Consolidation of Environmental Flow Requirements

Integrated Water Resources Management Plan for the Orange-Senqu River Basin

2014

Report No. ORASECOM 016/2014

The ***Support to Phase 3 of the ORASECOM Basin-wide Integrated Water Resources Management Plan*** Study was commissioned by the Secretariat of the Orange-Senqu River Basin Commission (ORASECOM) with technical and financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ) in delegated cooperation with the UK Department for International Development (DFID) and the *Australian Department of Foreign Affairs and Trade (DFAT)* implemented through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)°.

Prepared by

in association with

Report No. ORASECOM 016/2014

Support to Phase 3 of the ORASECOM Basin-wide integrated Water Resources Management Plan

Consolidation of Environmental Flow Requirements

Integrated Water Resource Management Plan for the Orange-Senqu River Basin

Compiled by : Delana Louw with contributions from Hermanus Maré

CONSOLIDATION OF ENVIRONMENTAL FLOW REQUIREMENTS

Integrated Water Resources Management Plan for the Orange-Senqu River Basin – Phase 3

ILLUSTRATIONS

Figures

Tables

ABBREVIATIONS AND ACRONYMS

AEC	Alternative ecological category
BBM	Building Block Methodology
CIDE*	Ctenopharyngodon idella (valenciennes, 1844)
DRIFT	Downstream Response to Imposed Flow Transformation
DRM	Desktop reserve model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EcoSpecs	Ecological Specifications
EFR	Environmental Flow Requirements
EIS	Ecological Importance and Sensitivity
EFR	Ecological Flow Requirements
EWR	
G&S	Goods & Services
HFSR	Habitat Flow Stressor Response
IERM	Intermediate Ecological Reserve Methodology
IFR	Instream Flow Requirements
IUCN	International Union for Conservation of Nature
MAR	Mean Annual Runoff
MAP	Mean Annual Precipitation
MRU	Management Resource Units
nMAR	Natural mean annual runoff
ORASECOM	Orange-Senqu River Commission
PAI	Physico Chemicalical Driver Assessment Index
PES	Present Ecological State
PPHI	Pseudocrenilabrus philander (weber, 1897)
Q	Discharge
REC	Recommended Ecological Category
RU	Resource Unit
SANBI	South African National Biodiversity Institute
SD	Slow Deep
SPATSIM	Spatial and Time Series Information Modelling
TPC	Threshold of Potential Concern
VEGRAI	Riparian Vegetation Response Assessment Index
WMA	Water Management Area

1. Introduction

1.1 CONTEXT AND OBJECTIVES OF THE STUDY

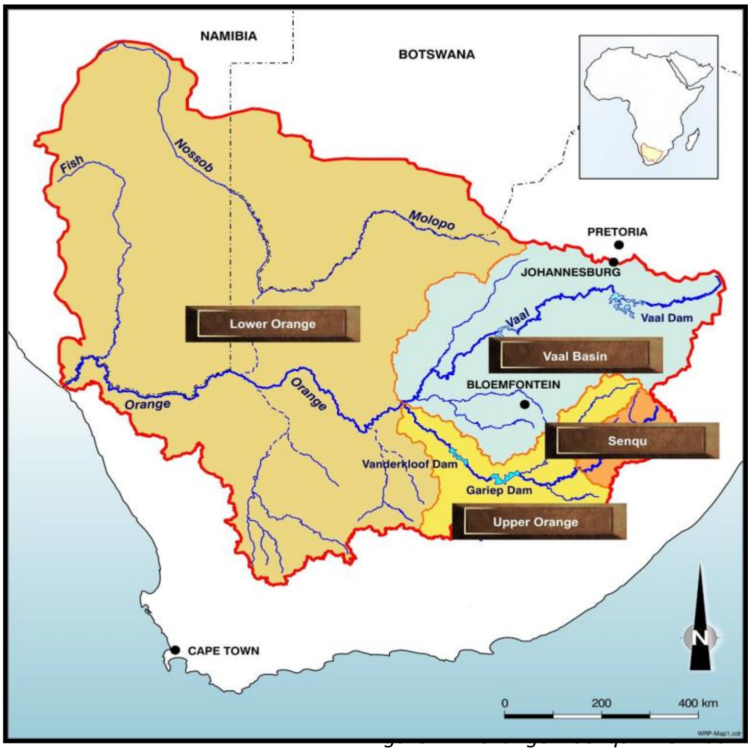
1.1.1 General Context

Southern Africa has fifteen (15) transboundary watercourse systems of which thirteen exclusively stretch over SADC Member States. The Orange–Senqu is one of these thirteen. The Southern African Development Community (SADC) embraces the ideals of utilising the water resources of these transboundary watercourses for the regional economic integration of SADC and for the mutual benefit of riparian states. The region has demonstrated a great deal of goodwill and commitment towards collaboration on water issues. Thus, SADC has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development. The proposed ORASECOM basin-wide IWRM fits in to this background.

1.1.2 Water resources context

The Orange - Senqu River originates in the highlands of Lesotho on the slopes of its highest peak, Thabana Ntlenyana, at 3 482m, and it runs for over 2 300km to its mouth on the Atlantic Ocean.

The river system is one of the largest river basins in Southern Africa with a total catchment area of more than 850,000km^2 and includes the whole of Lesotho as well as portions of Botswana, Namibia and South Africa. The natural mean annual runoff at the mouth is estimated to be in the order of 11,500Mm3, but this has been significantly reduced by extensive water utilisation 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. Two of these dams are situated in Lesotho, five in Namibia and 24 in South Africa. The largest five reservoirs are those formed by the Gariep, Vanderkloof, Sterkfontein, Vaal and Katse Dams with capacities ranging from 1 950 Mm^3 to 5 675 Mm^3. The Orange-Senqu river basin is a highly complex and integrated water resource system with numerous large inter-basin transfers which allow water to be moved from one part of the basin to another as well as into and out of neighbouring basins. For example, the Sterkfontein Dam (2 617Mm^3) is supplied from the adjacent Tugela basin and the Katse-Mohale dams system (2 910Mm^3) located in Lesotho augment the Vaal Dam (2 122Mm^3) which supplies water to the industrial heartland of South Africa. The Gariep Dam (5 675 Mm^3) and Vanderkloof Dam (3 237 Mm^3) on the Orange River downstream of Lesotho are the largest reservoirs in the Orange-Senqu river system respectively. Both dams are used to regulate the river flow for irrigation purposes as well as to generate hydro-electricity during the peak demand periods with a combined installed capacity of 600 MW. Releases from Vanderkloof Dam into the Orange River are dictated by the downstream flow requirements.

The tributaries downstream of the Vaal confluence are the Molopo-Nossob sub-basin system. Surface flow from this system has not reached the main stem of the Orange River in living memory. Further downstream, the Fish River sub-basin, entirely located within Namibia accounts for the two (Hardap, Naute Dams) of the five dams regulating the flows from Namibia into the Orange River.

The most important and highly utilised tributary of the Orange-Senqu system is the Vaal River which supplies water to the industrial heartland of Southern Africa, the Vaal Triangle including Pretoria. The Vaal River System also provides water to 12 large thermal power stations which produce more than 90% of South Africa's electricity, as well as water to some of the world's largest gold, platinum and coal mines.

The Orange-Senqu river basin is clearly one of the most developed and certainly most utilised river basins in the SADC region, with at least 9 major intra - and inter - basin water transfer schemes.

The complexity of this transboundary system and the resultant need for a sophisticated management system in the Orange-Senqu river basin is one of the key drivers of the proposed project to develop an Integrated Water Resources Management Plan for the basin.

1.1.3 Phase 3 of the Basin-wide IWRM Plan

The basin-wide Integrated Water Resources Management (IWRM) Plan will provide a framework for management, development and conservation of water resources in the Orange-Senqu River Basin, serving to advise Parties on optimising overall water resource utilisation.

Since the establishment of ORASECOM in 2000, a significant number of studies have been completed or are in process and have provided the building blocks for the Basin-wide IWRM Plan. Phase I of the ORASECOM IWRM planning programme was implemented between 2004 and 2007 and focused on collating existing information that described the water resources of the Basin. Phase II of the IWRM Planning Programme (2009 to 2011) focused on bridging the planning gaps identified in Phase I. A Transboundary diagnostic analysis (TDA) has been carried out under the ongoing UNDP-GEF project and National and Strategic Action Plans are in the process of being finalised.

1. INTRODUCTION

Strategically, ORASECOM has approached the point where, with some exceptions, sufficient preparatory work has been done to move towards drafting a Basin-Wide IWRM Plan. Representatives of the four member countries have tentatively defined an "overall objective" for preparing a Basin-wide IWRM Plan:

> "*To provide a framework for sustainable development and management of the water resources, taking into account the need for improved distribution and equitable allocation of benefits, in order to contribute towards socio-economic upliftment of communities within the basin, and ensure future water security for the basin States*."

The plan will set out the actions necessary to achieve the strategic objectives of ORASECOM as well as those of the basin States. Some of these will be short term and others longer term. In the context of IWRM planning, once approved, "the Plan" will signify a transition from planning to implementation of the actions that are determined in the Plan. Moreover it will signify the transition of ORASECOM from a reactive to a pro-active mode, technically competent advisor to the Parties as envisaged in the ORASECOM Agreement.

The IWRM Plan will include an implementation plan that identifies activities that will be implemented collectively by all the Parties through ORASECOM and the existing bilateral institutions and those that will be implemented separately by the Parties. The IWRM Plan will be forward looking (10 years in scope) and provide a framework that enables the basin to realise economic and social benefits associated with better water resources management. In addition, the IWRM Plan should strive to link the water sector with national economic growth and poverty alleviation strategies based on the fact that IWRM is not an end in itself but rather a means to achieve economic and social development.

In summary, the objective of this consultancy is to develop a comprehensive 10 year IWRM Plan for the whole of the Orange-Senqu Vaal River Basin. The IWRM Plan will include an implementation plan that identifies activities that will be implemented collectively by all the Parties through ORASECOM and the existing bilateral institutions and those that will be implemented separately by the Parties.

1.2 This Report

1.2.1 Rationale

This study (Phase 3 of the IWRM Plan) consists of five work packages to address all the requirements and actions for the preparation, tabling and approval of the IWRMP. This report focus on Work Package 4e, which is one of the sub-work packages of Work Package 4. Work package 4 comprises the following sub-work packages, effectively the technical studies component of the Phase 3 work.

- **Work Package 4a: Conduct an economic analysis of water use based on water accounting.**
- **Work Package 4b: Consolidate water demands and infrastructure development plans**. The task comprises consolidation into a database, updating and filling of gaps for some parts of the basin.
- **Work Package 4c-i: Update the basin planning model and conduct a model based situation analysis**. 4c-Part i comprises the modelling work that has to be done before any new scenarios can be investigated
- **Work Package 4c-ii: Application of the basin planning model for testing and evaluation of scenarios**
- **Work Package 4d: Update ORASECOM Water Information System**: All information collected as well as results generated will be consolidated in the WIS.
- **Work Package 4e: Consolidate available knowledge on environmental flow requirements and water quality assessments**. The consolidation work will form part of the SAP work but the results will be required for consolidation in the water resources models.
- **Work Package 4f: Consolidate knowledge on economic approaches to water management**

These Sub-Work Packages are critical to finalising the inputs required for the drafting of the IWRM Plan.

1.2.2 Environmental Flow Requirements

Environmental Flow Requirements (EFR) describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems (Hirji and Davis 2009).

Different components of the flow regime maintain different parts of aquatic ecosystems. Thus, loss of one component of the flow regime will affect a system differently than will loss of some other component. Ecosystems can be held at different conditions by ensuring that the flows required to maintain that condition are available. In general, the closer to natural that the desired condition of the aquatic system is, the greater the volume of the original flow regime that will be required as an EFR.

The most important characteristics of a natural flow regime are usually: degree of perenniality; magnitude of the low flows in the dry and wet season; small and medium floods that occur every year and large floods that occur over longer intervals. Identifying these flow components and understanding the ecosystem consequences of their loss or modification is central to an EFR assessment, which should aim to predict how ecosystem condition will change with changes in the flow regime as a result of water-resource development or some other changes in the basin.

1.2.3 Objective of the report

The objective of this report is two-fold:

- To consolidate information on work carried out on environmental flow requirements at key points basin-wide
- To provide information for decision-makers and other stakeholders on the implications of different combinations of water resource development scenarios on the ecological status at each key point as well as vice versa (the implications of maintaining different levels of ecological status) on different development options

1.2.4 Structure of the report

The Report comprises 5 substantive chapters as follows:

- Chapter 1 provides an introduction and context to the report
- Chapter 2 comprises a review of the various EFR (EWR) studies that have taken place basin-wide over the last 16 years and provides details on the methods used and the locations of the sites. It also provides a consolidation of the evaluations carried out at each site
- Chapter 3 describes the preliminary test scenarios that have been used to investigate the implications of different development scenarios on ecological status as well as the implications on development options of maintaining certain ecological states through the maintenance of EFRs.
- Chapter 4 provides analyses of the findings from investigation of the preliminary test scenarios.
- Chapter 5 provides conclusions to be taken forward.

2. Existing EFR studies[1]

This section provides an overview of the sites in the Orange-Senqu Basin where EFR studies have been completed, the methods used to evaluate Present Ecological Status (PES), target conditions and the associated EFRs and the results of relevance to this study.

There have been at least 12 full EFR studies undertaken for different parts of the Orange-Senqu Basin (Table 2.1; Figure 2-1), plus several smaller, desktop studies. These studies were carried out over a period of around 16 years, and used different methods, or different levels of development of the same methods, for both the assessment of present ecological state (PES) and for the evaluation of ecological flow requirements.

2.1 Methods

2.1.1 Assessment of present ecological state

All of the studies based their assessment of PES on Kleynhans (1996; Table 2.2), although the details of assessment have been updated and expanded at various points over the years. As a result, the assessments done for the earlier studies tend to be less structured, and often less detailed, than those done for later studies. Nonetheless, because they are based on the same concepts and definitions, the outcomes are directly comparable. There are also slight terminological differences between the studies. For example, the PES assessments for Lesotho rivers refer to "states" rather than the more-commonly used "categories", but as the Lesotho work was based on Kleynhans (1996) there is a direct translation between states and categories, viz.: State 1 = Category A, State 2 = Category B, etc.

The later studies followed a more rigid approach based on the ecological classification (EcoClassification) process (Kleynhans and Louw, 2007). The steps of the PES determination process are summarised below:

- Undertake biophysical surveys and collate available relevant information.
- Derive the natural reference condition.
- Run a suite of ecological state (EcoStatus) model for the driver (eg hydrology, water quality, geomorphology) and response (fish, macroinvertebrates, riparian vegetation) components to determine the PES of each component.
- Combine these states to determine an integrated state based on ecological endpoints, i.e. the EcoStatus.
- List the pressures and indicated whether flow- or non-flow-related.

1 Taken from: Project Concept Note for "Development and Implementation of basin-wide Environmental Flow regime" in the Orange-Senqu River Basin.

Table 2.1: Relevant EFR assessments for rivers in the Orange-Senqu Basin

Sub-basin	Dates	Rivers	Method	No. of sites	Study	Key references	Company
Senqu	1997-2002	Matsoku Malibamatso Senqu Senqunyane	DRIFT(1)[2]	7	LHDA study: Flow releases downstream of Katse and Muela Reservoirs.	Metsi (2000)/LHDA (2003)	Southern Waters
	2002	Nqoe	Treaty Provision[3]	1	Treaty Provision – no study	LHDA (2002)	Southern Waters
	2006-2007	Senqu	DRIFT(1)	1	Lesotho Highlands Water Project : LHWC Contract 001 : Consulting services for the feasibility study for Phase II – Stage 2	Brown et al. (2008)	Southern Waters
Caledon	2005-2006	Phuthiatsana	DRIFT(1)	1	Environmental and Social Impact Assessment (ESIA) for the Metolong Dam	Metolong Authority (2012)	Southern Waters
	2008-2010	Caledon	HFSR[4]	2	GIZ IWRM Phase 2: EFR study	Louw & Koekemoer (2010)	Rivers for Africa
		Kraai	HFSR	1			
Vaal	2009-2012	Upper Vaal	HFSR	11	Comprehensive Reserve of the Upper Vaal River (2009) National Water resources Classification (2012	DWA 2009a DWA 2011	KAS WRP
	2007-2011	Middle Vaal	HSFR	4	Comprehensive Reserve of the Middle Vaal River. Review of the Middle Vaal River Serve National Water resources Classification (2012)	DWA (2009b) Koekemoer & Louw (2012) DWA (2011)	Golder KAS WRP
	2007-2011	Lower Vaal	HFSR	4	Comprehensive Reserve of the Lower Vaal River. National Water resources Classification (2012	DWA (2009c) Koekemoer & Louw (2012)	Golder KAS WRP
Molopo	2008-2010	Molopo	Scenario assessment	1	GIZ IWRM Phase 2: EFR study	Louw and Koekemoer (2010)	KAS
Fish	2010-2013	Fish	EReFM[5]	2	GEF TDA/SAP	In press	Rivers for Africa
Orange	2008-2010	Orange	HFSR	4	GIZ IWRM Phase 2: EFR study	Louw and Koekemoer (2010);	Rivers for Africa
Orange	2010-2013	Orange	HFSR	1	GEF TDA/SAP	In press	Rivers for Africa

[2] Downstream Response to Imposed Flow Transformations, Version 1 (King and Brown 2003)
[3] Treaty (Article 7(10)) provision to 100% of natural flow of Nqoe River from Muela.
[4] Habitat Flow Stressor Response (Hughes and Louw 2010)
[5] Ephemeral Rivers eFlows Methodology

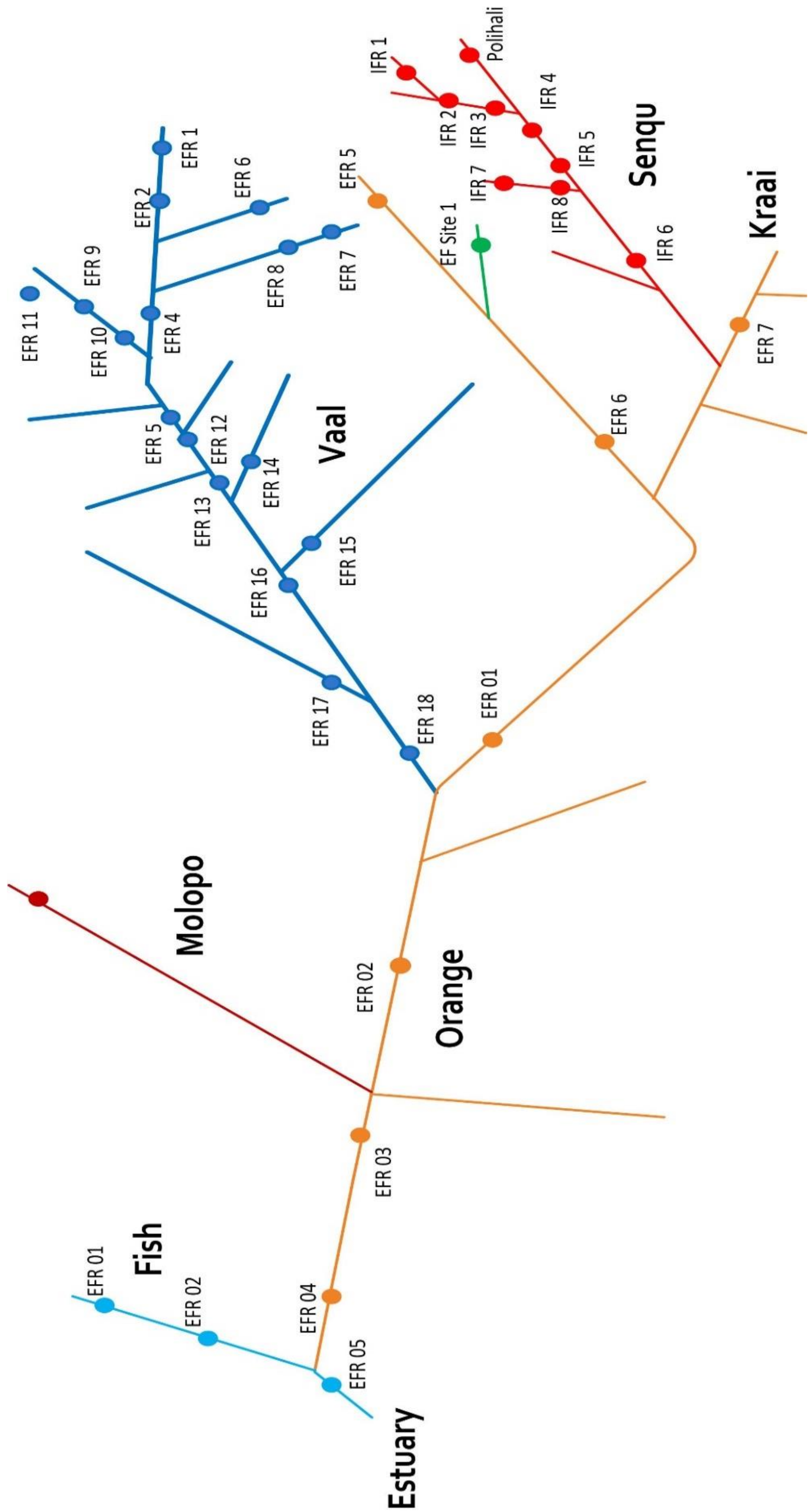


Figure 2-1: Schematic of location of EFR sites showing the location of the EFR sites for the studies listed in Table 2.1 (adapted from Orange-Senqu SAP).

Table 2.2: Definitions of the present ecological state (PES) categories (after Kleynhans 1996).

Ecological Category	PES % Score	Description of the habitat
A	90-100%	Still in a Reference Condition.
B	80-90%	Slightly modified from the Reference Condition. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C	60-80%	Moderately modified from the Reference Condition. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	40-60%	Largely modified from the Reference Condition. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	20-40%	Seriously modified from the Reference Condition. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	0-20%	Critically / Extremely modified from the Reference Condition. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.

2.1.2 Evaluation of environmental flow requirements

There is a broad regional differentiation in the methods used to evaluate environmental flow requirements (EFRs) for the rivers in the basin:

- Downstream Response to Imposed Flow Transformations (DRIFT)(1) methodology (King et al. 2003) was applied in Lesotho.
- Habitat Flow Stressor Response (HFSR) (Hughes and Louw 2011) was applied in South Africa.
- Ephemeral River eFLows (EReF)6 method was applied in Namibia.
- Estuarine Flow Requirement method was applied on the Orange Estuary.

All the methods focus on developing relationships between different aspects of the riverine ecosystem and flow and can thus be used, within reason, to explore alternative flow regimes. Additional detail is provided on their use in this study in Section 3.5. Table 2.3 provides a broad level comparison of process and outputs of these EFR methods.

2.1.2.1 Determination of Target State

To synchronise the studies, the term "target state" has been used to identify the ecological condition that a particular EFR is expected to maintain. The assessments for rivers in Lesotho and those in South Africa also differ in the manner in which the "target state" was identified.

In Lesotho, the target state, and associated EFRs, for IFR Sites 1, 2, 3 and 7 were agreed in 2003 following protracted negotiations between the Lesotho Highlands Development Authority and the World Bank. While ecological condition was taken into account, the driving concern was maximizing the transfer of water to South Africa. The target state, and associated EFRs, for the Polihali site have yet to be finalised and the target state used in this study is that recommended in the Feasibility Studies (LHWC 2006). Similarly, the target states for IFR sites 4, 5 and 6 on the Senqu River will depend on the final decisions

6 This method was developed and applied on the Fish River during the recent EFR study. As the method had no specific name, the approached was called the EReF method for reference purpose.

regarding EFR releases from Polihali Dam. For those sites, the target states used in this study are the PES. For EF Site 1, on the Phuthiatsana River downstream of Metolong Dam, the target state is that provided for in the Metolong Authority IFR Policy (Metolong Authority 2013).

Table 2.3: Comparison of process and outputs of EFR methods

Considerations	HFSR	DRIFT(1)	EReF	Estuary
Input hydrology	Monthly time series	Daily data	Daily data	Monthly data
Low flows	Stress indices set for fish and macroinvertebrates and required stress specified linked to ecological state.	Response curves linking biophysical indicators to flow change	Identification of flow indicators to rate responses and convert into an Ecological Category	Identification of flow ranges associated with mouth closure
High flows	Determination of flood classes and specifications of number of events linked to ecological state.			Identification of flow ranges associated with sediment resetting events
Output	Ecological categories	Ecological categories, plus predicted changes in abundance of indicators	Ecological categories linked to different flow regimes	Ecological categories
	Annual volume of EFlows	Annual volume of EFlows		Annual volume of EFRs
	Monthly flow duration curves (discharge) and volume for lowflows	Monthly flow duration curves (discharge) and volume for lowflows		Monthly volumes
	Timing, duration, peak and volume of intra-annual floods	Timing, duration, peak and volume for intra-annual and inter-annual floods		
Can be used to evaluate flow scenarios?	Yes	Yes	Scenario based method	Scenario based method
Can be used to extrapolate EFRs?	Yes (to ecologically similar sites)	Limited	N/a	N/a

In South Africa, **implementation** of EFRs (the Reserve) requires one of two legal steps following the Reserve Assessment (DWAF 1998; Orange-Senqu SAP):

- **If a Classification process has not been conducted in the basin/sub-basin** of concern, the target category and the EFR required to meet it must be signed off by the Director of Water Affairs or her representative. Typically this target state is the Recommended Ecological Category (REC) that arises out of the EFR assessments. The signed off Reserve is then known as a **Preliminary Reserve**, which denotes that it was signed off without having gone through a Classification Process.
- **If a Classification process has been concluded in the basin**, the agreed target categories and their EFRs are decided based on **a combination of ecological social and economic criteria** and the Resource Quality Objectives are published in the Government Gazette and, pending public comment, are thereafter written in to law.

Classification has been concluded for the Vaal sub-basin (DWA 2011), but has not yet been undertaken for the Caledon and Orange Rivers. Thus, for the purposes of this study, the REC was used as the target state for sites on the Caledon and Orange Rivers.

2.2 Study sites

Difference in methods notwithstanding, there are detailed EFR data that can be used to evaluate future flow scenarios, available for 35 sites in the basin (Figure 2-1), and less detailed information available for a further six sites. The key findings from these EFR assessments are provided in Table 2.4. The data for sites situated in the Senqu, Caledon and Orange sub-basins are used further in the analysis of preliminary flow regimes in this study (Section 4). Site photographs are provided in Annex 1.

2.3 Results

2.3.1 Introduction

This section summarises the results of the existing EFR studies of relevance to this study. These exclude the EFR sites in the Vaal Basin because Classification has been concluded for the Vaal sub-basin (DWA 2011), which negates the need for evaluation of additional flow scenarios for that part of the system.

Table 2.4: Key findings from EFR assessments in the Orange-Senqu Basin

River	Tributary	Site	Method	nMAR (MCM)	PES	Target EC	EFR	
							MCM	% nMAR
SENQU SUB-BASIN								
Senqu	n/a	Polihali	DRIFT(1)	730	C	D	136.0	18.63%
Senqu	Matsoku	IFR 1	DRIFT(1)	87	B	C	34.8	40.00%
Senqu	Malibamatso	IFR 2	DRIFT(1)	576	C	D	88.1	15.30%
Senqu	Malibamatso	IFR 3	DRIFT(1)	774	C	C	224.5	29.00%
Senqu	n/a	IFR 4	DRIFT(1)	1572	B	B	Dependent on IFR 3	
Senqu	n/a	IFR 5	DRIFT(1)	1924	B	B	Dependent on IFR 3	
Senqu	Senqunyane	IFR 7	DRIFT(1)	355	B	D	78.1	22.00%
Senqu	n/a	IFR 6	DRIFT(1)	3330	B	B	Dependent on IFR 3 and 7	
CALEDON SUB-BASIN								
Orange	Caledon	EFR05	HSFR	57	C/D	C/D	14.32	25.17%
Caledon	Nqoe	IFR 11	N/A	5	B	B	4.8	100.00 %
Caledon	Phuthiatsana	EF Site 1	DRIFT(1)	73	C/D	C/D	15.4	21.09%
Orange	Caledon	EFR06	HSFR	1348	C	C	259.9	19.28%

2. EXISTING EFR STUDIES

River	Tributary	Site	Method	nMAR (MCM)	PES	Target EC	EFR	
							MCM	% nMAR
VAAL SUB-BASIN								
Orange	Vaal	EWR 1	HSFR	332	B/C	B	130.9	39.40%
Orange	Vaal	EWR 2	HSFR	458	C	C	62.3	13.61%
Vaal	Klip	EWR 6	HSFR	95	B/C	B/C	25.3	26.54%
Orange	Vaal	EWR 3	HSFR	858	C	C	122.7	14.30%
Vaal	Wilge	EWR 7	HSFR	23	A/B	A/B	10.8	45.89%
Vaal	Wilge	EWR 8	HSFR	474	C	C	64.5	13.59%
Orange	Vaal	EWR 4	HSFR	1977	C	B/C	None	
Blesbok spruit	Suikerbosrand	EWR 9	HSFR	31	C	B/C	10.9	34.65%
Blesbok spruit	Suikerbosrand	EWR 10	HSFR	149	C/D	C/D	61.4	41.10%
Vaal	Blesbokspruit	EWR 11	HSFR	29	D	D	6.2	21.21%
Orange	Vaal	EWR 5	HSFR	2288	C/D	C	-	-
Orange	Vaal	EWR 12	HSFR	2546	D	D	832.8	32.70%
Orange	Vaal	EWR 13	HSFR	2654	C/D	C/D	859.8	32.39%
Vaal	Vals	EWR 14	HSFR	146	C/D	C/D	24.9	17.05%
Vaal	Vet	EWR 15	HSFR	413	C/D	C/D	46.1	11.16%
Orange	Vaal	EWR 16	HSFR	1699	D	D	422.2	24.85%
Vaal	Harts	EWR 17	HSFR	148	D	D	107.2	72.51%
Orange	Vaal	EWR 18	HSFR	3347	C	C	257.4	7.69%
Orange	Vaal	EWR 19	HSFR	404	C	C	171.1	42.37%
ORANGE SUBCATCHMENT								
Orange	Kraai	EFR07	HSFR	683	C	C	135.0	19.78%
Orange		EFR01	EcoClassification, Level 4	6737	C	C	None	Orange
Orange	n/a	EFR02	HSFR	10573	C	C	1797.0	17.00%
Orange	n/a	EFR03	HSFR	10513	C	B	2341.0	22.27%
Orange	n/a	EFR04	HSFR	10335	C	B/C	1478.9	14.31%
Orange	Molopo	EFR08	Flow Plan	10	C	B/C	3.5	34.17%
Orange	Fish	EFR 01	HSFR	-	B/C	B	Flood requirements for Hardap Dam	
Orange	Fish	EFR 02	HSFR	613	B/C	B/C	245.2	40.00%
Orange	n/a	EFR 05	HSFR	11373	B/C	B	1667.3	14.66%
Orange River Estuary		Estuary	Estuary	11373	D	C	4469.8	39.50%

2.3.2 LHWP Phase 1

For the IFR sites that are proximal to LHWP Phase 1 structures (IFR Sites 1, 2, 3 and 7), the target states were set in 2003 (see LHDA, 2003). Prior to the establishment of the LHWP Phase 1 dams, the sites were all in a B category. The latest available comprehensive PES assessments were completed in 2006, five years after implementation of the agreed EIFRs (LHDA 2007), and showed that the conditions of the rivers at IFR Sites 2, 3 and 7 were better than the target condition. A programme to update the monitoring results is currently underway, but the 2013/14 PESs are not yet available and it is not known whether the target conditions will be revised.

For the EFR sites that are distal to LHWP Phase 1 structures, target states were not set as these will change with subsequent phases of the LHWP. For the purposes of this study, however, the target states were set at PES (2006).

Table 2.5: PES and target states for LHWP Phase 1 sites

EFR site	River	Date assessed	State	Water Quality	Geomorphology	Fish	Macro-invertebartes	Riparian vegetation	Ecostatus
IFR 1	Matsoku	2008	PES	B	C	C	C	C	C
			Target	C	C	C	C	C	C
IFR 2	Malibamatso	2006	PES	B	C	C	B/C	C	C
		2003	Target	D	D	D	D	D	D
IFR 3	Malibamatso	2006	PES	B	C	C	B/C	C	C
		2003	Target	D	D	D	D	D	D
IFR 4	Senqu	2006	PES	B	C	B	B	B	B
		2003	Target	C	B	C	C	C	C
IFR 5	Senqu	2006	PES	B	B	B	B	B	B
		2003	Target	B	B	B	B	B	B
IFR 6	Senqu	2006	PES	B	B	B	B	C	B/C
		2003	Target	B	B	B	B	C	B/C
IFR 7	Senqunyane	2006	PES	B	C	C	B	C	B/C
		2003	Target	D	D	C	D	C	C/D

The EFRs for the LHWP Phase 1 sites are summarised in Table 2.6. As previously mentioned, only the EFRs for IFR Sites 1, 2, 3 and 7 have been set (LHDA 2003). Those for IFR Sites 4, 5 and 6 are the flows expected that those sites, if the EFRs at the proximal sites are met, and will change once the EFRs for Polihali Dam have been finalised.

Table 2.6: EFRs for the LHWP Phase 1 sites

EFR site	Target state	nMAR	Lowflows		High flows		Total EFR	
			(% MAR)	MCM	(% MAR)	MCM	(%MAR)	MCM
IFR 1	C	86.6	6.2%	5.4	8.0%	6.9	40.2%	34.8
IFR 2	D	576.0	6.2%	35.5	9.1%	52.6	15.3%	88.1
IFR 3	D	774.0	9.4%	73.1	19.8%	153.4	29.3%	226.5
IFR 4	C	1572.3	27.6%	434.7	27.4%	430.9	55.1%	865.6
IFR 5	B	1924.0	33.4%	642.4	28.7%	551.6	62.0%	1193.0
IFR 6	B	3330.3	46.0%	1533.1	19.2%	637.9	65.2%	2171.0
IFR 7	D	354.8	15.8%	55.9	6.3%	22.2	22.0%	78.1

Importantly, up until 2006 flows at IFR Sites 1, 2 and 7 exceeded the required EFR volumes (Table 2.7), which explains the better than target condition at each of those sites (Table 2.5).

Table 2.7: Average flow at IFR Sites 1, 2 and 7 from 2003 to 2006 compared with agreed EFRs

EFR site	Target state	PES (2006)	nMAR	Lowflows		High flows		Total EFR	
				(% MAR)	MCM	(% MAR)	MCM	(%MAR)	MCM
IFR 1	C		86.6	6.2%	5.4	8.0%	6.9	40.2%	34.8
		B	86.6	55.2%	47.8	30.6%	26.5	91.7%	79.4
IFR 2	D		576.0	6.2%	35.5	9.1%	52.6	15.3%	88.1
		C	576.0	12.9%	74.5	7.1%	41.0	18.9%	109.0
IFR 7	D		354.8	15.8%	55.9	6.3%	22.2	22.0%	78.1
		C	354.8	0.2%	60.8%	0.1%	40.0%	28.4%	100.76

2.3.3 LHWP Phase 2

To date only one EFR site has been assessed for Polihali Dam (LHWP Phase 2), although flow at IFR Sites 4, 5 and 6 will also be affected by the dam. At the time of the assessment (2008) the PES was Category C (Table 2.8). Apart from some assumed altered hydrological patterns as a result of landuse activities[1], the major factors contributing to the PES were non flow related and included:

- accelerated supply of sediment to the river (non-flow related);
- removal of riparian vegetation;
- dominance of alien woody riparian vegetation (Salix fragilis);
- reduction in fish abundances as a result of habitat changes, specifically those related to over-supply of sediment.

Table 2.8: PES and target states for the Polihali IFR Site (Brown et al. 2008)

EFR site	River	Date assessed	State	Water Quality	Geomorphology	Fish	Macro-invertebartes	Riparian vegetation	Ecostatus
Polihali	Senqu	2008	PES	B/C	B	C	-	C	C
			Target	-	-	-	-	-	D

The target condition for the Polihali site is a D, i.e., maintain PES, but it was expected that trapping of sediments by the dam should result in a general move towards natural in the downstream river, which would be offset by some of the impacts associated with a reduction in flows. The EFR for the Polihali site is summarised in Table 2.9.

Table 2.9: EFR for the Polihali site

EFR site	Target state	nMAR	Lowflows		High flows		Total EFR	
			(% MAR)	MCM	(% MAR)	MCM	(%MAR)	MCM
Polihali	D	547.7	9.8%	53.7	6.9%	38.0	16.7%	91.7

[1] Landuse changes similar to that in the Senqu River have been shown to reduce the depth of the soil and infiltration of rainfall, and result in less resistance to runoff. The effect is higher instantaneous discharges off the catchment (lower baseflows, faster runoff and higher peak flows (e.g., Gregory and Walling 1983).

2.3.4 Metolong Dam

The EFR assessment for the Phuthiatsana River downstream of Metolong Dam was completed in 2006. The EFR was adjusted in 2013 in alignment with new hydrology, and the target condition for EF Site 1 and its associated EFR was set in the Metolong Dam IFR Policy (Metolong Authority 2013). Metolong Dam is under construction and is due for closure in October 2013. The PES for EF Site 1, based on data from the Baseline Monitoring Programme, is C/D (Table 2.10). Apart from some assumed altered hydrological patterns as a result of landuse activities[1], the major factors contributing to the PES were non flow related and included:

- accelerated supply of sediment to the river (non-flow related);
- down-cutting of the channel;
- sand-mining;
- removal of riparian vegetation;
- dominance of alien woody riparian vegetation (*Salix fragilis*);
- reduction in fish abundances as a result of habitat changes, specifically those related to over-supply of sediment.

Table 2.10: PES and target states for EFR sites on the Phuthiatsana River downstream of Metolong Dam

EFR site	River	Date assessed	State	Water Quality	Geomorphology	Fish	Macro-invertebartes	Riparian vegetation	Ecostatus
EF 1	Phuthiatsana	2012	PES & Target	C	C	D	C	D	C/D
EF 2	Phuthiatsana	2012	PES & Target	C	C	D	C	D	C/D
EF 3	Phuthiatsana	2012	PES & Target	D	C	D	C	D	C/D

The target state for EF Site 1 is also a C/D, i.e., maintain PES. This was possible because, trapping of sediments by the dam should result in a general move towards natural in the downstream river, which would be offset by the reduction in flows. The EFR for the EF Site 1 is summarised in Table 2.11.

Table 2.11: EFR for the Metolong EF Site 1

EFR site	Target state	nMAR	Lowflows		High flows		Total EFR	
			(% MAR)	MCM	(% MAR)	MCM	(%MAR)	MCM
EF Site 1	C/D	66.4	13.7%	9.1	9.6%	6.4	23.2%	15.4

[1] Landuse changes similar to that in the Senqu River have been shown to reduce the depth of the soil and infiltration of rainfall, and result in less resistance to runoff. The effect is higher instantaneous discharges off the catchment (lower baseflows, faster runoff and higher peak flows (e.g., Gregory and Walling 1983).

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

The PES was calculated using the EcoClassification process of Kleynhans and Louw (2007). A summary of the PES for the different components is provided in Table 2.12 .

A summary of the flow- and non-flow-related issues affecting the PES is provided in Table 2.13.

The target state exceeded the PES for the Orange River downstream of Boegoeberg Dam and the Molopo wetlands, based an evaluation of Ecological Importance and Sensitivity (EIS). High or Very High EIS provides motivation for improvement, but the attainability thereof also has to be considered. This information is also provided in Table 2.12. Table 2.13 summarises the actions that would achieve the target state.

EFRs are provided in Table 2.14 as a summary of the EFR rules provided in Annex 2.

Table 2.12: Summary of PES and target states (2010)

EFR site	State	Hydrology	Water quality	Geomorphology	Fish	Macro-invertebrates	Instream	Riparian vegetation	Riverine fauna	Ecostatus	EIS
C5	PES	A/B	B/C	C	D	C	D	C	n/a	C/D	Low
C6	PES	E	C	C/D	D	D	D	B	n/a	C	Low
K7	PES	A/B	B/C	A/B	C	C	C	C	n/a	C	Moderate
M8	PES	D/E	B	B	C	C	C	C/D	n/a	C	High
M8	Target	n/a	B	B	B	B	B	B/C	n/a	B	
O1	PES	E	D	C/D	C/D	C	C	B/C	C	C	Moderate
O2	PES	E	C	C	C	C	C	B	C	C	High
O3	PES	E	C	C	C	C	C	B/C	C	C	High
	Target	n/a	C	C	B	B	B	B	B	B	
O4	PES	D	C/D	C	C	C	C	C	C	C	High
	Target		C/D	C	B/C	B/C	B/C	B	B/C	B/C	

Table 2.13: Reasons for PES and actions required to achieve the target state

EFR site	PES	PES reasons	Target	Requirements to achieve target
C5	C/D	Non-flow related only. Grazing, trampling, bank erosion, sedimentation, alien vegetation and fish species	C/D	n/a
C6	C	Most significant impacts are reduction in base flows, sedimentation, bank erosion and the present of alien fish species.	C	n/a
K7	C	Most significant impacts are non-flow related (alien vegetation and fish species, grazing, trampling, bank erosion)	C	n/a

EFR site	PES	PES reasons	Target	Requirements to achieve target
M8	C	Although hydrology is significantly reduced, the major impacts on the wetland are non-flow related, i.e. pesticide spraying, backup effect from poorly designed road crossings, burning of reeds and presence of alien fish species.	B	n/a
O1	C	Releases for hydropower (major impact), barrier effects of the dams, water quality problems and the destruction of and removal of vegetation on floodplains for agriculture.	C	n/a
O2	C	Loss of frequency of large floods, agricultural return flows, higher low flows than natural in the dry season, drought and dry periods, decreased low flows at other times, release of sediment, presence of alien fish species and barrier effects of dams	B/C	Outlet constraints limit implementation of EFR and the target EC cannot be achieved
O3	C	Decreased frequency of large floods. Agricultural return flows, agricultural activities and associated water quality impacts. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. Presence of alien fish species and barrier effects of dams and alien vegetation. Decreased sedimentation.	B	Reinstate droughts (i.e., lower flows than present during the drought season).Improved (higher) wet season base flows. Clear vegetation. Improved agricultural practices.
O4	C	Decreased frequency of large floods. Agricultural return flows and mining activities – water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. Presence of alien fish species and barrier effects of dams. Decreased sedimentation due to lack of large floods and upstream dams. Alien vegetation.	B/C	Improved (higher) wet season base flows. Clear vegetation aliens. Control grazing and trampling.

Table 2.14: Summary of EFR results as a percentage of the natural MAR

EFR site	State	Maintenance low		Drought low		High		Long term mean	
		(%MAR)	MCM	(% MAR)	MCM	(% MAR)	MCM	(% MAR)	MCM
C5	C/D	13.8	7.9	5.8	3.3	11.4	6.5	26	14.8
C6	D	8.8	118.6	0.3	3.4	10.5	141.5	20.1	270.9
K7	C	11.4	77.8	0	0.00	8.4	57.3	18.1	123.5
O2	C	11.6	1226.6	4.4	465.2	5.4	571	15.2	1607.2
O3	C	8.4	883.1	2.6	273.3	4.7	494.1	11.9	1251.1
	B	17.6	1850.3	3.4	157.4	4.7	494.1	19.2	2018.5
O4	C	6.3	651.1	0.9	35.6	4.2	434.1	8.9	919.8
	B/C	10.1	1043.9	1.3	134.4	4.2	434.1	12.2	1260.9

2.3.6 Research project on environmental flow requirements of the Fish River and the Orange Senqu River Mouth: Determination of Fish River EFR

The PES was calculated using the EcoClassification process of Kleynhans and Louw (2007). A summary of the PES for the different components is provided in Table 2.15. A summary of the flow- and non-flow-related problems that result in the PES is provided in Table 2.16.

The target state exceeded PES for both sites, although improvement is mostly related to non-flow related impacts, such as overgrazing. This information is provided in Table 2.16. Table 2.16 also summarises the actions that would achieve the target state.

Table 2.15: Summary of PES and target states (2012)

EFR site	State	Hydrology	Water quality	Geomorphology	Fish	Facro-invertebrates	INSTREAM	Riparian vegetation	Riverine fauna	Ecostatus	EIS
Fish 1	PES	C	C	B/C	B	C	B/C	B/C	B	B/C	High
	Target	C	C	B/C	B	B	B	B	B	B	
Fish 2	PES	C	C	B/C	B	B	B	C	B	C	High
	Target	C	C	B/C	B	B	B	C+	B	C+	

Table 2.16: Reasons for PES and actions required to achieve the target state

EFR site	PES	PES reasons	Target	Requirements to achieve target
Fish 1	B/C	Flow-related impacts: Abstraction and flow reduction caused by dams, e.g. Hardap Dam. Irrigation return flows. Non-flow-related impacts: Nutrients and salinity elevated due to the irrigation return flows. Grazing and browsing pressure (mainly goats), vegetation removal at settlements, sewage discharges into the Fish River.	B	Improvement would require an increase in the state of riparian vegetation (improved flooding regime) and macro-invertebrates (improved nutrient status). This would be unlikely to be achievable.
Fish 2	C	Flow-related impacts: Abstraction and flow reduction caused by dams, e.g. Hardap Dam. Non-Flow-related impacts: Elevated nutrient and salt levels. High grazing and browsing pressure (mainly goats).	C+	An overall improvement in the EcoStatus could not be achieved by flow related mitigation measures as the instream biota components were already in a B EC. The riparian vegetation could be improved within the C EC by minimizing trampling and grazing pressure of goats.

2.3.7 Research project on environmental flow requirements of the Fish River and the Orange Senqu River Mouth: Determination of lower Orange River EFR

The PES was followed applying the EcoClassification process of Kleynhans and Louw (2007). A summary of the PES for the different components are provided in Table 2.17 . A summary of the flow- and non-flow-related problems that result in the PES is provided in Table 2.18.

The target state exceeded PES for EFR O5 because it has a high EIS. The actions required to achieve this improvement are similar to the upstream recommendations at EFR O4 (Table 2.16).

EFRs are provided in Table 2.19 as a summary of the EFR rules provided in Annexure A.

Table 2.17: Summary of PES and target states (2012)

EFR site	State	Hydrology	Water quality	Geomorphology	Fish	Facro-invertebrates	INSTREAM	Riparian vegetation	Riverine fauna	EcoStatus	EIS
O5	PES	C	C	B/C	B/C	B/C	B/C	B/C	B	B/C	High
	Target	C	C	B	B	B	B	B	B	B	

Table 2.18: Reasons for PES and actions required to achieve the target state

EFR site	PES	PES reasons	Target	Requirements to achieve target
O5	B/C	Flow-related impacts: Decreased frequency of small and moderate floods. Agricultural return flows and mining activities cause water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. Non-flow-related impacts: Presence of alien fish species and barrier effects of dams. Alien vegetation.	B	Increased (from present) wet season base flows. Reinstate dry season droughts.

Table 2.19: Summary of EFR results as a percentage of the natural MAR

EFR site	State	Maintenance low		Drought low		High		Long term mean	
		(%MAR)	MCM	(% MAR)	MCM	(% MAR)	MCM	(% MAR)	MCM
O5	B/C	6.4	722.2	1.0	109.2	4.5	512.9	10.9	1234.0
C6	B	10.2	1154.4	1.3	150.1	5.5	626.7	14.7	1667.3

2.3.8 Research project on environmental flow requirements of the Fish River and the Orange Senqu River Mouth: Determination for Orange River Estuary

The PES was determined using the estuary methods set out in DWAF (2008). A summary of the PES for the different estuary components are provided in Table 2.20. A summary of the flow- and non-flow-related problems that result in the PES is provided in Table 2.21. In this case, the target state is represented by the REC.

Orange Estuary EFR requires improvement due to the high ecological and conservation importance of the system. The Orange Estuary, a designated Ramsar site (a wetland of international importance), is currently on the Montreux Record (list of Ramsar sites around the world that are in a degraded state) as a result of a belated recognition of the severely degraded state of the salt marsh on the south bank. The Namibian section of the Orange Estuary was recently included in the proclamation of the Sperrgebiet National Park in Namibia. However, the section in South Africa is still in the process of being formally protected through legislation. The Orange Estuary is one of only two estuaries on the Namibian coast, the other being the Kunene River mouth. The functional importance of the estuary is also deemed to be very high, because the sediment supply from the Orange River catchment feeds the beaches towards the north of the mouth. The sediment input from the river is very important for flatfish in the nearshore environment in the vicinity of the Orange Estuary as it provides the habitat they depend on.

From a biodiversity and conservation perspective the estuary is thus rated as 'Highly Important'. Thus the REC for the estuary is an A or it's best attainable state which is estimated as an ecological category C.

The EFR to maintain the PES require 39.9% of the natural MAR (includes both a baseflow and flood requirement). The EFR to achieve the REC require about 39.5% of the natural MAR, but additional yield could be achieved as long as required low flows are achieved.

Table 2.20: Summary of PES and target states for the orange Estuary (2012)

EFR site	State	Hydrology	Hydrodynamics	Water quality	Physical habitat	Microalgae	Macrophytes	Invertebrates	Fish	Birds	EIS
Est	PES	D	C	D	B	E	D	D	D	E	High
	Target	D	B	C	B	D	C	B	C	D	

Table 2.21: Reasons for PES and actions required to achieve the target state

EFR site	PES	PES reasons	Target	Requirements to achieve target
Est	D	Flow-related impacts: Decreased frequency of all floods. Agricultural return flows and mining activities cause water quality problems. Higher low flows than natural in the dry season, drought and dry periods preventing mouth closure and related back-flooding of saltmarshes with fresher water. Non-flow-related impacts: road infrastructure in the form of the old causeway crossing the saltmarshes and old bridge crossings; gill netting of indigenous fish species and considerable fishing effort at the mouth on both sides of the estuary; riparian infrastructure such as levees preventing flooding of low-lying floodplain; dust from mining activities; and wastewater disposal (sewage and mining return flow); grazing and hunting.	C	Reinstate dry season and drought flows, i.e. reduce winter flows to below 2 m^3/s for one to two months at a time in winter, for two to four times in 10 years, to allow for mouth closure and related back flooding of saltmarshes Controlling the fishing effort on both the South African and Namibian side through increased compliance and law enforcement. Removal of the remnant causeway that still transects the saltmarshes to improve circulation during high flow and floods events. This will also assist with increasing the water circulation into the lower marsh areas. Decreasing nutrient input from the catchment downstream of Vioolsdrift, through improved agricultural practices. Controlling windblown dust and wastewater from mining activities. Reduce/remove grazing and hunting pressures.

3. Definition of preliminary test scenarios

3.1 Natural flow conditions

The flow under natural (pre-development) conditions was determined at each of the EWR sites. The natural hydrology used for this purpose was developed as part of Phase II of the ORASECOM IWRM Planning Programme (2009 to 2011). In particular along the Lower Orange it was important to take into account the impact of river losses and losses as result of evapotranspiration from riparian growth along the river, as these losses were not included in the process used to create the hydrology. These losses are quite significant as under normal operating conditions they accumulate to approximately 615 Mm^3/a. Due to the extremely dry semi-dessert to desert areas along the Lower Orange, very little contribution from rainfall runoff enter the Orange River in this part of the basin. The result of this phenomenon is that the flow even under natural conditions reduces along the Orange River basically from the Orange Vaal confluence to the Orange River mouth. In dry periods it can result in zero flow in the Lower Orange even under natural conditions, while there are at the time flow occurring in the Upper Orange and or Lower Vaal.

The flow regime for natural conditions therefore included the impacts of these losses along the Lower Orange as well as some in the Lower Vaal.

3.2 Water-resource developments in the Present Day (2012) Scenario

The monthly simulated flow sequences at each EWR site were determined from analyses carried out with the Water Resources Yield Model (WRYM) using the WRYM data setup for the integrated Orange Senqu Vaal system. By doing this the effects of all the current developments, transfers, demands, return flows, operating rules, demands, existing infrastructure etc within the Orange Senqu Basin were all captured in the model and thus taken into account in the modelling process. The natural hydrology used in this model setup was developed as part of Phase II of the ORASECOM IWRM Planning Programme (2009 to 2011). The hydrology covers the historic period 1920 to 2004 hydrological years. To be able to determine the impact of a specific Scenario on the flow regime at each of the EWR sites, the development level and related infrastructure applicable to the scenario was kept constant over the entire simulation period (1920 to 2004).

For the present day scenario, all the demands and return flows as well as all water-related infrastructure were set at the 2012 development level. This present day or "base" scenario (Scenario 1) models the estimated actual water use regardless of whether it is lawful or not.

The following important components are as listed from 1) to 18) below define this present day Scenario used to produce the current day flow regimes at the different EWR sites:

1) All the urban/industrial and mining demands imposed on the Orange Senqu and Integrated Vaal system will be at 2012 development level.
2) Irrigation will be based on 2012 allocations where applicable.
3) Irrigation in the Vaal at lawful plus 34%. (In the Vaal reconciliation study it was identified that there are a significant amount of unlawful irrigation in the upper Vaal, utilizing the transferred water from Lesotho and the Tugela. Currently only 66% of that has been removed.)
4) The treatment acid mine drainage (AMDS) water in the Vaal System for re-use purposes.
5) Transfer from LHWP to Vaal equal to 780 million m^3/a according to the current agreement.
6) EWR releases from Katse and Mohale based on the latest implemented results as used in the Orange Reconciliation Study.
7) EWR for Orange as currently released for the river mouth (287.5 million m^3/a) as obtained from the ORRS (referenced as ORRS EWRs).
8) Transfer to the Eastern Cape through the Orange/Fish tunnel based on the latest data from the Orange Annual Operating Analysis. This is based on the allocation and scheduled irrigation area and current supply to Port Elizabeth.
9) Current transfer schemes and related operating rules from the Caledon to the Modder River catchment in place (Welbedacht to Bloemfontein and Novo Transfer).
10) Orange/Riet transfer. Current demands will be modelled in detail as part of the system.
11) Orange/Vaal (Douglas) transfer. Current demands will be modelled in detail as part of the system.
12) Operational losses from the Lower Vaal will be in line with the latest calibration done for the Vaal Reserve study.
13) Hydro-power at Gariep and Vanderkloof dams will be generated in accordance with downstream demands when below the Storage Control Curve (SCC).
14) Minimum operating level for Gariep at equal to the minimum operating level for power generation.
15) Minimum operating level for Vanderkloof Dam is equal to the minimum operating level for power generation.
16) Spills from Douglas Weir and contributions from the Lower Orange hydrology will not be used to supply Lower Orange demands, as there is no storage available in the lower Orange to be able to utilize these flows in practice.
17) Metolong Dam – This dam is currently under construction in Lesotho and will soon start to impact on the downstream flow regime.
18) Set the additional salt loads and salinity recharge rates to those applicable to 2012 development level.

3.3 POSSIBLE FUTURE WATER-RESOURCE DEVELOPMENTS FOR INCLUSION IN PRELIMINARY TEST SCENARIOS

Various **key components or factors** were identified that will significantly impact on the existing flow regimes in future. These components, or factors, were obtained from previous and current studies. The following important components/factors were identified in this process:

- Increase in demand and return flows – The 2040 development level projected demands and return flows were selected for this purpose. To be able to supply the increased demands in the Greater Bloemfontein system it was required to increase the capacity of the Novo Transfer Scheme and Tienfontein pump station in the Caledon River in line with that given in the Greater Bloemfontein Water Supply System Reconciliation Study reports.
- The inclusion of EWRs at selected key points in the system. At Augrabies only the summer months EWR were imposed on the system as the winter months EWR resulted in excessively high flows at the river mouth.
- The inclusion of the already agreed Phase II of the LHWP (Polihali Dam and connecting tunnels)
- The possible raising of Gariep Dam to restore the balance in the Orange after the implementation of Polihali Dam.
- Utilizing the lower level storage in Vanderkloof Dam as a possible option to restore the balance in the Orange after the implementation of Polihali Dam.
- The development of Bosberg Dam in the Upper Orange to counteract the impacts of Polihali Dam on the Orange System and to provide for increasing future demands.
- Using one of the possible dams in Lesotho previously identified for possible further phases of the LHWP to support the Orange River as a possible option to restore the balance in the Orange after the implementation of Polihali Dam.
- The building of Vioolsdrift Dam to decrease the operational requirements in the system to increase the system yield in particular for development along the lower Orange and to be able to provide the correct flows at the correct time for the Orange River mouth environmental requirements. **Without a dam at Vioolsdrift it will not be possible to regulate the flows to adhere to the river mouth environmental requirements**.
- The building of Neckartal Dam in the Fish River (Namibia). This dam is already at the planning stage. The recommended EWR applicable to this dam need to be included.
- Increasing the irrigation area to be supplied from Naute Dam located in Namibia.
- Include the reserve as determined for the Vaal River System.

Over and above the base scenario (Scenario 1) five additional preliminary test scenarios were defined to capture the listed factors and components that are expected to significantly impact on future flow regimes in the system. The definitions of the five additional preliminary test scenarios are as follows:

Preliminary Test Scenario 2 (PTS-2 resulting in Flow regime 2, FR2): As the base or present day Scenario (Scenario 1) defined in Section 3.1 but with the following changes:

- Include Metolong Dam with its recommended EWR.
- Include the option of treating acid mine drainage and seepage water in the Vaal System for re-use purposes.
- Include the recommended or target EWRs

Preliminary Test Scenario 3 (PTS-3 / FR3): As Preliminary Test Scenario 2 but with the following changes:

- Increase demands and return flows to the 2040 development level.
- Include Polihali Dam as Phase II of the LHWP is scheduled to be in place by 2020.
- Include the 10m Raising of Gariep Dam.
- Utilize the lower level storage in Vanderkloof Dam.
- Include Vioolsdrift Dam in the Lower Orange (FSL = 230 m.a.s.l. FSV 1990 Mm^3)
- Include Neckartal Dam as it should be in place long before 2040.
- Add the increased irrigation supplied from Naute Dam.

Preliminary Test Scenario 4 (PTS-4 / FR4): As Preliminary Test Scenario 3 but with the following changes:

- Add the recommend and agreed Vaal Reserve requirements. The main impact on the flow regime in the Orange will be as result of the EWR downstream of Douglas Weir.

Preliminary Test Scenario 5 (PTS-5 / FR5): As Preliminary Test Scenario 4 but with the following changes:

- Exclude the Vaal Reserve requirement below Douglas as it significantly impacts on the yield available in the Vaal system. (Reduction of approximately 100 million m^3/a)
- Include a dam in Lesotho in support of the Orange System. For this purpose Ntoahae was included with a capacity of 1 550 million m^3.

Preliminary Test Scenario 6 (PST-6 / FR6): As Preliminary Test Scenario 5 but with the following changes:

- Exclude Ntoahae Dam in Lesotho.
- Include Bosberg Dam (FSL = 1 385 m.a.s.l. FSC = 3 102 million m^3) in the Upper Orange to support the Orange System.

These preliminary test scenarios, which cover a range of different of possible alternatives (infrastructure development and the level of strictness with which EFRs are applied) will be used to get a better understanding of what may or may not be possible or realistic. This will provide a sort of decision-aid framework when it comes to looking further at the different development possibilities through the investigation of stakeholder driven development scenarios

These scenarios and related components are summarised in **Table 3.1**. Monthly flow files were generated for each of the scenarios defined at each of the identified EWR sites.

3.4 WATER BALANCE RELATED FINDINGS

Although it is not the main purpose of this report to address water balance related issues other than the satisfaction of the EFRs it was regarded as important to highlight the following which will serve to guide discussion of future development options that may underpin the IWRM Plan:

- The inclusion of the recommended EFRs (RECs) will result in a significant deficit in the Orange River System. The historic firm yield was found to be reduced by 722 million m^3/a when the recommended EWRs were introduced in the system in comparison with a reduction of 288 million m^3/a when only the existing EWR is supplied This would require that the **existing demands imposed on the system be reduced significantly or that additional yield be created by means of storage and reduction in system losses**.
- To be able to provide the required environmental flow requirements at the river mouth will in practice not be possible through releases from Vanderkloof Dam as this dam is located very far (1 300km) upstream of the river mouth. A dam at Vioolsdrift on the Lower Orange is, however, in the planning process. This dam is located fairly close to the river mouth with only the Fish River from Namibia entering the Orange River downstream of Vioolsdrift Dam. From Vioolsdrift Dam it should be possible to regulate the river flow, and provide for the environmental requirements of the estuary fairly accurately, in particular in periods when mouth closure is required.
- Adhering to the recommended EFR at Augrabies is resulting in too high flows at the River Mouth. Due to this problem it was decided to include only the summer flow environmental requirements as it is important to obtain river mouth closure during some winter months when natural flows would be very low. Even with this variation in place, it was clear that the higher Augrabies EFR resulted in an artificial increase in the yield available from Vioolsdrift Dam. This is due to the fact that the higher EFR at Augrabies are then stored in Vioolsdrift Dam as it is not required by the river mouth, but can then be utilized to increase the Vioolsdrift yield.

Based on these findings it is recommended that:

- A balance between the reduction in yield and the recommended EFRs be obtained as the reduction in yield is quite substantial and cannot at all be accommodated by means of the existing infrastructure.
- The imbalance between the EFR at Augrabies and the Estuary EFR need to be resolved.
- The planning of Vioolsdrift Dam must involve the capability of supplying the Estuary EWR in the correct manner. When determining the yield available from Vioolsdrift Dam the sensitivity of the yield on the imposed EFRs should be thoroughly investigated.

Table 3.1: Possible future water-resource developments considered in the Preliminary Test Scenarios Green = included; orange = excluded.

Preliminary test Scenario	Development level	High demand	Metolong dam	AMDS treated	Target EFRs (RECs)	Polihali	Raised Gariep	Vander-kloofLstorage	Vioolsdrift Dam	Vaal Reserve	Lesotho Dam	Bosberg Dam	Neckartal with EFR (RO opt)	Naute irrigation
PTS1 PD	2012	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No
PTS2	2012	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No
PTS3	2040	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes
PTS4	2040	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
PTS5	2040	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes
PTS6	2040	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes

3.4.1 EFR sites affected by the Preliminary Test Scenarios

The locations of the various possible future water-resource developments included in the preliminary test scenarios (Table 3.1) are such that not all of the EFR sites will be affected by all of the resultant test flow regimes. Indeed, the EFR sites that are proximal to LHWP Phase 1 structures (IFR Sites 1, 2, 3 and 7) will not be affected by any of the flow regimes. The EFR sites affected by each of the flow regimes are shown in Table 3.2.

Table 3.2: EFR sites affected by the test flow regimes.

River	Site	PTS 2	PTS 3	PTS 4	PTS 5	PTS 6
Matsoku	IFR 1	×	×	×	×	×
Malibamatso	IFR 2	×	×	×	×	×
Malibamatso	IFR 3	×	×	×	×	×
Senqu	IFR 4	×	√	√	√	√
Senqu	IFR 5	×	√	√	√	√
Senqu	IFR 6	×	√	√	√	√
Senqunyane	IFR 7	×	×	×	×	×
Senqu	Polihali	×	√	√	√	√
Phuthiatsana	EF Site 1	√	√	√	√	√
Orange	EFR 01	×	×	×	×	×
Orange	EFR02	√	√	√	√	√
Orange	EFR03	√	√	√	√	√
Orange	EFR04	√	√	√	√	√
Caledon	EFR05	×	×	×	×	×
Caledon	EFR06	√	√	√	√	√
Kraai	EFR07	×	×	×	×	×
Fish	EFR 01	×	×	×	×	×
Fish	EFR 02	×	×	×	×	×
Orange	EFR 05	√	√	√	√	√
Orange	Estuary	√	√	√	√	√

3.5 USE OF EXISTING DATA TO EVALUATE TEST FLOW REGIMES

3.5.1 Format of data supplied for test flow regimes

The monthly time series flow results, produced by the Water Resource Yield Model, representative of each EWR site, were imported in series of spreadsheets containing the data for each scenario analysed. Monthly flow durations were derived using the standard percentile calculation method of MS Excel.

A further spreadsheet utility was compiled to collate the flow duration data in a form for graphical comparison and evaluation. This utility made use to dynamic referencing allowing indirect linking to the source spreadsheets based on file names, sheet names and cell references. This had the benefit of eliminating the need for direct formula and cell referencing.

This utility spreadsheet made it possible for the ecological specialists to inspect, compare and evaluated individual month's distributions graphically, though drop-down selection lists to navigate between months and activating or deactivating any scenario during the evaluation process

3.5.2 DRIFT(1)

Drift(1) requires daily flow data for evaluation of scenarios. However, the test flow regime data was only available in a monthly format. Thus, analysis of the test flow regimes for the sites where the assessment of the EFR had been done using DRIFT required some manipulation of the data. This means that some of the detail inherent in the original assessments was be lost, and the predicted ecological conditions are approximations that attempted to make best use of available data.

The approach adopted for these sites was two-fold:

- Check seasonal volumes against LHWP scenarios evaluated at the time of the study
  - If volumes similar, expect predicted condition to be similar.
- Cross-check in DRIFT database
  - Obtain monthly hydrological data. Dates: 1920-2004
  - Plot monthly hydrological data to assess inter-annual variability.
  - Calculate monthly averages
  - Calculate season averages
  - Check MAR against category plot to obtain best attainable condition for MAR available.
  - Subtract intra-annual flood allocations for best attainable condition from seasonal.
  - Check seasonal flow regime averages against season distribution for best attainable condition for MAR available.
  - Adjust attainable condition according to outcome of 7.

3.5.3 HFSR

Previously, scenarios or test flow regimes were only evaluated at EFR O5, the Orange Estuary and at the sites on the Fish River. At the other Orange (outside of Lesotho), Caledon and Kraai EFR sites, three scenarios were evaluated, i.e. maintenance of the PES, allowing a one category drop in condition and allowing a one category improvement in condition. This information was used to assess the scenarios in this project. It is possible to state whether the PES will be maintained or whether there is a likelihood that the condition will change. Where there are uncertainties that require specialist input, the predicted condition is provided with a '?' and an arrow that indicates the direction of possible change.

At EFR O5 a range of flow scenarios linked to potential future developments were investigated. Those predictions were used to evaluate the new scenarios at higher confidence than for the upstream sites.

3.5.4 Estuarine flow requirement method

Methods to determine the EFR of estuaries were established soon after the promulgation of the National Water Act (NWA) and have been in use since then (DWAF, 2008). These methods follow a generic methodology which can be carried out at different levels of effort, to determine the desired health state (also called recommended ecological category (REC) in South Africa) and the associated flow allocation (called ecological reserve in South Africa). This study followed a desktop approach based on DWAF (2008).

As part of this study, simulated average monthly flows to the head of the Orange Estuary were evaluated to predict changes in the abiotic conditions - also called abiotic states (CSIR 2013) - of the estuary. The abiotic components (hydrology, hydrodynamics, water quality and physical habitat) were evaluated using spread sheet models, while the biotic components were derived from the abiotic scores based on relationships identified in CSIR (2013).

The scores provided as part of this study represent a low confidence assessment and should only be viewed as indicative of the possible responses to proposed flow alterations (i.e. simulated flow scenarios). It is recommended that refined hydrological scenarios be evaluated by the full complement of estuarine scientists (abiotic and biotic specialists) to ensure a high confidence assessment.

4. Results of analysis of preliminary test scenarios

4.1 Senqu Basin

The seasonal flow volumes expected at each site under each test scenario flow regime are provided in Table 4.1.

Preliminary Test Scenarios PTS-2, 3, 4 and 5, are the only ones that generate flow regimes that affect the LHWP sites (Table 3.2). All four scenarios included Polihali Dam with the same EFR releases, hence their impact on the flow regimes at each of the sites was the same. The changes with Polihali Dam in place result in a flow regime that is mid-way between the original LHWP scenario of Minimum Degradation and Design Limitation (Table 4.1), which were expected to have a low to negligible impact on the overall river condition at those sites.

4.2 Phuthiatsana River

All of the test flow regimes include Metolong Dam with the agreed EFR releases. As such the predicted condition for all cases is the target state (C/D).

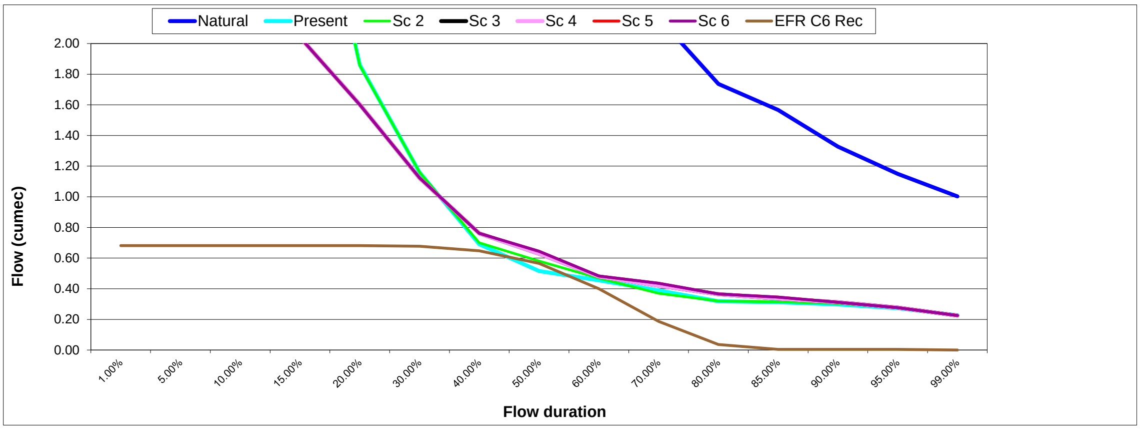
4.3 Caledon River (EFR C6)

The test scenario flow regimes (apart from PTS1a and PTS1b, which are different versions of present day) all impact on the Caledon River in the same way because they are all linked to increased demands from Bloemfontein.

The test flows meet the target condition during the dry season (September; Figure 4.1, note - scenarios are similar and the plotted lines lie on top of each other). This is because the EFRs were set considerably lower than the modelled present day hydrology. However, it is highly likely that the modelled data do not reflect reality as regular occurrences of zero or very low flow have been reported in the lower sections of the river.

In the wet season (March; Figure 4.1), the test flows are lower than the target EFR or 20% of the time. This situation occurs in all the wet season months. Currently, the wet season flows are supporting the PES, thus it is important to maintain good conditions during the wet season. Thus, the failure to meet the EFR may result in a drop in condition to a D/E category.

Note: The results provided for Scenario 1 – Present Day are based on the modelled flows for those sites based on the agreed IFRs. In reality there is more flow arriving at some of the proximal sites than required for the EFR (see Table 4.1), and as a result, their present condition is probably better than predicted.



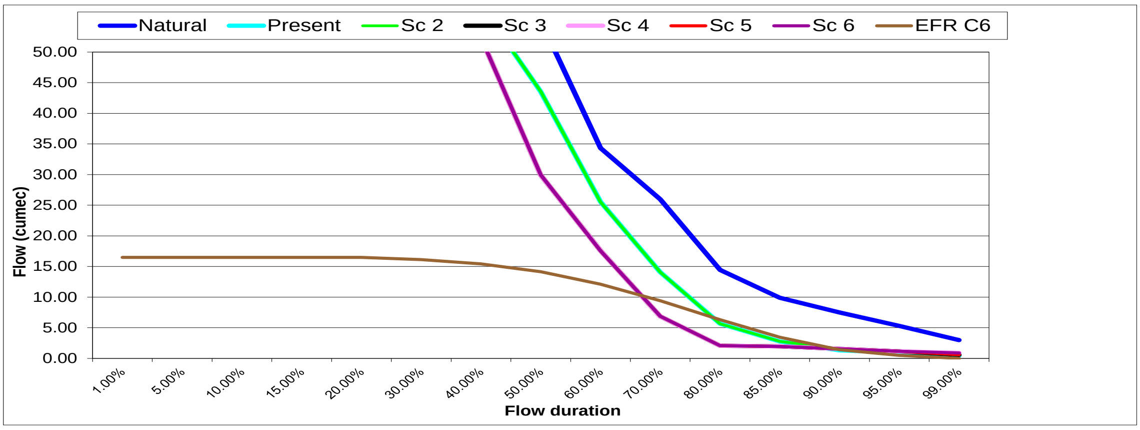


Figure 4-1: Flow duration graph for September (top) and March (bottom) comparing scenarios to the target EFR

4.4 ORANGE RIVER DOWNSTREAM OF BOEGOEBERG DAM

There are four EFR sites situated downstream of Boegoeberg Dam. EFR O2 is immediately downstream of Boegoeberg Dam and improvement will be difficult to achieve the REC due to impacts related to the presence of the dam (i.e. barrier effect and sedimentation). A scenario evaluation was therefore not undertaken at EFR O2. EFR O3 (downstream of Augrabies called Blouputs), EFR O4 (Vioolsdrift) and EFR O5 (Sendelinsdrift) are therefore the key sites with EFR O5 being the most important as it is situated the furthest downstream and closest to the estuary. The objectives to achieve the REC at all these sites would be to improve summer base flows and to reinstate droughts during the winter season

4.4.1 EWR O3 Scenario evaluation

Two variations of the flow regimes were run where the 'a' included the winter low flows as a demand at EFR O5 and the 'b' version excluding it. The results are illustrated in Table 5.1 and Figure 4.2. The flow regimes for September are provided as a flow duration graph in Figure 4.2.

Low flows:

All the flow regimes include the increased EFR flows required during the wet season and is therefore an improvement from the present day. However, neither the a or b version of the flow regimes meet the REC for the dry season. The PTS-2/FR2 is a significant improvement on present day and therefore should maintain the PES and might improve it. PTS4/FR4 is similar to present day and will probably maintain the PES, however improvement is unlikely in spite of the improvements in the wet season. PTS/FRs 3, 5 and 6 have significantly lower flows than present. Although this is not a problem during the drought season (where the objective was to decrease flows from present), the general low flows will be likely to result in an EC lower than PES.

High flows:

The impacts on floods (high flows) were only broadly examined due to a lack of specific flood analysis associated with the flow regimes. As a general rule, PTS-5 and 6 will be worse than PTS 3 and 4 as they include more large dams as scenario drivers.

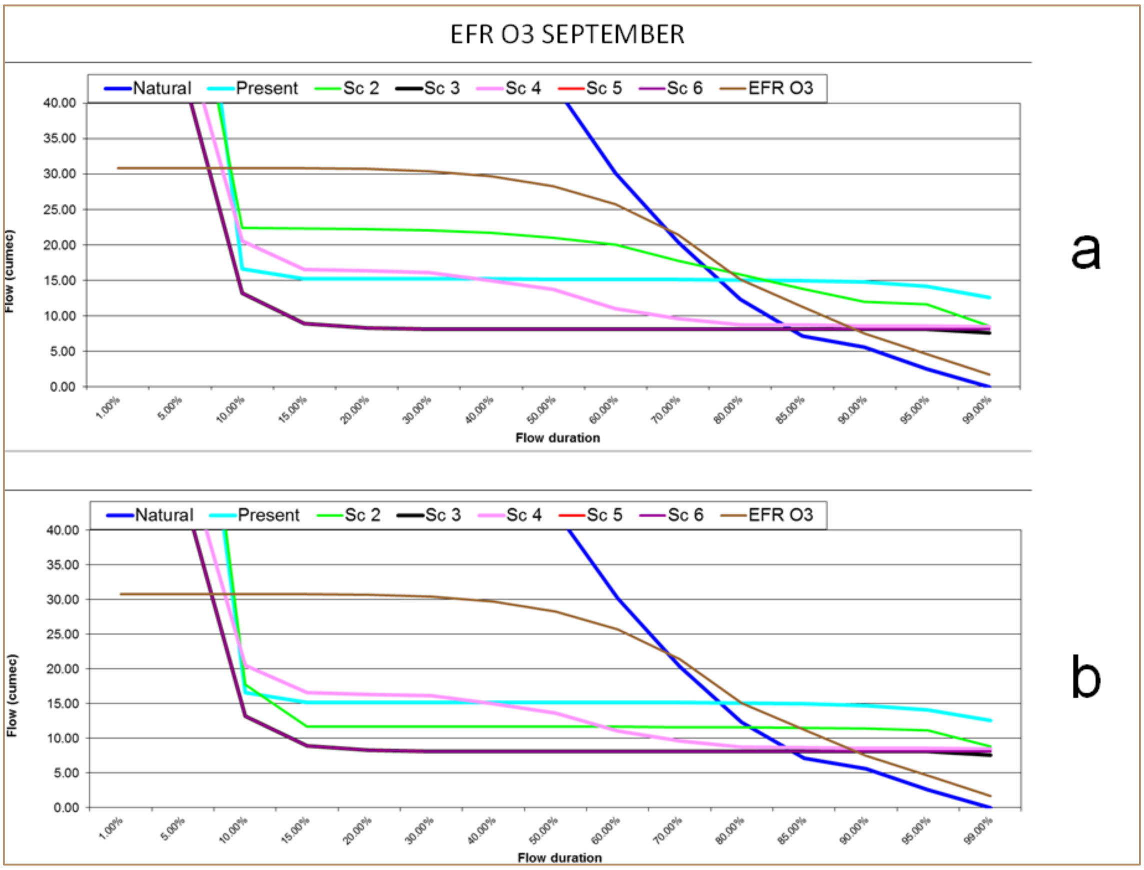


Figure 4-2: EFR O3: Flow duration graphs for September comparing the flow regimes to natural, the target EFR and present day.

4.4.2 EWR O4 Scenario evaluation

LOW FLOWS:

All flow regimes show an improvement during the wet season.

During the dry seasons (Figure 4.3) all the 'a' versions of the flow regimes are the same and so are the 'b' versions. The 'a' version shows an improvement above present day but insufficient to achieve the REC. It is doubtful whether the additional seasonal variability to include some droughts in the system would, with the improved wet season flows, achieve the REC. The PES will however be maintained with some improvement within category or half a category higher than the PES.

The 'b' versions fall below present day and at best, the PES will be maintained due to the improved wet season flows.

HIGH FLOWS:

In the same manner described at EFR O3, high flows are considered and the initial conclusions based on the low flows are adjusted to consider the fact that PTS-5 and 6 include large dams.

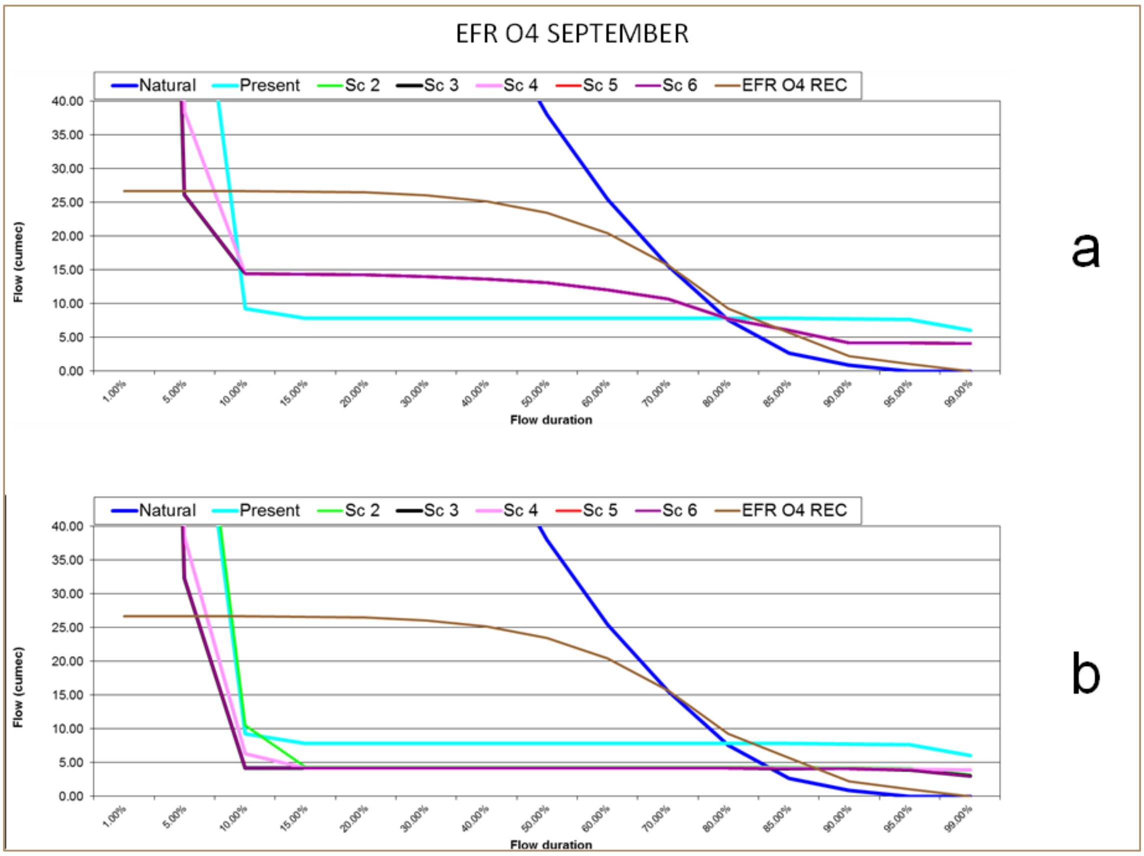


Figure 4-3: EFR O4: Flow duration graphs for September comparing the flow regimes to natural, the target EFR and present day.

4.4.3 EWR O5 Scenario evaluation

All flow regimes are very similar in the 'a' version and one cannot distinguish between them. All low flow regimes are similar to the REC EFR (Figure 4.4). Flow regimes under PTS-2, 3 and 4 should achieve the REC. Due to the impact on the floods, Flow Regimes under PTS 5 and 6 will not achieve the REC or maintain the PES.

The 'b' versions fall below present day and at best, the PES will be maintained with Flow Regime 2b. This is due to the improved wet season base flows as well as no impact on the floods. The other 'b' flow regimes are likely to degrade to a C or lower due to the impact on floods.

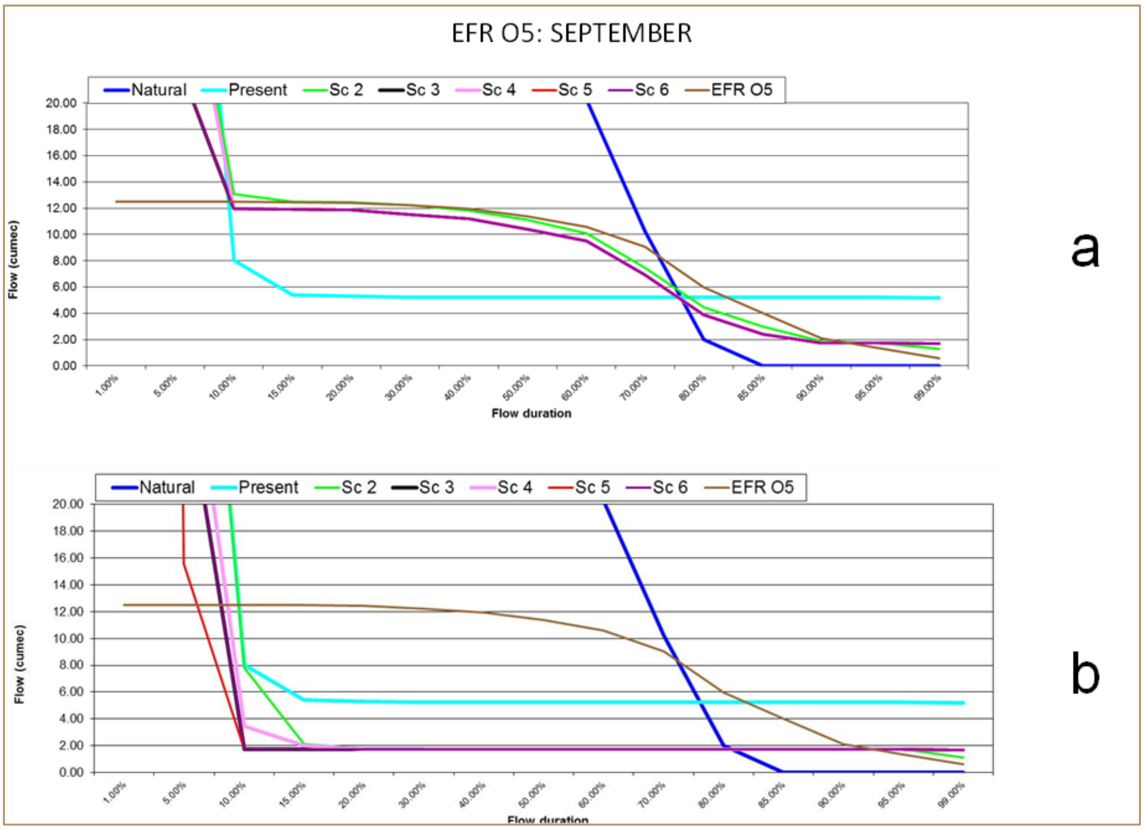


Figure 4-4: EFR O5: Flow duration graphs for September comparing the flow regimes to natural, the target EFR and present day

Table 4.1: Summary of modelled and measured flows at LHWP Phase 1 sites under LHWP scenarios, test flow regimes, agreed EFR (LHDA 2003) and actual flows in the river (PD-Measured)

Site	Season	Months	Naturalised	EFR	PD – Modelled (FR 1)	PD – Measured (2003-2006)	Minimum Degradation	Treaty	Design Limitation	4th Scenario	FR 2	FR 3	FR 4	FR 5	FR 6	FR 7
IFR 1	Wet	Oct - Apr	77.32	36.70	31.00	68.30	72.10	1.50	29.40	25.80	31.00	31.19	31.19	31.12	31.27	31.27
	Dry	May to Sep	14.81	5.40	5.00	11.08	6.60	2.50	5.40	5.40	5.00	5.00	5.00	5.00	5.00	5.00
IFR 2	Wet	Oct - Apr	478.05	61.70	62.29	80.52	324.60	15.60	162.80	75.30	62.29	62.38	62.49	62.42	62.07	62.07
	Dry	May to Sep	81.39	26.40	19.88	29.06	34.90	6.20	21.40	21.40	19.88	19.91	19.91	20.00	19.91	19.91
IFR 3	Wet	Oct - Apr	638.25	195.90	176.49	192.96	359.20	74.60	271.60	195.90	176.49	176.76	176.87	176.73	176.54	176.54
	Dry	May to Sep	108.54	30.50	37.27	28.31	76.30	20.20	42.90	30.50	37.27	37.30	37.30	37.39	37.30	37.30
IFR 4	Wet	Oct - Apr	1343.43	702.60	880.31	-	702.60	80.60	481.60	580.30	880.31	474.19	474.30	474.16	473.97	473.97
	Dry	May to Sep	215.34	86.20	143.23	-	86.20	23.70	60.40	122.70	143.23	83.65	83.65	83.74	83.65	83.65
IFR 5	Wet	Oct - Apr	1624.73	974.60	1161.50	-	974.60	386.30	695.00	620.10	1161.50	755.04	755.14	755.00	754.82	754.82
	Dry	May to Sep	272.52	219.20	200.34	-	219.20	100.10	134.20	100.10	200.34	140.74	140.74	140.82	140.74	140.74
IFR 6	Wet	Oct - Apr	2730.00	1825.60	2047.22	-	1825.60	1127.40	1435.90	1307.40	2047.22	1640.09	1640.09	1621.99	1640.09	1640.09
	Dry	May to Sep	531.09	345.40	416.37	-	345.40	311.90	345.40	311.90	416.37	356.24	356.23	350.71	356.23	356.23
IFR 7	Wet	Oct - Apr	251.99	62.10	33.97	88.02	200.30	36.60	294.80	58.60	33.97	33.69	33.58	33.72	33.91	33.91
	Dry	May to Sep	51.25	16.00	9.26	12.74	30.90	11.10	60.00	18.60	9.26	9.23	9.23	9.14	9.23	9.23

4.5 ESTUARY

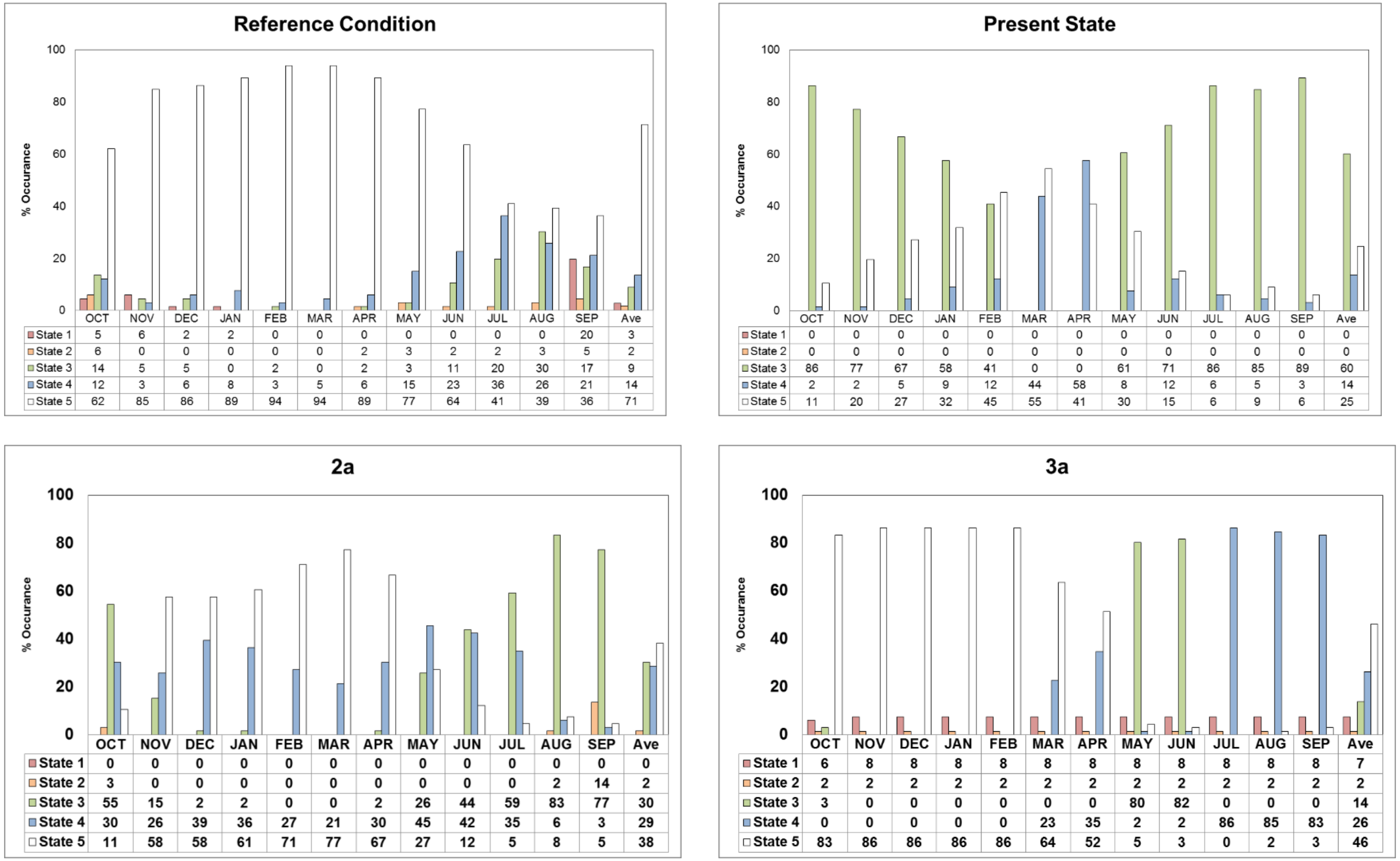
Based on historical data and projected future flow modifications, five abiotic conditions (or states) were identified for the Orange Estuary (Table 4.2). Following a precautionary approach and to reduce the uncertainty in the correlation between measured and simulated river inflow data and abiotic states, broad flow ranges were identified and linked to river inflow. Also note that 'State 1: Closed and hyper saline' is only a predicted condition as extended periods (>6 month) of zero inflow have not been observed under the present inflow regime.

Table 4.2: Typical abiotic conditions linked to river inflow

State	***Description***	***Flow range (m^3/s)***
1	Closed for extended period and hyper saline	0
2	Closed, with strong marine influence	0–5
3	Marine dominated (open mouth)	5–20
4	Brackish (open mouth)	20–50
5	Freshwater dominated (open mouth)	>50

The flow regimes under the present state scenario (PTS-1), 2a, 3a,and 4a are very similar in the 'a' version and one cannot distinguish between them. Flow regime 5a and 6a represent a decline in condition to an E. Flow regime 3a and 4a should achieve the REC in combination with non-flow related remedial actions. Due to the impact on the floods, Flow Regime 5a and 6a will not achieve the REC or maintain the PES.

The 'b' versions fall below present day and at best, the PES will be maintained at with Flow Regime 2b. This is due to the improved wet season base flows as well as no impact on the floods. As a result of the impact on floods, 3b and 4b are likely to degrade the estuary to a D/E and 5b and 6b to an E.



Reference Condition

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	5	6	2	2	0	0	0	0	0	0	0	20	3
State 2	6	0	0	0	0	0	2	3	2	2	3	5	2
State 3	14	5	5	0	2	0	2	3	11	20	30	17	9
State 4	12	3	6	8	3	5	6	15	23	36	26	21	14
State 5	62	85	86	89	94	94	89	77	64	41	39	36	71

Present State

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	0	0	0	0	0	0	0	0	0	0	0	0	0
State 3	86	77	67	58	41	0	0	61	71	86	85	89	60
State 4	2	2	5	9	12	44	58	8	12	6	5	3	14
State 5	11	20	27	32	45	55	41	30	15	6	9	6	25

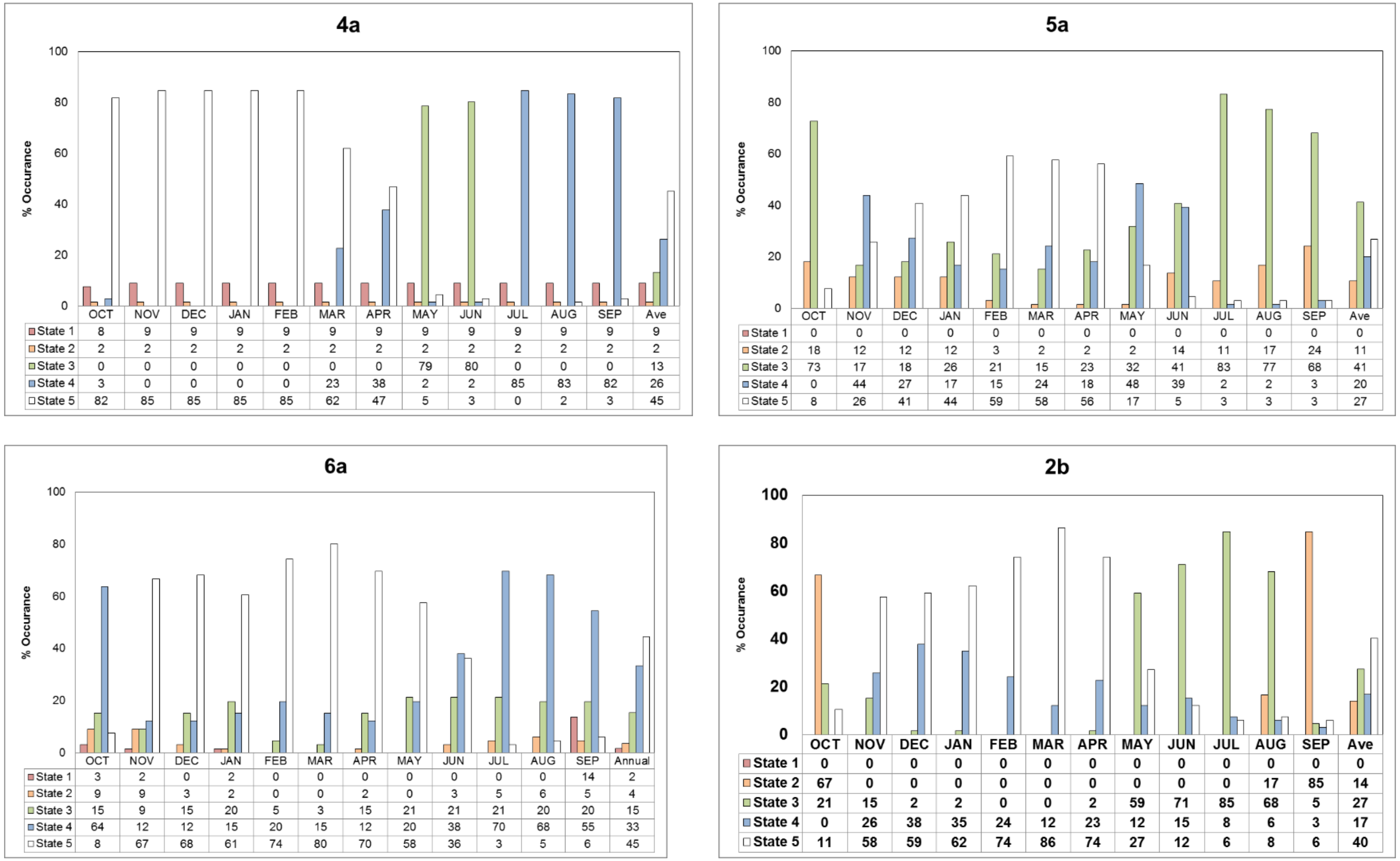
2a

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	3	0	0	0	0	0	0	0	0	0	2	14	2
State 3	55	15	2	2	0	0	2	26	44	59	83	77	30
State 4	30	26	39	36	27	21	30	45	42	35	6	3	29
State 5	11	58	58	61	71	77	67	27	12	5	8	5	38

3a

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	6	8	8	8	8	8	8	8	8	8	8	8	7
State 2	2	2	2	2	2	2	2	2	2	2	2	2	2
State 3	3	0	0	0	0	0	0	80	82	0	0	0	14
State 4	0	0	0	0	0	23	35	2	2	86	85	83	26
State 5	83	86	86	86	86	64	52	5	3	0	2	3	46

Figure 4-5: Estuary: The percentages monthly and annual occurrences of the various abiotic states under Reference Condition, Present State, 2a and 3a.



4a

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	8	9	9	9	9	9	9	9	9	9	9	9	9
State 2	2	2	2	2	2	2	2	2	2	2	2	2	2
State 3	0	0	0	0	0	0	0	79	80	0	0	0	13
State 4	3	0	0	0	0	23	38	2	2	85	83	82	26
State 5	82	85	85	85	85	62	47	5	3	0	2	3	45

5a

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	18	12	12	12	3	2	2	2	14	11	17	24	11
State 3	73	17	18	26	21	15	23	32	41	83	77	68	41
State 4	0	44	27	17	15	24	18	48	39	2	2	3	20
State 5	8	26	41	44	59	58	56	17	5	3	3	3	27

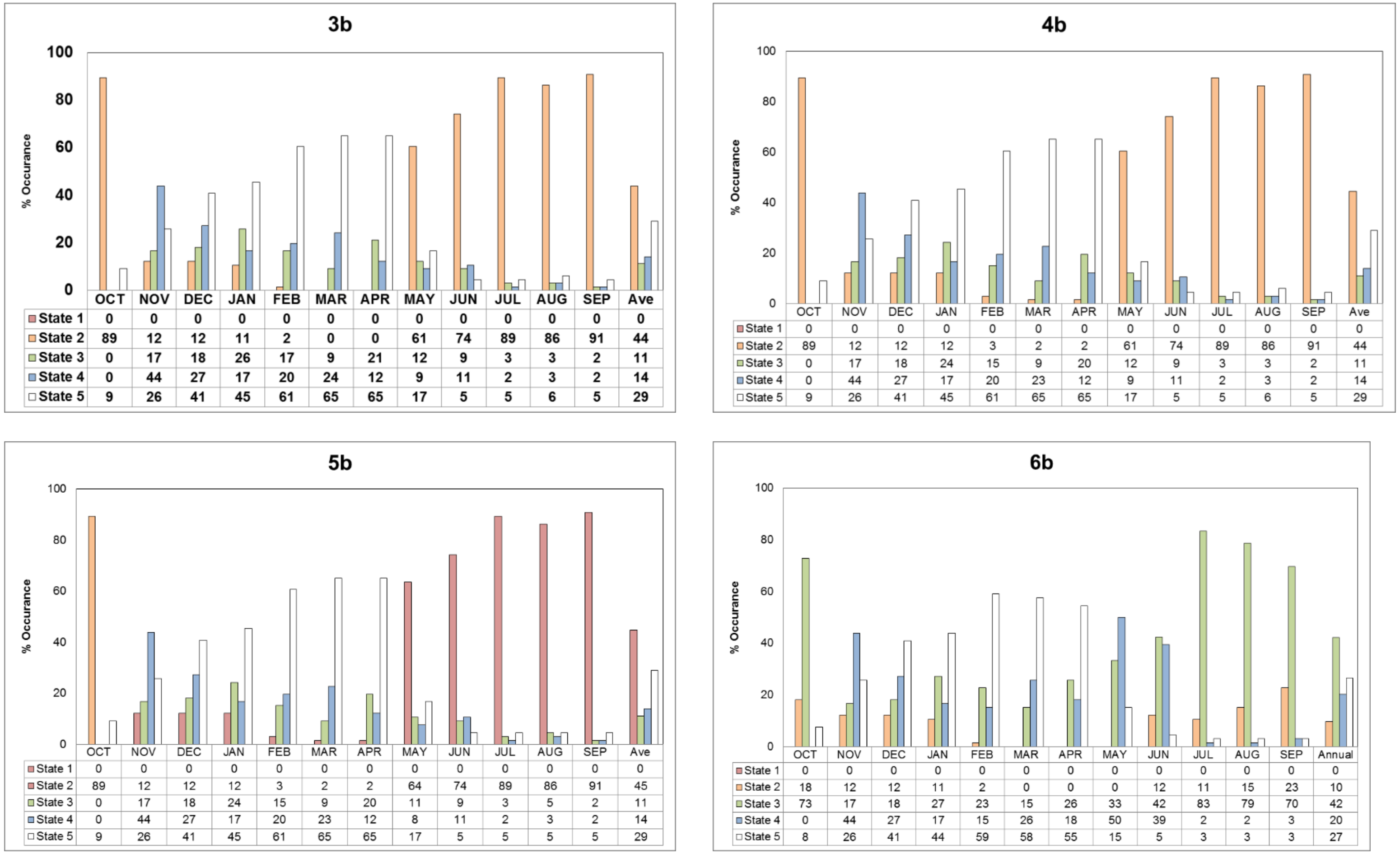
6a

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual
State 1	3	2	0	2	0	0	0	0	0	0	0	14	2
State 2	9	9	3	2	0	0	2	0	3	5	6	5	4
State 3	15	9	15	20	5	3	15	21	21	21	20	20	15
State 4	64	12	12	15	20	15	12	20	38	70	68	55	33
State 5	8	67	68	61	74	80	70	58	36	3	5	6	45

2b

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	67	0	0	0	0	0	0	0	0	0	17	85	14
State 3	21	15	2	2	0	0	2	59	71	85	68	5	27
State 4	0	26	38	35	24	12	23	12	15	8	6	3	17
State 5	11	58	59	62	74	86	74	27	12	6	8	6	40

Figure 4-6: Estuary: The percentages monthly and annual occurrences of the various abiotic states under flow regime 4a, 5a, 6a and 2b.



3b

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	89	12	12	11	2	0	0	61	74	89	86	91	44
State 3	0	17	18	26	17	9	21	12	9	3	3	2	11
State 4	0	44	27	17	20	24	12	9	11	2	3	2	14
State 5	9	26	41	45	61	65	65	17	5	5	6	5	29

4b

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	89	12	12	12	3	2	2	61	74	89	86	91	44
State 3	0	17	18	24	15	9	20	12	9	3	3	2	11
State 4	0	44	27	17	20	23	12	9	11	2	3	2	14
State 5	9	26	41	45	61	65	65	17	5	5	6	5	29

5b

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Ave
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	89	12	12	12	3	2	2	64	74	89	86	91	45
State 3	0	17	18	24	15	9	20	11	9	3	5	2	11
State 4	0	44	27	17	20	23	12	8	11	2	3	2	14
State 5	9	26	41	45	61	65	65	17	5	5	5	5	29

6b

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	18	12	12	11	2	0	0	0	12	11	15	23	10
State 3	73	17	18	27	23	15	26	33	42	83	79	70	42
State 4	0	44	27	17	15	26	18	50	39	2	2	3	20
State 5	8	26	41	44	59	58	55	15	5	3	3	3	27

Figure 4-7: Estuary: The percentages monthly and annual occurrences of the various abiotic states under flow regime 3b to 6b

5. Conclusions

The conclusions focus on the degree to which the flow regimes resulting from each of the preliminary test scenarios meet the ecological objectives (target or PES). The results are provided on a catchment basis considering all EFR sites. The sites displayed in the tables are, however, ONLY the sites which are impacted on by the test flow regimes.

Table 5.1 show the change in Ecological Category from the target and PES. A '?' indicates uncertainty and the arrow indicates the direction of change in cases where there is uncertainty. Table 5.2 indicates whether the test flow regimes meet the target EC. Table 5.3 indicates whether the test flow regimes maintain PES.

Table 5.1: Predicted Ecological Category for each Flow Regime at a range of EFR sites.

Site	Polihali	EF Site 1	EFRC6	EFR03	EFR04	EFR 05	Estuary
Target	D	C	D	B	B/C	B	C/D
PES (FR 1)	C	C/D	D	C	C	B/C	D
PTS/FR 2a	D	C/D	D	B/C?↑	C?↑	B	C/D
PTS/FR 2b	D	C/D	D	C?↓	C/D?	B/C?↓	D?↑
PTS/FR 3a	D	C/D	D/E?	C/D↓	C?↑	B	D?↑
PTS/FR 3b	D	C/D	D/E?	C/D↓	C/D?	C	D/E
PTS/FR 4a	D	C/D	D/E?	C?↑	C?↑	B	D?↑
PTS/FR 4b	D	C/D	D/E?	C?↑	C/D?	C	D/E
PTS/FR 5a	D	C/D	D/E?	D?	C?↓	C?↓	E
PTS/FR 5b	D	C/D	D/E?	D?	C/D?	D?↓	E
PTS/FR 6a	D	C/D	D/E?	D?	C?↓	C?↓	E
PTS/FR 6b	D	C/D	D/E?	D?	D?	D?↓	E

*Table 5.2: Indication of whether the flow regimes meet the **target***

Test Flow Regime	Polihali	EF Site 1	EFRC6	EFR03	EFR04	EFR 05	Estuary
PTS/FR 2a	✓	×	✓	×	×	✓	✓
PTS/FR 2b	✓	×	✓	×	×	×	×
PTS/FR 3a	✓	×	×	×	×	✓	×
PTS/FR 3b	✓	×	×	×	×	×	×
PTS/FR 4a	✓	×	×	×	×	✓	×
PTS/FR 4b	✓	×	×	×	×	×	×
PTS/FR 5a	✓	×	×	×	×	×	×
PTS/FR 5b	✓	×	×	×	×	×	×
PTS/FR 6a	✓	×	×	×	×	×	×
PTS/FR 6b	✓	×	×	×	×	×	×

*Table 5.3: Indication of whether the flow regimes meet **PES***

Test Flow Regime	Polihali	EF Site 1	EFRC6	EFR03	EFR04	EFR 05	Estuary
PTS/FR 2a	×	✓	✓	✓	✓	✓	✓
PTS/FR 2b	×	✓	✓	✓	×	✓	✓
PTS/FR 3a	×	✓	×	✓	✓	✓	✓
PTS/FR 3b	×	✓	×	✓	×	×	×
PTS/FR 4a	×	✓	×	×	✓	✓	✓
PTS/FR 4b	×	✓	×	×	×	×	×
PTS/FR 5a	×	✓	×	×	✓	×	×
PTS/FR 5b	×	✓	×	×	×	×	×
PTS/FR 6a	×	✓	×	×	✓	×	×
PTS/FR 6b	×	✓	×	×	×	×	×

There are subtle differences in the evaluation of the test flow regimes for the Orange River EFR sites that are not apparent in Table 5.3. To illustrate some of these, the flow regimes were ranked using a linear scale (numberless) in the form of a traffic diagram (i.e., green is good (go) and red is not good (stop) which aids visual interpretation. The ranking indicated that only FR 2a (present day with EFR O5 release) has the potential to meet the target flows at most sites. FR 4a, which includes an EFR from the Vaal River, improves flows at some, but not all of the EFR sites. Development of scenarios should therefore consider optimising 4a (and possible 3a which are also ranked reasonably high on the traffic diagrams) to determine whether the target flows can be met.

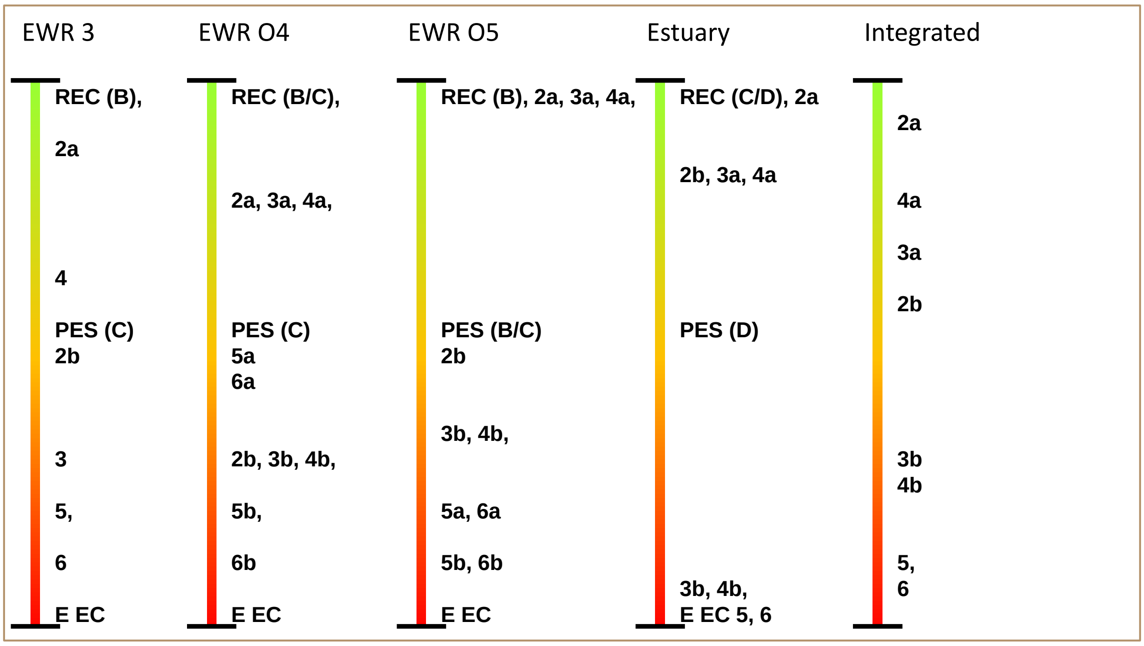


Figure 5-1Ranking of test Flow Regimes

The conclusions and specifically the ranking of the test scenarios provide an indication of the sensitivity of the ecosystem to the different scenario variables. Scenario development for stakeholder discussion and for planning regarding development options can be guided by these results. It must be noted that this is part of the strategic planning and that scenario development is inherently an iterative process. These preliminary consequences also provide guidance to evaluate any future and final scenarios if significantly different from the test scenarios.

6. References

Brown, C., Rall, J., Boucher, C. and Rountree, M. 2008. Instream Flow Requirements Supporting Report. Lesotho Highlands Water Project : LHWC CONTRACT 001 : Consulting Services for the feasibility study for Phase II – Stage 2. Report No. LHWC 001/18-2007. 74 pp.

CSIR (2013). Orange-Senqu River Basin Research project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. Estuary and Marine EFR assessment, Volume 1: Determination of Orange Estuary EFR. Technical Report 32, Rev2. (Atlas Project ID 71598).

Department of Water Affairs and Forestry (DWAF). 1998.

Department of Water Affairs and Forestry (DWAF). 2008. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 2. South Africa, Pretoria.

Department of Water Affairs (DWA). 2009a. Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: EWR Scenario Report: Volume 1. Report produced by Koekemoer Aquatic Services and Rivers for Africa. Report no: RDM/WMA8C000/01/CON/0209.

Department of Water Affairs (DWA). 2011. Classification of Significant Water Resources (River, Wetlands, Groundwater and Lakes) in the Upper, Middle and Lower Vaal Water Management Areas (WMAs) 8,9,10: Status Quo Report. Report No. RDM/WMA8,9,10/00/CON/CLA/0211. Prepared by WRP Consulting Engineers (Pty) Ltd in association with DMM Development Consultants CC, Rivers for Africa eFlows Consulting (Pty) Ltd, Conningarth Economists, Koekemoer Aquatic Services and Zitholele Consulting (Pty) Ltd.

Department of Water Affairs (DWA). 2012. Resource Directed Measures: Comprehensive Reserve determination study for selected water resources in the Middle Vaal Water Management Area. Environmental Water Requirements: Re-assessment of the EWR Scenarios. Report produced by Koekemoer Aquatic Services and Rivers for Africa (Pty) Ltd. Report no: RDM/ WMA09C000/ 01/CON/ 0112. Pretoria, South Africa.

Hirji, R. and Davies, R. 2009. Environmental Flows in water resources policies, plans and projects: Finding and recommendations. World Bank Environment and Development Series. Washington D.C.

Hughes, D. and Forsythe . 2006.

Hughes, D. and Louw, D. 2011.

King, J.M., Brown, C.A. and Sabet, H. 2003. A scenario-based holistic approach to environmental flow assessments for regulated rivers. *Rivers Research and Applications* 19 (5-6). Pg 619-640.

Kleynhans, C.J. 1999. A procedure for the determination of the ecological reserve for the purposes of the national water balance model for South African Rivers. Institute for Water Quality Studies. Department of Water Affairs and Forestry, Pretoria, South Africa.

Kleynhans, C.J. and Louw, D. 2007

LHDA Operations and Maintenance Group. 2002. Flow Releases Downstream of Katse and Muela Reservoirs. LHDA Report, Maseru, April 2002.

Lesotho Highlands Development Authority (LHDA). 2003. IFR Policy for Phase I. LHDA Report, Maseru, June 2003.

Lesotho Highlands Development Authority (LHDA). 2007. Consultancy and Project Management Services to Implement Instream Flow Requirements Biophysical Monitoring Procedures Downstream of Phase 1 Dams: Task 3: Results of the 12-month Monitoring Programme. LHDA Contract 1237, Maseru, January 2007. 160 pp.

Lesotho Highlands Water Commission (LHWC). 2006. Lesotho Highlands Water Project. LHWC Contract 001. Consulting services for the feasibility study for Phase II. Section – Hydrology and Yield Analysis. Prepared by Consult 4 Consortium and SEED Consult. 38 pp.

Louw M.D. and S Koekemoer (Eds). 2010. Deliverable 12: Volume 1: Environmental Flow Requirements Produced for WRP as part of Support to Phase II ORASECOM Basin Wide Integrated Water Resources Management Plan. 193 pp.

Metolong Authority. 2013. Metolong Dam and Water Supply Programme (MDWSP) Environmental Flow Policy. Report No. 6590/107596. Draft. November 2012. 25 pp.

Rivers for Africa (2013a). Orange-Senqu River Basin Research project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. Volume 2: Determination of Fish River EFR.

Rivers for Africa (2013b). Orange-Senqu River Basin Research project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. Volume 3: Determination of Lower Orange River EFR. Technical Report 29, Rev1. (Atlas Project ID 71598).

ANNEXES

Annex 1: Site photographs

IFR SITE 1

On the Matsoku River near the village of Seshote (29⁰15'21"S, 28⁰33'51"E), representing the Matsoku River from the site of Matsoku Weir to the confluence with the Malibamats'o River (IFR Reach 1;Annex Figure 1).

Annex Figure 1: IFR Site 1 on the Matsoku River near Seshote.

IFR SITE 2

On the Malibamats'o River downstream of the Katse Bridge (29°21'08"S, 28°31'32"E), representing the Malibamats'o River from Katse Bridge to the confluence with the Matsoku River (IFR Reach 2; Annex Figure 2).

Annex Figure 2: IFR Site 2 on the Malibamats'o River immediately downstream of Katse Dam.

IFR Site 3

On the Malibamats'o River at Paray (29°29'52"S, 28°39'04"E), representing the Malibamats'o River from the confluence with the Matsoku River to the confluence with the Senqu River (IFR Reach 3; Annex Figure 3).

Annex Figure 3:IFR Site 3 on the Malibamats'o River at Paray.

IFR Site 4

On the Senqu River at Sehonghong (29°44'20"S, 28°45'19"E), representing the Senqu River from the confluence with the Malibamats'o River to the confluence with the Tsoelike River (IFR Reach 4; Annex Figure 4).

Annex Figure 4: IFR Site 4 on the Senqu River near Sehonghong.

IFR Site 5

On the Senqu River at Whitehills (30°03'56"S, 28°24'28"E), representing the Senqu River from the confluence with the Tsoelike River to the confluence with the Senqunyane River (IFR Reach 5; Annex Figure 5).

Annex Figure 5: IFR Site 5 on the Senqu River at Whitehills.

IFR Site 6

On the Senqu River at Seaka Bridge (30°21'48"S, 28°11'30"E), representing the Senqu River from the confluence with the Senqunyane River to the Lesotho/South Africa border (IFR Reach 6; Annex Figure 6).

Annex Figure 6:IFR Site 6 on the Senqu River at Seaka Bridge.

IFR Site 7

On the Senqunyane River at Marakabei (29°32'09"S, 28°09'15"E), representing the Senqunyane River from the site of the proposed Mohale Dam to the confluence with the Lesobeng River (IFR Reach 7; Annex Figure 7).

Annex Figure 7: IFR Site 7 on the Senqunyane River at Marakabei.

Polihali site

On the Senqu River at Ha Polihali just downstream of the confluence with the Khubelu River (Annex Figure 8).

Annex Figure 8: Polihali site on the Senqu River at Ha Polihali.

EF Site 1

On the Phuthiatsana River c. 16 km downstream of Metolong Dam near Thaba-Bosiu (S29° 20.150'; E27° 41.221; Annex Figure 9).

Annex Figure 9: EF Site 1 on the Phuthiatsana River c. 16 km downstream of Metolong Dam

Site EF 2

On the Phuthiatsana River downstream of the Road Bridge near Ha Mosalla (S29° 21.460' E27° 36.670'; Annex Figure 10).

Annex Figure 10: EF Site 2 on the Phuthiatsana River downstream of the Road Bridge near Ha Mosalla.

SITE EF 3

On the Phuthiatsana River c. 300 m downstream of the bridge at Masiakoneng/Mazenod (DWA CQ45; S29° 14.979'; E27° 55.341'; Annex Figure 10).

No image available

Annex Figure 11: EF Site 2 on the Phuthiatsana River c. 300 m downstream of the bridge at Masiakoneng/Mazenod.

EFR O2 Boegoeberg

On the Orange River downstream of the Boegoeberg Dam wall (Annex Figure 12) within MRU Orange D, RAU D.1 (representative of the river reach from Boegoeberg Dam wall to upstream of Augrabies Falls).

Annex Figure 12: EFR O2 on the Orange River downstream of Boegoeberg Dam wall

EFR O3 Augrabies

On the Orange River downstream of the Augrabies Falls (Annex Figure 12) within MRU Orange E, (representative of the river reach from downstream of Augrabies Falls to Vioolsdrift Weir).

Annex Figure 13: EFR O3 on the Orange River at Blouputs downstream of the Augrabies Falls

EFR O4 VIOOLSDRIFT

On the Orange River downstream of the Vioolsdrift gauging weir (Annex Figure 14) within MRU Orange F, (representative of the river downstream of Vioolsdrift Weir to the Fish River confluence).

Annex Figure 14: EFR O4 on the Orange River downstream of the Vioolsdrift gauging weir

EFR O5 SENDELINGSDRIFT

On the Orange River downstream upstream of Sendelingsdrift at the Potjiespram camp site (Annex Figure 15) within MRU Orange G, (representative of the river downstream of the Fish River confluence to the estuary).

Annex Figure 15: EFR O5 on the Orange River upstream of Sendelingsdrift

EFR C5 Upper Caledon

On the Caledon River (Annex Figure 16) within MRU Caledon B, (representative of the river downstream of source to the end of the mostly inaccessible area).

Annex Figure 16: EFR C5 on the upper Caledon River

EFR C6 Lower Caledon

On the Caledon River (Annex Figure 17) within MRU Caledon D, (representative of the river in the Tussen Die Rivier Game Reserve).

Annex Figure 17: EFR C6 on the lower Caledon River

EFR K7 Kraai River

On the lower Kraai River (Annex Figure 18) within MRU Kraai D, (representative of the river downstream of Joggemspruit to the Orange confluence).

Annex Figure 18: EFR K7 on the lower Kraai River

EFR M8 Molopo Wetland

On the lower Kraai River (Annex Figure 19) within MRU UMolopo A, (representative of the river from the source to the end of the wetted wetland section).

Annex Figure 19: EFR M8 on the upper Molopo Wetland

EFR Fish 1

On the Fish River (Annex Figure 20) within MRU Fish A, (representative of the river from Hardap Dam to the proposed Neckartal Dam).

Annex Figure 20: EFR Fish 1 on the Fish River between Hardam Dam and the Neckartal Dam site

EFR Fish 2

On the Fish River (Annex Figure 21) immediately downstream of the Seeheim gauging weir within MRU Fish B.1, (representative of the river from the proposed Neckartal Dam to the Löwen confluence).

Annex Figure 21: EFR Fish 2 on the Fish River downstream of the Seeheim gauging weir

EFR Fish Ai-Ais

On the Fish River (Annex Figure 22) within MRU Fish B.2, (representative of the river from the Löwen confluence to the Orange River confluence).

Annex Figure 22: EFR Fish 2 on the Fish River downstream of the Neckartal Dam site