Orange-Senqu River Basin

Orange-Senqu River Commission Secretariat
Governments of Botswana, Lesotho, Namibia and South Africa

UNDP-GEF
Orange-Senqu Strategic Action Programme
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Summary Report

Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth

Technical Report 37
Rev 0, 08 November 2013

UNDP-GEF
Orange-Senqu Strategic Action Programme

Summary Report

Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth

This report was compiled by Rivers for Africa, e-Flows Consulting (PTY) LTD (iwre@icon.co.za), Pretoria, South Africa with assistance from Ministry of Environment and Tourism, Directorate of Parks and Wildlife Management during surveys and hydrological observed/real time data obtained from Ministry of Agriculture, Water and Forestry, Department of Water Affairs and Forestry, Namibia.

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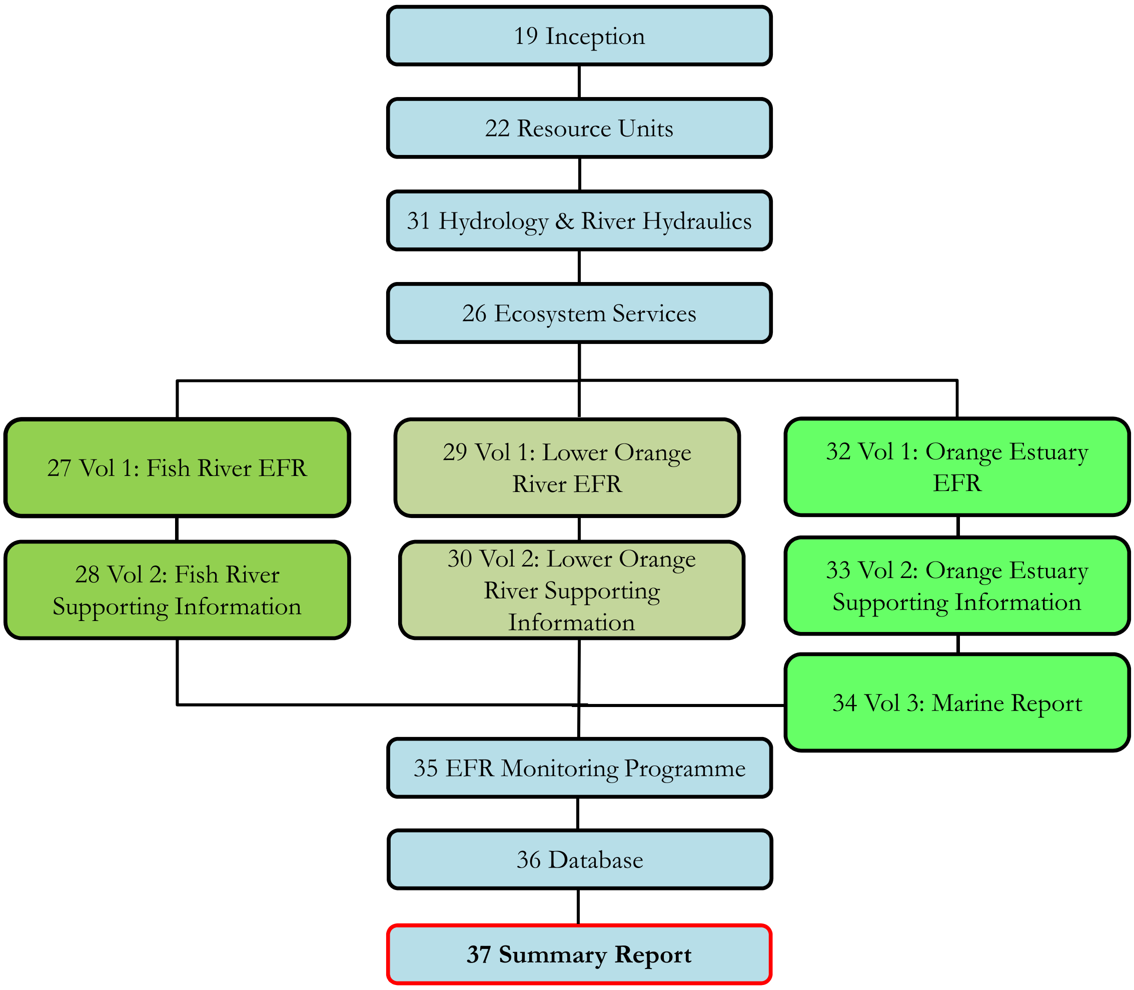
Report list

A list of the Technical Reports that form of this study is provided below. A diagram illustrating the linkages between the reports is also provided.

Technical Report No	Report
19	Inception Report, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
22	Delineation of the Study Area – Resource Unit Report, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
26	Consequences of Scenarios on Ecosystem Services, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
27	River EFR assessment, Volume 1: Determination of Fish River EFR Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
28	River EFR assessment, Volume 2: Fish River EFR, supporting information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
29	River EFR assessment, Volume 1: Determination of the lower Orange River EFR Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
30	River EFR assessment, Volume 2: Lower Orange River EFR, supporting information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
31	River and Estuary EFR assessment, Hydrology and River Hydraulics Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
32	Estuary and Marine EFR assessment, Volume 1: Determination of Orange Estuary EFR Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
33	Estuary and Marine EFR assessment, Volume 2: Orange Estuary EFR: Supporting Information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
34	Estuary and Marine EFR assessment, Volume 3: Assessment of the Role of Freshwater Inflows in the Coastal Marine Ecosystem Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
35	EFR monitoring programme, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
36	Database, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth

Technical Report No	Report
37	**Summary Report, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth**

Bold indicates current report.



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Project manager
Christoph Mor

Technical team members

Team member	Association	Component
Prof J Adams	Nelson Mandela Metropolitan University	Estuary: Macrophytes
Dr A Deacon	Private	Rivers: Fauna
Mr P Huizinga	Private Consultant	Estuary: Hydrodynamics
Mr G Huggins	Nomad Socio-Economic Consultancy	Orange-Senqu River ecosystem services
Dr L Hutchins	Department Environmental Affairs	Orange Plume behaviour
Mr J Koekemoer	Koekemoer Aquatic Services	Rivers: Fish
Ms S Koekemoer	Koekemoer Aquatic Services	Rivers: Diatoms
Dr P Kotze	Clean Stream Biological Services	Rivers: Fish
Dr S Lamberth	Private Consultant	Estuary: Fish; nearshore marine environment
Dr T Lamont	Department Environmental Affairs	Orange Plume behaviour
Dr M Luck-Vogel	CSIR, Stellenbosch	Remote sensing
Ms D Louw	Rivers for Africa	Rivers: Team leader
Mr J Mackenzie	Bioriver Solutions	Rivers: Riparian vegetation
Dr A Meyer	CSIR, Stellenbosch	Primary production
Dr R Palmer	Nepid Consultants	Rivers: Macro-invertebrates
Dr A Pulfrich	Pisces	Marine invertebrates
Ms C Roberts	Independent	Fish River ecosystem services
Mr M Rountree	Fluvius Environmental Consultants	Rivers: Geomorphology
Dr P Scherman	Scherman Colloty & Associates	Rivers: Water quality
Dr G Snow	Nelson Mandela Metropolitan University	Estuary: Microalgae
Dr S Taljaard	CSIR, Stellenbosch	Estuary: Water quality
Mr A Theron	CSIR, Stellenbosch	Estuary: Sediment dynamics
Dr Jane Turpie	Anchor Environmental Consultants	Estuary: Birds, ecosystem services and

		marine linkages
Ms L van Niekerk	CSIR, Stellenbosch	Estuary: Hydrodynamics
Dr P Wolski		Database
Prof T Wooldridge	Nelson Mandela Metropolitan University	Estuary: Invertebrates

Authors of this report

Authors	Association
Mr Greg Huggins	Nomad Socio-Economic Consultancy
Delana Louw	Rivers for Africa
Ms Lara van Niekerk	CSIR, Stellenbosch

Executive summary

Introduction

The 'Orange-Senqu Strategic Action Programme' Project supports ORASECOM in developing a basin-wide plan for the management and development of water resources, based on integrated water resources management (IWRM) principles (ORASECOM, 2011a). Rivers for Africa was appointed to address the: Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. The study area for this project is the Orange River downstream of the Fish River confluence (including the estuary and immediate marine environment) and the Fish River.

The objective of this study was to:

- Determine the present ecological state (PES) and describe alternative ecological states.
- Set the environmental flow requirement (EFR).
- Address scenarios which include future developments and growth and determine the ecological implications.

Study sites

EFRs are undertaken at specific study sites called EFR sites. The following EFR sites were selected:

- EFR O5: One EFR site was selected in the Orange River downstream of the Fish River confluence. The site is situated approximately 6 km upstream of Sendelingsdrift in the /Ai-/Ais-Richtersveld Transfrontier Park.
- The Orange Estuary functions as a distinct EFR site and comprises the whole estuary.
- EFR Fish 1: This site is selected upstream of the proposed Neckartal Dam and downstream of Hardap Dam.
- EFR Fish 2: The site is selected downstream of the proposed Neckartal Dam and immediately downstream of Seeheim gauge
- EFR Fish Ai-Ais: The reach downstream of the Löwen River with the focus on /Ai-/Ais Hot Springs Resort was also selected for some less detailed assessment than at the other two Fish River EFR sites.
- Orange nearshore marine environment: For the purpose of this study the Orange River nearshore marine environment is defined as one degree north (~ 100 km) and one degree south (~ 100 km) of the Orange Estuary, and offshore to the 200 m depth contour.

Method

The first step in the process is to apply the ecological classification (EcoClassification) process. This process consists of various sub-steps as follows:

- Determine and categorise the present ecological state (PES). This is done by evaluating reference conditions to establish the A ecological category. Thereafter, all anthropogenic impacts are considered, a range of models are applied, and a PES is defined within a range of ecological categories from A (near natural) to F (critically modified).
- Define the ecological importance as well as the socio-cultural importance. This process is undertaken by rating a range of criteria and supplying an importance rating ranging from low to very high.
- Based on the importance rating, derive a recommended ecological category (REC) which is either set to maintain the PES (if importance is low or moderate) or to improve the PES (if the importance is high or very high).

The next step in the process is either to set EFRs for different ecological categories, and/or to evaluate different scenarios and predict the change from the PES. A scenario is a combination of developments and management interventions (drivers) that are possible in the future and usually linked to a likely time frame. Typical examples of drivers are construction of new dams, increased water use and implementing environmental flow requirements.

Based on information collated during the study, a flow requirement can be set, recommendations regarding scenarios can be made and an optimisation process can be followed to attempt to minimise impacts on the ecology, the ecosystem services and on the yield of the system.

No official method exists for determining the EFR of the nearshore marine environment in South Africa or Namibia. However, following Van Ballegooyen et al (2003) the following aspects were addressed:

- evaluated the legislative requirement for setting an EFR for the nearshore marine environment;
- determined the ecosystem extent (biogeographic boundaries);
- identified key resource utilisation of the ecosystem and set environmental objectives based on resource use;
- identify abiotic components (habitat) that will respond to the flow modification based on the scenario evaluation;
- described the implications of flow alteration on key biological components;
- evaluate the socio-economic implications of flow alteration;
- provide EFR recommendations.

Results

The ecological classification results are summarised in the table below.

EFR site	***PES***	***Ecological Importance***	***REC***	***Causes and sources***
Fish 1	B/C	High	B	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 irrigation return flows. Grazing and browsing pressure (mainly goats), vegetation removal at settlements, sewage discharges. Improvement would require an increase in the state of riparian vegetation (improved flooding regime) and macro-invertebrates (improved nutrient status).
Fish 2	C	High	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). An overall improvement in the ecological status could not be achieved by flow related mitigation measures as the instream biota components were already in a B ecological category. The riparian vegetation could be improved within the C ecological category by minimising trampling and grazing pressure of goats.
O5	B/C	High	B	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. Improvement requires increased (from present) wet season baseflows and droughts to be reinstated, i.e. decreased flow at times during the dry season.
Estuary	D	Very High	C	Flow-related impacts: Decreased frequency of small and moderate floods. Higher low flows than natural in the dry season preventing mouth closure and related backflooding. Agricultural return flow activities cause water quality problems. Non-flow-related impacts: Road infrastructure (crossing saltmash) and levees. Recreational fishing (specifically, uncontrolled catches a few orders of magnitude greater than legal bag limits) and gill netting. Mining activities. Grazing and hunting on the flood plain. Improvement requires increased (from present) dry season base flows and droughts to be reinstated, i.e. decreased flow at times during the dry season to facilitate mouth closure two to four times in 10 years. Institute non-flow-related measures (e.g. remove causeway, reduce nutrient input and fishing pressure).

The EFR results are summarised in the table below.

EFR site	***PES***	***REC***	***EFR comment***
Fish 2	C	C+	A range of environmental release options from the eminent Neckartal Dam was investigated to determine the impact on ecological status. The options that consisted of a 40% and 50% release of the inflow both maintained the PES. The other release options will have a negative effect on the ecological status. These two release options will also maintain the current provision of ecosystem services.
O5	B/C	B	EFRs to maintain the PES requires 10.85% of the natural mean annual runoff (MAR). EFRs to achieve the REC require 14.66% of the natural MAR. A range of scenarios was investigated and only scenarios that included EFR releases maintained the PES. All other scenarios resulted in a state worse than the PES and also had a negative impact on ecosystem services.
Estuary	D	C	EFRs to maintain the PES require 39.9% of the natural MAR. EFRs to achieve the REC require 39.5% of the natural MAR. A range of scenarios was investigated and only scenarios that reinstated dry seasonal and drought flows achieved the REC. All other scenarios resulted in a decline in the PES and also had some impact on ecosystem services.

Conclusions

The conclusions in terms of optimised release options (Fish River) and scenarios (Orange River and Estuary) are summarised in the table below.

EFR site	***PES***	***REC***	***EFR conclusions and recommendations***
Fish 2	C	C+	The options that consisted of a 40% and 50% release of the inflow both maintained the present ecological state but did have a significant impact on yield. An optimised release option that has elements of both the 40 and 50% release options was designed. This option minimised the impact on yield while still maintain the PES, albeit at a higher risk of resulting in ecological degradation than the 40 and 50%. The optimised release option will have no impact on the current provision of ecosystem services.
O5	B/C	B	None of the scenarios (Sc) that did not include an EFR maintained the PES. An optimised scenario (Sc 9) was developed which will maintain the PES, might achieve the REC and also includes some of the most likely development options. This scenario will have no impact on the current provision of ecosystem services.
Estuary	D	C	Sc 2 to 4 maintained the PES, but with some decline in invertebrate, fish and bird health. None of the scenarios achieved the REC based solely on flow. An optimised scenario (Sc 9) was developed which will maintain the PES and might achieve the REC in conjunction with a range of non-flow related mitigations. Sc 9 also includes some of the most likely development options. This scenario will have negligible impact on the current provision of estuary ecosystem services and little impact on the ecosystem service of the nearshore environment.

Further work recommendations

Further work recommendations consisted of the following:

- implementation of the monitoring programme that was designed as part of this project within the context of an adaptive management framework;
- updating the monitoring baseline;
- undertaking specific studies to improve understanding to improve ecological specifications and thresholds of potential concern;
- further investigating the role of the Orange River inflow to the nearshore marine environment through detailed field studies in conjunction with remote sensing observations.

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Abbreviations

AMD	*Acid mine drainage*
BBM	*Building Block Methodology*
BCLME	*Benguela Current Large Marine Ecosystem*
DAFF	*Department of Agriculture, Forestry and Fisheries*
DRIFT	*Downstream Response to Imposed Flow Transformations*
DRS	*Dissolved reactive silicate*
DWA	*Department Water Affairs*
EC	*Ecological category*
EcoClassification	*Ecological classification*
EcoSpecs	*Ecological specifications*
EcoStatus	*Ecological status*
EFR	*Environmental flow requirement*
ESIA	*Environmental and social impact assessment*
EWRM	*Ecological water resources monitoring*
GIS	*Geographic Information System*
HEC-RAS	*Hydrologic Engineering Centers River Analysis System*
HFSR	*Habitat Flow Stressor Response*
ICP	*Inductively coupled plasma*
IHI	*Index of habitat integrity*
IWRM	*Integrated water resources management*
LORMS	*Lower Orange River Management System*
MAR	*Mean annual runoff*
MRU	*Management resource unit*
NASS2	*Namibian Scoring System version 2*
nMAR	*Natural mean annual runoff*
NWA	*National Water Act*
NWRS	*National Water Resources Classification System*
ORASECOM	*Orange-Senqu River Commission*
PES	*Present ecological state*
pMAR	*Present day mean annual runoff*
REC	*Recommended ecological category*

RHP	*River Health Programme*
RO	*Release option*
RO Opt	*Optimised release option*
SASS5	*South African Scoring System version 5*
Sc	*Scenario*
TIN	*Total inorganic nitrogen*
TPC	*Threshold of potential concern*
WMA	*Water Management Area*

1. Introduction

1.1 Background

The Orange-Senqu River riparian States (Botswana, Lesotho, Namibia and South Africa) are committed to jointly addressing threats to the shared water resources of the basin. This is reflected in bilateral and basin-wide agreements between the riparian states and led to the formation of the Orange-Senqu River Commission (ORASECOM) in 2000. The 'Orange-Senqu Strategic Action Programme' supports ORASECOM in developing a basin-wide strategic action plan for the management and development of water resources, based on Integrated Water Resources Management (IWRM) principles (ORASECOM, 2011a).

Environmental flow requirements (EFR) of the ephemeral but nevertheless significant Fish River, and the Orange River, from its confluence with the Fish River downstream to the Orange River mouth were not covered in any detail by a previous study conducted during 2009-2010. This area is to be the subject of this Research Project (Technical Report 22).

1.2 Previous studies

Information from previous studies that played a direct role in this study are described below:

- EFR undertaken as part of Support to Phase II ORASECOM Basin Wide Integrated Water Resources Management Plan (Louw and Koekemoer (Eds), 2010). This study determined the flow requirements at four EFR sites in the Orange River and four EFR sites in tributaries of the Orange River. The study area excluded the Orange River downstream of the Fish River confluence, the Fish River and the Orange Estuary. The most downstream river site is situated at Vioolsdrift.
- The Orange-Senqu Joint Baseline Survey undertaken during 2010 with the aim of providing a broad understanding of the state of the aquatic ecosystem at river sites throughout the basin using a range of ecosystem health monitoring protocols (ORASECOM 2011b,c).
- In 2004 an EFR was undertaken on the Orange Estuary as part of the Lower Orange River Management Study (LORMS) study. The assessment was based on limited available literature (CSIR, 2004). It highlighted the need for a decrease in the baseflows to the estuary and related need for estuary mouth closure.
- The Benguela Current Large Marine Ecosystem (BCLME) programme, Project No. BEHP/BAC/03/04 provided some baseline survey information of species and biodiversity in estuarine habitats in the region with a focus on the Orange Estuary (Van Niekerk et al., 2008).

- The scoping paper on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth served as a literature review for the marine study (ORASECOM, 2011a).

1.3 Objectives of the study

The objectives of this study were to:

- develop EFR methodologies with specific emphasis on the ephemeral nature of the Fish River;
- determine the present ecological state (PES) and describe alternative ecological states;
- set the EFR;
- address scenarios in terms of the existing and new dams in the Fish and lower Orange River (also providing input to release specifications);
- value resource economics (Ecosystem Services) and provide changes of different scenarios to the resource economics;
- determine monitoring specifications and design a long term monitoring programme;
- design and apply a stakeholder programme during the duration of the project;
- design and use a Geographic Information System (GIS) database according to ToR specifications.

1.4 Report structure

The report structure is outlined below.

Chapter 1: Introduction
This chapter provides an overview of the study area, information from previous studies that played a direct role in this study and the study objectives.

Chapter 2: Study area
Details of the study area are provided. EFR sites in the Fish River and Orange River is discussed as well as the Orange Estuary and nearshore marine environment.

Chapter 3: Methods
The methods applied during the various tasks of the study are outlined in this chapter.

Chapter 4 - 6: **Ecological classification and environmental flow requirement results**
These three chapters provide the ecological classification and environmental flow requirement results for the Fish and Orange River as well as for the Orange Estuary.

Chapter 7: Marine environmental flow requirement
This chapter outlines the role of the Orange River inflow in the adjacent marine ecosystem as well as the implications of flow alteration on abiotic processes, primary production and selected biological components. The marine environmental flow requirements are discussed.

Chapter 8: Ecosystem services
The importance of ecosystem services is summarised and the consequences of scenarios are discussed.

Chapter 9: Monitoring programme
The ecological specifications and thresholds of potential concern are outlined and a monitoring programme for the environmental flow requirement sites in the Fish and Orange Rivers and Orange Estuary is provided.

Chapter 10: Conclusions
Conclusions based on the implications of different scenarios on the ecological state and ecosystem services are provided. The impact on yield was also considered as whether there are any additional scenarios that can be investigated to minimise impacts.

Chapter 11: Recommendations
Recommendations are made in terms of further work required with specific emphasis on monitoring recommendations and EFR implementation recommendations.

2. Study area

The study area is the Orange River downstream of the Fish River confluence (including the estuary and immediate marine environment) and the Fish River (Technical Report 22).

2.1 Fish River

The Fish River basin is located within southern Namibia and is one of the largest river basins in Namibia. The river basin is relatively under-developed and has a low population density due to the highly arid and generally infertile nature of the soil. The Fish River rises to the south of Windhoek and flows in a generally southwards direction for a distance of 635 km before its confluence with the Orange River about 80 km northwest of Noordoewer (Technical Report 22).

The total area of the Fish River basin is 95,680 km^2 and includes various tributaries. The Kam, Schlip and Kalf tributaries originate in the central highland area south of Rehoboth before joining the mainstream of the Fish River whilst the Narub and Usib Rivers flow from the eastern foothills of the Naukluft Mountains. The Hutup, Lewer and Kanibes Rivers drain from the northern and eastern parts of the Schwarzrand Mountains. The Löwen and Gaub Rivers originate in the Great Karas Mountains and the Konkiep in the western Schwarzrand (Crerar and Maré, 2005).

Based on the updated estimates of natural runoff from the Fish River carried out as part of this study, a total potential natural runoff of 613 million cubic metres (M^{3}m) per annum (/a) is generated from the Fish River basin, but only 571 M^{3}m/a of this reaches the Orange River under natural conditions, as an estimated 42 M^{3}m/a is lost due to evaporation and riverbed losses. These losses could be exacerbated by the encroachment of vegetation into the riparian zone of rivers (Mallory, pers. comm.).

There are two major dams on the Fish River system: Hardap Dam in the middle Fish River close to Mariental, and Naute Dam on the Löwen River close to Keetmanshoop. Hardap Dam has a gross storage capacity of 294 M^{3}m/a, and is used to supply water to irrigation and the total water requirement for Mariental. Naute Dam is significantly smaller than Hardap Dam and has a gross storage capacity of 84 M^{3}m/a. Naute Dam supplies water to Keetmanshoop, as well as irrigation. Water is supplied directly from the dams via pipeline and few releases are made from these dams (Crerar and Mare, 2005).

The study area is shown in Figure 1.

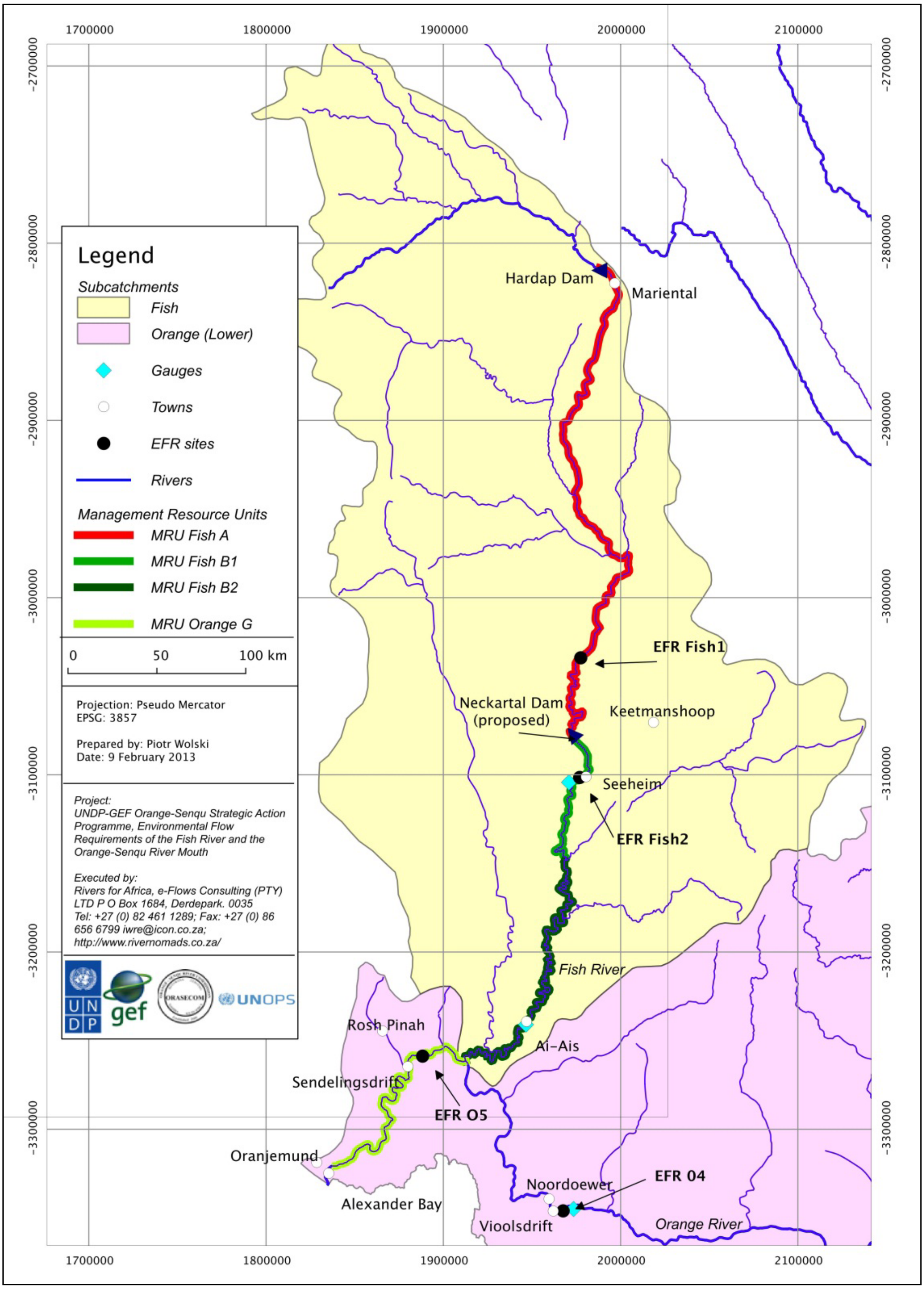


Figure 1. The Fish River basin, Namibia

2.1.1 Management resource units

Two management resource units (MRUs) were delineated in the Fish River (Figure 1). Refer to Technical Report 22 for more detail regarding the process and methods.

- MRU Fish A: Represents the section of river from Hardap Dam to the proposed Neckartal Dam.
- MRU Fish B: Represents the rest of the river.

It was identified that due to the operation of Naute Dam, an additional MRU break at the confluence of the Naute Dam would be required. MRU Fish B was therefore sub-divided as follows:

- MRU Fish B.1: proposed Neckartal Dam to the Löwen River confluence;
- MRU Fish B.2: Löwen River confluence to the Orange River confluence.

2.1.2 Study sites

EFR sites are selected within MRUs and the EFRs determined at the EFR site, are representative of the flow requirements of the MRU. Two EFR sites within MRU Fish B.1 and Fish B.2 therefore had to be selected downstream of Hardap Dam (Figure 1). The sites were initially selected from Google Earth imagery as well as from photographs taken during a reconnaissance visit in 2010 (Louw et al., 2010) and were ground-truthed during a field visit in February 2012. The sites are:

- EFR Fish 1: The site is situated upstream of Neckartal Dam within MRU Fish A. The coordinates are -26.283184, 17.760286.
- EFR Fish 2: The site is situated immediately downstream of the Seeheim gauging weir within MRU B2.1. The coordinates are -26.820588, 17.785650.

Cross-sectional and biophysical surveys were undertaken at these sites.

To add to the evaluation of different flow regimes, an additional 'site' was selected in the /Ai-/Ais Hot Springs Resort area to represent MRU Fish B.2. This area or 'site' is referred to as EFR Fish Ai-Ais. No cross-sectional surveys were undertaken and the site represents a reach with the focus on the area around /Ai-/Ais Hot Springs Resort (referred to as EFR Fish Ai-Ais). Limited biological data collection was undertaken at the site.

More detailed reasons for including EFR Fish Ai-Ais (albeit at a low level of detail) later during the study were:

- EFR release options (ROs) had to be evaluated in detail at EFR Fish 2. However, due to the significant river losses, potential inflows from tributaries and to take cognisance of the Naute Dam, consequences as identified at EFR Fish 2 had to be verified further downstream;
- due to the presence of a waterfall in the Witputs area (downstream of the Löwen River confluence and upstream of /Ai-/Ais Hot Springs Resort) there is a notable difference in

the fish species composition of the lower Fish River (below the waterfall, EFR Fish Ai-Ais) and the upper Fish River reaches (EFR Fish 1 and 2);

- specific localised water quality issues at and upstream of /Ai-/Ais Hot Springs Resort;
- Changes in operation of Naute Dam.

EFR Fish 1

EFR Fish 1 is situated in the Lower Foothills (Technical Report 22) section of the Fish River which represents the larger section of the river and is assumed to be homogenous in terms of ecosystem functioning. The reach is a mixed alluvial and bedrock controlled system. The EFR site is located approximately 65 km upstream of the proposed Neckartal Dam site. Large alluvial lateral bars flank a narrow channel which forms a series of long pools interspersed by short cobble and bedrock riffles. The pools are primarily bedrock controlled being situated generally on the outer bends of the river against small bedrock cliffs. The floor of the pools is also bedrock (largely clear of sediment), and the sides of the pools are either bedrock (outer bed) or sandy alluvium (lateral bars on the inner bend) (Figure 2).

Figure 2. EFR Fish 1 located in MRU Fish A

EFR Fish 2

The site is located within the Upper Canyon, a rift valley formation (Technical Report 28). Within the flat base of this valley, the main Fish River has incised slightly in to the bedrock base and the channel forms a series of long bedrock pools interspersed with cobble and bedrock-controlled riffles (Figure 3). EFR Fish 2 is located approximately 26 km downstream of the proposed Neckartal Dam near Seeheim and downstream of the Seeheim gauging weir.

Figure 3. EFR Fish 2 located in MRU Fish B.1

EFR Fish Ai-Ais

Downstream of the confluence with the Löwen River, the gradient increases, causing the Fish River to incise more strongly into the underlying rocks. The original intense meandering planform of this reach has been preserved, the meanders having become deeply incised due to uplift and the subsequent incision. The degree of meandering and of channel incision is far higher in the Lower Canyon than the Upper Canyon (Figure 4). The incised channel has cut through the Nama sediments and much of the underlying Namaqua complex.

Figure 4. EFR Fish Ai-Ais located in MRU Fish B.2

2.2 Lower Orange River

The portion of the Lower Orange River included in this study is downstream of the Fish River confluence to the Orange Estuary (Figure 1).

Rainfall within the lower Orange River is very low (50 mm in the west) and strongly variable. The potential evaporation rates are highest in the western parts.

Land-use is primarily irrigation and mining, with the area highly dependent on water from the upper Orange River via releases from the Vanderkloof Dam. Large mining operations occur in various parts, with mining activities (present and defunct) found along the whole stretch to the mouth. The water quality in the Lower Orange Water Management Area (WMA) is affected by upstream activities in the Vaal and Orange River catchments. Water requirements on the lower Orange (downstream of the confluence with the Fish River) are limited. There is significant water use in the lower reaches of the Orange River with water supply to irrigation (10 Mm^3/a), domestic use at Alexander Bay and Oranjemund (7,4 Mm^3/a) and for mining at Rosh Pinah (24,4 Mm^3/a).

The various large impoundments notably the Gariep and Vanderkloof dams in South Africa and the Naute and Hardap dams on the Fish River in Namibia, have reduced summer flood peaks in the lower Orange River and Orange River estuary by as much as 50%. Except for the releases through the Orange–Fish tunnel (Eastern Cape) and those into the Vanderkloof canals, all the releases from Gariep and Vanderkloof Dams are made directly into the Orange River to supply downstream users. These river releases are also used to simultaneously generate hydropower.

2.2.1 Management resource units

Two MRUs were delineated in the Orange River (Figure 1) and outlined below. Refer to Technical Report 22 for more detail regarding the process and methods.

- MRU Orange G: Represents the section of river from the Fish River confluence to the estuary.
- MRU Orange H: Represents the estuary.

2.2.2 Study sites

One EFR site was selected in the Orange River downstream of the Fish River confluence. The site was initially selected from Google Earth imagery and based on photographs from various field trips undertaken by Mr Johan Koekemoer during 1998–2002 and ground-truthed during a field visit undertaken in February 2012. The EFR site is located in MRU Orange G approximately six kilometres upstream of Sendelingsdrift and situated in the /Ai-/Ais-Richtersveld Transfrontier Park. The landuse immediately downstream is associated with ecotourism while mining and irrigation are the main anthropogenic activities further downstream.

EFR O5 is situated in a reach which is a mixed alluvial and bedrock controlled system and consists of a weakly braided/multichannel reach (at moderate flows). Although the bar and channel bed consisted of large cobbles with isolated patches of silty fines (lee/slackwater deposits such as in the backwater channel), coarse sands and gravels were largely absent from the site. One area of exception was along a narrow strip immediately adjacent to active channel. This zone of sand and cobbles was probably a consequence of high level energy zone (cobble deposit) and high suspended load arising from the Orange (accounting for the sand) during floods (Figure 5).

Figure 5. EFR O5 located in MRU Orange G

2.3 Orange Estuary

The Orange Estuary is situated between the towns of Alexander Bay in South Africa and Oranjemund in Namibia (Figure 6). The study area extended from the mouth to the head of tidal influence at the Sir Ernest Oppenheimer Bridge, approximately 11 km upstream, and included the banks up to the 5 m contour. The total area is approximately 2,700 ha. The estuary of the Orange River comprise an (almost) permanently open river mouth, a 2 to 3 m deep tidal basin, a braided channel system, located between sand banks covered with pioneer vegetation, and a severely degraded saltmarsh on the south bank of the river mouth.

Figure 6. Rehabilitated saltmarsh area in Orange Estuary near mouth

2.4 Nearshore environment

For the purpose of this study the Orange River nearshore marine environment is defined as one degree north (~ 100 km) and one degree south (~ 100 km) of the Orange Estuary mouth, and offshore to the 200 m depth contour (Figure 7). The study area is situated near the centre of the Namaqua bioregion, a cool-temperate bioregion that extends from Sylvia Hill, north of Lüderitz in Namibia, to Cape Columbine in South Africa (Lombard et al. 2004). This bioregion is characterised by high levels of primary production both on the shore (algae) and offshore (phytoplankton).

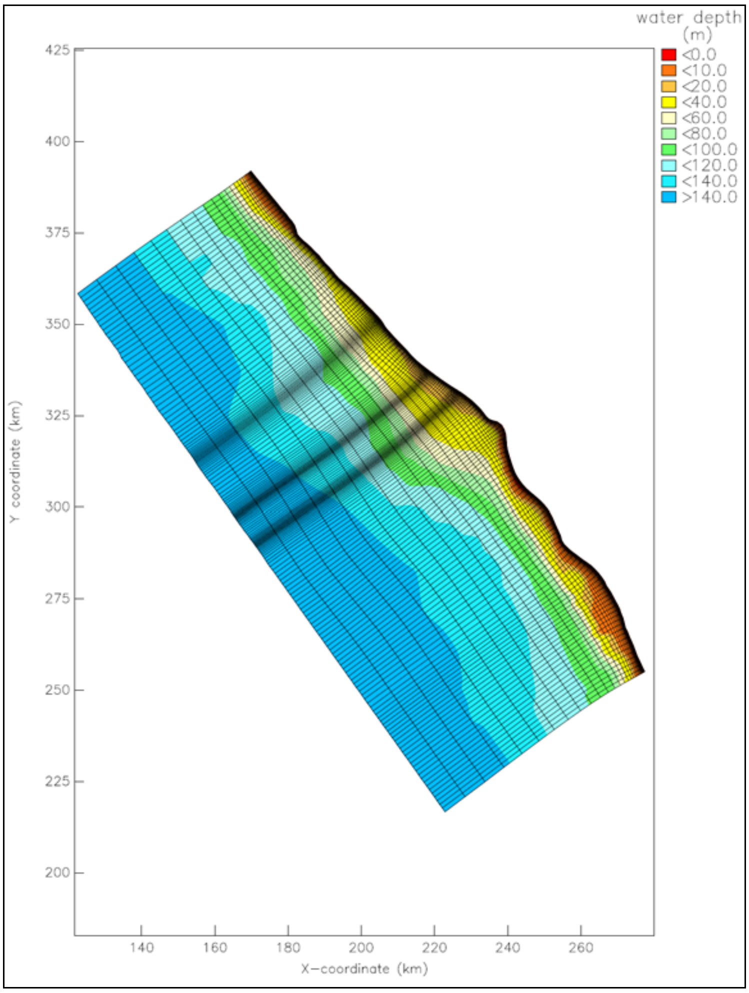


Figure 7. The computational grid and bathymetry used as basis for the nearshore marine flow and sediment dynamics model

The Orange River drains into the southern section of the Benguela Current adjacent to the widest part of the continental shelf and at the southern boundary of the Lüderitz-Orange River Cone upwelling cell. This upwelling cell forms the boundary between the northern and southern Benguela. The surface currents in the vicinity of the river inflow are on average to the northeast. Since the freshwater inflow from the river lies on top of the seawater due to density differences, it can be assumed that on average the plume of the river will also flow in a north-eastern direction. The discharge from the estuary typically forms a plume of buoyant freshwater where it drains into the sea, the nature of which, is shaped by the discharge volume and prevailing wind conditions (Shillington et al. 2006, Gan et al. 2009).

3. Methods

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 the desired condition of the aquatic system, the greater the volume of the original flow regime that will be required as an EFR.

There is a broad regional differentiation in the methods used to evaluate EFRs for the rivers in the Orange-Senqu River basin:

- Downstream Response to Imposed Flow Transformations (DRIFT) methodology (King et al., 2003) was applied in Lesotho.
- Habitat Flow Stressor Response (HFSR) (Hughes and Louw, 2010) was applied in South Africa.
- The ephemeral river EFR method developed during this study was applied in Namibia.
- Estuarine Flow Requirement method (DWAF, 2008) was applied on the Orange Estuary.

All the methods focus on developing relationships between different aspects of the aquatic ecosystem and flow and can thus be used, within reason, to explore alternative flow regimes.

The methods have been slightly modified in the development and evolution of the various approaches for rivers, estuaries, wetlands and groundwater, but essentially the same generic steps are followed in each:

Step 1: Initiate the study
This entails defining the study area, the study team, and the level of study.

Step 2: Define the resource units
Delineate the geographical boundaries of the resource by breaking down the catchment into water resource units which are each significantly different from the other to warrant their own specification of the reserve, and clearly delineate the geographic boundaries of each unit.

Step 3: Ecological classification
The ecological classification (EcoClassification) step entails estimating the reference and present condition and ecological importance in order to determine the recommended ecological category (REC). The reference condition refers to the natural, un-impacted characteristics of a water

resource, and must represent a stable baseline. This usually requires expert judgment in conjunction with local knowledge and historical data. The present ecological status (PES) of resource quality (water quantity, water quality, habitat and biota), is assessed in terms of the degree of similarity to reference conditions. This helps to identify what may be desirable or achievable as a REC. The status of the aquatic system is described in terms of ecological categories A to F. A is described as near natural whereas F will be critically modified.

Step 4: Quantify EFR

The EFR is quantified for different ecological states. This is the most technically demanding of the steps; the rules are rigorous procedures for deriving site-specific numerical objectives which are appropriate for a specific ecological state. Processes generally followed in southern Africa follow either a top-down or bottom-up holistic EFR approach (Tharme, 2000):

- Top-down approach: These are methods such as the Downstream Response to Imposed Flow Transformation (DRIFT) (Brown and King, 2001) and the method developed and used for the Fish River. These methods typically evaluated different flow regimes and predict the resulting ecological category (EC). Similarly the estuary EFR method follows a scenario-based approach, in which a range of scenarios are evaluated and the ecological consequences for the biotic and abiotic components predicted based on the altered simulated flow regime.
- Bottom-up approach: These are methods such as the Building Block Methodology (BBM – King and Louw, 1998) and the Habitat Flow Stressor Response (HFSR) method (Hughes and Louw, 2010). Both these methods consist of a process to determine a flow regime that would result in a range of ecological states. Different flow regimes can then be evaluated and the ecological state determined.

Step 5: Ecological consequences of scenarios

Scenarios are evaluated in terms of the predicted future condition of each scenario as described in Step 4.

Step 6: Decide on management category

The management authority considers the recommended category in the light of other factors, and makes a decision (A to D). Presently this step is undertaken in South Africa through the National Water Resources Classification System (NWRCS) as prescribed in the National Water Act (NWA – no 36 of 1998).

Step 7: Flow requirement specification

This entails the setting of the resource quality objectives (quantitative specifications), and the water quantity and quality parameters of the flow requirement. In a flow requirement study, these are presented as monitoring recommendations.

3.1 Ecological classification approach

The Ecological Classification (EcoClassification) process for rivers and estuaries was followed according to the methods of Kleynhans and Louw (2007) and DWAF (2008) respectively.

3.1.1 Present ecological state

EcoClassification refers to the determination and categorisation of the PES (health or integrity) of various biophysical attributes of rivers compared to the natural (or close to natural) reference condition. The purpose of EcoClassification is to gain insight into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints has to be considered.

The state of a river is expressed in terms of biophysical components:

- habitat components (physico-chemical, geomorphology, hydrology), which provide a particular habitat template;
- biological responses (fish, riparian vegetation and macro-invertebrates).

Similarly, the state of an estuary is expressed in terms of the following biophysical components:

- habitat components (hydrology, hydrodynamics, water quality and structural habitat);
- biological responses (microalgae, riparian vegetation, invertebrates, fish and birds).

Different processes are followed to assign an EC (A→F; A = Natural, and F = critically modified) to each component. Ecological evaluation in terms of expected reference conditions, followed by integration of these components, represents the ecological status or EcoStatus of a water resource. Thus, the EcoStatus can be defined as the totality of the features and characteristics of a river or estuary that bear upon its ability to support an appropriate natural flora and fauna (modified from: Iversen et al., 2000). This ability relates directly to the capacity of the system to provide a variety of goods and services.

The EcoClassification steps are listed below:

- determine reference conditions for each component;
- determine the PES for each component, as well as for the EcoStatus;
- determine the trend for each component, as well as for the EcoStatus;
- determine the reasons for the PES and whether these are flow or non-flow related;
- determine the ecological importance and/or sensitivity of the biota and habitat;
- considering the PES and the ecological importance and sensitivity, suggest a realistic REC for each component, as well as for the EcoStatus;
- determine alternative ecological categories for each component, as well as for the EcoStatus (if relevant).

Table 1. Description of ecological categories. Categories A to D are within the desired range, whereas E and F are not (Kleynhans and Louw, 2007)

EC	***description***
A	**Unmodified, or approximate natural condition**; the natural abiotic template should not be modified. The characteristics of the resource should be determined by unmodified natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.
B	**Largely natural with few modifications.** A small change in natural habitats and biota may have taken place, but ecosystem functions are essentially unchanged. Only a small risk of modifying the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be completely mitigated by the presence of sufficient refuge areas.
C	**Moderately modified.** A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.
D	**Largely modified.** A large loss of natural habitat, biota and basic ecosystem functions has occurred. Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota depending on (the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
E	**Seriously modified.** The loss of natural habitat, biota and basic ecosystem function is extensive
F	**Critically modified.** Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

3.1.2 *Ecological importance*

Rivers

An updated ecological importance and sensitivity model, developed by Dr CJ Kleynhans (DWAF, 1999) and updated during 2010 was used for this study. The ecological importance of a river is estimated and classified by considering a number of components surmised to be indicative of these characteristics.

The following ecological aspects were considered as the basis for the estimation of ecological importance and sensitivity:

- the presence of rare and endangered species, unique species (i.e., endemic or isolated populations) and communities, intolerant species and species diversity were taken into account for both the instream and riparian components of the river;

- habitat diversity was also considered. This included specific habitat types such as reaches with a high diversity of habitat types, i.e., pools, riffles, runs, rapids, waterfalls, riparian forests, etc.

The ecological importance and sensitivity categories are summarised in Table 2.

Table 2. Ecological importance and sensitivity categories (Modified from DWAF, 1999)

Categories	***General Description***
Very high	Quaternaries/delineations that are considered to be unique on a national or even international level based on unique biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually very sensitive to flow modifications and have no or only a small capacity for use.
High	Quaternaries/delineations that are considered to be unique on a national scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) may be sensitive to flow modifications but in some cases, may have a substantial capacity for use.
Moderate	Quaternaries/delineations that are considered to be unique on a provincial or local scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually not very sensitive to flow modifications and often have a substantial capacity for use.
Low/Marginal	Quaternaries/delineations that are not unique at any scale. These rivers (in terms of biota and habitat) are generally not very sensitive to flow modifications and usually have a substantial capacity for use.

Estuaries

Estuary importance is an expression of the value of a specific estuary to maintaining ecological diversity and functioning of estuarine systems on local and wider scales. Estuary importance takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity importance and functional importance of the estuary into account. The biodiversity importance score is in turn based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. The rationale for selecting these variables, as well as further details on the estuary importance index, are discussed in Turpie et al. (2002) and updated in DWAF (2008). The importance scores ideally refer to the system in its natural condition. The scores have already been determined for all South African estuaries, apart from the functional importance score, which is derived by specialists in a workshop.

Consideration is also given to the conservation importance of an estuary to ensure that national and regional biodiversity commitments are met in the region, i.e. situated in a protected area, Ramsar site or a declared desired protected area (Turpie et al., 2012).

3.1.3 Recommended ecological category

The REC is relevant from an ecological viewpoint only and is derived from the ecological importance. As a general rule, the possibility for improving the PES will be investigated if the ecological importance and sensitivity is high to very high. In cases where improvement is deemed to be the appropriate recommendation, the restoration potential of the river is first considered and plays a role in the decision whether to recommend improvement.

3.2 Fish River environmental flow requirement method

The standard processes to determine flow requirements in Southern Africa follow the HFSR method (Hughes and Louw, 2010) and the DRIFT method (Brown and King, 2001). Both these methods have been applied on perennial and seasonal rivers rather than ephemeral rivers. Although there is no reason why the flood component of either of these methods could not be used to determine a flooding regime, certain adaptations was required to determine the low or baseflows.

As the Neckartal Dam is due to be constructed during 2013/2014, it was determined that a scenario-based approach would be most appropriate rather than determining requirements to maintain a certain ecological river state (or health). The main issue is that the releases (and their effects on yield) from Neckartal Dam were simulated using a monthly model, but to be able to evaluate these from an EFR perspective they had to be converted to daily flows that were routed down the channel system. This was achieved by translating simulated monthly flow volumes into daily flow releases and tributary inflows which were then routed through the channel system using the Hydrologic Engineering Centers River Analysis System (HEC-RAS) model.

This implied that different flooding regimes routed through Neckartal Dam would be evaluated downstream of the dam and the implications on the ecological state determined. Recommendations would then be made of an optimised flow regime that can be used as a rule to operate Neckartal Dam releases. Furthermore, it was decided that rather than just evaluating the impacts of the different flooding regime at EFR sites, a routing approach would be followed to determine the impact of the different flow regimes on a reach base.

3.3 Orange River environmental flow requirement method

The HFSR method (Hughes and Louw, 2010) was applied to determine the flow requirements at EFR O5. This is the same method used at the upstream EFR sites. The method is applied in four steps.

- Stress indices are set for fish and macro-invertebrates to aid in the determination of low flow requirements. The stress index describes the consequences of flow reduction on flow dependent biota. It therefore describes the habitat conditions for fish and macro-invertebrate indicator species for various low flows. These habitat conditions for different flows are rated from 10 (zero flow) to 0, which is optimum habitat for the indicator species.
- Stress requirements are determined for different seasons, for different ecological states and for the different indicators. These requirements are then converted to flow to represent the low flow requirement.

- High flow (flood) requirements are set consisting of a range of flood classes. The months during the wet season when these floods should occur as well as the duration of the event are specified.
- High and low flow requirements are integrated and an EFR rule is provided as final output.

3.4 Estuary environmental flow requirement method

The Estuary ERF method comprises a number of basic steps, namely:

- interrogation of the simulated hydrological data to provide an indication – descriptive or statistically – of change in the flow regime;
- in order to present complex abiotic processes in a simplified, easily accessible manner for interpretation by biotic components, the estuary is zoned into a number of representative areas;
- identification of physical states based on typical flow ranges that occur in a specific estuary. Generically these states may range from a series of freshwater-dominated states to more marine-dominated states. In the case of temporarily open estuaries, closed mouth states also become relevant;
- once physical states have been identified – linked to specific flow ranges – they are superimposed on the natural, present and future hydrological scenarios. In its most simplified form, changes in the distribution of the physical states can be represented by the difference in the percentage occurrence of the physical states over the modelled period;
- the simplified complex abiotic processes information is presented on temporal and spatial scales appropriate for biotic response interpretation. Biotic response assessments – expressed in terms of change in species richness, abundance and community composition in this method – are typically based on site-specific field data, published literature, preference and tolerance ranges or modelled data. Each biotic component needs to identify key influencing abiotic variables, and together with responses that may be triggered by other biotic components, predict expected responses.

3.5 Nearshore marine environmental flow requirement method

No official method exists for determining the EFR of the nearshore marine environment in South Africa or Namibia. However, Van Ballegooyen et al (2003) developed an assessment framework for the evaluation of the EFR of the nearshore marine environment based on international best practice. This study used a modified version of the proposed framework to evaluate a range of freshwater scenarios by means of the following steps:

- Determine the legislative requirement for setting an EFR for the nearshore marine environment: Review the policies and legislation of relevance to the assessment and management of the freshwater requirements of the marine environment, including particular obligations under various treaties and international agreements.

- Definition of the ecosystem extent (biogeographic boundaries) and describe key properties: The boundaries of ecosystem of relevance to the assessment need to be defined based on the extent of the marine ecosystem potentially impacted by change of freshwater inflow (i.e. an appropriate definition of the ecological 'footprint'). A description of the ecosystem and its key components is also required to ensure a comprehensive EFR assessment and appropriate ecosystem management recommendations.
- Identify resource utilisation in ecosystem: The resource utilisation needs to be identified in order that, as a minimum, appropriate keystone/indicator species can be selected for the assessment of the freshwater requirements of the marine environment.
- Setting of environmental objectives: Based on the identified policy and legislative requirements, resource utilisation and characteristics of the ecosystem under consideration; specific management and environmental quality objectives need to be developed.
- Hydrological scenario assessment: Describe the changes in the past, present and future flow regime of the catchment to provide context to the assessment.
- Identification relevant abiotic components (habitat) and assess the response to flow modification: The critical abiotic components (e.g. salinity, nutrients, sediments, etc.) influencing the quality of the required habitats during the various life-cycle stages of the key biotic species need to be identified. The various abiotic (and biotic) components need to be integrated and/or aggregated, such that they are relevant to determining the biotic response.
- Describe the implications of flow alteration on selected biological components: This include the following:
    - selection of keystone or indicator species: Based on the management objectives, the defined ecosystem boundary and resource utilisation, keystone and/or indicator species need to be identified to minimise the complexity of the assessment, allow for the setting of clear and measurable environmental objectives, and ensure practical and effective management advice;
    - determination of life-cycle and habitat requirements: An analysis of the various life-cycle stages of the identified keystone or indicator species is required to identify the habitat requirements for the various life-cycle stages and consequently the abiotic (and biotic) components of relevance;
    - predict the possible responses, if any, to predicted change in abiotic components: Provide an analysis of the biotic responses to predicted abiotic change.
- Evaluation of socio-economic importance of marine aquatic ecosystems and resource uses: The outcomes of the scientific assessment of the potential impacts associated with changes in freshwater inflow into marine ecosystems need to be linked to the socio-economic implications of these changes as this is the primary basis upon which water resource allocations are likely to be made. Based on the outcome of this step, there may be modification of the recommended freshwater requirements for the nearshore marine ecosystems under consideration.

- Recommendation of Freshwater Requirements: The adequacy of the scientific assessment will be determined by whether or not there is sufficient understanding and/or measurements to translate management and environmental quality objectives into specific freshwater requirements or target values, based on usage of the nearshore marine environment as an existing or potential future resource. Typically this is only possible for a specific coastal and nearshore region once existing and potential future resource utilisation in the region of interest has been mapped and there is a reasonable understanding of the functioning of the ecosystems of relevance.

3.6 Scenarios

All EFR methods followed are in essence scenario based i.e. different flow regimes are evaluated and the ecological states predicted. A realistic set of scenarios were therefore required to enable a spread of different flow regimes to be tested and for recommendations to be made. Recommendations made during this study can be used to optimise scenarios during further studies and attempt to minimise negative impacts on all users.

Scenarios consist of combinations of different drivers. The drivers were combined within the likely time-frame that these developments could take place so as to derive plausible development scenarios. The combination of drivers that result in scenarios are illustrated in Table 3. A flow regime for each scenario is produced at the EFR site and then evaluated to predict the consequences on the ecological state.

Table 3. Time lines, scenario and driver combinations

Time frame	***Scenario***	***Orange River drivers***	***Fish River drivers***
Present day	Sc OF 1	Modelled present day current releases and use included.	
2013 – 2020	Sc OF 2	Metolong Dam, Tandjieskoppe, acid mine drainage (AMD) treated.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 3	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
	Sc OF 4	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
2020 – 2040	Sc OF 5	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Post 2040 – maximum foreseeable development	Sc OF 6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 7	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.

Time frame	***Scenario***	***Orange River drivers***	***Fish River drivers***
	Sc OF 8	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (EFR O4 released), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation

Three Fish River drivers are included in Table 3, i.e. Neckartal Dam with no EFR release, Neckartal Dam with an EFR release and increased Naute Dam irrigation. To minimise the numbers of scenario iterations, various EFR release options (RO) from Neckartal Dam was evaluated prior to designing the scenarios. The optimised EFR release option was selected as the driver 'Neckartal Dam with EFR release' as specified in Table 3. A summary of the different EFR ROs from the proposed Neckartal Dam which represent a percentage of inflows into the dam are provided below.

- EFR RO 0%
- EFR RO 10%
- EFR RO 20%
- EFR RO 30%
- EFR RO 40%
- EFR RO 50%

The optimised release option consisted of components of both the 30% and 40% ROs.

4. Ecological classification and environmental flow requirement results: Fish River

4.1 Ecological classification

The results of the EcoClassification process are summarised in Table 4. The colours assigned to the different ECs in this report follow the standardised colour scheme in Kleynhans and Louw (2007).

Table 4. EcoClassification summary of the three Fish River EFR sites

EFR Fish 1: EcoClassification description

Ecological importance and sensitivity: HIGH
Highest scoring metrics: Rare and endangered instream and riparian species, critical instream habitat, and refugia, diversity of riparian habitat types.
PES: 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
REC: B
HIGH ecological importance and sensitivity was motivation for improvement of the EcoStatus. Improvement would require an increase in the state of riparian vegetation (improved flooding regime) and macro-invertebrates (improved nutrient status).

Ecological categories

Components	***PES***	***REC***
Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B/C
Fish	B	B
Macro-invertebrates	C	B
Instream	**B/C**	**B**
Riparian vegetation	B/C	B
Riverine fauna	B	B
EcoStatus	**B/C**	**B**
Ecological importance and sensitivity	HIGH	

EFR Fish 2: EcoClassification description

Ecological importance and sensitivity: HIGH
Highest scoring metrics: Rare and endangered instream and riparian species, critical instream habitat and refugia, diversity of riparian habitat types and features.
PES: 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).
REC: B
HIGH ecological importance and sensitivity provides motivation for improvement of the EcoStatus. However an overall improvement in the EcoStatus could not be achieved by flow related mitigation measures as the instream biota components were

Ecological Categories

Components	***PES***	***REC***
Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B/C
Fish	B	B
Macro-invertebrates	B	B
Instream	**B**	**B**
Riparian vegetation	C	C+[1]
Riverine fauna	B	B
EcoStatus	**C**	**C+**

already in a B EC. The riparian vegetation could be improved within the C EC by minimising trampling and grazing pressure of goats.	**Ecological importance and sensitivity** HIGH
EFR Fish Ai-Ais: EcoClassification description	***Ecological Categories***

Ecological importance and sensitivity: HIGH
All the factors for the upstream EFR sites as well as the presence of private Nature Reserves and the /Ai-/Ais Richtersveld Transfrontier Park contributed to the HIGH ecological importance and sensitivity.
PES: C
Flow-related impacts: Altered flow due to reduced flooding caused by limited number (and magnitude) of spills and seepage from Naute Dam.
Non-Flow-related impacts: Vegetation clearing, although mitigated, and similar to EFR Fish 1.
Sewage discharge at /Ai-/Ais Hot Springs Resort resulting in elevated nutrient levels.

Components	***PES***
IHI hydrology	C
Physico-chemical	C
Geomorphology	B
Fish	C
Macro-invertebrates	B
Riparian vegetation	B/C
Riverine fauna	C
Ecological importance and sensitivity	HIGH

4.2 Environmental flow requirement results

Each release option was tested and the ecological state predicted. The consequences of the EFR release options at EFR Fish 2 are summarised in Table 5.

Table 5. Consequences of EFR release options at EFR Fish 2

Components	***PES (REC)***	***RO 0%***	***RO 20%***	***RO 30%***	***RO 40%***	***RO 50%***
Physico-chemical	C	D	C/D	C/D	C	C
Geomorphology	B/C	C/D	C	C	C	C
Fish	B	D	C/D	C	B	B
Macro-invertebrates	B	D	B/C	B/C	B	B
Instream	**B**	**D**	**C**	**C**	**B**	**B**
Riparian vegetation	C	D	C/D	C/D	C	C
Riverine fauna	B	D	C/D	C	B	B
EcoStatus	**C**	**D**	**C/D**	**C**	**C**	**C**

The summary indicates that both RO 40% and 50% would meet the ecological objectives, i.e. for the PES to be maintained. Under the RO 30% there is deterioration in all components and even though the EcoStatus is maintained in a C EcoStatus, it will be a much lower C. Due to the drop in the instream EC, this RO does not meet the ecological objectives. RO 20% and RO 0% have the most severe impact on all components and the ecological objectives are therefore not met.

The consequences of the ROs at EFR Fish Ai-Ais are summarised in Table 6.

Table 6. Consequences of EFR release options at EFR Fish Ai-Ais

Components	***PES (REC)***	***RO 0%***	***RO 20%***	***RO 30%***	***RO 40%***	***RO 50%***
Physico-chemical	C	E	D	D	C/D	C/D
Geomorphology	B	C	C	C	C	C
Fish	C	D/E	D	C/D	C	C
Macro-invertebrates	B	E	D	C/D	C	B
Instream	**B/C**	**D**	**C**	**C**	**B/C**	**B/C**
Riparian vegetation	B/C	D	C	C	B/C	B/C
Riverine fauna	C	D	D	C/D	C	C
EcoStatus	**B-B/C**	**D-D/E**	**C/D-D**	**C-C/D**	**B-B/C**	**B - B/C**

The summary indicates that only RO 50% would meet the ecological objectives, i.e. for the PES to be maintained. RO 40% results in the deterioration of the macro-invertebrates by one EC but maintains the EcoStatus. RO 30%, RO 20% and RO 0% do not meet the ecological objectives for any of the components. RO 0% has the potential to fall below a D EC.

A comparison of the consequences of the ROs at EFR Fish 2 and EFR Fish Ai-Ais is provided in Figure 8. The X and ✓ indicate where the ecological objectives are met. The colour scheme in the arrow below the table illustrates the degree to which the ecological objectives are met (light green implies all objectives are met) or not (red implies all objectives are not met).

Release option	***0%***	***20%***	***30%***	***40%***	***50%***
EFR Fish 2	×	×	×	✓	✓
EFR Fish Ai-Ais	×	×	×	✓	✓

Figure 8. A comparison of the consequences of the EFR ROs at EFR Fish 2 and EFR Fish Ai-Ais

The EFRs for EFR Fish 1 were not determined through a scenario-based approach as the ROs were only relevant downstream of this site. EFR Fish 1 required improvement in flooding requirements and water quality to achieve the EFR. The flooding requirements were determined and, if accepted, would have to be released from Hardap Dam. This site will play an important role in monitoring as it would not be impacted by Neckartal Dam.

The analysis shows that only the RO 50% will fully meet the ecological objectives. The RO 40% has the potential to meet all the ecological objectives, but with a higher risk of failure than the RO 50%.

5. Ecological classification and environmental flow requirement results: Lower Orange River

5.1 Ecological classification

The results of the EcoClassification process are summarised in Table 7. The issues resulting in the PES is similar to the upstream EFR O4 site at Vioolsdrift (Louw and Koekemoer (Eds), 2010). The REC trend is also similar in that both sites have a high ecological importance and sensitivity and improvement would require the same steps to be taken.

Table 7. EcoClassification summary of the Orange River EFR O5 site

Ecological importance and sensitivity: HIGH
Highest scoring metrics: Rare and endangered instream and riparian species. Unique instream and riparian species. Important migration corridor for various species. Site is situated in the /Ai-/Ais–Richtersveld Transfrontier Park.

PES: 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.

REC: B
Increased (from present) wet season baseflows. Reinstate dry season droughts.

Components	***PES***	***REC***
Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B
Fish	B/C	B
Macro-invertebrates	B/C	B
Instream	**B/C**	**B**
Riparian vegetation	B/C	B
Riverine fauna	B	B
EcoStatus	**B/C**	**B**
Ecological importance and sensitivity	HIGH	

5.2 Environmental flow requirement results

A summary of the EFR for the PES of a B/C and the REC of a B, is provided in Table 8.

Table 8. EFR requirements at EFR O5 for the PES and the REC

Hydrology	B/C PES	B REC
Natural mean annual runoff (nMAR) (Mm^3)	11,373	11,373
Maintenance low flows (%nMAR)	6.35	10.15
Drought low flows (%nMAR)	0.96	1.32
High flows (%nMAR)	4.51	4.51
Long-term mean (%nMAR)	10.85	14.66
Present-day mean annual runoff (pMAR) (Mm^3)	4641	4641
Maintenance low flows (%pMAR)	15.54	24.87

Hydrology	B/C PES	B REC
Drought low flows (%pMAR)	2.36	3.22
High flows (%pMAR)	11.05	11.05
Long-term mean (%pMAR)	26.6	35.93

The next step in the process was to evaluate the OF Scenarios and predict the resulting ecological state. OF refers to the Orange Fish and indicates that each scenario (Sc) includes drivers from both systems. OF 4, OF 5 and OF 8 were not evaluated as these supply the REC EFR as specified at EFR O4 and, by implication, EFR O5. The river assessment therefore focused on Sc OF 2, OF 3, and OF 6 and OF 7. Scenarios OF 2 and OF 3 were sufficiently similar to be combined, as were Sc OF 6 and OF 7.

The responses in terms of impact on Ecological Categories are summarised in Table 9.

Table 9. Consequences of EFR scenarios at EFR O5

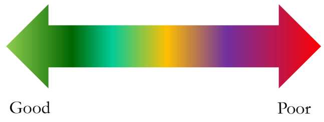
Components	***PES***	***REC***	***Sc OF 2, 3***	***Sc OF 6, 7***
Physico-chemical	C	C	C	D/E
Geomorphology	B/C	B	B/C	C/D
Fish	B/C	B	B/C	D/E
Macro-invertebrates	B/C	B	B/C	D/E
Instream	B/C	B	B/C	D/E
Riparian vegetation	B/C	B	B/C	C/D
Riverine fauna	B	B	B	D
EcoStatus	**B/C**	**B**	**B/C**	**D**

Sc OF 3 maintained the PES whereas Sc OF 7 dropped the EC to a D/E for the instream components and resulted in a D EcoStatus. None of the scenarios met the REC, however it must be noted that none of these scenarios included the REC EFR as a demand. Sc OF 2 and Sc OF 3 did not meet the REC but maintained the PES. Sc OF 6 and OF 7 did not meet the ecological objectives and the instream components would be in an unsustainable state. It is assumed that Sc OF 4, 5 and possibly 8 will meet the REC as it is included in the scenario as a demand. It must be noted however that this statement is only based on the provision of the low flows as it is likely that the impact on the high flows, due to the increasing number of large dams, cannot be mitigated.

A further summary in terms of meeting the ecological objectives are provided in Table 10. The X and ✓ indicate where the ecological objectives are met. The colour scheme in the arrow below the table illustrates the degree to which the ecological objectives are met (light green implies all objectives are met) or not (red implies all objectives are not met).

Table 10. Degree to which ecological objectives are met at EFR O5 under each flow scenario

Scenario	***Sc OF 4, OF 5, OF 8***	***Sc OF 2***	***Sc OF 3***	***Sc OF 6***	***Sc OF 7***
EFR O5	✓	×	×	×	×



6. Ecological classification and environmental flow requirement results: Orange Estuary

6.1 Ecological classification

6.1.1 Present ecological state

The status rating allocated to the various abiotic and biotic parameters for the Orange Estuary are used to calculate the overall health state. The Orange Estuary has an overall health rating of 51 relative to the natural condition. This is mostly attributed to the following factors:

- significant freshwater flow modification – both loss of floods and increased baseflows;
- lack of estuary mouth closure and resulting backflooding of saltmarshes with fresher water;
- road infrastructure i.e. the old causeway across the saltmarshes and old bridge crossings;
- nutrient input from catchment downstream of Vioolsdrift;
- gill-netting of indigenous fish species and considerable fishing effort at the mouth on both sides of the estuary;
- riparian infrastructure – levees preventing backflooding;
- mining activities;
- wastewater disposal (sewage and mining return flow);
- grazing and hunting.

The estuary state for the Orange Estuary under present conditions and the study confidence levels are provided in Table 111.

Table 11. The present ecological state for the Orange Estuary and confidence levels

Variable	***Health score***	***Confidence***
Hydrology	D	Low/Medium
Hydrodynamics and mouth condition	C	Low
Water quality	D	Medium
Physical habitat alteration	B	Medium
Microalgae	E	Low
Macrophytes	D	Medium
Invertebrates	D	High
Fish	D	Medium
Birds	E	Medium
Present ecological status	***D***	***Medium***

The overall state for the Orange Estuary translates to a PES of D, representing a largely modified system.

6.1.2 Ecological importance

Following South Africa's accession to the Ramsar Convention, the Orange Estuary was designated a Ramsar Site, i.e. a wetland of international importance, on 28/06/1991 (Cowan, 1995). Namibia ratified the Ramsar Convention in 1995, after which the designated area was enlarged and the Namibian part of the wetland was designated too. In September 1995 the South African Ramsar Site was placed on the Montreux Record (a list of Ramsar Sites around the world that is in a degraded state) as a result of a belated recognition of the severely degraded state of the saltmarsh on the south bank (CSIR, 2001). The implication is that the Orange Estuary may lose its status as a Ramsar Site unless the condition of the saltmarsh can be restored.

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. Turpie et al. (2002) ranked the Orange as the seventh most important estuary in South Africa in terms of conservation importance. The Orange Estuary is also one of only two estuaries on the Namibian coast, the other being the Kunene River mouth.

The ecological importance has already been determined for all South African estuaries, apart from the functional importance score, which is derived by specialists in a workshop (DWAF, 2008). The functional importance score determined at a specialist workshop held in Stellenbosch in March 2013 is provided below in Table 12.

Table 12. Estimation of the functional importance of the Orange Estuary

Functional importance score	***Rated out of 100***
a. Estuary: Input of detritus and nutrients generated in estuary	20
b. Nursery function for marine-living fish	80
c. Movement corridor for river invertebrates and fish breeding in sea	20
d. Migratory stopover for coastal birds	60
e. Catchment detritus, nutrients and sediments to sea	100
f. Coastal connectivity (way point) for fish	80
Functional importance score – Max (a to f)	**100**

In this case, the functional importance of the estuary was deemed to be very high (100), since the sediment supply from the Orange River catchment feeds the beaches to the north of the mouth. The sediment input from the river is also very important for flatfish species (soles, skates and rays) in the offshore environment in the vicinity of the mouth as it provides the habitat on which they depend.

The estuary importance rating for the Orange Estuary is provided below in Table 13.

Table 13. The importance rating for the Orange Estuary

Criterion	***Weight***	***Rating***
Estuary size	15	100
Zonal rarity type	10	90
Habitat diversity	25	100
Biodiversity importance	25	99
Functional importance	25	100
Estuary importance score		**99**

The estuary importance for the Orange, based on its present state, was therefore estimated to be 99 out of 100, i.e. the estuary is rated as 'highly important'.

6.1.3 Recommended ecological state

The REC represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' EC, based on its present condition (or PES). The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection, or desired protection, of a particular estuary, as shown below in Table 1414.

Table 14. Estuary protection status and importance, and the basis for assigning a REC

Protection status and importance	***REC***	***Policy basis***
Protected area Desired protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health.
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category.
Important	PES + 1, min C	Important estuaries should be in an A, B or C category.
Low to average importance	PES, min D	Estuaries to remain in a D category.

* BAS = Best attainable state

The PES for the Orange Estuary is a D. The estuary is rated as 'highly important', it is a designated Ramsar Site, a Protected Area on the Namibian side; and a desired protected area in the South African Biodiversity Plan for the 2011 National Biodiversity Assessment (Turpie et al., 2012). The REC for the estuary is therefore an A or its best attainable state which is estimated as a category C.

The following key actions are required to improve the health of the system:

- decreasing the winter baseflows;
- enhance nursery function for estuarine dependant fish species;
- improve the water exchange into the lower marsh areas high flow and flood events;
- decreasing nutrient input from the catchment;
- reduce/control destruction of habitat (e.g. wind-blown dust from mining activities, grazing, reducing number of access roads).

6.2 Environmental flow requirements results

The following scenarios (Sc) were evaluated as part of this study (Table 15).

Table 15. Summary of the scenarios evaluated in this study

Scenario	*MAR (Mm³/a*)*	*Orange River drivers*	*Fish River drivers*
Sc OF 2	4 411.05	Metolong Dam, Tandjieskoppe, acid mine drainage (AMD) treated.	Neckartal Dam. Increase in Naute Dam irrigation.
Sc OF 3	4 418.26	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 4	4 469.77	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 5	3 837.16	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 6	2 326.26	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam. Increase in Naute Dam irrigation.
Sc OF 7	2 329.31	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.

* Mean annual runoff (MAR) is provided as Million cubic metres per year (Mm³/a).

Note that for simplicity sake, scenarios refer to the NUMBER and exclude OF. OF refers to the Orange Fish and indicates that each scenario includes drivers from both systems.

The individual health scores, as well as the corresponding EC under different scenarios, are provided in the following table. The estuary is currently in a D category. It would deteriorate slightly under Sc 2, 3 and 5, but would likely remain in a D category. The estuary would improve under Sc 4 (decrease baseflows) to a C/D category. Under Sc 6 and 7 the estuary would significantly decline in health to an F category.

Scenario 4 plus anthropogenic measures (indicated as Sc 4 + Anth) provides an evaluation of the contribution of non-flow-related impacts – removal of the causeway, reduction in baseflows to allow for mouth closure, a 50% decrease in nutrients, decreasing fishing effort. It suggests that if some of these are achieved in conjunction with the flow regime of Sc 4, the estuary condition could be raised to a C category.

The health score and corresponding EC under the runoff scenarios are provided below in Table 16.

Table 16. Estuary health score and corresponding EC under the various runoff scenarios

Component	Weight	Present	Scenario 2	3	4	5	6	7	4 + Anth
Hydrology	25	D	D	D	D	D	F	E	D
Hydrodynamics and mouth condition	25	C	D	D	B	D	F	F	B
Water quality	25	D	D	D	D	D	E	D	C
Physical habitat alteration	25	B	B	B	B	C	F	F	B
Microalgae	20	E	E	E	E	E	E	E	E
Macrophytes	20	D	D	D	D	D	F	F	C
Invertebrates	20	D	E	E	C	D	F	F	B
Fish	20	D	E	D	D	E	E	E	D
Birds	20	E	E	E	E	F	F	F	D
Ecological category		**D**	**D**	**D**	**C/D**	**D**	**F**	**F**	**C**

For a high-confidence study, the 'recommended environmental flow requirement' scenario is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the REC. Where any component of the health score is less than a D category, modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. Based on this assessment, the best attainable state for the estuary is a C category.

None of the scenarios presented as part of this study meet the REC of C based solely on river inflow.

Therefore the recommended EFR is Sc 4 in conjunction with the recommended remedial measures outlined below.

- Decreasing the winter baseflows sufficiently to allow for mouth closure and related backflooding of the saltmarshes with brackish water to reduce soil salinities.
- Controlling the fishing effort on both the South African and Namibian side through controlled access, increased compliance and law enforcement. This also requires the alignment of fishing regulations (e.g. size and bag limits) and management boundaries on either side of the transboundary estuary.
- 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.

The flow requirements recommended for the Orange Estuary are the same as those described for Sc 4. A flow duration table of the mean monthly flows (in m^3/s) for the scenario is presented below in Table 17.

Table 17. Summary of the mean monthly flow (in m^3/s) distribution under Sc 4

Duration	***Oct***	***Nov***	***Dec***	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***
10%	54.8	258.4	151.1	518.2	1544.7	646.5	571.0	158.5	63.2	30.3	31.3	30.2
20%	34.0	74.5	108.6	162.3	847.2	459.9	278.5	128.9	48.7	29.0	29.1	29.8
30%	32.9	71.0	82.2	105.7	216.5	295.1	139.5	76.1	46.5	28.3	28.5	28.9
40%	31.5	69.4	79.0	94.7	138.3	177.7	116.7	66.7	42.9	27.2	26.5	28.2
50%	28.8	66.7	62.6	84.6	99.4	133.6	104.7	60.4	38.9	26.2	24.1	25.0
60%	25.3	63.4	52.8	62.1	77.6	102.6	90.8	55.4	35.2	25.2	20.2	19.4
70 %	17.7	41.3	42.2	35.6	51.5	63.6	57.0	44.5	21.3	19.1	15.3	10.5
80%	9.9	22.1	23.7	25.5	39.0	45.3	40.1	13.2	11.3	11.2	8.5	3.8
90%	4.1	8.8	18.8	18.1	34.1	38.6	16.0	7.7	5.9	6.7	4.7	0.0
99%	0.0	0.0	11.0	9.6	29.2	28.4	8.2	5.9	4.3	3.8	2.6	0.0

7. Marine environmental flow requirement

7.1 Role of the Orange River inflow in the adjacent marine ecosystem

The influence of the Orange-Senqu River on marine biota is likely to differ between nearshore and offshore, especially with regards to the surf zone which is often described as a closed system (McLachlan et al., 1981). The export of sediment, nutrients and detritus to the sea are undoubtedly important but it is sediment that shapes both near and offshore habitats. Nutrients from the river serve to stimulate phytoplankton and zooplankton production in the nearshore marine environment, ultimately benefitting the larval, juvenile and adult fish that depend on this food source. Floating debris offers refuge to juvenile fish whereas detritus may be broken down into useful nutrients, serve as a substrate for micro-flora and fauna or be consumed directly by detritivorous fish and invertebrates. Sediment export replenishes the nearshore habitats that are continuously eroded by oceanic currents and also provides a refuge for many fish by increasing turbidity. Turbidity, in turn, will serve to increase the catchability of many species, especially the larger individuals that move into the turbid environment in search of concentrated prey. The freshwater plume centred on the mouth of the estuary will provide cues for the migration of estuarine-dependent juvenile and adult fish into and out of the estuary. The strength of these cues will ultimately dictate how many individuals of these species recruit into the marine fisheries. River plumes also serve as a temperature refuge from cold upwelling for coastal migrants thereby maintaining connectivity between populations, habitats and biogeographical regions.

7.2 Implications of flow alteration on abiotic processes and primary production

The changes in the abiotic environment under the various proposed development scenarios were assessed relative to reference condition. For all of the proposed development options relevant metrics was normalised relative to the magnitude of the metric under either reference condition. When the metrics are normalised relative to reference condition, each of the metrics is reported as 100% under reference condition and typically at lower percentages for both present state and the remainder of the proposed development options. The river inflow under reference conditions were typically a factor of 2 – 3 times greater than under the present state. The final step was to translate these percentage changes in nearshore marine habitats (under the various developments scenarios) into significance ratings. The mapping between percentage changes in the relevant metric and the significance of these changes under the various development scenarios is summarised in Table 18 below. The significance of the predicted changes relative to reference conditions typically range between 0 for reference conditions (i.e. minimal change) to -2 to -3 for present state conditions as well as expected conditions under proposed future development scenarios (i.e. moderately significant to highly significant decreases).

Table 18. Mapping used to translate changes (%) into significance ratings/indices of predicted change

Significance rating	Metric reported as a % of the magnitude of the metric under natural conditions	Metric reported as a % of the magnitude of the metric under present day conditions	Comment
3	200% to 400%	200% to 400%	Highly significant increase.
2	150% to 200%	150% to 200%	Moderately significant increase.
1	125% to 150%	125% to 150%	Discernible increase.
0	75% to 125%	75% to 125%	Minimal change.
-1	50% to 75%	50% to 75%	Discernible decrease.
-2	25% to 50%	25% to 50%	Moderately significant decrease.
-3	0% to 25%	0% to 25%	Highly significant decrease.

The changes in the freshwater, sediment and dissolved reactive silicate (DRS) inputs into the marine environment were assessed based on the significance ratings described in Table 18. In terms of these significance ratings (with respect to inflows to the marine environment) it is not possible to discern between present day conditions and Sc 2 to 5. However Sc 6 and 7, at a rating of -3, compared to the rating of -2 for Sc 2 to 5, are significantly worse than the other proposed scenarios.

The above results (indices of change) characterise only the changes of freshwater and associated fluxes (sediments, nutrients, etc.) into the marine environment. This information can be used to assess potential changes in nearshore and offshore marine environments based on expert opinion and/or model simulated changes in water quality and/or sediment-related marine habitats. The model simulated changes in water quality and sediment-related marine habitats is reported in the sections 5.2 (benthic habitats) and 5.3 (pelagic habitats) of Technical Report 34.

Table 19 provides the freshwater, dissolved reactive silicate (DRS), turbidity and sediment inflows to the nearshore marine environment under the various proposed future development scenarios. The inflows for the various scenarios are expressed in terms of the significance ratings specified in Table 18. All ratings are relative to reference conditions.

Table 19. Freshwater, DRS, turbidity and sediment inflows to the nearshore marine environment under the various proposed future development scenarios

Scenario	Total freshwater discharge volume	Total discharge of sediments (annual average of 66-year period)			
		Salinity	DRS	Turbidity	Sediments
Natural	0	0	0	0	0
Present	-2	-2	-2	-2	-2
Scenario 2	-2	-2	-2	-2	-2
Scenario 3	-2	-2	-2	-2	-2
Scenario 4	-2	-2	-2	-1/-2	-2

Scenario	*Total freshwater discharge volume*	*Total discharge of sediments (annual average of 66-year period)*			
		Salinity	*DRS*	*Turbidity*	*Sediments*
Scenario 5	-2	-2	-2	-2	-2
Scenario 6	-3	-3	-3	-3	-3
Scenario 7	-3	-3	-3	-3	-3

7.3 Implications of flow alteration on selected biological components

7.3.1 Marine habitat and communities

Communities within marine habitats are largely ubiquitous throughout the southern African West Coast region, being particular only to substrate type or depth zone. Least variation is amongst seaweeds and invertebrates but only marginally more amongst fish. These biological communities consist of many hundreds of species, often displaying considerable temporal and spatial variability (even at small scales).

North of the Orange-Senqu River mouth the shoreline is predominantly a sandy coast formed by the northward littoral transport of coarse marine sediments. Rocky intertidal habitats are represented only by occasional small rocky outcrops that host benthic communities strongly influenced by sediments. South of the river mouth, the coastline is dominated by rocky shores, with occasional short beaches interspersed between rocky headlands. The surf-zone immediately in front of the mouth is a highly reflective sandy shore. The deeper water marine ecosystems comprise primarily unconsolidated seabed sediments, much of it terrigenous, with subtidal reef habitats being limited to the shallow nearshore regions (<40 m). The pelagic ecosystem is also influenced by river flow. Reduced salinity and increased turbidity in the surface layers are associated with the influence of the Orange-Senqu plume and are usually discernible in a 50 km radius from the mouth but may expand to 100 km or more during and after floods.

Historical changes in discharge volumes, shifts in seasonal flow variation and shifts in mouth closure events have most likely resulted in seasonal reversals of some abiotic components with potential serious consequences for the estuary and ultimately the marine environment beyond (Taljaard, 2005). Such changes would almost certainly have influenced the community composition and abundance of fish and invertebrate communities surrounding the mouth of the estuary, and presumably must be having some impact on those species that rely on seasonal cues for entering or exiting the estuary.

7.3.2 Influence on invertebrates in offshore soft sediments

An array of environmental factors and their complex interplay is ultimately responsible for the structure of benthic communities of which water depth and sediment composition are two of the major components of the physical environment determining invertebrate community structure off the Namibian and South African coastline. Diversity, distribution and abundance of invertebrate communities in the mixed terrigenous and marine deposits of the coastal zone are controlled by both the granulometric properties of the sediments and complex interactions between physical and biological factors at the sediment–water interface.

What must be kept in mind, however, is that marine communities in the Benguela are frequently exposed to naturally elevated suspended-sediment levels. They can thus be expected to have behavioural and physiological mechanisms and adaptations for coping with or capitalising on, this feature of their habitat, and are unlikely to be significantly affected by suspended sediment plumes generated by river discharges.

Pelagic invertebrate communities

The pelagic invertebrate communities of the Benguela are highly variable both spatially and temporally, their abundances largely being determined by the upwelling regime. Catchment flow is also highly variable and important but usually on a local scale adjacent to river mouths.

Along the southern African West Coast, where turbid water is a natural occurrence, inhibition of primary production in the near-shore environment is likely to be negligible. Suspended inorganic material can also enhance food availability to filter-feeding organisms by providing an extensive surface for the adsorption of dissolved organic material and microorganism colonization. However, the amount of organic matter ingested and assimilated generally increases with increasing particle concentration up to a threshold level above which the filter-feeding mechanism becomes overloaded, and filtration rate again declines in order to maintain assimilation rates and minimise energy loss. On the whole, the effect of suspended sediment loads on juvenile and adult invertebrates are usually beneficial, occasionally negative but at sub-lethal levels.

Rock lobster

West coast rock lobster *Jasus lalandii* sustain a large fishery and are an important invertebrate predator in kelp bed habitats in the region. Lobster are tolerant of high suspended sediment loads but sedimentation or heavy siltation of nearshore reefs may reduce the carrying capacity of an otherwise suitable habitat, therefore potentially directly affecting rock-lobster populations, or reducing regional recruitment where sedimentation is widespread. This may consequently have important implications for the success of the commercial harvest of this resource in an area.

Declines in lobster catches off Namibia coincided with, or followed shortly after, Orange-Senqu flood events in 1955, 1958, 1967, 1974, 1976 and 1988 Penney et al. (2008). Off South Africa, declines coincided with the 1938, 1944, 1955, 1958, 1967 and 1988 flood events. Even the 1948 flood appears to coincide with a minor dip in catches during the period of otherwise rapid expansion of this fishery between 1945 and 1951. Only the 1976 flood did not seem to coincide with a catch decline in the South African fishery.

The above said, a number of factors including massive over-fishing have contributed to the decline of Namibian and South African rock lobster resources over the past 50 years. Recovery of the over-fished resources has been severely limited by highly variable recruitment which, to a large extent, results from the extreme environmental variability, and generally harsh conditions, of the central

Benguela region. Coupled with declines in growth rate since the late 1980s, productivity was further reduced. Furthermore, since 1988, large-scale environmental changes have contributed to increased frequency and severity of low oxygen events, and occasional massive floods have deposited substantial quantities of mobile sediment into the nearshore ecosystems.

7.3.3 Fish and fisheries

Types of fish (and fisheries) response to changes in freshwater inflow to the marine environment fall into four broad categories (Lamberth et al., 2009):

1. apparent negative responses to reduced flow, that are most likely due to rainfall/climate patterns throughout a biogeographical region rather than local flow rates;
2. negative responses to local reduced flows that are real, e.g. reduced flow from the catchment will result in reductions in turbidity, preferred sediments, nutrient loads, phyto- and zooplankton production and ultimately reduced biomass and catches;
3. cases of zero or negligible response, either positive or negative, to changes in flow;
4. situations where flow reduction has a positive effect on catches. Correlations like these often prove to be less due to ecological drivers than to various aspects of fleet behaviour (and fisheries management).

7.3.4 Influence on nearshore nomadic coastal fish

Given the predominantly cool water of the Benguela upwelling region, linefish such as *silver kob Argyrosomus inodorus* and west coast steenbras *Lithognathus aureti* tend to be distributed within the warmer-water areas along the west coast. These warm areas are limited and tend to be in shallow bays, estuaries or warm-water plumes in the vicinity of estuary mouths. Hypothetically, the southward distribution of Angolan dusky kob *Argyrosomus coronus* and west coast steenbras *L. aureti*, both non-estuarine marine species, to as far as Langebaan Lagoon, may depend on the availability of warm-water refugia offered by estuary mouths and plumes. Consequently, a reduction in river flow may influence the distribution of these species by reducing the extent and availability of these refugia. A similar process is likely to facilitate exchange between South African, Namibian and Angolan stocks of *Argyrosomus inodorus, Pomatomus saltatrix* and *Lichia amia*. All three of these species as well as *Lithognathus lithognathus* and *L. aureti*, are important commercial and/or recreational fish in the region.

Most nearshore and estuarine fish either prefer or are tolerant of turbid waters and only move away when conditions approach tolerance levels. In turn, higher fish densities than those in surrounding waters were associated with turbidity plumes from marine mining activity to the north of the Orange River (Clark et al., 1998). In reality, high flood-induced turbidity in the Orange and other nearshore areas appear to attract many ‘turbidity-adapted’ fish probably in response to potential refuge, parasite removal and / or more concentrated prey. Indeed, aggregations of ‘turbidity adapted’ fish most notably silver kob *Argyrosomus inodorus*, start occurring in the surf-zone adjacent to the Orange Mouth up to two weeks prior to a flood event, probably in response to the first physico-chemical signals from the catchment. This said, the predictability of these aggregations and increased catchability make these fish vulnerable to over-exploitation.

7.3.5 Influence on demersal soft-sediment fish

Flow-driven changes in the magnitude and nature of sediment export to the marine environment will result in concomitant shifts in the diversity and abundance of fish that are distributed according to sediment preference or intensity of turbidity plumes off the Orange-Senqu mouth. The best examples of these are bottom-dwelling flatfish species such as sole and skates which are distributed according to sediment type and particle size or small pelagic fish such as anchovy which find refuge in the surface layer turbidity plumes. Coincidental events such as floods, major dam construction and fishery collapse suggest a number of relationships, short and long-term between catchment flow and fish and fisheries in the marine environment. Species that were historically important in the demersal trawl fishery such as west coast sole *Austroglossus microlepis* now contribute less than 1% of the fish biomass in this soft sediment habitat..

West coast sole

West coast sole *Austroglossus microlepis* are targeted in South African and Namibian waters whereas east coast sole *Austroglossus pectoralis* are caught on South Africa's eastern seaboard. There are two recognised stocks of west coast sole a southern population centred on the Orange-Senqu mouth and a northern population opposite the Skeleton Coast (Crawford et al., 1987). The trawl fishery for the southern population collapsed in the 1970s. The South African fishery has never recovered whereas there's been a resumption of the fishery in Namibian waters. It is not known whether this represents a recovery of the southern stock or a shift of the northern one southward. Worth mentioning, is that South Africa's east coast sole fishery has remained stable over the same time period.

Fishers in the sole trawl industry here and elsewhere in the world have long used rainfall (terrestrial runoff) as a predictor of catches in the following season. From 1970 to 1980, dam storage capacity on the Orange-Senqu rose from 10% to 90% of that in the present day. The west coast sole fishery collapsed in the mid 1970s. Demersal trawl survey data (Department of Agriculture, Forestry and Fisheries (DAFF): 1984-2011) indicate a weak but positive relationship between Orange-Senqu flow and biomass estimates. However, there are stronger but negative relationships between sole and their predators e.g. gurnard *Chelidonichthys capensis* and smooth-hound shark *Mustelus mustelus*. Damming saw sediment discharge into the sea change in composition from predominantly silt to cohesive clays. Hypothetically, this influenced the burying ability and crypsis of juvenile sole leaving them more exposed to predators on the sediment surface and abrupt stock collapse. Changes in nutrient and food availability may also have played a role. In comparison, the stability in South Africa's east coast sole fishery may be partly attributed to there being no substantial change in the nature and volume of terrigenous sediment reaching the sea in that region.

Small-pelagic fish

Small pelagic fish, notably anchovy, sardine and round-herring are the mainstay of the small pelagic purse-seine fishery on the South African and Namibian coast, the largest commercial fishery in the region. Small pelagic fish play a key role in regulating ecosystem function arising through their mid-level trophic position and influence on the abundance of both the plankton they feed on and the predators that feed on them (DAFF, 2012). Up until this project, there has been no real consideration given to the influence of catchment flows on the distribution of these pelagic fish in the BCLME.

Although ichthyoplankton (fish eggs and larvae) comprise a minor component of the overall zoo and phytoplankton biomass, it remains significant due to its dominance by small-pelagic fish (including pilchard, anchovy, and round-herring) and the commercial importance of this fishery in the region. High densities of larval and juvenile anchovy *Engraulis encrasicolus* are associated with the turbidity plume off the Orange and other estuaries on the west coast. The use of river plumes as refugia or juvenile nursery areas is characteristic of many small pelagic fish populations globally. Given the generally strong relationship between recruitment and end-of-the-year spawner biomass, it could also be expected that river flow, plume size and its influence on juvenile fish density may provide an additional useful predictor of said spawner biomass. Preliminary analysis of Orange-Senqu River flow and pelagic fish biomass indicated a positive relationship between river-flow and juvenile densities of the three small-pelagic species but only the anchovy-flow one was significant. More robust analysis and numerical modelling of all variables should improve on this. Further, although on average only 10 – 20% of juvenile anchovy density can be explained by flow, higher densities of juveniles persist off the Orange-Senqu and other river mouths in years when they're in low abundance or absent from other parts of the Namibian and South African coast.

Intertidal, subtidal and surf-zone fish

Most surf-zone, intertidal and subtidal fish on the Namibian and South African coast are common to sandy, rocky and mixed shore habitats but differ in abundance according to proportions of rock and sand and degree of exposure (Clark, 1997). In contrast to the low diversity of invertebrate communities on mixed shores in the region, fish species diversity and abundance is greatest at intermediate levels of exposure but also increases with habitat heterogeneity from sandy to mixed shores. These shores are characterised by extensive sand movement (terrigenous and marine) and the repeated scouring or burial of algal and invertebrate communities. Similarly, in the immediate nearshore, relationships between fish assemblages and flow from the Orange-Senqu are likely to be indirect and according to the influence of catchment flow and sediment dynamics on the distribution of kelp and the burying or exposure of subtidal reefs.

Links between the rocky intertidal fish assemblage and the Orange Catchment, both positive and negative, are more tenuous than in other nearshore habitats. The 1988 Orange River floods diluted coastal waters causing mass mortalities of shallow-water invertebrates and kelps but fish escaped to deeper more saline waters. In contrast, floods frequently result in aggregations of fish adapted to low salinity and high turbidity in the Orange-Senqu nearshore. In turn, the estuary and it's plume may offer refuge from low-oxygen events and other potentially lethal conditions in the sea (Lamberth et al., 2010).

7.4 Marine environmental flow requirements

The nature and volume of sediment transport are the most important components of freshwater flow from the Orange-Senqu to the marine environment in particularly with regards to shaping benthic habitats and maintenance of the refuge and foraging area provided by the river plume. There is unlikely to be any discernible change from Sc 1 – 4 and probably 5 as most of the significant change has already occurred from reference to the present day. Scenarios 6 and 7 however, could be severe both in terms of flow and export of sediment to the sea. The impacts of both these scenarios are magnified by the development of a large dam at Vioolsdrift and it's close proximity to the sea relative to existing impoundments in the catchment.

Three selected objectives of a marine EFR for the Orange-Senqu would be re-establishment of benthic habitat suitable to sole and ultimately the fishery, maintenance of the river plume for juvenile small-pelagic fish and maintenance of the turbid warm-water in the nearshore suitable to nomadic fish that occurs in the high-flow season.

Collapse of the sole fishery occurred during the 1970s when 80% of the current dams came into existence and drastically altered sediment export to the sea. Re-establishment of this benthic habitat is likely unachievable under any of the scenarios as it would require redesign of most impoundments in the catchment to secure sediment releases. More feasibility is maintenance and enhancement of the river plume and seasonal warm water 'cell' that occurs during high-flow in the nearshore. These are both likely to persist under Sc 2 – 5 and would be optimised in Sc 4.

8. Ecosystem services

8.1 Background

This part of the report provides a qualitative description of the socio-economic contribution made in the form of ecosystem services supplied by the lower Orange-Senqu River system, including its estuary and main tributary, the Fish River. Ecosystem services provided by rivers, wetlands and estuaries include their attributes that provide aesthetic, recreational, cultural and spiritual value, the provisioning of goods such as fish and raw materials, and the ecosystem functions that save costs, such as water quality amelioration or the provision of nursery areas for fish and macro-invertebrates exploited by marine fisheries. Collectively, these are known as ecosystem services. Capacity to provide ecosystem services depends on the nature of the ecosystem, as well as its integrity. Principles of sustainability require that these values and the ecological functioning that underlies them are not unduly compromised. In particular, this part of the study evaluated the tangible and intangible benefits obtained from the river and estuary ecosystems to people living in the area and beyond, and how these are affected under different scenarios

8.2 Rationale and study approach

The study was based on site visits and a limited number of interviews with key stakeholders, as well as examination of existing published and unpublished information. This was followed by an assessment of how the supply of these services might be impacted under different scenarios, based on the predictions of ecological specialists as to how the characteristics and functioning of the river and estuarine systems are likely to change.

The lower parts of the Orange-Senqu River basin fall in a highly arid environment characterised by very low population densities. As such, the numbers of people benefiting directly from ecosystem services in these parts of the system are much lower than for the upper parts of the basin, particularly in South Africa and Lesotho. Nevertheless, once considering both direct and indirect benefits, ecosystem services generated by these areas are more important than might otherwise be assumed by the low population densities.

The study area was divided into three sections, as follows:

- the lower Fish River between Hardap Dam and its confluence with the Orange River, a distance of about 500 km. This was subdivided into two reaches for the assessment, i.e. from the Hardap Dam to the proposed Neckartal Dam, and from the proposed Neckartal Dam to the Orange River confluence;
- the lower Orange River between the Fish River confluence and the head of the estuary, a stretch of about 140 km.

- the Orange River Estuary, which stretches from just upstream of the Harry Oppenheimer bridge, approximately 11 km from the sea, to the river mouth.

8.3 Description of ecosystem services

8.3.1 Lower Fish River

The lower Fish River flows through the administrative regions of Hardap and Karas and the catchment from which it draws water can be divided into four tenure types: state, freehold, traditional authority and local authority. The largest area (72%) is freehold land, which is owned by private individuals or companies and state. This land comprises mostly commercial farmland. While irrigated agriculture takes place in the area immediately below Hardap Dam (and at Naute Dam on the Löwen River), most of the farming is extensive livestock framing. In more recent years, however, land use is changing on freehold land and moving more to commercial conservation (private parks) and tourism, especially the land adjacent to the Fish River south of Seeheim in the Karas Region. Freehold land owned by government is partly utilised for resettlement. Fifteen per cent of the land in the basin is communal, which is owned by the government but controlled by a range of bodies, mostly Nama traditional authorities, and regional and local authorities. The population density of southern Namibia is extremely low, estimated to be approximately 0,5 inhabitants per km^2.

Despite low population densities and distances that many people live away from the river, important riparian goods and services are present and form a key component of many vulnerable peoples' livelihoods. In particular, subsistence livelihoods supplemented with harvested goods on the communal lands around the Neckartal Dam site are important.

Most people along the Fish River obtain their water from deep boreholes that are located some distance away from the river, rather than river water or groundwater that is associated with the river. Important exceptions to this include the Hardap Irrigation Scheme and the town of Mariental which are dependent on water from the Hardap Dam. The /Ai-/Ais Hot Springs Resort depends on a shallow alluvial aquifer in the Fish River for most of their water requirements.

Fishing from the pools provides an important and affordable source of protein for, especially, the poorer communities living close to it, e.g. in Snyfontein and Gibeon, as well as for farm workers and other labourers working in the area. Fishing takes place year round, except at high flows, from the river and pools. The pools are also used as watering points for livestock and banks provide valuable grazing, especially during dry times.

Some, albeit limited harvesting of reeds takes place for handicrafts. Wood is the main source of energy for cooking in the area and the river is the main source of this wood. Other resources harvested include veld foods and medicines. Sand is quarried intermittently along the river at varying scales, for example at Seeheim. Cultivation in the area is limited to small household gardens and bana grass along the river banks for fodder.

Extensive small-stock farming supplemented with hunting traditionally on freehold land downstream of Neckartal Dam to /Ai-/Ais Richtersveld Transfrontier Park boundary. Increasingly however, land use is moving over to landscape-based tourism, especially further south. With regard to recreational use, local residents partake in picnicking, swimming and fishing at settlements along the river.

Hardap irrigation scheme, Gibeon and the /Ai-/Ais Hot Springs Resort were identified as contributing to the pollution in the river in the form of untreated sewage and agro-chemicals. Blackfly larvae were noted in the river at the bridge between Tses and Berseba. Flow of the river, as well as reed beds that have become established, provide important purification services. Reducing flow of the river, as well as large-scale removal of reeds such as the spraying operation below Hardap, will negatively affect these services.

8.3.2 Orange River downstream of the Fish River confluence

Because of the aridity of the area, population densities are low. Population densities would be even lower, were it not for mining. Significant socio-economic features of the river include the following:

- The /Ai-/Ais Richtersveld Trans-Frontier Park with associated infrastructure in close proximity to the river.
- A series of mining operations either alongside the river or drawing on river resources. These include the Trans Hex Operations, Baken, Rosh Pinah and Daberas. Most are large scale operations but there are a number of new small-scale operations reworking old mine dumps.
- The Sendlingsdrift Border Post and associated settlement.
- The Brandkaros Alexcor development with associated agricultural business. This has been closed down for the last few years, the campsite and chalets were locked and all the orchards have died. Over the last twelve months, a few hectares have been planted out with luserne and the campsite has reopened.
- The town of Sanddrift associated with the mining operations.
- The Grootderm settlement – located just upstream of the estuary. All economic activity here has ceased, school and shops closed town and most of the populace have left.

Because population densities are low, the utilisation of natural resources is relatively insignificant. However, there is some degree of reliance on natural resources by people of Nama descent and by other people who are resident in the area. Interviews revealed that the Orange River and its resources are used, to a limited extent, for the following:

- fishing – recreation, but also subsistence;

- gathering of sedges and reeds, as well as timber and firewood;
- grazing;
- hunting.

Representatives of the Nama communities who were interviewed indicated that fishing is an important source of subsistence. It was reported that fishing may be the primary source of income for a small number of individuals and families. Fishing takes place throughout the year, but venturing into the river during months of high flows is believed to be dangerous. Fishing gear is mostly confined to rods and hand-lines but traps and gillnets are also used.

Reeds (*Phragmites australis*) are harvested from the river banks to construct traditional *matjieshuise* (or *haru oms* in Nama). In the informal settlement areas many of these huts form the primary residential structures. Reeds are also used to make floor mats and sleeping mats. Sedges such as *Cyperus marginatus* are available but are only used to a very limited extent.

The riparian zone is also used for grazing and browsing by livestock. *Cynodon dactylon* is one of the important species for grazing in this river stretch. There appears to be an increase in utilisation of the area by goats, particularly of *Seasia pendulina*, *Diospuros lyceoides* and *Acacia karroo*. *Tamarix usneoides* is an indigenous plant species that is used by cattle and small game as a natural salt lick.

In terms of cultural services, tourism is important. The Orange River is a central feature of the /Ai-/Ais Richtersveld Transfrontier Park, which is an important tourist destination. The presence of the /Ai-/Ais Richtersveld Transfrontier Park and its unique position within an Arid Biodiversity Hotspot on Earth makes it an attractive tourist destination. The Orange River is a key feature of the park, and is used for canoeing, rafting, swimming, fishing as well as contributing to the aesthetic value of the landscape. It is also important for nature-based activities such as bird watching.

Other cultural services include ritual use which is of low magnitude given the low densities of people. The significance of ritual use is however high and the Orange River occupies a central place as a feature in people's lives. Purification rituals were mentioned as of particular importance with respect to the river. The river also plays an important role in local mythologies.

The river has waste assimilation and dilution attributes linked closely to baseflows and flooding. In the study area the impacts associated with upstream farming are evident, as are some mining-related water quality issues. Outbreaks of cyanobacteria, have been reported in recent years.

8.3.3 Orange Estuary

The estuary forms the western part of the boundary between Namibia and South Africa. There are two small towns adjacent to the estuary i.e. Oranjemund in Namibia, and Alexander Bay in South Africa. These two towns, which both exist by virtue of the diamond mining activities along the Namibian and South African coasts, are linked by a bridge that spans the estuary near its head.

The estuary offers provisioning services in the form of sand, pebbles, fish, game, grazing and plant resources such as *Phragmites* reeds. With the possible exception of fish, grazing and illegal dog-hunting, there is currently little demand for these services, and hence they have low value.

There is no legal commercial fishery on the estuary but illegal gillnetting does take place. It appears that very little use is made of the estuary for recreational purposes although easier boat access may change this. Marine shore-angling at the river mouth area, both into the estuary and surfzone, is more popular than angling in the estuary proper. Participants comprise anglers from within the settlements of Alexander Bay and Oranjemund as well as a substantial number from beyond the local community. Both settlements have angling clubs which, apart from catching fish, are also important from a social perspective. The magnitude and spatial and temporal distribution of angling effort has shifted according to changes in fishing and environmental management measures by both the Namibian and South African authorities. Implementation of cross-border bag-limits by the Namibian government saw effort displacement to the Northern Cape coast, especially the mouth of the Orange Estuary. Shore-angling effort is strongly seasonal with peaks during floods and high flows and corresponding aggregations of kob and steenbras. The level of sophistication is quite high with anglers co-ordinating their trips according to flow reports from dams in the upper catchment. Catches may be exceptionally high and the popularity of the venue is enhanced by the virtual absence of any fisheries law enforcement. On the other hand, the prohibition on offroad vehicles on beaches as well as the removal of the causeway that provided access to the beach, reduced fishing effort on the South African side. This situation is set to change as the SA Department of Environmental Affairs and Tourism has provided a concession to the Richtersveld Community to operate a boom and charge offroad vehicle users for access to the beach on the South African side. Fishing effort on the Namibian side has remained unchanged and is still relatively high compared to effort elsewhere on the west coast. Fishing regulations such as bag and size limits differ between the two countries, even though anglers are fishing in the same waters at the Orange River mouth.

The estuary also attracts visitors who come to see the river mouth, or for bird watching. The river mouth in itself is an impressive site, particularly with its setting in a desert landscape.

Regulating services provided by estuaries typically include nursery functions for species utilised in fisheries beyond the estuary, exports of nutrients and sediments, water treatment functions and carbon sequestration. The level of carbon sequestration is dependent on the plant growth forms in the estuary, and their extent and productivity and carbon sequestration of saltmarshes in temperate regions is important. If the saltmarsh in the Orange Estuary was rehabilitated, carbon sequestration would likely once again become a significant function of the Orange Estuary.

The Orange Estuary is thought to be particularly important as a nursery area since it is one of only four permanently open systems on the west coast of South Africa, accounting for about one third of the estuarine area. The next estuary north of the Orange River is the Cunene in northern Namibia. Furthermore, the high diversity and abundance of estuarine dependant and marine species suggests that the Orange Estuary is a more important nursery area than was previously thought. It is also an important coastal waypoint, aggregation area and temperature refuge for exploited nomadic fish species such as kob moving back and forth between Namibian and South African waters.

8.3.4 Nearshore marine environment

Rivers carry nutrients from their catchments which they discharge into the marine zone. Sediment outputs from rivers can play an important role in maintaining benthic habitats offshore, which has knock-on effects for demersal (bottom dwelling) fisheries. The continental shelf offshore of the mouth of the Orange Estuary is thought to be a critical nursery area for several fish stocks that make up a large proportion of the value of commercial fisheries in South Africa. Juvenile anchovy *Engraulis encrasicolus*, a mainstay of the pelagic industry utilise the turbidity plume as a nursery whereas west coast sole *Austroglossus microlepis* distribution and abundance varies according to the amount and type of sediment discharged from the catchment. Although their importance is indisputable, these linkages are not well understood.

8.4 Consequences of scenarios (Orange River and Estuary) and release options (Fish River) on the ecosystem services

Scenarios were evaluated in terms of their potential impacts on the supply of ecosystem services, and the value or benefits derived from these. The assessment was based on expert opinion of the direction and approximate magnitude of changes (for example, no change = 1; a 50% increase = 1.5; and a 20% decrease = 0,8). The estimates for this assessment were based on estimates of ecosystem changes made by ecological experts.

8.4.1 Fish River ecosystem services consequences

The ROs consist of a range of environmental flow releases from 0% release of the inflow to an environmental release of 50% of the inflow. Only RO 40% and 50% were considered to have sufficiently low negative impacts to be acceptable. These consequences are summarised per ecosystem service in Table 20. The colours refer to the following:

- Red denotes a scenario with an overall negative impact with a substantial/moderate implication for either the significance or the magnitude of ecosystems services.
- Orange denotes a scenario with an overall negative impact with a minor implication for either the significance or the magnitude of ecosystems services.
- Light green denotes a scenario with status quo maintained or an overall positive impact with a minor implication for either the significance or the magnitude of ecosystems services.
- Dark green denotes a scenario with an overall positive impact with a substantial/moderate implication for either the significance or the magnitude of ecosystems services.

Table 20. Summary of the consequences of release options on the Fish River ecosystem services

Services values	***Description***	***Release option***				
		0%	***20%***	***30%***	***40%***	***50%***
Harvested resources	Fish, reeds, riparian foods, medicines					
Grazing	Important in dry periods					
Recreational	Swimming, picnicking					
Nature-based tourism	Important in lower reach					
Water quality amelioration	Pollution (irrigation return flows, waste water from settlements)					
Pest control	Control of black fly larvae					

8.4.2 Orange River ecosystem services consequences

The impacts of Sc OF 2 and OF 3 were similar, although they differed by the inclusion of a recommended EFR release from the Neckartal Dam, and were generally low. Scenarios OF 6 and OF 7 included the Polihali, Vioolsdrift and Boskraai Dams. Although scenario OF 6 included more irrigation development, the impacts of these two scenarios were also similar, and in this case were considered to be severe and unacceptable. The consequences are summarised in Table 21.

Table 21. Summary of the consequences of release options on the Orange River ecosystem services

Services Values	***Description***	***Scenarios***		
		OF 2 –5, 8	***OF 6***	***OF 7***
Harvested resources	Limited number of people (important)			
Grazing	Limited number of people (important)			
Recreational	Limited number of people (important)			
Nature-based tourism	Associated with Orange River and Park			
Water quality amelioration	Upstream pollutants			
Pest control	Control of black fly			

8.4.3 Orange Estuary and nearshore marine ecosystem services consequences

Impacts of Sc OF 2, OF 3 and OF 4 are relatively small, and the values of the services involved are small. Scenario OF 4 has a negligible impact if not a slight improvement in value. Impacts are slightly greater under Sc OF 5, and are significant under Sc OF 6 and OF 7. Because the value of sediment exports to the marine environment is unknown and could be high, the latter scenarios also pose an unacceptable level of risk. The consequences are summarised in Table 22.

Table 22. Summary of the consequences of release options on the Orange Estuary ecosystem services

Services/values	***Description***	***Sc2, 3***	***Sc4***	***Sc 5***	***Sc6***	***Sc 4+anth****
Harvested resources	Negligible.					
Grazing	Small herd supported.					
Recreation	Moderate value.					
Nature-based tourism	Small value in the order of <ZAR 1m.					
Water quality amelioration	Negligible value.					
Export of nutrients	Small localised value in inshore environments.					
Export of sediments	Low value due to human influence.					
Nursery function	Contributes about ZAR 7.5m of the value of Western Cape fisheries.					

* Sc 4 plus anthropogenic measures.

9. Monitoring programme

9.1 Introduction

The objectives on the proposed monitoring programme for the Fish and Orange rivers and the Orange Estuary were to:

- set ecological specifications (EcoSpecs) and thresholds of potential concern (TPCs) for rivers and the estuary;
- provide a river monitoring programme;
- update the design of the existing Orange Estuary monitoring programme with the findings of this study.

9.2 Method

As part of the broader research project, EFRs that would maintain the individual river reaches and estuary in particular ecological states, termed the EC, were defined. Monitoring the ecological responses allows the predictions made during an EFR study to be tested.

Ecological water resources monitoring (EWRM) more specifically involves the measurement of EcoSpecs to determine whether the EC is attained (Kleynhans et al., 2009). EcoSpecs must be quantifiable, measurable, verifiable and enforceable, and ensure protection of all components of the resource that make up ecological integrity. In addition, TPCs are set as upper and lower levels of change for selected environmental indicators. These are used to prompt an assessment of the causes of the extent of change, which in turn provides the basis for deciding whether management actions are needed or if the TPC needs to be recalibrated.

EWRM should be undertaken within a structured framework following the principles of adaptive management. This will provide a decision framework within which monitoring results can be interpreted in terms of the attainment of objectives set for the condition and integrity of the resource. The design of a cost-effective monitoring programme for the rivers is based on different levels of monitoring.

- Level 1: Desktop approaches at a high frequency (e.g. annually).
- Level 2: Surveys and specialist analysis at low frequency (e.g. every three years).

9.3 Fish and Orange rivers ecological specifications and thresholds of potential concern

The PES and REC determined at the different EFR sites provide the broad, qualitative EcoSpecs for each component (see Tables 23 –25). The objectives to improve the PES to the REC are provided in the last column.

Since EFR Fish 1 is situated upstream of Neckartal Dam, it is in the ideal position to serve as a monitoring control site, providing operation of Hardap Dam does not change from the present. The purpose of the control site would be to aid in the interpretation of monitoring results obtained at EFR Fish 2 and in the determination of the causes and source of changes from the baseline. As this is a control site, only the PES is representative of the baseline.

Table 23. EFR Fish 1: EcoSpecs as ecological categories

Components	***PES***
Physico-chemical	C
Geomorphology	B/C
Fish	B
Macro-invertebrates	C
Instream	**B/C**
Riparian vegetation	B/C
Riverine fauna	B
EcoStatus	**B/C**

Table 24. EFR Fish 2: EcoSpecs as ecological categories

Components	***PES***	***REC***	***Objectives to achieve the REC***
Physico-chemical	C	C	
Geomorphology	B/C	B/C	No improvement necessary as the floods cannot be provided.
Fish	B	B	Already in a B PES; no improvement required.
Macro-invertebrates	B	B	Already in a B PES; no improvement required.
Instream	**B**	**B**	Already in a B PES; no improvement required.
Riparian vegetation	C	C+[1]	The floods cannot be provided. The only issue that can be addressed is non-flow related, i.e. addressing the overgrazing by goats. This would only improve the vegetation within the C category
Riverine fauna	B	B	Already in a B PES; no improvement required.
EcoStatus	**C**	**C+**	**The only improvement that can be made within the EcoStatus category is non-flow related, i.e. controlling grazing (goats) and only relevant for riparian vegetation. All other EcoSpecs therefore will describe the ECs for the PES.**

Table 25. EFR O5: EcoSpecs as ecological categories

Components	PES	REC	Objectives to achieve the REC
Physico-chemical	C	C	
Geomorphology	B/C	B	
Fish	B/C	B	Improve wet season baseflow and reinstate droughts.
Macro-invertebrates	B/C	B	Improve wet season baseflow and reinstate droughts.
Instream	**B/C**	**B**	Improve wet season baseflow and reinstate droughts.
Riparian vegetation	B/C	B	Improve wet season baseflow, control alien vegetation and grazing.
Riverine fauna	B	B	Already in a B PES; no improvement required
EcoStatus	**B/C**	**B**	**The key improvement is flow-related, i.e. improving the wet season baseflows and reinstating droughts. Water quality improvements required for the estuary will have a positive effect on the river. Control of alien vegetation and grazing, although difficult, will also benefit the river.**

Quantitative (frequency and timing) and measurable EcoSpecs and TPCs are provided for the PES for various components (e.g. geomorphology, water quality, riparian vegetation, fish and macro-invertebrates), and their respective indicator species, guilds or habitats in the Technical Report 35. These were based on the baseline survey undertaken mainly during June 2012.

9.4 River monitoring programmes

9.4.1 Fish River: Level 1 and 2

The monitoring programmes are summarised in Table 26 and 27.

Table 26. Fish River: Level 1 monitoring programme

Indicator	Monitoring action	Temporal scale (frequency and timing)	Spatial scale
Geomorphology			
Presence of pools	Map the area of full pools either by using aerial, Google Earth, satellite imagery or with handheld GPS on site (see detail actions required below the table).	Annually: Nov or Dec.	EFR Fish 1 EFR Fish 2
Water quality and diatoms (described in chapter 5)			
Salinity/dissolved oxygen/temperature	Install loggers in pools that will measure these variables. Collect data.	Continuous. Collect data for analysis every month.	EFR Fish 1 EFR Fish 2 New site: EFR Fish Ai-Ais
All variables measured as part of the ESIA[1]	Existing monitoring to be continued (assumption).	Three monthly.	Existing sites[2]: SW1, SW2, SW3, SW4 New site: EFR

Indicator	*Monitoring action*	*Temporal scale (frequency and timing)*	*Spatial scale*
			Fish Ai-Ais
If the ESIA programme is discontinued, the alternative is the following:			
pH, Electrical Conductivity, nitrate-N, nitrite-N, ammonium-N, phosphate-P, metal ICP (inductively coupled plasma) spectrometric scan	Measure water quality variables.	Three monthly.	Existing sites[2]: SW1, SW2, SW3, SW4 New site: EFR Fish Ai-Ais
Diatoms	Field work linked to water quality measurements.	Six monthly.	EFR Fish 1 EFR Fish 2 EFR Fish Ai-Ais
Riparian vegetation			
Woody vegetation	Aerial photograph. Fixed point photos (linked to alternative geomorphological monitoring which requires a site visit).	Annually.	EFR Fish 1 EFR Fish 2
Reeds	As above.	Annually.	EFR Fish 1 EFR Fish 2
Alien vegetation	As above.	Annually.	EFR Fish 1 EFR Fish 2
Macro-invertebrates			
Gomphid larvae	Visual assessment[3] for use by regulatory agencies.	Annually.	EFR Fish 2

1 Environmental and social impact assessment undertaken for Neckartal Dam
2 Existing water quality site names: See Technical Report 28 for map and description of water quality measuring sites.
3 Refer to Technical Report 35, Appendix A.

Table 27. Fish River: Level 2 monitoring programme

Indicator	*Monitoring action*	*Temporal scale (frequency and timing)*	*Spatial scale*
Geomorphology			
Size and depth of pools	Resurvey of hydraulic cross-sections.	5–10 years (low priority).	EFR Fish 1 EFR Fish 2
Riparian vegetation			
Woody vegetation	Fixed point photos, field assessments.	Every three years.	EFR Fish 2
Reeds	Fixed point photos, field assessments.	Every three years.	EFR Fish 2
Alien vegetation	Fixed point photos, field assessments.	Every three years.	EFR Fish 2
Population structure	Field assessment.	Every three years.	EFR Fish 2
Fish			
Labeobarbus aeneus, *L.*	Field assessment (electrofishing).	Every three years, dry	EFR Fish 2 (key)

Indicator	Monitoring action	Temporal scale (frequency and timing)	Spatial scale
kimberleyensis, *Labeo capensis*, *L. umbratus*, *Clarias gariepinus*, *Barbus paludinosus*, and *Oreochromis mossambicus*		season (same month as baseline).	EFR Fish 1 EFR Fish Ai-Ais
Macro-invertebrates			
Composition and abundance	Field assessment (NASS2[1]) (low priority).	Every three years. Within three months of a high flow event.	EFR Fish 2

1 Namibian Scoring System version 2.

9.4.2 Orange River level 1 and 2

The monitoring programmes are summarised in the following Tables 16 and 17.

Table 28. Orange River: Level 1 monitoring (water quality and diatoms) programme

Indicator	Monitoring action	Temporal scale (frequency and timing)	Spatial scale
All variables measured as standard by DWA[1].	Improve frequency and include in formal monitoring programme.	Monthly, or determined by monitoring programme.	D8H012Q01 gauging weir
All variables measured as standard by DWA as well variable for RHP[2]	Install additional logger for RHP.	Continuous.	At the new DWA gauge at Sendelingsdrift
Diatoms	Field work (recommendation to incorporate park rangers to collect data).	Six monthly.	EFR O5

1 Department Water Affairs, South Africa.
2 River Health Programme.

Table 29. Orange River: Level 2 monitoring programme

Indicator	Monitoring action	Temporal scale (frequency and timing)	Spatial scale
Geomorphology			
Channel pattern (planform) (low priority)	Assessment of aerial photographs or high resolution satellite imagery.	Every five years.	EFR O5
Active channel size (very low priority)	Resurvey of the hydraulic cross-sections at each EFR site.	When triggered by other indicators.	EFR O5
Riparian vegetation			
Woody vegetation	Field assessments.	Every three years.	EFR O5
Reeds	Field assessments.	Every three years.	EFR O5
Alien vegetation	Field assessments.	Every three years.	EFR O5

Indicator	*Monitoring action*	*Temporal scale (frequency and timing)*	*Spatial scale*
Sedges	Field assessments.	Every three years.	EFR O5
Population structure	Field assessment.	Every three years.	EFR O5
Fish			
L. aeneus, *L. kimberleyensis*, *L. capensis*, *L. umbratus*, *C. gariepinus*, *B. paludinosus*, *Austroglanis sclateri*, *B. hospes*, *B. trimaculatus*, *Mesobola brevianalis*, *Pseudocrenilabrus philander*, *O. mossambicus*, and *Tilapia sparrmanii*	Field assessment (electrofishing).	Every three years (dry season, same as baseline).	EFR O5 and other sites in the MRU
Macro-invertebrates			
Composition and abundance	Field assessment (SASS5[1]) (high priority).	Every three years.	EFR O5

1 South African Scoring System version 5.

9.5 Orange Estuary ecological specifications and thresholds of potential concern

The EcoSpecs and TPCs for the Orange Estuary are based on a REC of a C to meet Ramsar criteria and protected area status requirements. The broad, qualitative EcoSpecs for the Orange Estuary are shown in Table 30.

Table 30. EcoSpecs as ecological categories at Orange Estuary

Components	PES	REC	Objectives to achieve the REC
Hydrology	D	D	Decrease baseflows in winter (reinstate droughts).
Hydrodynamics	C	B	Facilitate mouth closure in winter two to four times in 10 years.
Water quality	D	C	Reduce nutrient input in lower Orange River.
Physical habitat	**B**	**B**	Already in a B PES; no improvement required.
Microalgae	E	D	Reduce baseflows in winter and decrease nutrient input.
Macrophytes	D	C	Reduce soil salinities, reduce nutrient input, remove cause way, control grazing and alien vegetation.
Invertebrates	D	B	Reduce baseflows in winter and facilitate mouth closure.
Fish	D	C	Reduce baseflows in winter and facilitate mouth closure, control fishing.
Birds	E	D	Reduce baseflows in winter and facilitate mouth closure.
EcoStatus	**D**	**C**	**Reduce flows, facilitate mouth closure, improve vegetation cover and food sources (invertebrates and fish).**

9.6 Orange Estuary monitoring programme

The monitoring programme is summarised in Table 31.

Table 31. Orange Estuary monitoring programme

Indicator	*Monitoring action*	*Temporal scale*	*Spatial scale*
Hydrology	Measure freshwater inflow into the estuary.	Continuous.	Vioolsdrift (D8H003) and Brand Kaross
Hydrodynamics	Record water levels in the estuary.	Continuous.	At bridge and mouth
Hydrodynamics	Aerial/satellite photographs of estuary (preferably on spring low tide).	Every three years.	Entire estuary up to Brand Kaross
Sediment dynamics	Bathymetric surveys, sediment grab samples.	Every three years.	Entire estuary
Water quality	Conductivity, temperature, turbidity, dissolved oxygen, pH, inorganic nutrients and organic content.	Monthly continuous.	At river inflow
	Longitudinal salinity and temperature profiles.	Seasonally, every year.	Entire estuary
	Longitudinal water quality measurements of system variables and inorganic nutrients.	Seasonal surveys, every three years.	Entire estuary
Microalgae	Phytoplankton: Water column chl-a measurements.	Survey during normal flows.	Entire estuary
	Benthic microalgae: Intertidal and subtidal benthic chl-a measurements.		
Macrophytes	Survey main channel to assess status of macroalgae and submerged macrophytes. Ground-truthed vegetation maps. Assess extent of invasive species. Record plant cover, sediment salinity and sediment moisture content at three transects. Depth to water table and ground water salinity in supratidal marsh.	Summer survey every three years.	Entire estuary
Invertebrates	Record species and abundance of zooplankton and benthic invertebrate species.	Summer and winter survey every three years.	Entire estuary
Fish	Record species, abundance and size composition of fish, based on seine-net and gill net sampling.	Summer and winter survey every three years.	Entire estuary
Birds	Full count of all water-associated birds, covering as much of the estuarine area as possible, from a boat and on foot (this is also part of the requirements of Ramsar).	Summer and winter survey every year.	Entire estuary

10. Conclusions

The conclusions focus on the implications of different scenarios on the ecological state and the ecosystem services. The impact on yield was also considered as well as whether there are any additional scenarios that can be investigated to minimise impacts.

10.1 Fish River

The Fish River PES ranges from a B/C to a C ecological category at the three sites. The major issues are the change in flow regime from Hardap Dam, water quality problems, and (specific to Seeheim), overgrazing by goats. The importance is high due to, amongst others, the presence of Red Data species, the importance of the riparian vegetation and pools as a refuge and critical habitat and, in the lower Fish River, the presence of the /Ai-/Ais-Richtersveld Transfrontier Park.

The high importance could warrant recommendations to improve the PES. This improvement is however not possible without EFR releases from Hardap Dam, and/or large flood releases from Neckartal Dam. Large flood releases from Neckartal Dam will not be possible due to the constraints on outlet size. Considering the issues and practicalities, the realistic aim is to maintain the PES after the construction of Neckartal Dam. Some localised improvement by addressing the anthropogenic issues at source (i.e. water quality and over grazing) might be possible.

A range of EFR release options (release relates to a percentage of the inflow that is released up to a maximum of a 100 m^3/s (size of the outlet)) from Neckartal Dam was evaluated. These percentages represent 0, 10, 20, 30, 40 and 50% environmental releases as a percentage of inflow to the dam. Only the 40 and 50% release option (RO) maintained the PES and the ecological recommendation would therefore be to implement the 50% environmental release.

As the RO 40 and 50% would have a significant impact on the yield of Neckartal Dam, an optimised RO (RO Opt) that will minimise the impacts on both the yield and the ecological status was investigated. The RO 30% has significantly less impact on yield and would therefore be more preferable from a water resources perspective. It was also noted that during certain times of the year, the 30% RO results in minimal impact on the ecological state. An optimised RO should therefore be a combination between RO 30% and RO 40%. The RO Opt entails releasing 40% of the inflow while the storage in the dam is above 60% of its full supply capacity dropping to 30% of the inflow should the storage in the dam drop below 60% of full capacity.

The evaluation of the RO Opt indicated that it has an even higher risk that the ecological objectives (i.e. the PES) would not be met than under RO 40%. However, as the yield was a significant improvement from RO 40%, this release option would represent the recommended EFR from Neckartal Dam and represent the Fish River driver in the scenarios.

The impact on the ecosystem services of the RO opt was evaluated and the conclusion was that the current level of ecosystem services will not be impacted on.

10.2 Orange River

The Orange River PES is a B/C at EFR O5. The major issues are the change in flow regime (key issue) and water quality problems. The importance is high due to, amongst others, the presence of Red Data species and the /Ai-/Ais-Richtersveld Transfrontier Park. The aims for flow requirements to improve the state to at least a B ecological category would require an improved flow regime with higher low (base) flows in summer and lower flows during the dry season, especially during drought times.

None of the scenarios that did not include the release of the EFR met the REC or the PES. Taking into consideration the ecological consequences results of the estuary EFR (see section 10.3), an optimised scenario referred to as Sc 9 (Table 32) was developed which supplied the EFR at EFR O5 and attempted to achieve the ecological objectives (C ecological category) at the estuary (see section 10.3). Scenario OF 4 was most likely to achieve the ecological objectives at the estuary, but it excluded future options such as Polihali Dam (Sc OF 5). Scenario OF 9 is therefore a deviation from Sc OF 5 in that it includes the EFR for EFR O5 as well as operating rules that were adjusted to limit flows to achieve the estuary requirements. Scenario OF 9 therefore represents the scenario with the least impact on yield and users as well as maintaining the PES and possibly achieving the REC at EFR O5. Achieving the REC will however depend whether sufficient floods can be released from (e.g.) Vioolsdrift Dam to mitigate the impact of the development of an increasing number of dams upstream.

The impact on the ecosystem services of Sc OF 9 was evaluated and the conclusion was that the current level of ecosystem services will not be impacted on.

Table 32 Sc OF 9 drivers

	Orange River drivers										**Fish River drivers**		
Scenario	**Metolong Dam**	**AMD treated**	**EFR flows**	**Optimised releases**	**Tandjieskoppe**	**Additional Namibian irrigation**	**Polihali Dam**	**Vioolsdrift balancing dam**	**Vioolsdrift large dam**	**Boskraai Dam**	**Neckartal Dam**	**Neckartal with REC EFR**	**Increased Naute irrigation**
Sc OF 4	Yes	Yes	2010	Yes	Yes							Yes	Yes
Sc OF 5	Yes	Yes	2010	Yes	Yes		Yes	Yes				Yes	Yes
Sc OF 9	Yes	Yes	2013	Yes	Yes		Yes	Yes				Yes	Yes

10.3 Orange Estuary

The Orange Estuary is estimated to be 51% similar to natural condition, which translates into a largely modified system with a PES of a D ecological category. Its present condition is mostly attributed to the following factors:

- significant freshwater flow modification (both loss of floods and increased baseflows);
- lack of estuary mouth closure and resulting back flooding of saltmarshes with fresher water;
- road infrastructure in the form of the old causeway crossing the saltmarshes and old bridge crossings;
- nutrient input from the catchment downstream of Vioolsdrift;
- gill netting of indigenous fish species and considerable fishing effort at the mouth on both sides of the estuary;
- riparian infrastructure - levees preventing back flooding;
- mining activities; and
- wastewater disposal (sewage and mining return flow); and
- grazing and hunting.

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 also 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 also 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’ and in the process of being declared a formal protected area on both the South African and Namibian side. Thus the REC for the estuary is an A or it’s best attainable state which is estimated as an ecological category C.

A scenario was therefore developed (Sc OF 9) which aimed at meeting the best attainable state of a C. This scenario must include the reduction of winter flows to below 2 m^3/s for one to two months in winter two to four times in 10 years to allow for mouth closure and related back flooding of saltmarshes.

Evaluation of this scenario indicated that while it can achieve a C/D rating through the manipulations of the baseflow regime (reinstitute mouth closure), it needs a number of non-flow related management intervention to improve to the desired C ecological category. The degree to which the Orange Estuary will recover is therefore strongly dependent on the commitment of local authorities and stakeholders to addressing the non-flow related issues.

Ecological benefits that will be derived from a C category include:

- a more natural mouth state, with closure occurring from time to time (two to four times a decade);
- improved water quality and related decrease in reed and microalgae growth;
- reversing the decline in the state of the saltmarshes;
- increasing the diversity and abundance of the estuarine invertebrates and over-exploited fish in the estuary.

Therefore the optimised EFR is Sc OF 9 in conjunction with the recommended remedial measures outlined below.

- 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.

It should be noted, however, that some of these proposed mitigation measures, such as the reduction in fishing pressure, would be difficult to achieve in the short-term. It is therefore strongly recommended that the estuary management plan currently being developed for the Orange Estuary prioritise these actions for future implementation. It is also recommended that the management plan proactively addresses potential issues stemming from estuary mouth closure:

- Determining the water level (relative to mean sea level) at which critical infrastructure and developments will be inundated if mouth closure occurs (e.g. by means of a Lidar survey of both South African and Namibian estuary floodplains);
- Investigating the protection of the aforementioned infrastructure (e.g. golf course on the Namibian side);
- Development of a mouth breaching protocol based on 'Guidelines for the mouth management of the Orange Estuary' (Van Niekerk and Huizinga, 2005);
- monitoring of water quality during the closed period.

10.4 Orange River, Fish River and Orange Estuary

As a final conclusion, the scenarios were considered at all three systems to enable integrated recommendations to be made in a systems context (Table 33).

Table 33. Summarised consequences of scenarios

Time frame	*Sc*	*Estuary*	*Orange River*	*Fish River*
Present day (PES)	REC	C	B	C
	1	D	C	C
2013 - 2020	2	D	C	D – E
	3	D	C	C
2020 - 2040	5	D	B – C	C
	9	C/D	B – C	C
	9+anth	C	B – C	C
Post 2040	6 & 7	F	D	D – E
	8	E	C	C

As can be seen from above, Sc OF 9 (accompanied with addressing the recommended anthropogenic measures – Sc 9 +anth) is the only scenario to achieve the REC at the estuary and will also maintain the PES at the Orange River and possibly achieve the REC. The PES at the Fish River will be maintained and there will be a negligible impact on the river and estuary ecosystem services. Some small reduction is expected in the nearshore marine ecosystem services (e.g. sediment and nutrient supply to the sea, demersal fisheries production) if this scenario is achieved through a large dam near the estuary.

11. Recommendations

11.1 Recommendations to improve the present ecological state determination

11.1.1 Fish River

The evaluation of confidence in available information and EcoClassification indicate whether further work is required to improve the predictions regarding ecological status.

Information availability at the EFR sites was generally moderate; although better for EFR Fish 2 due to the recent impact assessment studies undertaken for the Neckartal Dam development. EcoClassification results for EFR Fish 1 and EFR Fish 2 were of moderate confidence. EcoClassification results for EFR Fish Ai-Ais were the lowest because surveys were less intensive than at the main (key) EFR sites.

In general, the main problem with confidence was the lack of historical data on biota (required to determine reference conditions) and measured hydrology (pre Hardap Dam). This will, however, have limited consequences on the ability to evaluate flow regimes, which is mainly dependent on an understanding of the flow requirements of indicator species and their response to an altered flow regime. No further work is therefore required to refine the reference conditions and hence improve the PES as this would be impossible without historical data.

11.1.2 Orange River

The confidence in the EcoClassification is generally moderate. Increased confidence will be achieved through monitoring and no other further work is recommended.

11.1.3 Orange Estuary

The confidence in the EcoClassification of the Orange Estuary is moderate. No further work is recommended to revise the PES and all further work should be targeted to improve the baseline, EcoSpecs and TPCs

11.2 Recommendations to improve environmental flow requirement determination

11.2.1 Fish River

The confidences in the EFR determination were generally moderate. No work is required to improve the confidence in the evaluation. As the construction of Neckartal Dam is imminent, the focus in the future should be on monitoring to verify the predicted responses of the altered flow regime and, within an adaptive management framework, to adjust the EcoSpecs and TPCs.

11.2.2 Orange River

Confidence in the low flow hydrology cannot be improved without improved gauged data. A gauging weir at Sendelingsdrift is currently being constructed.

The biophysical response confidence was high and no further work is recommended to improve these requirements. The emphasis of further work should be to test and verify the predicted biophysical responses to a changed flow and quality regime. This will form part of monitoring, EcoSpecs and TPC recommendations.

11.2.3 Orange Estuary

A key constraint in the overall confidence of the EFR is determining the flow range at which the Orange Estuary closes. At present the only recorded mouth closure events occurred between 1993 and 1996. It is therefore critical that the historical low flow estimates be retrospectively refined based on the readings of the new gauging weir at Vioolsdrift.

11.3 Monitoring recommendations

The monitoring programme (chapter 9) was designed according to the principles of adaptive management to provide guidance on how to address issues if the EcoSpecs and TPCs (Rogers and Bestbier, 1997) are exceeded. It is recommended that the monitoring programme be initiated as soon as possible and prior to the construction (with specific reference to disturbance of the river) of Neckartal Dam.

Apart from the general recommendation that the monitoring programme must be implemented as soon as possible, additional work is targeted to:

- improve confidence in the EcoSpecs and TPCs;
- improve the understanding of certain specific issues (such as uncertainty on the sources of nutrient levels) to allow for affective actions during monitoring and within the adaptive management framework.

The further work therefore required is structured according to:

- additional surveys and analyses required to improve the monitoring baseline;
- specific monitoring studies to improve understanding and to update the EcoSpecs and TPCs;
- general monitoring recommendations.

11.3.1 *Additional studies to improve the baseline*

Additional surveys to improve the baseline information is summarised in Table 34.

Table 34. Rivers and estuary: Additional baseline surveys

Component	***Baseline survey***	***Temporal scale***
Rivers		
Water quality	EFR Fish 1 and EFR Fish 2: Additional salinity, dissolved oxygen and temperature measurements to be added to baseline (prior to Neckartal Dam construction). EFR Fish Ai-Ais (new quality site): All water quality measurements.	Continuous
Diatoms	EFR Fish 2: Diatom collection (linked to water quality measurements prior to Neckartal Dam construction).	At least two dry season and wet season sampling.
Fish	All Fish River sites: Electrofishing.	One dry season survey
Estuary		
Hydrology	Determine what the actual discharge was to correlate with historical mouth closure.	1993 – 1996
Hydrodynamics and macrophytes	Lidar survey up to the 5 m mean sea level contour.	Any time
Sediments	Sediment core samples along the entire estuary (10 – 20 m deep).	Once off
	Sample suspended sediment load at Vioolsdrift.	Daily
Invertebrates	Survey to account for the seasons and recruitment.	Seasonal (i.e. quarterly)
Fish	Survey to account for the seasons. Possible additional surveys in surf-zone required.	Seasonal (i.e. quarterly)
Nearshore marine environment		
Sediments	Sample suspended sediment load at Vioolsdrift.	Daily
Remote sensing	Observations on turbidity, salinity, temperature and chlorophyll-a.	Daily
Fish	Small pelagic acoustic surveys on the South African and Namibian coast.	Twice annually (i.e. quarterly)
Invertebrates	Benthic and beach monitoring on both the Namibian and South African side.	Annual (i.e. quarterly)

11.3.2 *Specific monitoring studies*

Specific studies required for better understanding of current issues are:

- Fish River nutrient assessment programme: The aims of such a programme will be to identify the sources of nutrients downstream of Hardap Dam irrigation, to identify hotspots and to establish reference conditions for total inorganic nitrogen (TIN) and phosphate. Sources will be identified by investigating the possibility of nutrient peaks via microbial remineralisation, and checking links between geology and nutrient levels to determine the possible influence of the geology of the area. The TIN and phosphate reference conditions can possibly be identified by monitoring a site upstream of Hardap Dam.

- Estuarine nutrient assessment programme: A comparison between the Vioolsdrift (D8H083Q01) and the Sir Ernest Oppenheimer Bridge (D8H012Q01) water quality stations indicate a significant increase in nutrient input below Vioolsdrift. As irrigated agriculture are predominantly concentrated in three areas along this stretch of the river, it is recommended that a few shallow boreholes be installed and monitored in the banks adjacent to these potential hotspots to attempt to identify the source and/or mechanism of the nutrients. Once the source has been identified, mitigation measures must be developed in consultation with the local famers and an agricultural specialist to reduce the input to the estuary.
- Toxin verification programme in the Orange Estuary: No sampling was done for toxic substances (e.g. trace metals, hydrocarbons, herbicides and pesticides) in the Orange Estuary during this study. It is therefore recommended that sediment samples be collected and analysed for toxic substances (i.e. trace metals, petroleum hydrocarbons, herbicides and pesticides). To assist with the interpretation of results, samples should also be analysed for sediment grain size distribution and organic content. A grid of sediment sampling stations should be selected across the estuary, specifically targeting depositional areas (characterised by finer sediment grain sizes and/or higher organic content).
- Metals verification programme in the rivers: Some metal levels were elevated during particular months of monitoring. The validity and source of these peaks must be investigated

11.3.3 General monitoring recommendations

- The use of the mini-SASS monitoring tool is recommended for more frequent (annual) assessment of conditions in the lower Orange River.
- Water quality loggers should be installed at the new Sendelingsdrift gauging weir to measure temperature, pH, electrical conductivity and dissolved oxygen.

11.4 EFR implementation recommendations

11.4.1 Fish River

The EFR should be implemented from the eminent Neckartal Dam and specific operating rules based on the RO Opt should be developed. To maintain the PES, specific emphasis on the maintenance of the pools is required. Pools are essential refugia and habitat within an ephemeral system. The EFR determination was based on a maximum release from Neckartal Dam of 100 m^3/s. Information has been released after the assessment that the outlet is 140 m^3/s (Mr Harold Koch, pers. comm.). This should be taken into account in the final design of the operating rules

11.4.2 Orange River and Orange Estuary

To achieve the REC (i.e. improve the health of the Orange Estuary) the following mitigation measures are required in the immediate future (i.e. before 2020):

- Decreasing nutrient input from the catchment downstream of Noordoewer/ Vioolsdrift, through improved agricultural practices.
- Removal of the remnant causeway that still transects the saltmarshes to improve circulation during high flow and flood events. This will also assist with increasing the water circulation into the intertidal and lower marsh areas.
- Controlling the fishing effort on both the South African and Namibian side through increased compliance and law enforcement. This also requires the alignment of the fishing regulations (e.g. size and bag limits) and management boundaries on both sides of the transboundary estuary. There also needs to be strict enforcement of the prohibition of gillnetting in the estuary.
- Controlling wind-blown dust and wastewater from mining activities to reduce smothering of saltmarshes.
- Livestock grazing by domestic (and feral) cattle needs to be appropriately managed as it further degrades the saltmashes, competes with the indigenous large herbivores and detract from the tourism potential and compete for valuable grazing resources.
- Alien invasive plants in the floodplain need to be controlled in order to restore the integrity of estuarine vegetation and maintain the meandering nature of the estuary channels. Large strands of alien invasive trees have been establishing themselves on the islands and flood plain in the upper reaches of the estuary after the 2010/11 floods which is in urgent need to intervention.
- Illegal dog-hunting and predation by feral dogs on the floodplain and islands needs to be curtailed.

In the long-term the only way to achieve the REC is to reinstate the dry season and drought flows to allow for mouth closure and related backflooding of the saltmarshes with brackish water to reduce soil salinities. One of the options to achieve this is the construction of a new dam at Vioolsdrift that will increase the storage in the lower Orange River. This option was incorporated in the recommended Sc OF 9, but it should be noted that Sc OF 9 will effectively only come in place between 2020 and 2040.

Therefore, regardless of which infrastructure option is pursued in the future, it is strongly recommend that the option of incrementally decreasing the baseflows in the dry season to the estuary be investigated, following an adaptive monitoring and management approach. During these periods of low flow, the water levels (increases in the low tide levels) in the estuary should be evaluated to see if there is any indication of mouth closure.

11.4.3 Nearshore marine environment

The main focus of the nearshore marine study was to establish if there is ecological connectivity between the Orange River and the sea. The work done as part of this study shows a clear link between the sediments being transported by the Orange Estuary and the nearshore marine habitat adjacent to the Orange Estuary. This in turn is driving a range of biological responses, e.g. increased fisheries production. However, the exact nature and strength of the dependencies would require intensive research into the future. Key aspects that needs investigation include studies in changes in trophic interactions (e.g. gurnard/sole predator interactions), dedicated satellite imagery studies to investigate long term effects of floods on the nearshore environment, and extending the ocean tracking network in southern Africa to include the marine environment adjacent to the mouth of the Orange Estuary (acoustic array that currently only Mozambique to Cape Point).

The Namibian and South African legislative framework make provision for the sustainable management of their biodiversity and fisheries in the context of their respective international biodiversity commitments. Thus said, at present both the Namibian and South African National Water acts are silent on the freshwater requirements of the nearshore marine environment. There is therefore no legal requirement to provide an EFR to the sea. In order to achieve the first, it is recommended that the various national frameworks and policies that regulate water resource management in these two countries be reviewed to address this aspect.

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