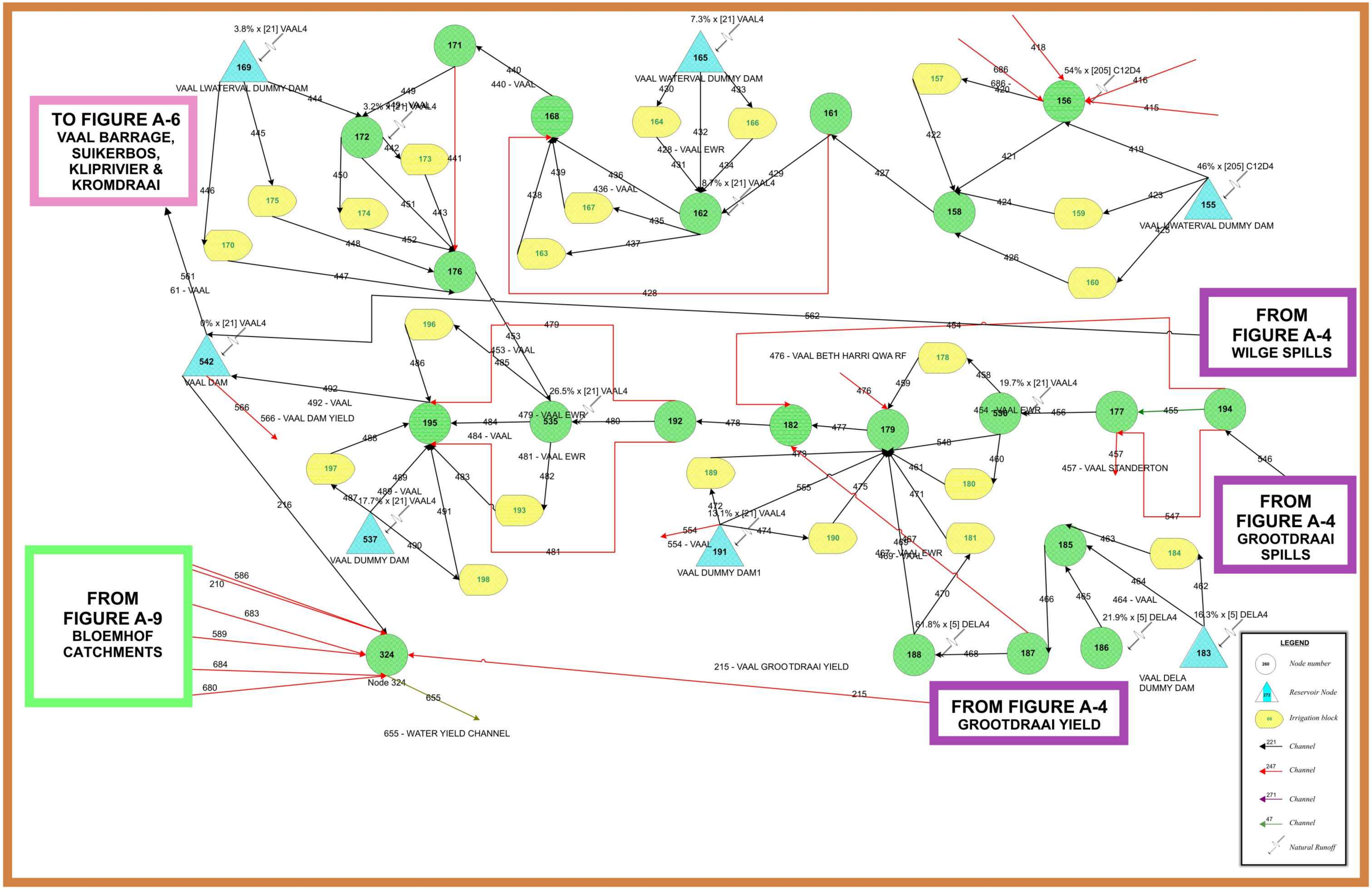
Last updated: 2011/04/20

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

Wilge and Grootdraai Schematic

Fig A-4



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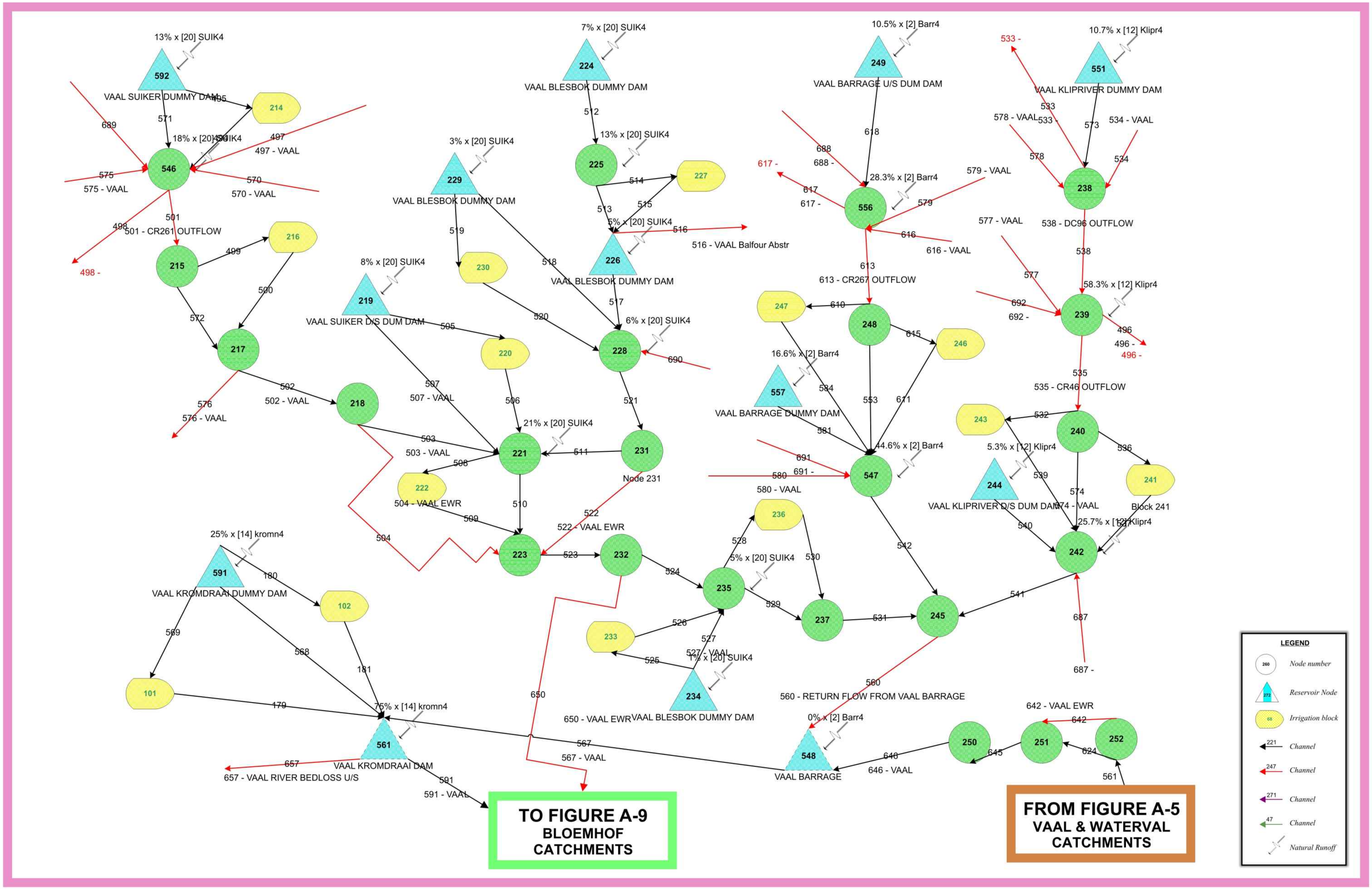
Last updated: 2011/04/20

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

Vaal Schematic

Fig A-5

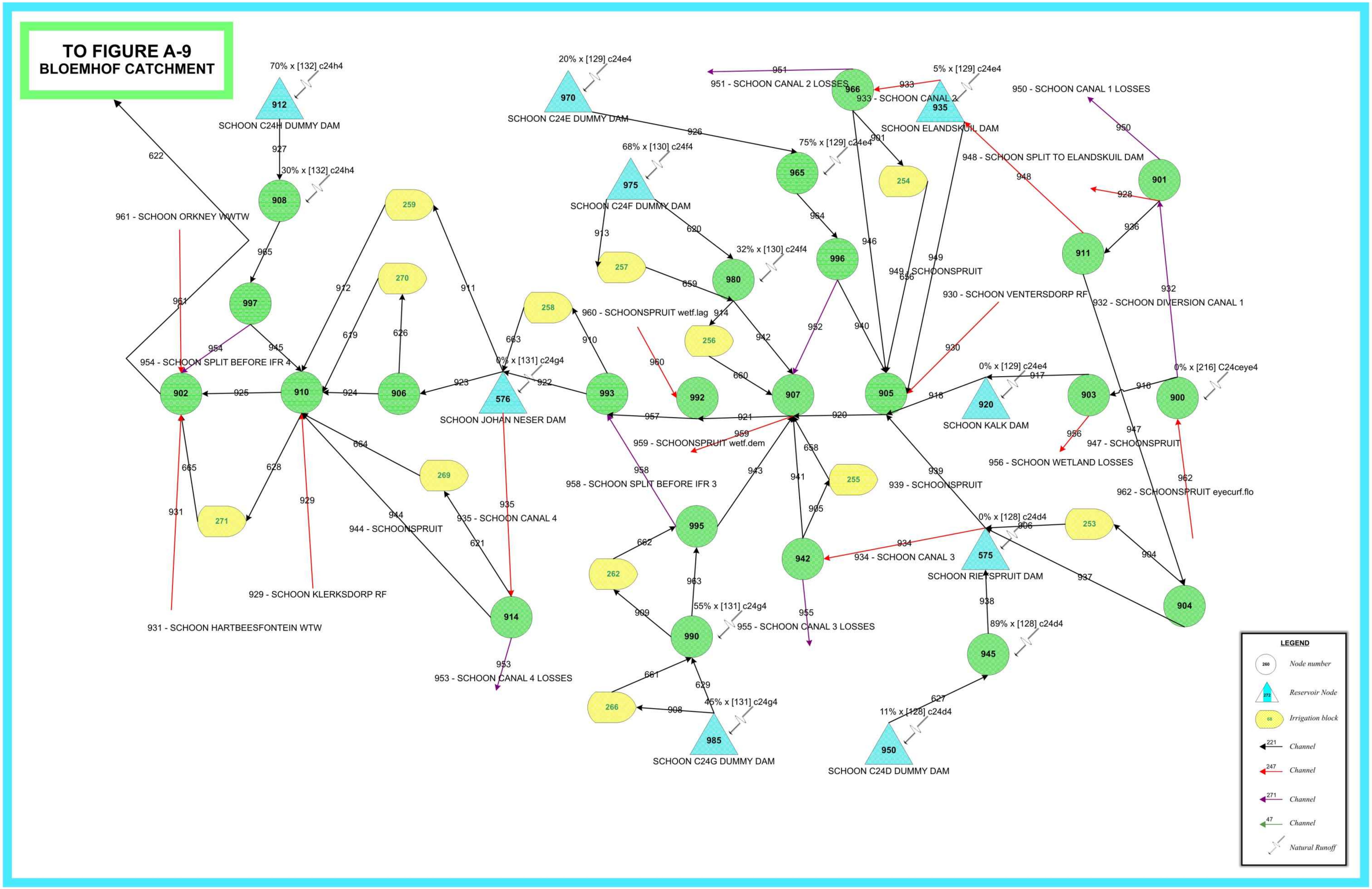


WRP_P0237_ORASECOM_Graphics_Fig 62.cdr
Last updated: 2011/04/20

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

Vaal Barrage Schematic

Fig A-6

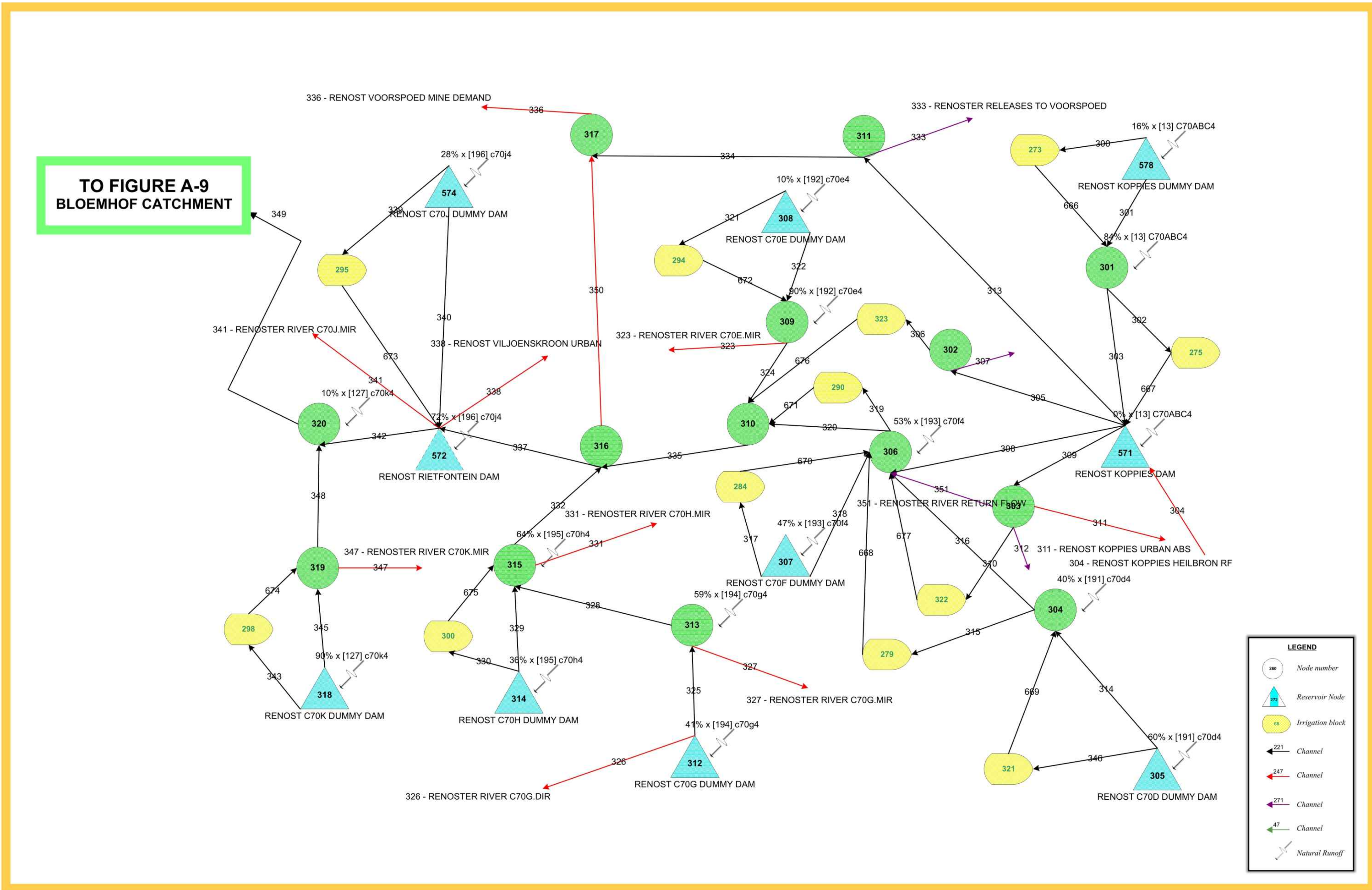


WRP_P0237_ORASECOM_Graphics_Fig 63.cdr
Last updated: 2011/04/20

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

Schoonspruit Schematic

Fig A-7

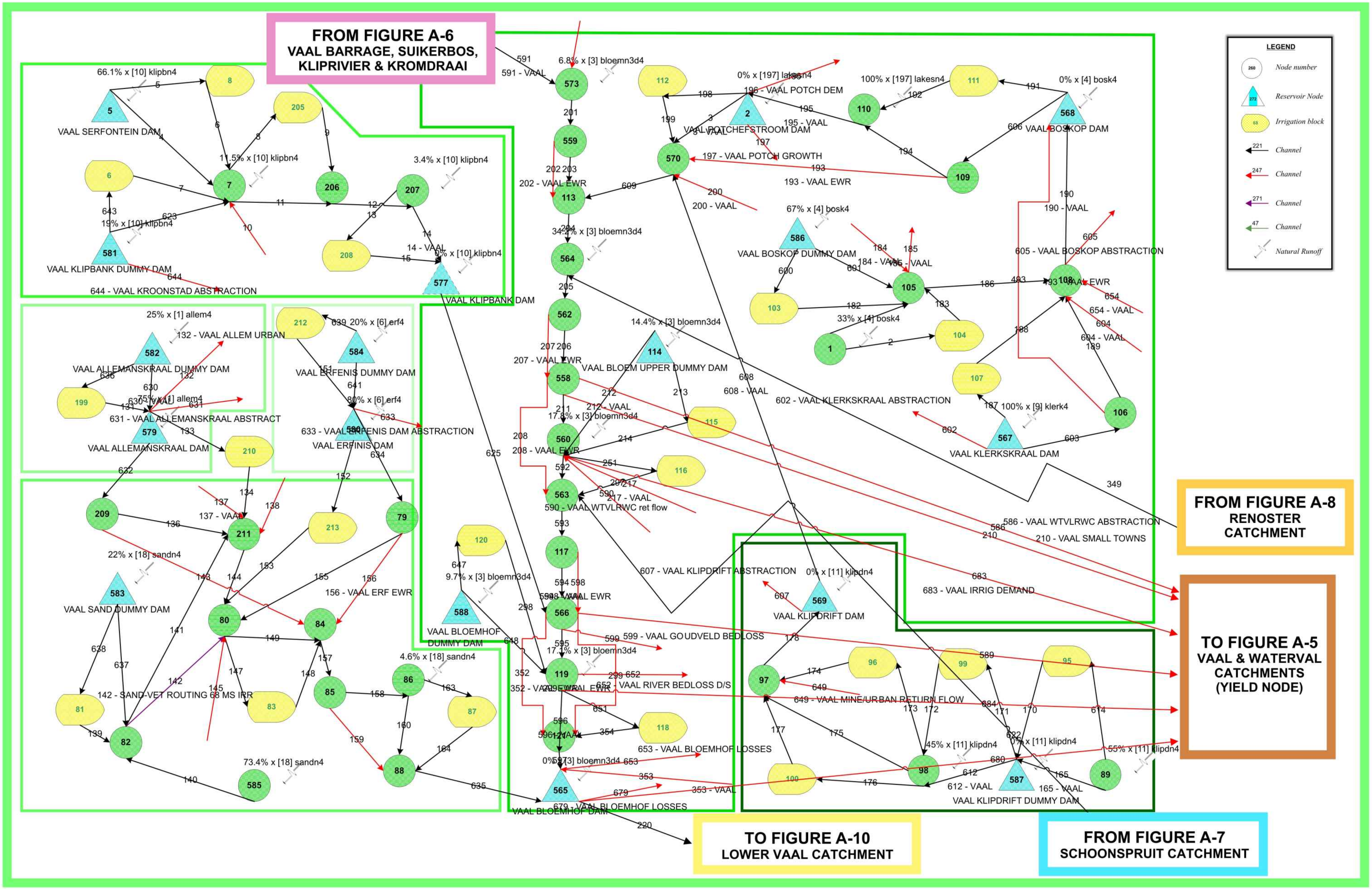


WRP_P0237_ORASECOM_Graphics_Fig 64.cdr
Last updated: 2011/04/20

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

Renoster Schematic

Fig A-8



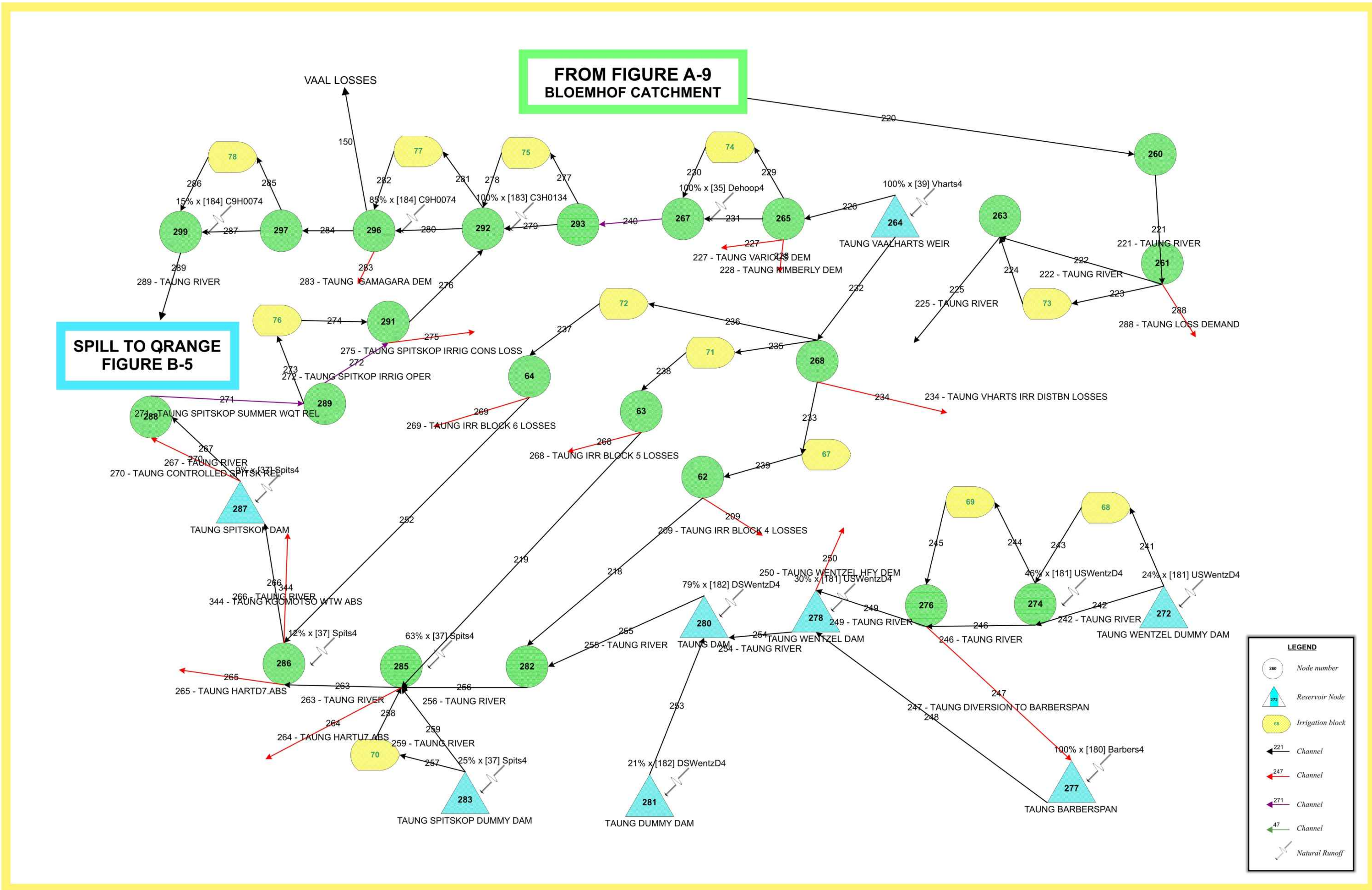
WRP_P0237_ORASECOM_Graphics_Fig 65.cdr
Last updated: 2011/04/20

On behalf of Federal Republic of Germany The Federal Government

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

Bloemhof Schematic

Fig A-9



WRP_P0237_ORASECOM_Graphics_Fig 66.cdr
Last updated: 2011/04/20

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

Lower Vaal Schematic

Fig A-10

APPENDIX B

MAPS AND NETWORK DIAGRAMS:

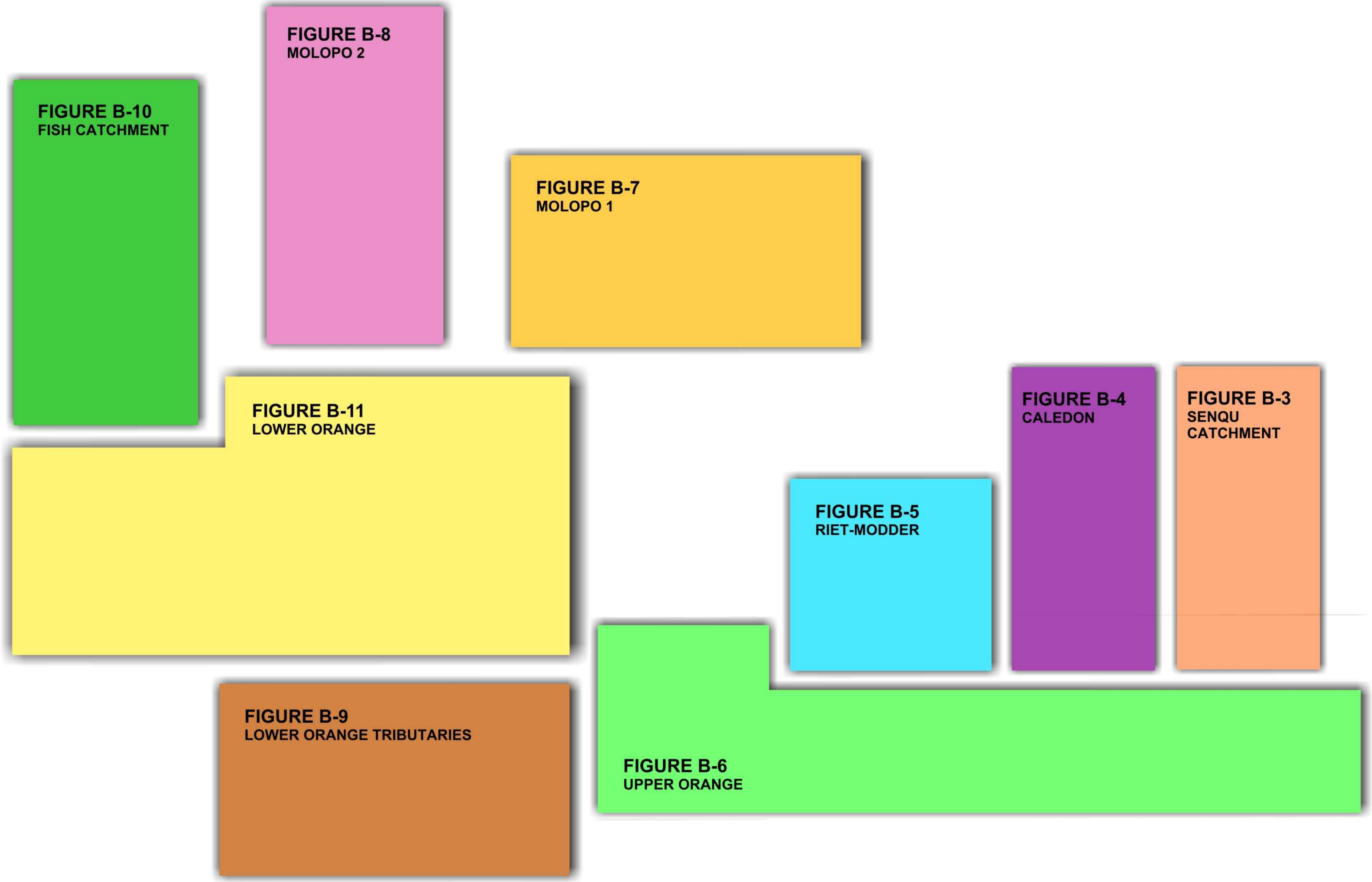
ORANGE

WRP_P0237_SUPPORT TO PHASE II ORASECOM_Figure B-1.apr

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

Orange River Catchment

Fig B-1

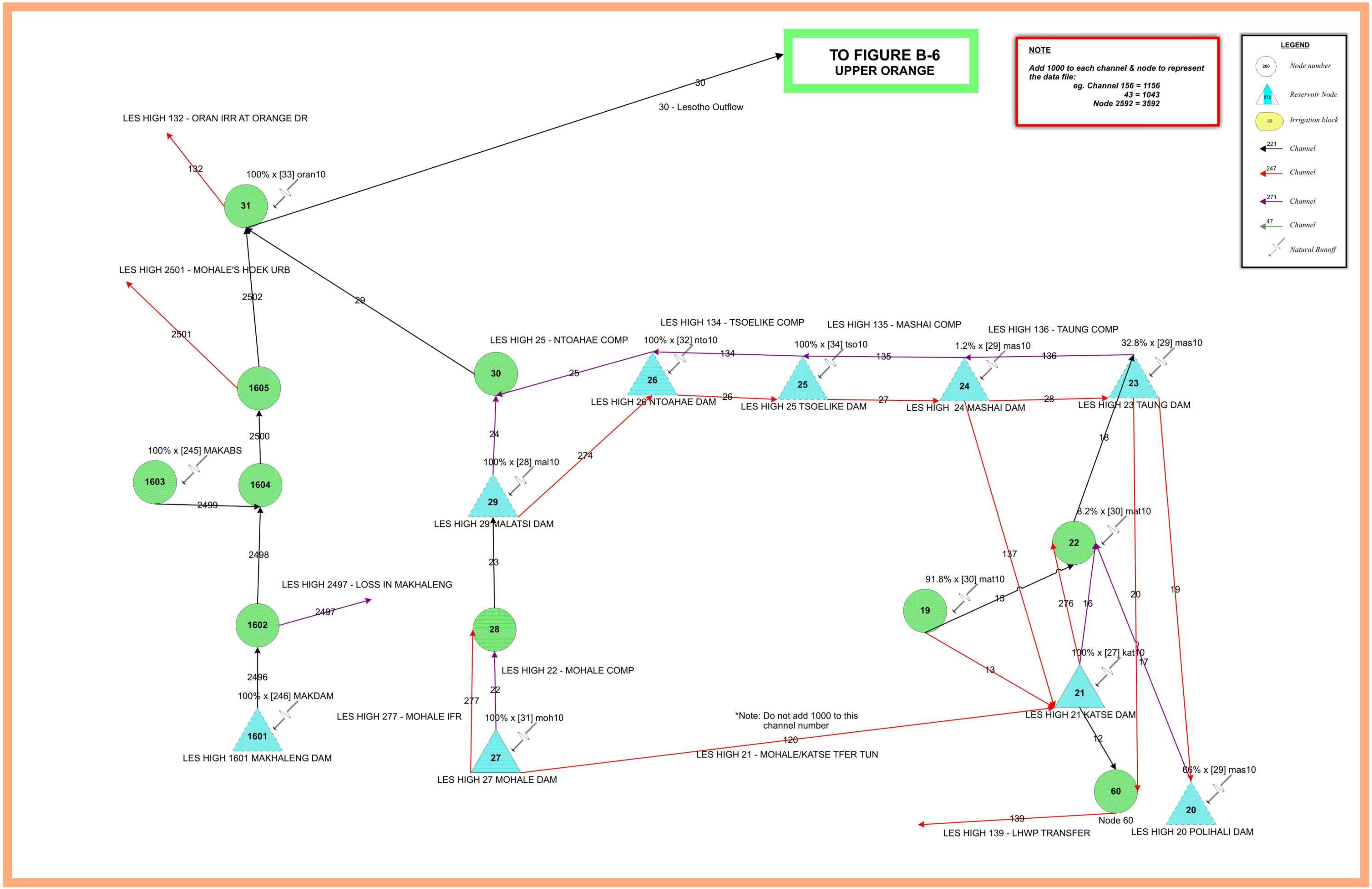


WRP_P0237_ORASECOM_Graphics_Fig 47.cdr
Last updated: 2011/04/20

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

Orange River Catchment

Fig B-2

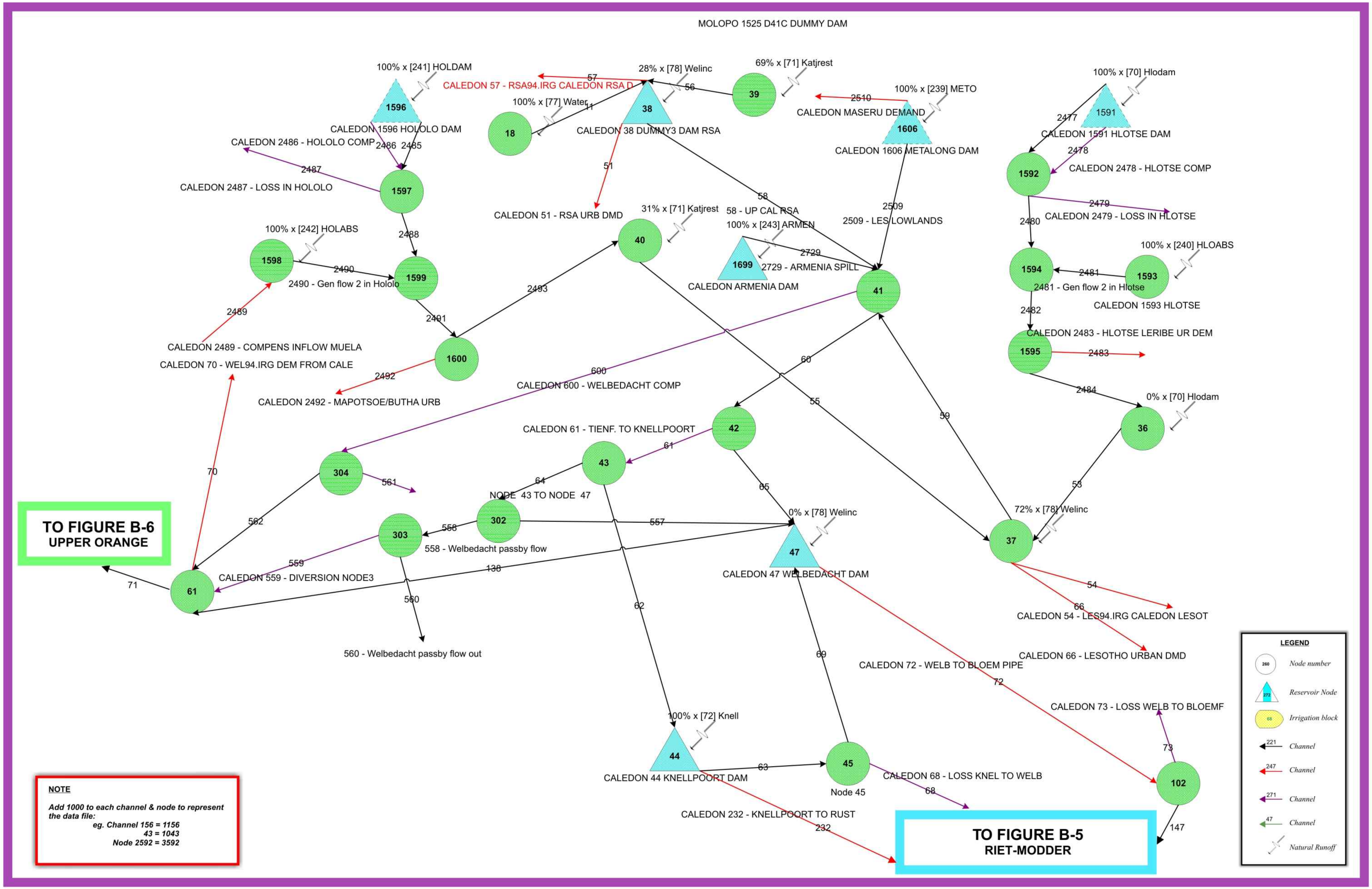


WRP_P0237_ORASECOM_Graphics_Fig 48.cdr
Last updated: 2011/04/20

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

Senqu Catchment

Fig B-3

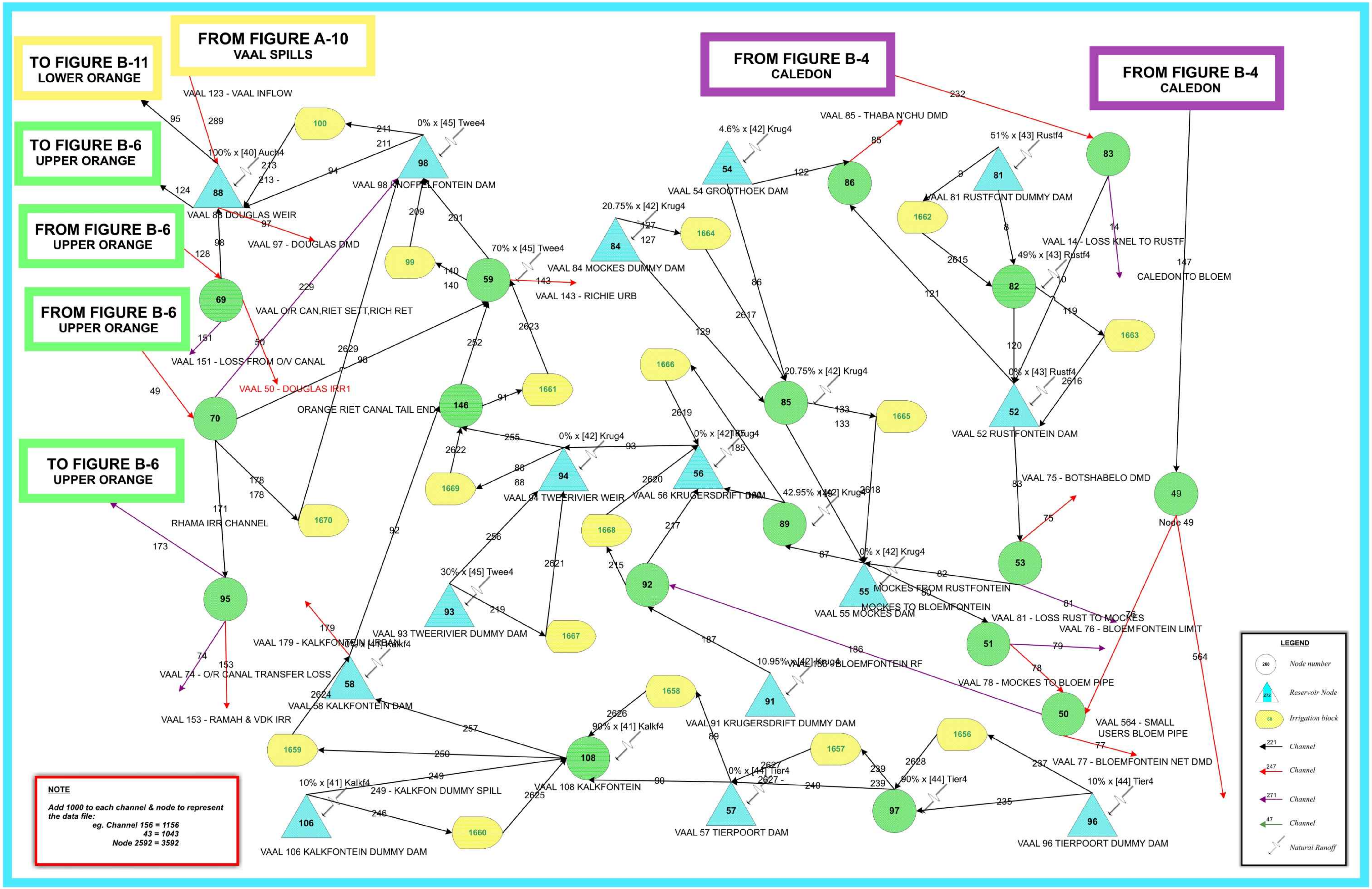


WRP_P0237_ORASECOM_Graphics_Fig 49.cdr
Last updated: 2011/04/20

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

Caledon Catchment

Fig B-4

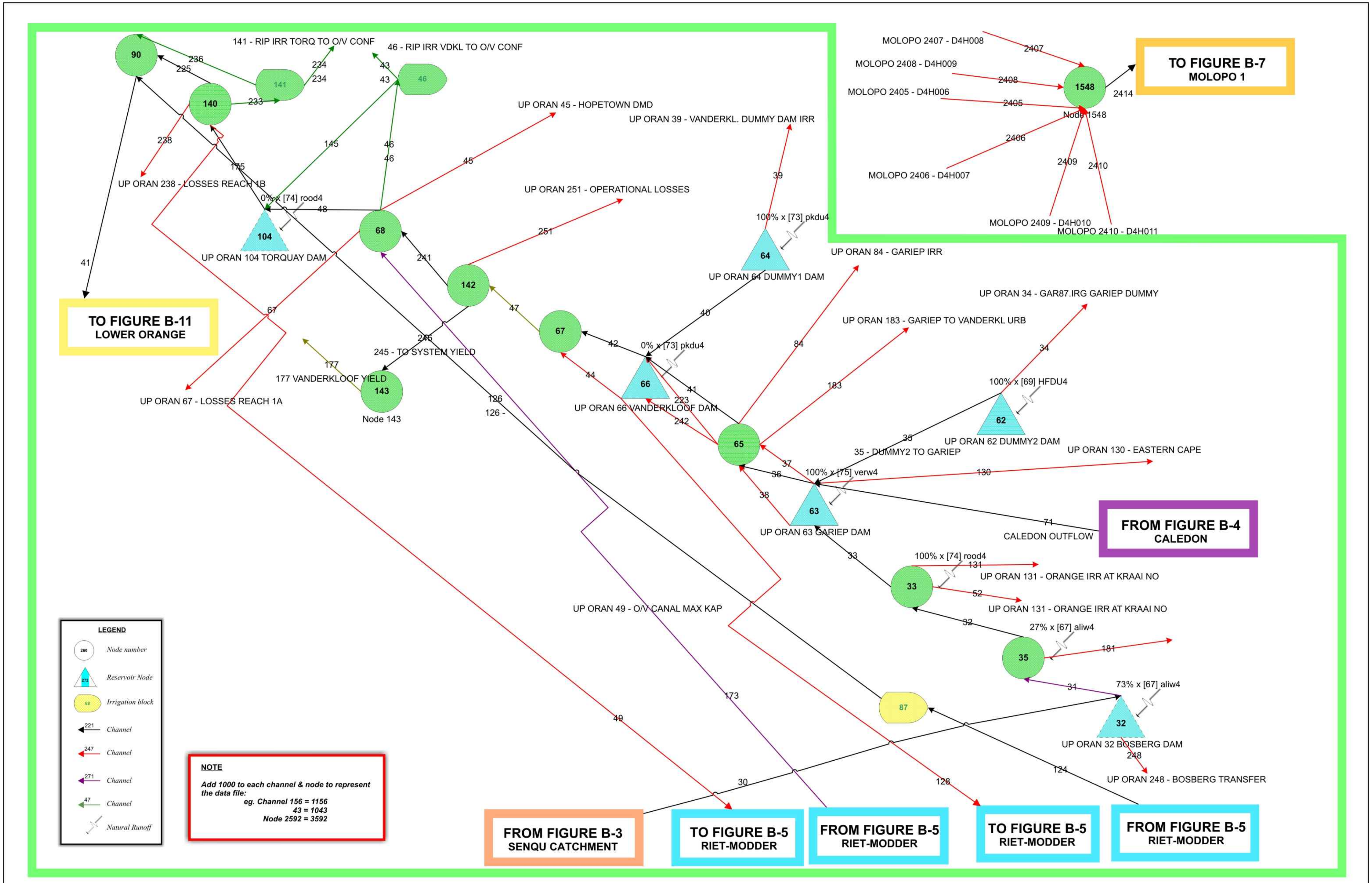


WRP_P0237_ORASECOM_Graphics_Fig 50.cdr
Last updated: 2011/04/20

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

Riet-Modder Catchment

Fig B-5

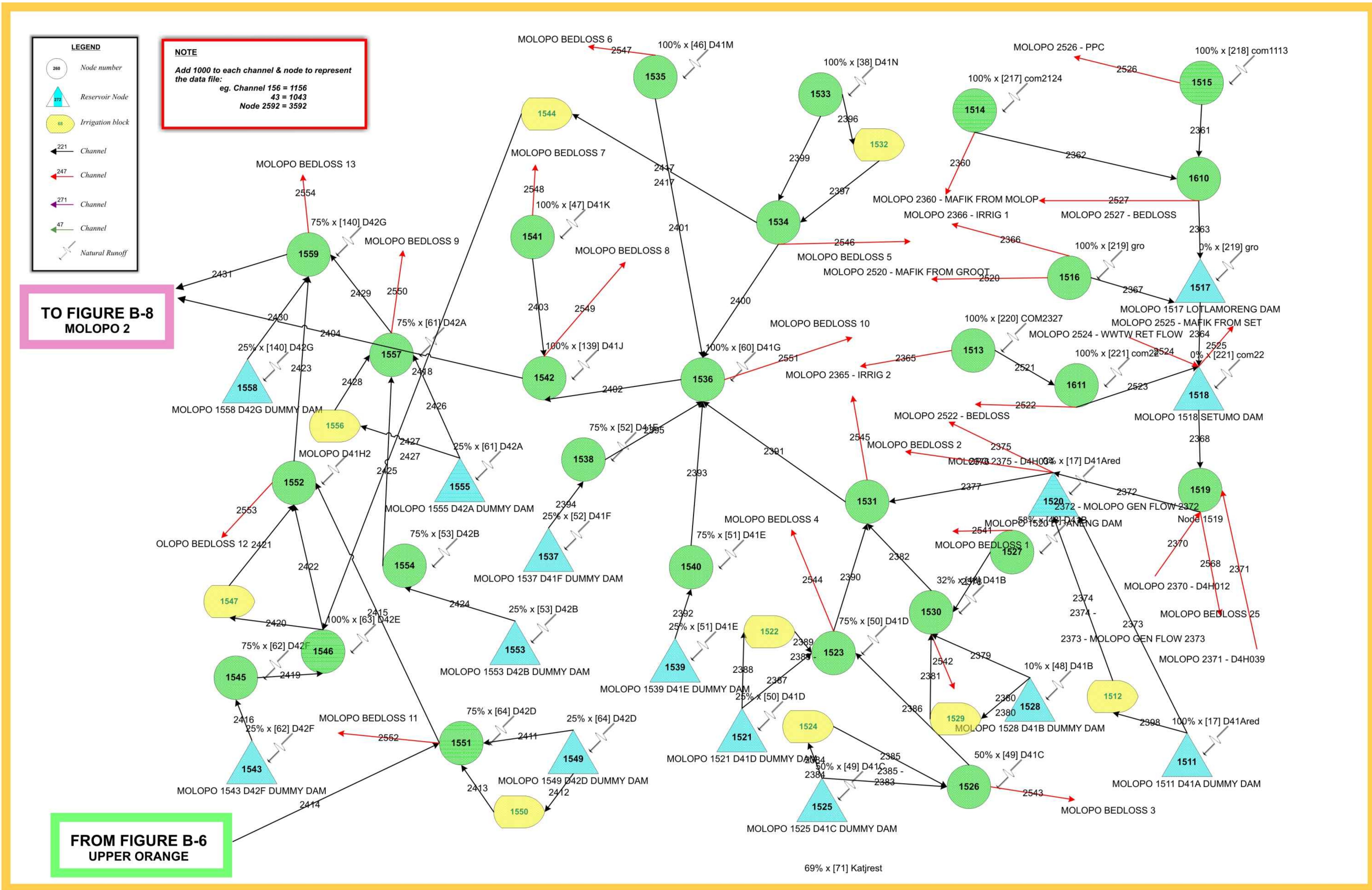


WRP_P0237_ORASECOM_Graphics_Fig 51.cdr
Last updated: 2011/04/20

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

Upper Orange Catchment

Fig B-6

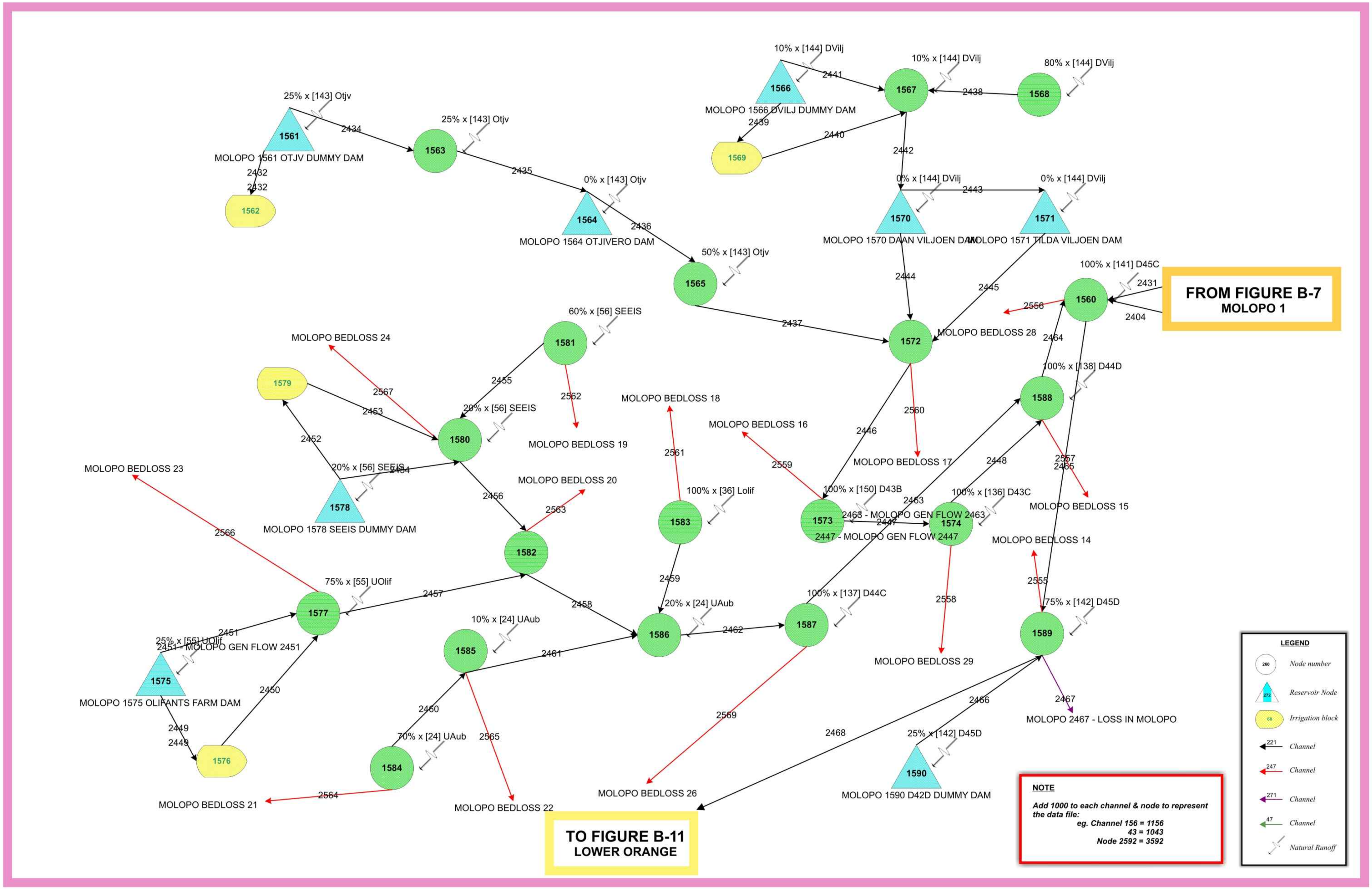


WRP_P0237_ORASECOM_Graphics_Fig 52.cdr
Last updated: 2011/04/20

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

Molopo 1 Catchment

Fig B-7

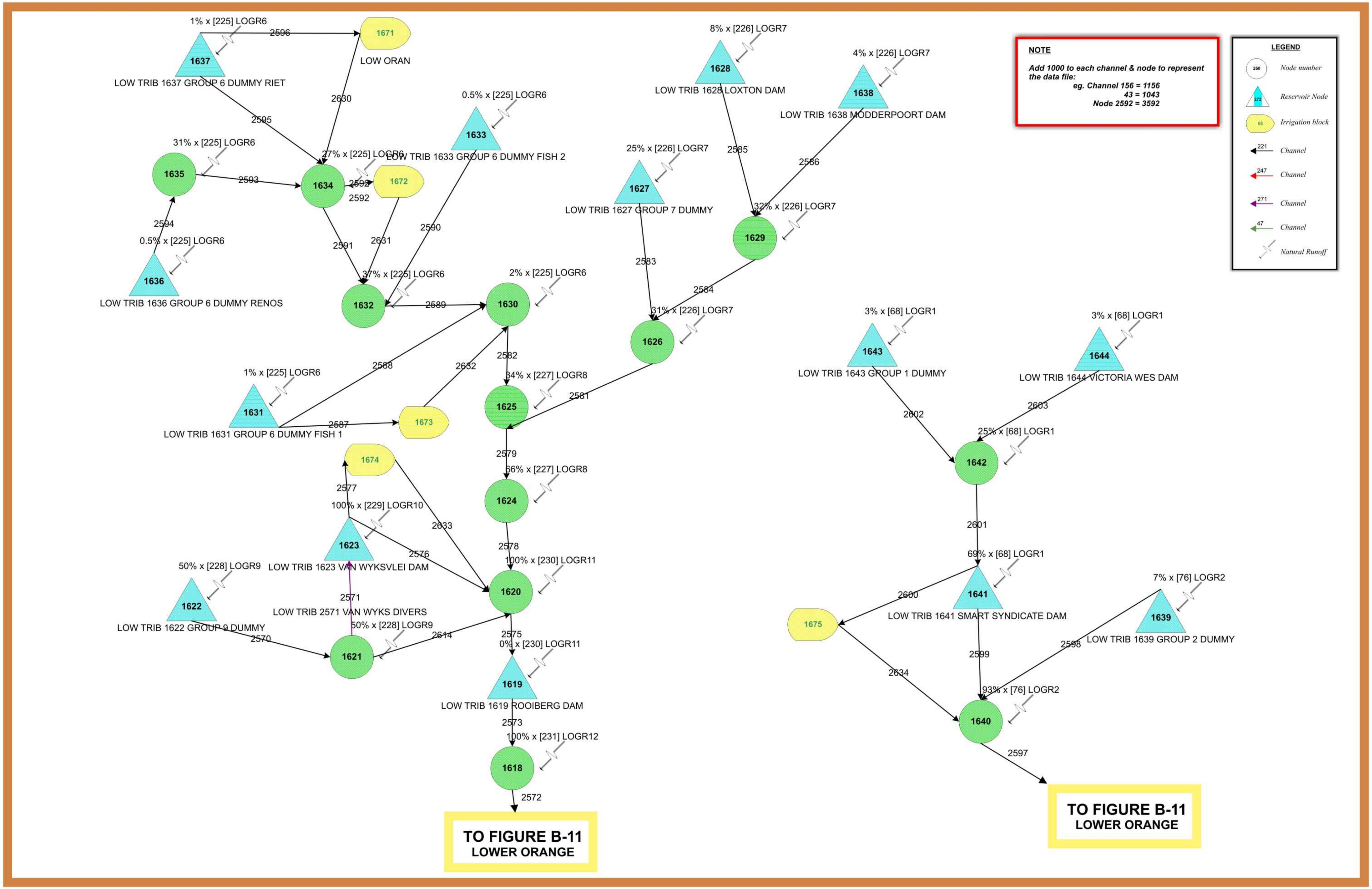


WRP_P0237_ORASECOM_Graphics_Fig 53.cdr
Last updated: 2011/04/20

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

Molopo 2 Catchment

Fig B-8

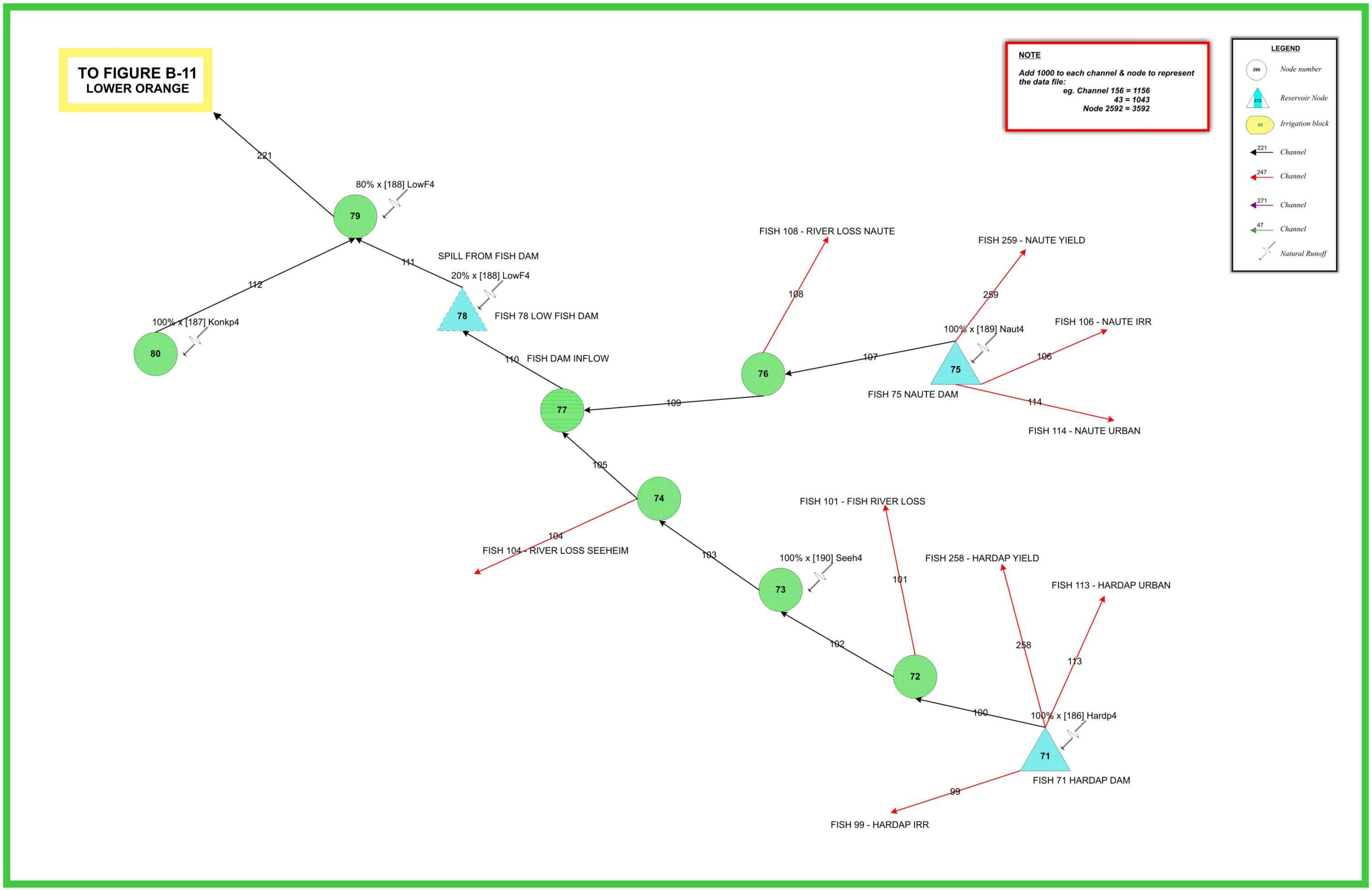


WRP_P0237_ORASECOM_Graphics_Fig 54.cdr
Last updated: 2011/04/20

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

Lower Orange Tributaries

Fig B-9

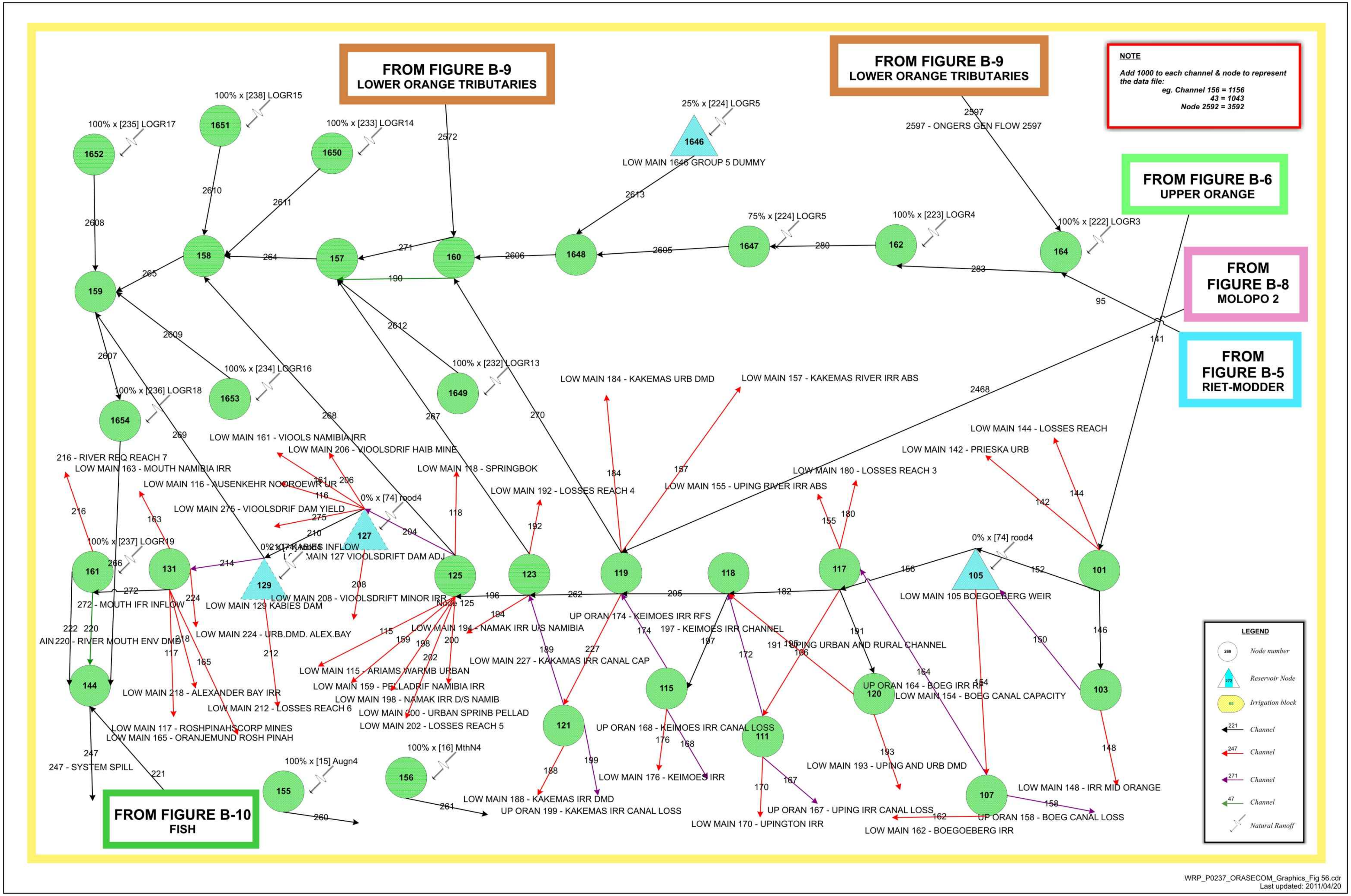


WRP_P0237_ORASECOM_Graphics_Fig 55.cdr
Last updated: 2011/04/20

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

Fish Catchment

Fig B-10



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

Lower Orange Catchment

Fig B-11

APPENDIX C

DETAILS OF DEMANDS AND RETURN FLOWS

1 TABLE C-1: DETAILS OF DEMANDS

Figure	Subcatchment	Channel no.	Channel name	Demand
A-3	Thukela	707	707 - UP THUK DEMAND 2 FROM WOODSTOCK	1.81
A-3	Thukela	587	587 - UP THUK WILGE RIVER LOSSES	0.00
A-3	Thukela	705	705 - UP THUKELA RIVER THWOOD IRRIG	3.31
A-3	Thukela	703	703 - UP THUKELA RIVER TM02 IRRIG	1.48
A-3	Thukela	710	710 - UP THUKELA RIVER THDRIE IRRIG	1.51
A-4	Grootdraai	552	552 - VAAL GROOT94.ABS	2.69
A-4	Grootdraai	681	681 - VAAL GROOTDRAAI LOSSES	6.25
A-4	Grootdraai	215*	215 - VAAL GROOTDRAAI YIELD	97.99
A-4	Wilge	564	564 - VAAL STERKFONTEIN LOSSES	31.25
A-4	Wilge	557	557 - VAAL WILG94.ABS	12.09
A-4	Wilge	559	559 - VAAL SAUL94	4.91
A-4	Wilge	404	404 - VAAL SAULSPOORT LOSSES	0.00
A-5	Vaal	457	457 - VAAL STANDERTON	10.63
A-5	Vaal	554	554 - VAAL VAAL94.ABS	0.74
A-5	Vaal	216*	216 – VAAL SYSTEM YIELD OPEN CHANNEL	1209.45
A-6	Suikerbos	576	576 - VAAL ERGO.Q	4.56
A-6	Suikerbos	516	516 - VAAL Balfour Abstr	1.55
A-6	Suikerbos	650	650 - VAAL EWR	0.00
A-6	Suikerbos	498	498 - WETLAND AND BEDLOSS	16.22
A-6	Klipbank & Barrage	533	533 - BEDLOSS	3.60
A-6	Klipbank & Barrage	496	496 - WETLAND	5.65
A-6	Klipbank & Barrage	617	617 - WETLAND	1.17
A-6	Krom	657	657 - VAAL RIVER BEDLOSS U/S	15.49
A-7	Schoonspruit	956	956 - SCHOON WETLAND LOSSES	1.21
A-7	Schoonspruit	928	928 - SCHOON VENTERSDORP	0.59
A-7	Schoonspruit	950	950 - SCHOON CANAL 1 LOSSES	5.15
A-7	Schoonspruit	955	955 - SCHOON CANAL 3 LOSSES	2.71
A-7	Schoonspruit	951	951 - SCHOON CANAL 2 LOSSES	1.04
A-7	Schoonspruit	953	953 - SCHOON CANAL 4 LOSSES	0.14
A-7	Schoonspruit	959	959 - SCHOONSPRUIT wetf.dem	14.45
A-8	Renoster	307	307 - RENOSTER KOPPIES GWS CANAL	0.98
A-8	Renoster	312	312 - RENOSTER KOPPIES GWS RIVER	0.80
A-8	Renoster	311	311 - RENOST KOPPIES URBAN ABS	0.98
A-8	Renoster	333	333 - RENOSTER RELEASES TO VOORSPOED	2.60
A-8	Renoster	336	336 - RENOST VOORSPOED MINE DEMAND	2.62
A-8	Renoster	338	338 - RENOST VILJOENSKROON URBAN	1.19

Figure	Subcatchment	Channel no.	Channel name	Demand
A-8	Renoster	323	323 - RENOSTER RIVER C70E.MIR MAIN STEM IRR	0.05
A-8	Renoster	326	326 - RENOSTER RIVER C70G.DIR FARM DAM IRR	0.05
A-8	Renoster	327	327 - RENOSTER RIVER C70G.MIR MAIN STEM IRR	0.10
A-8	Renoster	331	331 - RENOSTER RIVER C70H.MIR MAIN STEM IRR	0.02
A-8	Renoster	341	341 - RENOSTER RIVER C70J.MIR MAIN STEM IRR	0.06
A-8	Renoster	347	347 - RENOSTER RIVER C70K.MIR MAIN STEM IRR	0.15
A-9	Mooi	185	185 – VAAL BOSKBL.Q	27.68
A-9	Mooi	605	605 - VAAL BOSKOP ABSTRACTION	0.00
A-9	Mooi	602	602 - VAAL KLERKSKRAAL ABSTRACTION	0.02
A-9	Mooi	196	196 - VAAL POTCH DEM	12.56
A-9	Mooi	197	197 - VAAL POTCH GROWTH	3.69
A-9	Klipdrift	607	607 - VAAL KLIPDRIFT ABSTRACTION	6.41
A-9	Vals	644	644 - VAAL KROONSTAD ABSTRACTION	8.86
A-9	Sand - Vet	631	631 - VAAL ALLEMANSKRAAL ABSTRACT	25.72
A-9	Sand - Vet	132	132 - VAAL ALLEM URBAN	15.21
A-9	Sand - Vet	633	633 - VAAL ERFENIS DAM ABSTRACTION	7.42
A-9	Bloemhof	210	210 - VAAL SMALL TOWNS	8.99
A-9	Bloemhof	586	586 - VAAL MIDVAAL ABSTRACTION	43.68
A-9	Bloemhof	589	589 - VAAL SEDIBENG ABSTRACT	42.79
A-9	Bloemhof	599	599 - VAAL GOUDVELD BEDLOSS	39.45
A-9	Bloemhof	652	652 - VAAL RIVER BEDLOSS D/S	18.81
A-9	Bloemhof	653	653 - VAAL BLOEMHOF LOSSES	78.11
A-9	Bloemhof	683	683 - VAAL IRRIG DEMAND	0.00
A-9	Bloemhof	684	684 - VAAL IRRIG DEMAND	0.00
A-9	Bloemhof	680	680 - VAAL BLOEMHOF DEMAND	10.10
A-10	Lower Vaal	288	288 - TAUNG LOSS DEMAND	0.00
A-10	Lower Vaal	250	250 - TAUNG WENTZEL HFY DEM	0.95
A-10	Lower Vaal	209	209 - TAUNG IRR BLOCK 4 LOSSES	0.19
A-10	Lower Vaal	268	268 - TAUNG IRR BLOCK 5 LOSSES	7.51
A-10	Lower Vaal	234	234 - TAUNG VHARTS IRR DISTBN LOSSES	126.99
A-10	Lower Vaal	344	344 - TAUNG KGOMOTSO WTW ABS	0.22
A-10	Lower Vaal	265	265 - TAUNG HARTD7.ABS	0.38
A-10	Lower Vaal	269	269 - TAUNG IRR BLOCK 6 LOSSES	1.42
A-10	Lower Vaal	264	264 - TAUNG HARTU7.ABS	2.81
A-10	Lower Vaal	228	228 - TAUNG KIMBERLY DEM	19.19
A-10	Lower Vaal	275	275 - TAUNG SPITSKOP IRRIG CONS LOSS	0.85
A-10	Lower Vaal	283	283 - TAUNG GAMAGARA DEM	7.64
A-10	Lower Vaal	227	227 - TAUNG VARIOUS DEM	25.21

Figure	Subcatchment	Channel no.	Channel name	Demand
A-10	Lower Vaal	150	VAAL LOSSES	119.47
B-3	Senqu	1132	LES HIGH 132 - ORAN IRR AT ORANGE DRAAI NODE	1.71
B-3	Senqu	3497	LES HIGH 2497 - LOSS IN MAKHALENG	16.97
B-3	Senqu	3501	LES HIGH 2501 - MOHALE'S HOEK URB	9.89
B-4	Caledon	3479	CALEDON 2479 - LOSS IN HLOTSE	9.95
B-4	Caledon	3487	CALEDON 2487 - LOSS IN HOLOLO	3.63
B-4	Caledon	3483	CALEDON 2483 - HLOTSE LERIBE UR DEM	0.88
B-4	Caledon	1054	CALEDON 54 - LES94.IRG CALEDON LESOTHO	8.17
B-4	Caledon	1066	CALEDON 66 - LESOTHO URBAN DMD	12.27
B-4	Caledon	3492	CALEDON 2492 - MAPOTSOE/BUTHA URB	11.15
B-4	Caledon	3510	CALEDON MASERU DEMAND	0.00
B-4	Caledon	1057	CALEDON 57 - RSA94.IRG CALEDON RSA DEMAND	32.28
B-4	Caledon	1051	CALEDON 51 - RSA URB DMD	13.19
B-4	Caledon	1561	CALEDON 561 - LOSS WELB comp	5.47
B-4	Caledon	1070	CALEDON 70 - WEL94.IRG DEM FROM CALEDON	30.65
B-4	Caledon	1073	CALEDON 73 - LOSS WELB TO BLOEMF	4.81
B-4	Caledon	1068	CALEDON 68 - LOSS KNEL TO WELB	0.82
B-5	Riet - Modder	1014	VAAL 14 - LOSS KNEL TO RUSTF	2.07
B-5	Riet - Modder	1075	VAAL 75 - BOTSHABELO DMD	9.22
B-5	Riet - Modder	1081	VAAL 81 - LOSS RUST TO MOCKES	2.10
B-5	Riet - Modder	1079	VAAL 79 - LOSS FROM MAZELSPOORT	1.92
B-5	Riet - Modder	1564	VAAL 564 - SMALL USERS BLOEM PIPE	2.52
B-5	Riet - Modder	1077	VAAL 77 - BLOEMFONTEIN NET DMD	37.81
B-5	Riet - Modder	1085	VAAL 85 - THABA N'CHU DMD	1.50
B-5	Riet - Modder	1179	VAAL 179 - KALKFONTEIN URBAN	1.71
B-5	Riet - Modder	1143	VAAL 143 - RICHIE URB	2.18
B-5	Riet - Modder	1074	VAAL 74 - O/R CANAL TRANSFER LOSS	4.42
B-5	Riet - Modder	1153	VAAL 153 - RAMAH & VDK IRR	57.50
B-5	Riet - Modder	1151	VAAL 151 - LOSS FROM O/V CANAL	10.33
B-5	Riet - Modder	1050	VAAL 50 - DOUGLAS IRR1	26.72
B-5	Riet - Modder	1097	VAAL 97 - DOUGLAS DMD	1.93
B-6	Upper Orange	1084	UP ORAN 84 - GARIEP IRR	19.71
B-6	Upper Orange	1183	UP ORAN 183 - GARIEP TO VANDERKL URB	5.24
B-6	Upper Orange	1248	UP ORAN 248 - BOSBERG TRANSFER	0.00
B-6	Upper Orange	1181	UP ORAN 181 - ORANGE IRR AT ALIWAL NODE	9.25
B-6	Upper Orange	1131	UP ORAN 131 - ORANGE IRR AT KRAAI NODE	18.02
B-6	Upper Orange	1052	UP ORAN 52 - URBAN DMD KRAAI NODE	10.70

Figure	Subcatchment	Channel no.	Channel name	Demand
B-6	Upper Orange	1130	UP ORAN 130 - EASTERN CAPE	647.27
B-6	Upper Orange	1034	UP ORAN 34 - GAR87.IRG GARIEP DUMMY	95.89
B-6	Upper Orange	1039	UP ORAN 39 - VANDERKL. DUMMY DAM IRR	49.90
B-6	Upper Orange	1251	UP ORAN 251 - OPERATIONAL LOSSES	195.17
B-6	Upper Orange	1045	UP ORAN 45 - HOPETOWN DMD	1.99
B-6	Upper Orange	1067	UP ORAN 67 - LOSSES REACH 1A	44.25
B-6	Upper Orange	1043	43 - IRRIG AREA VDK TO TORQUAY	116.66
B-6	Upper Orange	1234	234 - IRRIG AREA TORQUAY TO OV CONF	39.73
B-6	Upper Orange	1238	UP ORAN 238 - LOSSES REACH 1B	11.76
B-6	Upper Orange	1177*	System Surplus Yield	175.00
B-7,8	Molopo	3376	MOLOPO 2376 - D4H035	0.00
B-7,8	Molopo	3375	MOLOPO 2375 - D4H034	0.00
B-7,8	Molopo	3467	MOLOPO 2467 - LOSS IN MOLOPO	7.64
B-7,8	Molopo	3541	MOLOPO BEDLOSS 1	1.84
B-7,8	Molopo	3542	MOLOPO BEDLOSS 2	2.65
B-7,8	Molopo	3543	MOLOPO BEDLOSS 3	4.26
B-7,8	Molopo	3544	MOLOPO BEDLOSS 4	3.47
B-7,8	Molopo	3545	MOLOPO BEDLOSS 27	8.25
B-7,8	Molopo	3546	MOLOPO BEDLOSS 5	9.87
B-7,8	Molopo	3547	MOLOPO BEDLOSS 6	1.84
B-7,8	Molopo	3548	MOLOPO BEDLOSS 7	0.51
B-7,8	Molopo	3549	MOLOPO BEDLOSS 8	4.31
B-7,8	Molopo	3550	MOLOPO BEDLOSS 9	3.43
B-7,8	Molopo	3551	MOLOPO BEDLOSS 10	12.84
B-7,8	Molopo	3552	MOLOPO BEDLOSS 11	7.25
B-7,8	Molopo	3553	MOLOPO BEDLOSS 12	6.56
B-7,8	Molopo	3554	MOLOPO BEDLOSS 13	9.26
B-7,8	Molopo	3555	MOLOPO BEDLOSS 14	3.46
B-7,8	Molopo	3556	MOLOPO BEDLOSS 28	19.33
B-7,8	Molopo	3557	MOLOPO BEDLOSS 15	1.03
B-7,8	Molopo	3558	MOLOPO BEDLOSS 29	3.11
B-7,8	Molopo	3559	MOLOPO BEDLOSS 16	12.13
B-7,8	Molopo	3560	MOLOPO BEDLOSS 17	0.87
B-7,8	Molopo	3561	MOLOPO BEDLOSS 18	1.21
B-7,8	Molopo	3562	MOLOPO BEDLOSS 19	0.26
B-7,8	Molopo	3563	MOLOPO BEDLOSS 20	0.09
B-7,8	Molopo	3564	MOLOPO BEDLOSS 21	0.35
B-7,8	Molopo	3565	MOLOPO BEDLOSS 22	0.25

Figure	Subcatchment	Channel no.	Channel name	Demand
B-7,8	Molopo	3566	MOLOPO BEDLOSS 23	0.39
B-7,8	Molopo	3567	MOLOPO BEDLOSS 24	0.35
B-7,8	Molopo	3568	MOLOPO BEDLOSS 25	11.64
B-7,8	Molopo	3569	MOLOPO BEDLOSS 26	1.95
B-7,8	Molopo	3526	MOLOPO 2526 - PPC	0.00
B-7,8	Molopo	3360	MOLOPO 2360 - MAFIK FROM MOLOP	4.68
B-7,8	Molopo	3527	MOLOPO 2527 - BEDLOSS	1.93
B-7,8	Molopo	3366	MOLOPO 2366 - IRRIG 1	0.00
B-7,8	Molopo	3520	MOLOPO 2520 - MAFIK FROM GROOT	0.00
B-7,8	Molopo	3365	MOLOPO 2365 - IRRIG 2	0.00
B-7,8	Molopo	3522	MOLOPO 2522 - BEDLOSS	0.00
B-7,8	Molopo	3525	MOLOPO 2525 - MAFIK FROM SET	3.25
B-10	Fish	1099	FISH 99 - HARDAP IRR	40.81
B-10	Fish	1113	FISH 113 - HARDAP URBAN	0.93
B-10	Fish	1258	FISH 258 - HARDAP YIELD	0.00
B-10	Fish	1101	FISH 101 - FISH RIVER LOSS	68.86
B-10	Fish	1114	FISH 114 - NAUTE URBAN	1.90
B-10	Fish	1259	FISH 259 - NAUTE YIELD	2.67
B-10	Fish	1106	FISH 106 - NAUTE IRR	4.52
B-10	Fish	1108	FISH 108 - RIVER LOSS NAUTE	6.10
B-10	Fish	1104	FISH 104 - RIVER LOSS SEEHEIM	92.02
B-11	Lower Main	1144	LOW MAIN 144 - LOSSES REACH 2	126.45
B-11	Lower Main	1180	LOW MAIN 180 - LOSSES REACH 3	130.85
B-11	Lower Main	1142	LOW MAIN 142 - PRIESKA URB	1.88
B-11	Lower Main	1148	LOW MAIN 148 - IRR MID ORANGE	135.04
B-11	Lower Main	1162	LOW MAIN 162 - BOEGOEBERG IRR	99.98
B-11	Lower Main	1155	LOW MAIN 155 - UPING RIVER IRR ABS.	62.22
B-11	Lower Main	1193	LOW MAIN 193 - UPING AND URB DMD	10.25
B-11	Lower Main	1170	LOW MAIN 170 - UPINGTON IRR	100.59
B-11	Lower Main	1158	UP ORAN 158 - BOEG CANAL LOSS	8.00
B-11	Lower Main	1167	UP ORAN 167 - UPING IRR CANAL LOSS	8.05
B-11	Lower Main	1168	UP ORAN 168 - KEIMOES IRR CANAL LOSS	5.37
B-11	Lower Main	1176	LOW MAIN 176 - KEIMOES IRR	64.42
B-11	Lower Main	1184	LOW MAIN 184 - KAKEMAS URB DMD	2.23
B-11	Lower Main	1157	LOW MAIN 157 - KAKEMAS RIVER IRR ABS	31.48
B-11	Lower Main	1199	UP ORAN 199 - KAKEMAS IRR CANAL LOSS	5.59
B-11	Lower Main	1188	LOW MAIN 188 - KAKEMAS IRR DMD	106.29
B-11	Lower Main	1194	LOW MAIN 194 - NAMAK IRR U/S NAMIBIA	9.78

Figure	Subcatchment	Channel no.	Channel name	Demand
B-11	Lower Main	1200	LOW MAIN 200 - URBAN SPRINB PELLAD	10.59
B-11	Lower Main	1198	LOW MAIN 198 - NAMAK IRR D/S NAMIB	35.09
B-11	Lower Main	1118	LOW MAIN 118 - SPRINGBOK	4.10
B-11	Lower Main	1208	LOW MAIN 208 - VIOOLSDRIFT MINOR IRR	7.52
B-11	Lower Main	1218	LOW MAIN 218 - ALEXANDER BAY IRR	10.05
B-11	Lower Main	1224	LOW MAIN 224 - URB.DMD. ALEX.BAY	7.45
B-11	Lower Main	1115	LOW MAIN 115 - ARIAMS WARMB URBAN	0.00
B-11	Lower Main	1159	LOW MAIN 159 - PELLADRIF NAMIBIA IRR	21.75
B-11	Lower Main	1275	LOW MAIN 275 - VIOOLSDRIF DAM YIELD	0.00
B-11	Lower Main	1161	LOW MAIN 161 - VIOOLS NAMIBIA IRR	0.00
B-11	Lower Main	1206	LOW MAIN 206 - VIOOLSDRIF HAIB MINE	0.00
B-11	Lower Main	1116	LOW MAIN 116 - AUSENKEHR NOOROEWR UR	22.80
B-11	Lower Main	1117	LOW MAIN 117 - ROSHPINAHSCORP MINES	15.89
B-11	Lower Main	1163	LOW MAIN 163 - MOUTH NAMIBIA IRR	0.00
B-11	Lower Main	1165	LOW MAIN 165 - ORANJEMUND ROSH PINAH	8.50
B-11	Lower Main	1216	216 - RIVER REQ REACH 7	66.50
B-11	Lower Main	1212	LOW MAIN 212 - LOSSES REACH 6	54.20
B-11	Lower Main	1202	LOW MAIN 202 - LOSSES REACH 5	143.92
B-11	Lower Main	1192	LOW MAIN 192 - LOSSES REACH 4	37.11
B-11	Lower Main	1220	LOW MAIN 220 - RIVER MOUTH ENV DMD	288.06
				4903.95

Note *: represents yields and not necessarily demands.

2 TABLE C-2: DETAILS OF RETURN FLOWS

Figure	Subcatchment	Channel no.	Channel name	Demand
A-4	Grootdraai	376	376 - VAAL GR URBAN	1.67
A-4	Grootdraai	377	377 - VAAL NET URBAN	4.13
A-4	Grootdraai	544	544 - VAAL SEEPGR	0.36
A-5	Vaal	415	415 - VAAL WAURBAN	9.36
A-5	Vaal	416	416 - VAAL SEEPWA	0.12
A-5	Vaal	418	418 - VAAL SASOL	4.20
A-5	Vaal	476	476 - VAAL BETH HARRI QWA RF	8.99
A-5	Vaal	686	686 - VAAL C12D4 URB	6.74
A-6	Suikerbos	575	575 - VAAL EASTM1	3.65
A-6	Suikerbos	497	497 - VAAL EASTM2	21.73
A-6	Suikerbos	570	570 - VAAL RAND WATER	60.26
A-6	Suikerbos	689	689 - VAAL SUIK4 URB 92	18.22
A-6	Suikerbos	690	690 - VAAL SUIK4 URB 8	1.58
A-6	Klipbank & Barrage	578	578 - VAAL CENTM	7.80
A-6	Klipbank & Barrage	534	534 - VAAL WESTM	0.00
A-6	Klipbank & Barrage	577	577 - VAAL RAND WATER	246.44
A-6	Klipbank & Barrage	580	580 - VAAL RAND WATER	13.08
A-6	Klipbank & Barrage	579	579 - VAAL RAND WATER	31.87
A-6	Klipbank & Barrage	616	616 - VAAL FWESTM	13.44
A-6	Klipbank & Barrage	692	692 - VAAL KLIP4 URB 97.6	58.15
A-6	Klipbank & Barrage	687	687 - VAAL KLIP4 URB 2.4	1.43
A-6	Klipbank & Barrage	688	688 - VAAL BAAR4 URB 47.7	8.42
A-6	Klipbank & Barrage	691	691 - VAAL BARR4 URB 52.3	9.23
A-7	Schoonspruit	930	930 - SCHOON VENTERSDORP RF	0.59
A-7	Schoonspruit	960	960 - SCHOONSPRUIT wetf.lag	4.41
A-7	Schoonspruit	931	931 - SCHOON HARTBEESFONTEIN WTW	1.39
A-7	Schoonspruit	961	961 - SCHOON ORKNEY WWTW	1.01
A-7	Schoonspruit	929	929 - SCHOON KLERKSDORP RF	6.72
A-8	Renoster	304	304 - RENOST KOPPIES HEILBRON RF	0.35
A-9	Mooi	184	184 - VAAL MINE DEWATERING	0.00
A-9	Mooi	604	604 - VAAL BOSKRET	51.00
A-9	Mooi	654	654 - VAAL RAND WATER	7.50
A-9	Mooi	200	200 - VAAL POTCH RET	9.96
A-9	Klipdrift	649	649 - VAAL MINE/URBAN RETURN FLOW	4.54
A-9	Vals	10	10 - VAAL KROONS	5.93
A-9	Sand - Vet	138	138 - VAAL WELKOM	1.40

Figure	Subcatchment	Channel no.	Channel name	Demand
A-9	Sand - Vet	137	137 - VAAL SEEPVET	1.80
A-9	Sand - Vet	145	145 - VAAL TAILWATER	10.78
A-9	Bloemhof	590	590 - VAAL WTVLRWC ret flow	1.55
A-9	Bloemhof	217	217 - VAAL MINE DEWATERING	18.00
A-9	Bloemhof	353	353 - VAAL BLOEM.EXC	0.00
B-4	Caledon	3489	CALEDON 2489 - COMPENS INFLOW MUELA	0.00
B-7,8	Molopo	3405	MOLOPO 2405 - D4H006	2.24
B-7,8	Molopo	3406	MOLOPO 2406 - D4H007	1.67
B-7,8	Molopo	3407	MOLOPO 2407 - D4H008	0.94
B-7,8	Molopo	3408	MOLOPO 2408 - D4H009	1.20
B-7,8	Molopo	3409	MOLOPO 2409 - D4H010	1.80
B-7,8	Molopo	3410	MOLOPO 2409 - D4H011	0.12
B-7,8	Molopo	3370	MOLOPO 2370 - D4H012	3.08
B-7,8	Molopo	3371	MOLOPO 2371 - D4H039	0.59
B-7,8	Molopo	3524	MOLOPO 2524 - WWTW RET FLOW	3.79
				673.27

3 TABLE C-3: DETAILS OF IRRIGATION BLOCKS

Figure	System	Block no	Demand chan no	Return flow chan no	Name	Area (km^2)	Average Demand (mill m^3/a)	Average Return flow (mill m^3/a)
A-4	wilge	135	558	382	558 - block demand	27.21	19.21	2.36
A-4	wilge	136	381	383	381 - block demand	18.06	12.65	1.56
A-4	wilge	137	387	388	387 - block demand	8.26	0.94	0.28
A-4	wilge	139	384	385	384 - block demand	20.45	2.92	0.75
A-4	wilge	142	391	392	391 - block demand	5.54	1.79	0.40
A-4	wilge	144	394	395	394 - block demand	17.03	9.84	1.36
A-4	wilge	146	398	400	398 - block demand	5.33	0.81	0.20
A-4	wilge	145	396	401	396 - block demand	22.06	3.97	0.90
A-4	wilge	149	407	408	407 - block demand	1.08	0.76	0.11
A-4	wilge	148	405	406	405 - block demand	1.32	0.81	0.11
A-4	wilge	152	410	412	410 - block demand	24.47	15.69	2.04
A-4	wilge	151	409	411	409 - block demand	21.85	14.83	1.87
A-4	grootdraai	124	357	358	357 - block demand	0.47	0.15	0.04
A-4	grootdraai	123	355	356	355 - block demand	2.21	0.62	0.13
A-4	grootdraai	128	364	365	364 - block demand	14.17	4.62	0.89
A-4	grootdraai	126	362	363	362 - block demand	8.55	4.49	0.65
A-4	grootdraai	131	372	373	372 - block demand	6.36	5.29	0.66
A-4	grootdraai	134	371	375	371 - block demand	4.89	4.14	0.51
A-5	vaal	184	462	463	462 - block demand	7.07	5.48	2.37
A-5	vaal	181	470	471	470 - block demand	3.12	1.96	0.94
A-5	vaal	189	472	473	472 - block demand	8.76	7.09	2.93
A-5	vaal	190	474	475	474 - block demand	5.25	4.29	1.79
A-5	vaal	180	460	461	460 - block demand	15.72	9.10	4.29
A-5	vaal	178	458	459	458 - block demand	25.82	16.42	7.49
A-5	vaal	160	425	426	425 - block demand	2.26	1.85	0.84
A-5	vaal	159	423	424	423 - block demand	1.39	1.14	0.52
A-5	vaal	157	420	422	420 - block demand	0.37	0.30	0.14
A-5	vaal	164	430	431	430 - block demand	2.45	2.01	0.84
A-5	vaal	166	433	434	433 - block demand	1.50	1.23	0.51
A-5	vaal	167	435	439	435 - block demand	2.44	1.93	0.82
A-5	vaal	163	437	438	437 - block demand	3.98	3.22	1.35
A-5	vaal	173	442	443	442 - block demand	3.49	2.86	1.19
A-5	vaal	170	446	447	446 - block demand	2.33	1.91	0.80
A-5	vaal	175	445	448	445 - block demand	1.43	1.17	0.49

A-5	vaal	193	482	483	482 - block demand	8.73	6.31	2.78
A-5	vaal	196	485	486	485 - block demand	50.19	39.24	16.56
A-5	vaal	197	487	488	487 - block demand	17.02	13.15	5.55
A-5	vaal	198	490	491	490 - block demand	2.92	2.36	0.99
A-5	vaal	174	450	452	450 - block demand	5.69	4.67	1.95
A-6	krom	101	569	179	569 - block demand	3.80	3.78	0.72
A-6	krom	102	180	181	180 - block demand	2.46	2.04	0.41
A-6	suikerbos	214	495	494	495 - block demand	0.99	1.22	0.27
A-6	suikerbos	216	499	500	499 - block demand	2.91	3.57	0.78
A-6	suikerbos	220	505	506	505 - block demand	1.10	1.35	0.19
A-6	suikerbos	222	508	509	508 - block demand	5.10	6.26	0.90
A-6	suikerbos	233	525	526	525 - block demand	0.48	0.53	0.08
A-6	suikerbos	227	514	515	514 - block demand	1.02	1.20	0.18
A-6	suikerbos	230	519	520	519 - block demand	0.32	0.39	0.06
A-6	suikerbos	236	528	530	528 - block demand	1.77	2.17	0.31
A-6	Klipbank & Barrage	241	536	537	536 - block demand	7.60	8.54	1.53
A-6	Klipbank & Barrage	243	532	539	532 - block demand	16.98	19.08	3.60
A-6	Klipbank & Barrage	246	615	611	615 - block demand	8.35	10.56	1.42
A-6	Klipbank & Barrage	247	610	584	610 - block demand	18.10	21.29	2.16
A-7	schoonspruit	253	904	906	904 - block demand	4.75	3.73	0.82
A-7	schoonspruit	254	901	656	901 - block demand	7.38	5.07	1.15
A-7	schoonspruit	255	905	658	905 - block demand	12.80	9.76	2.16
A-7	schoonspruit	257	913	659	913 - block demand	0.58	0.68	0.08
A-7	schoonspruit	256	914	660	914 - block demand	0.75	0.44	0.06
A-7	schoonspruit	266	908	661	908 - block demand	0.67	0.87	0.11
A-7	schoonspruit	262	909	662	909 - block demand	0.58	0.60	0.08
A-7	schoonspruit	258	910	663	910 - block demand	12.86	5.37	0.33
A-7	schoonspruit	259	911	912	911 - block demand	0.72	0.53	0.05
A-7	schoonspruit	269	621	664	621 - block demand	1.09	0.81	0.06
A-7	schoonspruit	270	626	619	626 - block demand	0.41	0.08	0.02
A-7	schoonspruit	271	628	665	628 - block demand	0.84	1.10	0.17
A-8	renoster	273	300	666	300 - block demand	2.82	2.38	0.32
A-8	renoster	275	302	667	302 - block demand	0.79	0.66	0.09
A-8	renoster	321	346	669	346 - block demand	0.88	0.90	0.02
A-8	renoster	279	315	668	315 - block demand	0.43	0.33	0.01
A-8	renoster	284	317	670	317 - block demand	0.36	0.37	0.01

A-8	renoster	290	319	671	319 - block demand	2.94	1.27	0.18
A-8	renoster	294	321	672	321 - block demand	0.53	0.56	0.02
A-8	renoster	300	330	675	330 - block demand	0.21	0.22	0.04
A-8	renoster	295	339	673	339 - block demand	4.59	1.47	0.07
A-8	renoster	298	343	674	343 - block demand	0.30	0.43	0.07
A-8	renoster	323	306	676	306 - block demand	3.00	2.94	0.36
A-8	renoster	322	310	677	310 - block demand	3.26	3.32	0.42
A-9	Sand - Vet	199	636	131	636 - block demand	4.82	2.40	0.48
A-9	Sand - Vet	210	133	134	133 - block demand	27.93	2.40	4.46
A-9	Sand - Vet	212	639	151	639 - block demand	2.74	2.94	0.35
A-9	Sand - Vet	213	152	153	152 - block demand	33.17	35.58	4.75
A-9	Sand - Vet	81	638	139	638 - block demand	1.27	0.59	0.14
A-9	Sand - Vet	83	147	148	147 - block demand	5.73	2.46	0.12
A-9	Sand - Vet	87	163	164	163 - block demand	16.64	9.40	0.41
A-9	vals	8	5	6	5 - block demand	0.00	0.00	0.00
A-9	vals	6	643	7	643 - block demand	6.02	6.01	0.67
A-9	vals	205	8	9	8 - block demand	12.57	5.10	0.96
A-9	vals	208	13	15	13 - block demand	10.17	6.31	0.94
A-9	Bloemhof	115	213	214	213 - block demand	3.04	4.34	0.69
A-9	Bloemhof	116	251	297	251 - block demand	10.18	14.81	2.36
A-9	Bloemhof	120	647	298	647 - block demand	2.75	3.58	0.28
A-9	Bloemhof	118	651	354	651 - block demand	20.67	31.60	4.81
A-9	mooi	103	600	182	600 - block demand	3.43	2.60	0.11
A-9	mooi	104	2	183	2 - block demand	2.07	1.61	0.06
A-9	mooi	107	187	188	187 - block demand	6.07	4.74	0.28
A-9	mooi	111	191	192	191 - block demand	17.10	13.28	0.73
A-9	mooi	112	198	199	198 - block demand	6.83	5.49	0.33
A-9	Klipdrift	95	614	170	614 - block demand	0.66	0.28	0.04
A-9	Klipdrift	99	171	172	171 - block demand	0.00	0.00	0.00
A-9	Klipdrift	96	173	174	173 - block demand	0.80	0.33	0.04
A-9	Klipdrift	100	176	177	176 - block demand	0.00	0.00	0.00
A-10	Lower Vaal	68	241	243	241 - block demand	1.17	1.20	0.14
A-10	Lower Vaal	69	244	245	244 - block demand	3.49	2.09	0.19
A-10	Lower Vaal	70	257	258	257 - block demand	0.88	0.49	0.05
A-10	Lower Vaal	67	233	239	233 - block demand	6.73	6.24	1.33
A-10	Lower Vaal	71	235	238	235 - block demand	169.39	269.58	72.99
A-10	Lower Vaal	72	236	237	236 - block demand	33.08	50.39	9.85
A-10	Lower Vaal	73	223	224	223 - block demand	20.00	27.37	2.30
A-10	Lower Vaal	74	229	230	229 - block demand	17.33	24.28	2.28

A-10	Lower Vaal	75	277	278	277 - block demand	16.74	23.46	2.22
A-10	Lower Vaal	76	273	274	273 - block demand	9.41	12.40	1.51
A-10	Lower Vaal	77	281	282	281 - block demand	5.31	7.44	0.70
A-10	Lower Vaal	78	285	286	285 - block demand	1.59	2.31	0.21
B-5	Riet - Modder	2662	1009	3615	2452 - IRRIG BLOCK DEMAND	1.13	1.10	0.37
B-5	Riet - Modder	2663	1119	3616	9 - IRRIG BLOCK DEMAND	3.37	1.64	0.62
B-5	Riet - Modder	2664	1127	3617	119 - IRRIG BLOCK DEMAND	1.84	2.27	0.56
B-5	Riet - Modder	2665	1133	3618	127 - IRRIG BLOCK DEMAND	5.50	2.65	0.67
B-5	Riet - Modder	2667	1219	3621	133 - IRRIG BLOCK DEMAND	15.00	3.55	0.37
B-5	Riet - Modder	2666	1185	3619	219 - IRRIG BLOCK DEMAND	9.00	4.19	0.96
B-5	Riet - Modder	2668	1215	3620	185 - IRRIG BLOCK DEMAND	8.80	8.45	1.80
B-5	Riet - Modder	2669	1088	3622	215 - IRRIG BLOCK DEMAND	33.90	39.21	3.23
B-5	Riet - Modder	2661	1091	3623	88 - IRRIG BLOCK DEMAND	35.82	12.78	3.92
B-5	Riet - Modder	2660	1246	3625	91 - IRRIG BLOCK DEMAND	28.00	14.30	1.41
B-5	Riet - Modder	2656	1237	3628	246 - IRRIG BLOCK DEMAND	1.40	1.23	0.32
B-5	Riet - Modder	2657	1239	3627	237 - IRRIG BLOCK DEMAND	0.60	0.52	0.14
B-5	Riet - Modder	2658	1089	3626	239 - IRRIG BLOCK DEMAND	7.40	7.61	0.74
B-5	Riet - Modder	2659	1250	3624	89 - IRRIG BLOCK DEMAND	7.40	5.97	0.59
B-5	Riet - Modder	1099	1140	1209	250 - IRRIG BLOCK DEMAND	6.41	8.34	0.61
B-5	Riet - Modder	1100	1211	1213	140 - IRRIG BLOCK DEMAND	38.53	65.20	2.90
B-5	Riet - Modder	2670	1178	3629	211 - IRRIG BLOCK DEMAND	123.35	171.06	7.45
B-5	Riet - Modder	1087	1124	1126	178 - IRRIG BLOCK DEMAND	73.90	92.77	10.07
B-7,8	Molopo	2512	3398	3374	2509 - IRRIG BLOCK DEMAND	13.21	0.94	0.25
B-7,8	Molopo	2524	3384	3385	2398 - IRRIG BLOCK DEMAND	4.42	0.21	0.08
B-7,8	Molopo	2522	3388	3389	2384 - IRRIG BLOCK	6.68	0.16	0.09

					DEMAND			
B-7,8	Molopo	2532	3396	3397	2388 - IRRIG BLOCK DEMAND	1.28	0.00	0.04
B-7,8	Molopo	2529	3380	3381	2396 - IRRIG BLOCK DEMAND	8.32	0.42	0.10
B-7,8	Molopo	2550	3412	3413	2380 - IRRIG BLOCK DEMAND	0.09	0.00	0.00
B-7,8	Molopo	2544	3417	3418	2412 - IRRIG BLOCK DEMAND	0.02	0.00	0.00
B-7,8	Molopo	2547	3420	3421	2417 - IRRIG BLOCK DEMAND	0.31	0.00	0.00
B-7,8	Molopo	2556	3427	3428	2420 - IRRIG BLOCK DEMAND	2.57	0.05	0.02
B-7,8	Molopo	2562	3432	3433	2427 - IRRIG BLOCK DEMAND	1.31	0.05	0.01
B-7,8	Molopo	2569	3439	3440	2432 - IRRIG BLOCK DEMAND	1.31	0.04	0.01
B-7,8	Molopo	2576	3449	3450	2439 - IRRIG BLOCK DEMAND	0.25	0.00	0.00
B-7,8	Molopo	2579	3452	3453	2449 - IRRIG BLOCK DEMAND	0.25	0.01	0.00
B-9	Lower Tributories	2675	3600	3634	124 - IRRIG BLOCK DEMAND	20.00	13.41	0.39
B-9	Lower Tributories	2671	3596	3630	2600 - IRRIG BLOCK DEMAND	7.70	0.34	0.02
B-9	Lower Tributories	2672	3592	3631	2596 - IRRIG BLOCK DEMAND	16.00	5.76	0.16
B-9	Lower Tributories	2673	3587	3632	2592 - IRRIG BLOCK DEMAND	13.10	0.49	0.03
B-9	Lower Tributories	2674	3577	3633	2587 - IRRIG BLOCK DEMAND	0.00	0.00	0.00

APPENDIX D

WATER BALANCE PER SUB-CATCHMENT

4 TABLE D-1: WATER BALANCES PER SUB-CATCHMENT: VAAL

Catchment	Natural Hydrology inflows	System inflows	Other inflows	SFRs	Demands	Irrigation blocks net	Evaporation net	Storage	Outflow from system	Balance
Grootdraai	460	0	6	0	107	16	48	-1	295	0
Thukela	694	0	0		8	0	6	-4	684	0
Wilge	771	477	0	0	48	72	64	0	1064	0
Vaal	823	1359	29	3	11	73	213	-18	1929	0
Suikerbos	100	0	105	0	22	14	8	0	161	0
Klip & Barrage	173	881	390	0	10	51	8	0	1375	0
Krom	42	1375	0	0	15	5	1	0	1396	0
Mooi	87	14	68	0	44	26	11	0	87	1
Klipdrift	21	0	5	0	6	1	5	0	14	0
Schoonspruit	62	48	14	0	25	24	9	0	65	1
Renoster	132	0	0	0	10	13	21	0	88	0
Vals	153	0	6	0	9	15	9	-1	126	1
Sand - Vet	417	0	14	4	48	45	78	-3	259	0
Bloemhof	131	2021	20	0	242	46	215	-14	1681	1
Lower Vaal	189	1681	0	0	313	333	84	0	1141	0
TOTAL	**4255**	**48**	**658**	**7**	**920**	**734**	**781**	**-42**	**2557**	**4**

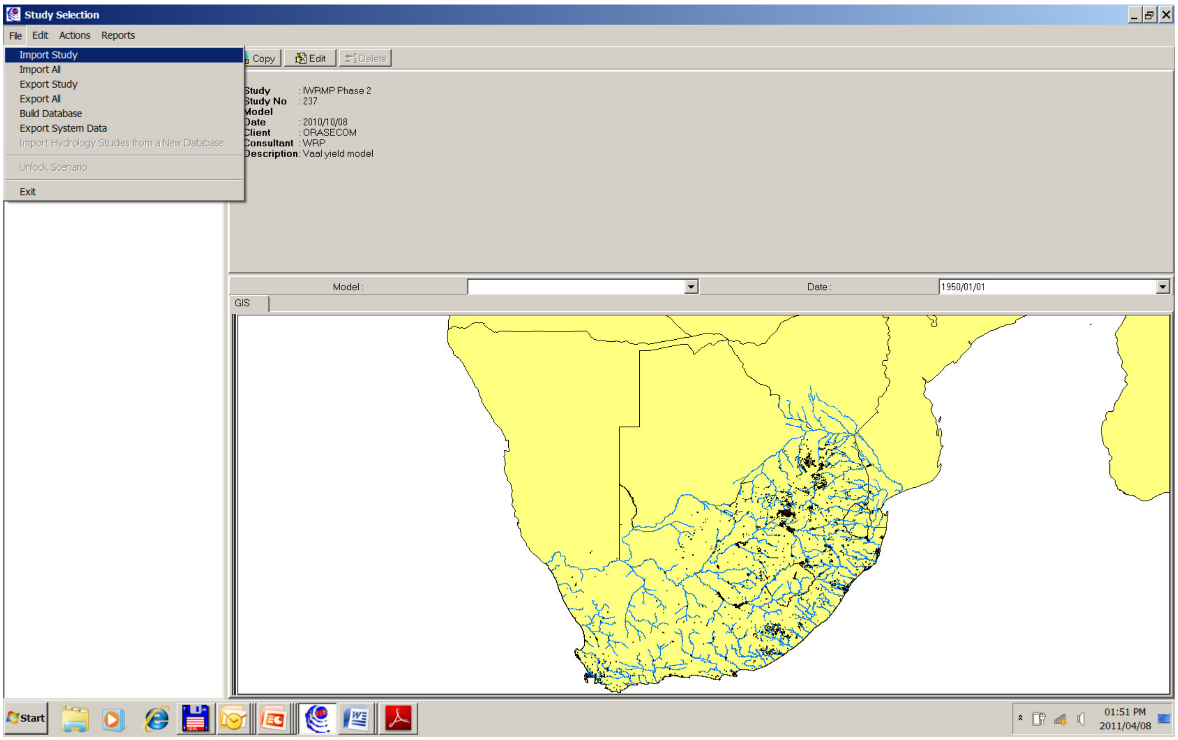
5 TABLE D-2: WATER BALANCES PER SUB-CATCHMENT: ORANGE

Catchment	Natural Hydrology inflows - SFRs	System inflows	Other inflows	Demands	Irrigation blocks net	Evaporation net	Storage	Outflow from system	Balance
Senqu	4105	0	0	29	0	9	8	4060	0
Caledon	1219	0	0	133	0	31	-1	1056	0
Upper Orange	1378	4287	0	1441	-10	720	12	3501	0
Vaal	375	1590	0	162	416	118	-4	1273	0
Lower Main	135	4500	0	1642	0	10	0	2983	0
Lower Tributary	162	0	0	0	20	23	-3	124	-1
Molopo	135	0	15	150	1	0	-1	0	0
Fish	695	0	0	218	0	66	-4	416	0
TOTAL	**8204**	**1141**	**15**	**3774**	**427**	**976**	**7**	**4177**	**-1**

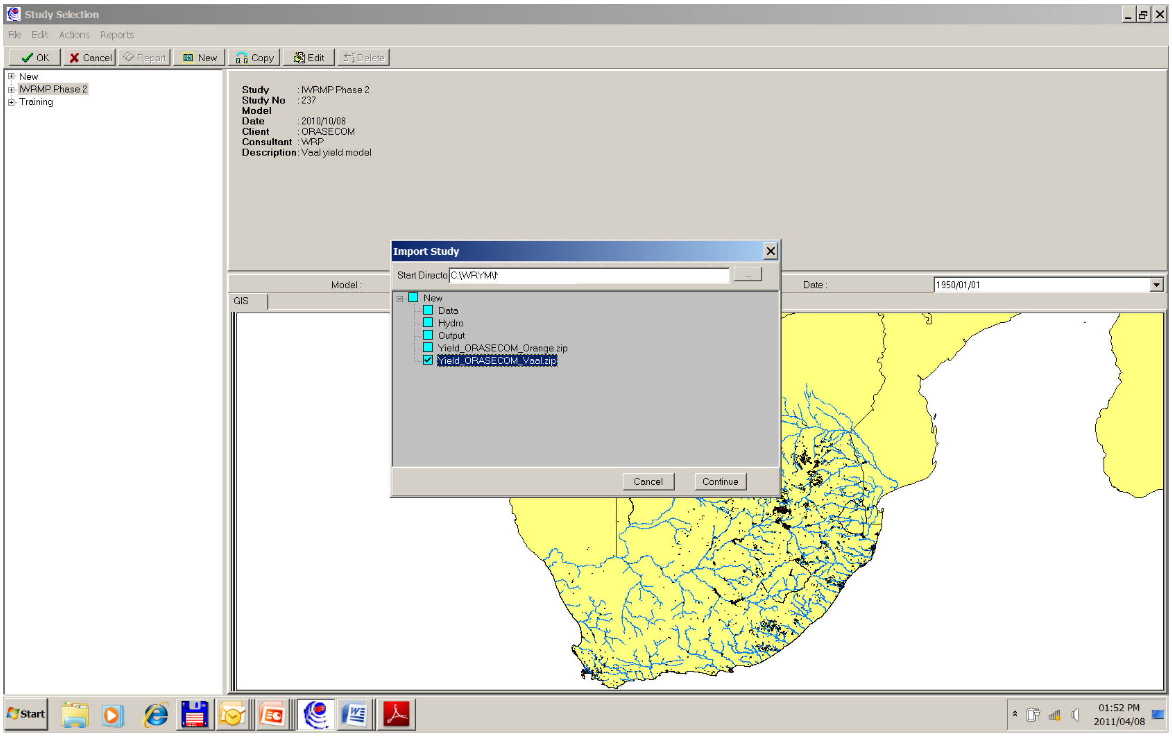
APPENDIX E

PROCEDURE FOR IMPORTING NEW STUDY INTO WRYM-IMS

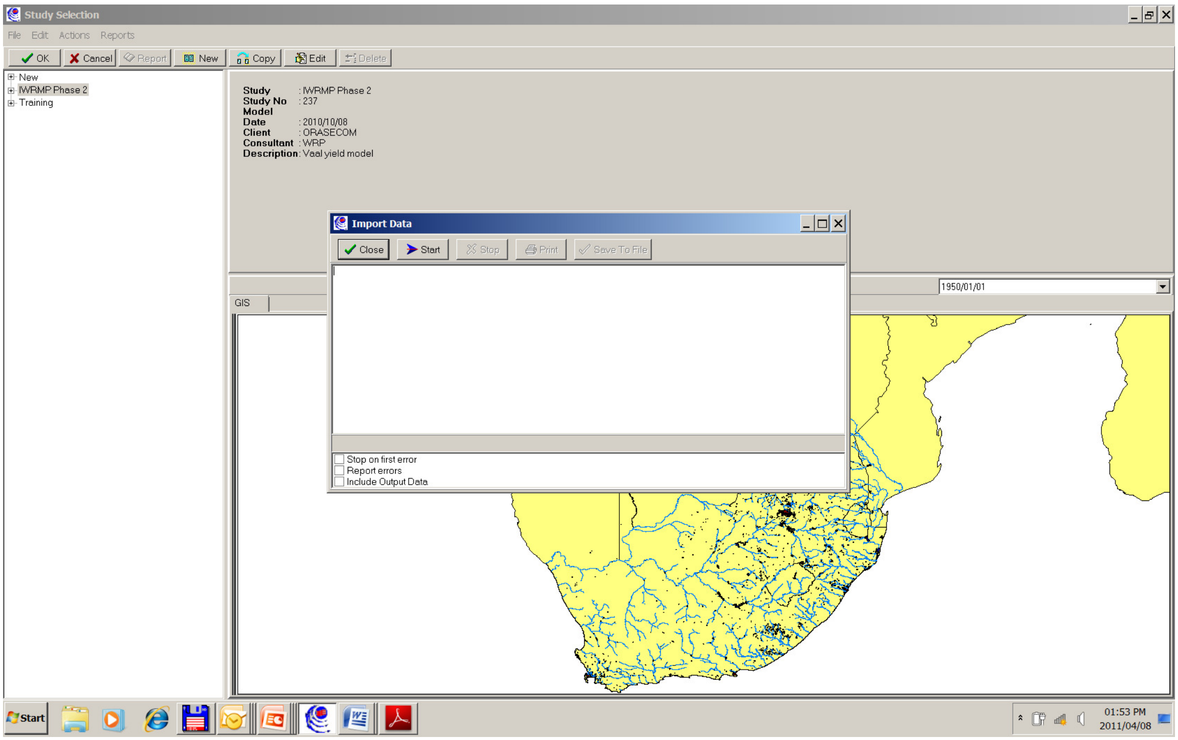
1. Copy the zipped folders from the CD and store in a directory on your C drive called C:\WRYM\ORASE
2. Copy the following folder from the CD: 4 Stand alone text file WRYM data and executables\WRYM\HYDRO\ORASE to a folder created on your computer called C:\WRYM\HYDRO\
3. Open the IMS
4. Go to File, import study



5. Browse for the folder C:\WRYM\ORASE
6. Open up the tree view and tick the box of the data set you want to import



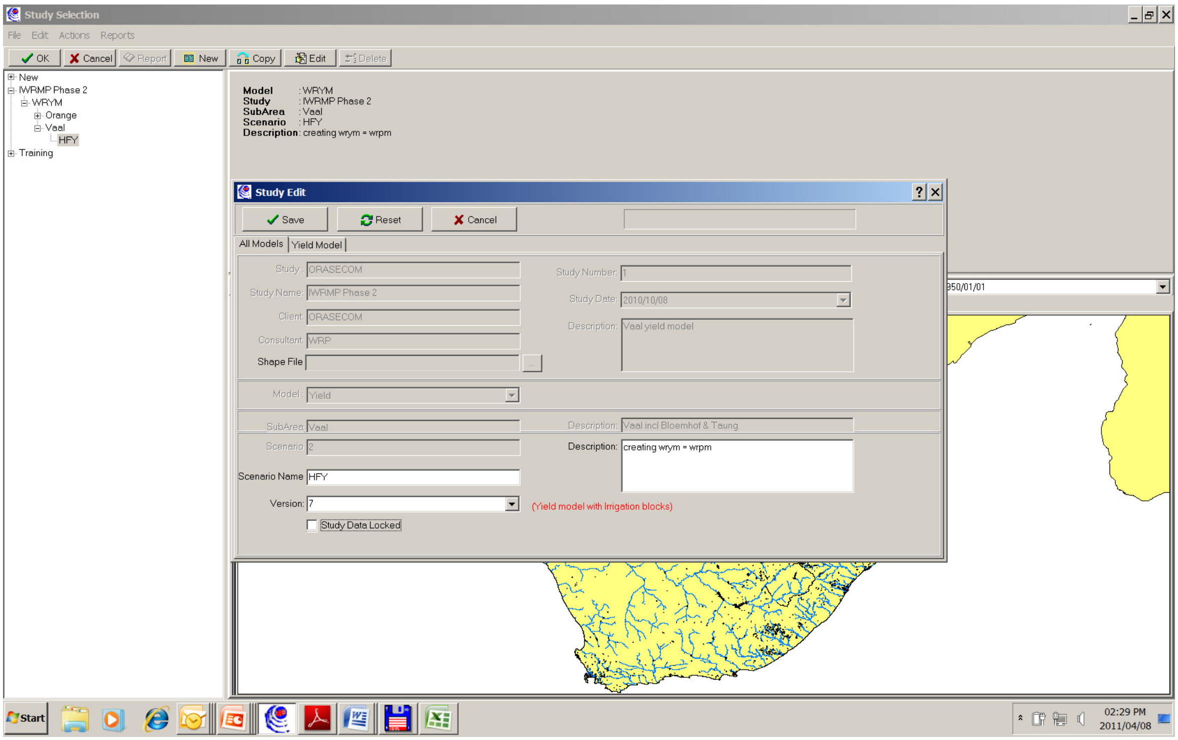
7. Click continue and then start. It will take about 10 – 15 mins



8. Click close when it is finished

9. Open the study

10. Click edit and untick the box “study data locked”



11. Click save

12. Click ok

13. Execute model

ORASECOM