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Governments of Botswana, Lesotho, Namibia and South Africa

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Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth

Volume 1: Determination of Fish River EFR

Technical Report 27
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Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth

Volume 1: Determination of Fish River EFR

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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 Management Resource Units, Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth
26	Consequences of Flow 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 3: 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 4: Lower Orange River EFR, Supporting Information Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth
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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

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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
37	Summary Report, Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth

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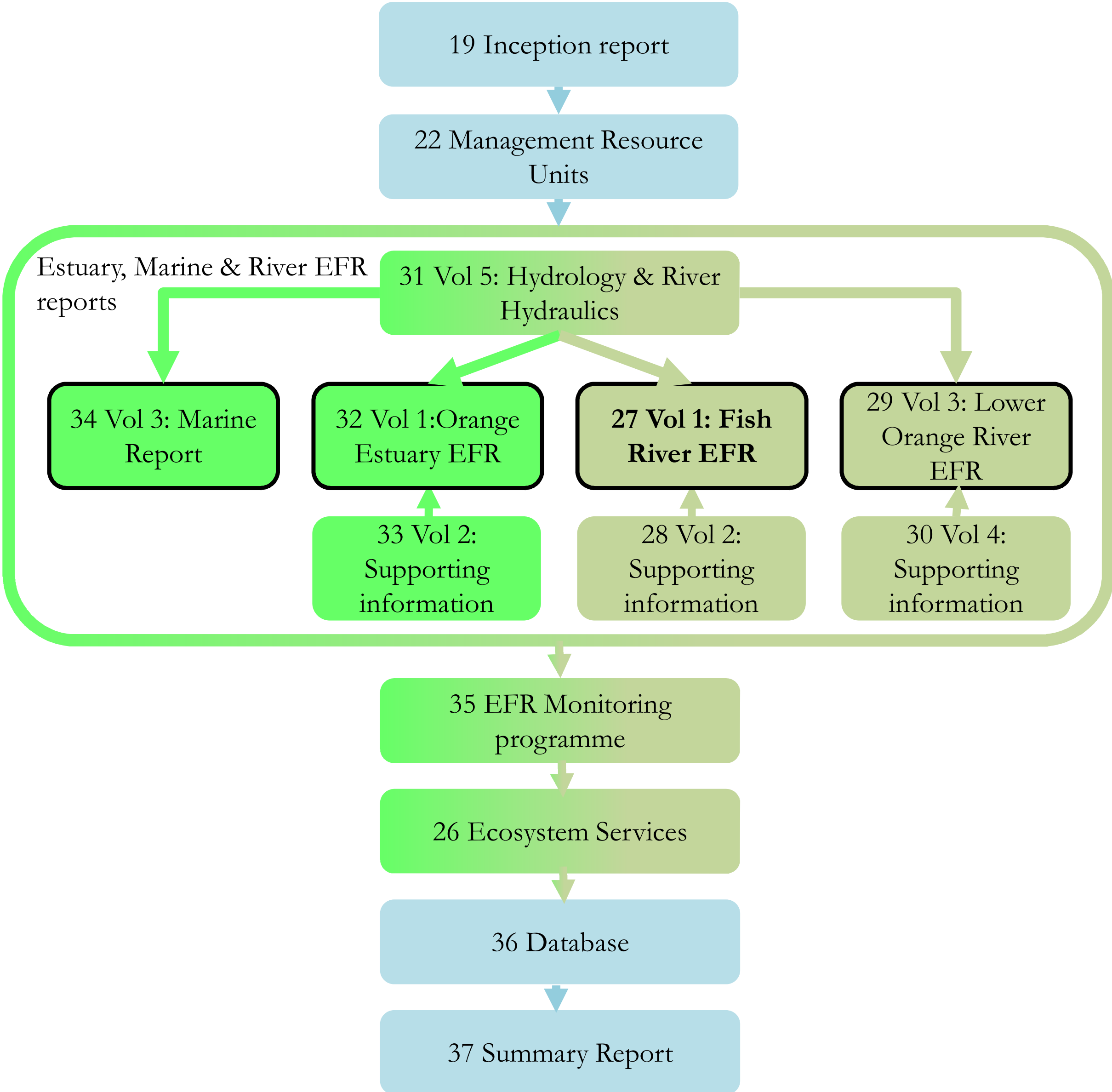
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Executive Summary

Background

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 (ORASECOM, 2012). This report focuses on the Fish River in Namibia.

The objectives of this Fish River EFR study were to:

- Develop Environmental Flow Requirement (EFR) methodologies with specific emphasis on the ephemeral nature of the Fish River.
- Determine the Present Ecological State (PES), importance and future ecological state.
- Set the EFR using the approach developed within this study.
- Address scenarios in terms of the existing and new dams in the Fish.

Location of EFR sites

EFRs are undertaken at specific study sites called EFR sites. EFR sites are selected within Management Resource Units (MRUs) and the EFRs determined at the EFR site, will be representative of the flow requirements of the MRU. Two EFR sites were selected in the Fish River downstream of Hardap Dam. The sites are:

- EFR Fish 1: The site is situated upstream of Neckartal Dam within MRU Fish A (reach from Hardap Dam to Neckartal Dam).
- EFR Fish 2: The site is situated immediately downstream of the Seeheim gauging weir within MRU B2.1 (reach from Neckartal Dam to the Löwen confluence).

To add value to the evaluation of operational scenarios, an additional area or 'site' was selected at the Ai-Ais area to represent MRU Fish B.2. This area or 'site' is referred to as EFR Ai-Ais.

EcoClassification

The EcoClassification process was followed according to the methods of Kleynhans and Louw (2007). EcoClassification refers to the determination and categorisation of the Present Ecological Reserve (health or integrity) of various biophysical attributes of rivers compared to the natural (or close to natural) reference condition. The state of the river is expressed in terms of biophysical components:

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

Different processes are followed to assign a category (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 river.

EcoClassification Results

The results of the EcoClassification process are summarised below.

EFR Fish 1: EcoClassification description

EIS: HIGH
Highest scoring metrics: Rare and endangered instream and riparian species, critical instream habitat, refugia and diversity of riparian habitat types and features.
PES: B/C
Flow-related impacts: Abstraction and flow reduction caused by dams, e.g. Hardap Dam, Irrigation return flows. Localised impacts closer to the Hardap Dam due to irrigation.
Non-flow related impacts: Nutrients and salinity elevated due to the irrigation return flows. Grazing and browsing pressure (mainly goats), vegetation removal at settlements, sewage discharges into the Fish River.
REC: B
HIGH EIS 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

Driver Components	***PES***	***REC***
IHI Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B/C
Response Components	***PES***	***REC***
Fish	B	B
Macro-invertebrates	C	B
Instream	**B/C**	**B**
Riparian Vegetation	B/C	B
Riverine Fauna	B	B
EcoStatus	**B/C**	**B**
EIS	HIGH	

EFR Fish 2: EcoClassification description

EIS: 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 EIS was motivation for improvement of the EcoStatus. This can however not be achieved as the grazing impacts are the main impacts to be addressed. The riparian vegetation can only be improved within the C and this improvement would be insufficient to achieve a B EC for riparian vegetation.

Ecological Categories

Driver Components	***PES***	***REC***
IHI Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B/C
Response Components	***PES***	***REC***
Fish	B	B
Macro-invertebrates	B	B
Instream	**B**	**B**
Riparian Vegetation	C	C+[1]
Riverine Fauna	B	B
EcoStatus	**C**	**C+**
EIS	HIGH	

EFR Ai-Ais: EcoClassification description	*Ecological Categories*
EIS: 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 EIS. **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 Resort resulting in elevated nutrient levels.	

Driver Components	*PES*
IHI Hydrology	C
Physico-chemical	C
Geomorphology	B
Response Components	***PES***
Fish	C
Macro-invertebrates	B
Riparian Vegetation	B/C
Riverine Fauna	C
EIS	HIGH

Environmental Flow Requirement results

As the Neckartal Dam is due to be constructed, 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). This implies that different flooding regimes routed through Neckartal Dam would be evaluated downstream of the dam and the implications on the ecological state determined. Neckartal Dam with different EFR release scenarios were the key driver as well as increased irrigation downstream of Naute Dam. These drivers were combined in Fish River scenarios and were evaluated to determine the ecological consequences. The release scenarios are referred to as Sc 0%, Sc 20%, Sc 30%, Sc 40% and Sc 50%. The percentage relates to the EFR that would be released as a proportion of the inflows to Neckartal Dam.

The consequences of the flow scenarios at EFR Fish 2 are summarised below.

Driver Components	*PES (REC)*	*Sc 0%*	*Sc 20%*	*Sc 30%*	*Sc 40%*	*Sc 50%*
Physico-chemical	C	D	C/D	C/D	C	C
Geomorphology	B/C	C/D	C	C	C	C
Response Components						
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 the 40 and 50% scenarios would meet the ecological objectives, i.e. for the PES to be maintained. Under the Sc 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 scenario does not meet the ecological objectives. Sc 20% and Sc 0% results in a worse deterioration in all the components than Sc 30% and the ecological objectives are not met for any of the components.

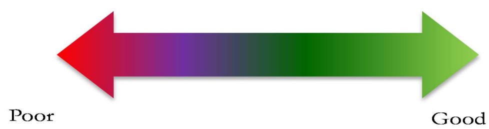
The consequences of the flow scenarios at EFR Ai-Ais are summarised below.

Driver Components	***PES (REC)***	***Sc 0%***	***Sc 20%***	***Sc 30%***	***Sc 40%***	***Sc 50%***
Physico-Chemical	C	E	D	D	C/D	C/D
Geomorphology	B	C	C	C	C	C
Response Components						
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 the 50% Scenario would meet the ecological objectives, i.e. for the PES to be maintained. Sc 40% results in the deterioration of the macro-invertebrates by one Ecological Category but maintains the EcoStatus. Sc 30%, Sc 20% and Sc 0% do not meet the ecological objectives for any of the components. Sc 0% has the potential to fall below a D EC.

A comparison of the consequences of the scenarios at EFR Fish 2 and EFR Ai-Ais are provided below

Scenario	***Sc 0%***	***Sc 20%***	***Sc 30%***	***Sc 40%***	***Sc 50%***
EFR Fish 2	×	×	×	✓	✓
EFR Fish 2	×	×	×	✓	✓



This analysis shows that only the 50% Scenario will fully meet the ecological objectives. The 40% Scenario has the potential of meeting all the ecological objectives, albeit with a higher risk of failure than the 50% Scenario.

As the 40% and 50% Scenario would have a significant impact on the yield of Neckartal Dam, an optimised scenario that will minimise the impacts on both the yield and the ecological status was investigated. Such a scenario should be between Sc 30% and Sc 40% and therefore a combination of the Sc 30 and Sc 40% was investigated.

The evaluation of the optimised scenario shows that this scenario has an even higher risk than the Sc 40% that the ecological objectives will not be met. However, as the yield was a significant improvement from the Sc 40%, this would be the scenario that would be included for further analysis below the confluence with the Orange River.

The EFRs for EFR Fish 1 were not determined through a scenario-based approach as the scenarios were only relevant downstream of this site. EFR Fish 1 required improvement in flooding requirements and addressing water quality issues 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.

Conclusions and recommendations

EcoClassification: The confidence in the data availability and information at the EFR sites were moderate, however data availability was better for EFR Fish 2 due to the recent impact assessment undertaken in the reach.

EcoClassification results for EFR Fish 1 and EFR Fish 2 were of moderate confidence. EcoClassification results for EFR Ai-Ais were the lowest because surveys were less intensive than at the main (key) EFR sites. In general the biggest problem with the confidences was the lack of historical data regarding the biota and historic measured hydrology data (pre Hardap Dam). This will however have limited consequences to the ability of evaluating operational flow scenarios which is more dependent on an understanding of the flow requirements of indicator species and how they will respond to a different flow regime than present.

No further work is therefore required to refine the reference conditions and therefore improving the PES as this would be impossible without historical data. Effort should rather be focussed on biomonitoring to confirm predictions on responses to the altered flow regime from the proposed Neckartal Dam within an Adaptive Management Framework.

EFR determination: The confidences in the evaluation 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 directed on monitoring to test the hypotheses in predicting the consequences of the altered flow regime.

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Abbreviations

ASPT	Average Score per Taxon
DRIFT	Downstream Response to Imposed Flow Transformations
EC	Ecological Category
EFR	Environmental Flow Requirement
EIS	Ecological Importance and Sensitivity
ESIA	Environmental and Social Impact Assessment
FRAI	Fish Response Assessment Index
FROC	Frequency of Occurrence
GAI	Geomorphological Diver Assessment Index
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HFSR	Habitat Flow Stressor Response
IHI	Instream Habitat Integrity
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
MAR	Mean Annual Runoff
MCB	Macro Channel Bank
MCM	Million Cubic Meters
MIRAI	Macroinvertebrate Response Assessment Index
MRU	Management Resource Unit
NASS2	Namibian Scoring System version 2
ORASECOM	Orange-Senqu River Commission
PAI	Physico-chemical Driver Assessment Index
PD	present day flow
PES	Present Ecological State
REC	Recommended Ecological Category
SANBI	South African National Biodiversity Institute
Sc	Scenario
STW	Sewage Treatment Works
VEGRAI	Riparian Vegetation Response Assessment Index

Fish species abbreviations

BAEN	*Labeobarbus aeneus*
BKIM	*Labeobarbus kimberleyensis*
BPAU	*Barbus paludinosus*
CCAR	*Cyprinus carpio*
CGAR	*Clarias gariepinus*
LCAP	*Labeo capensis*

LUMB	*Labeo umbratus*
OMOS	*Oreochromis mossambicus*
TSPA	*Tilapia sparrmanii*

Terminology

Use of the terms ephemeral and seasonal in the report: Ephemeral is a specific type of seasonal river. According to the ToR, the Fish River is referred to as ephemeral and this terminology will be used for the Fish River and its tributaries.

1. Introduction

1.1 Background

As per the Terms of Reference (ToR), 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' 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).

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 the completed GIZ study, during 2009-2010. This area is to be the subject of this Research Project. (ORASECOM, 2011a)

1.2 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 (ORASECOM, 2012). This report focuses on the Environmental Flow Requirements of the Fish River in Namibia.

The Fish River catchment 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 (ORASECOM, 2012).

The total area of the Fish River Basin is 95,680 km² 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, 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 Groot 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 m³/a is generated from the Fish River basin, but only 571 million m³/a of this reaches the Orange River under natural conditions, as an estimated 42 million m³/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 million m^3 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 million m^3. 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.

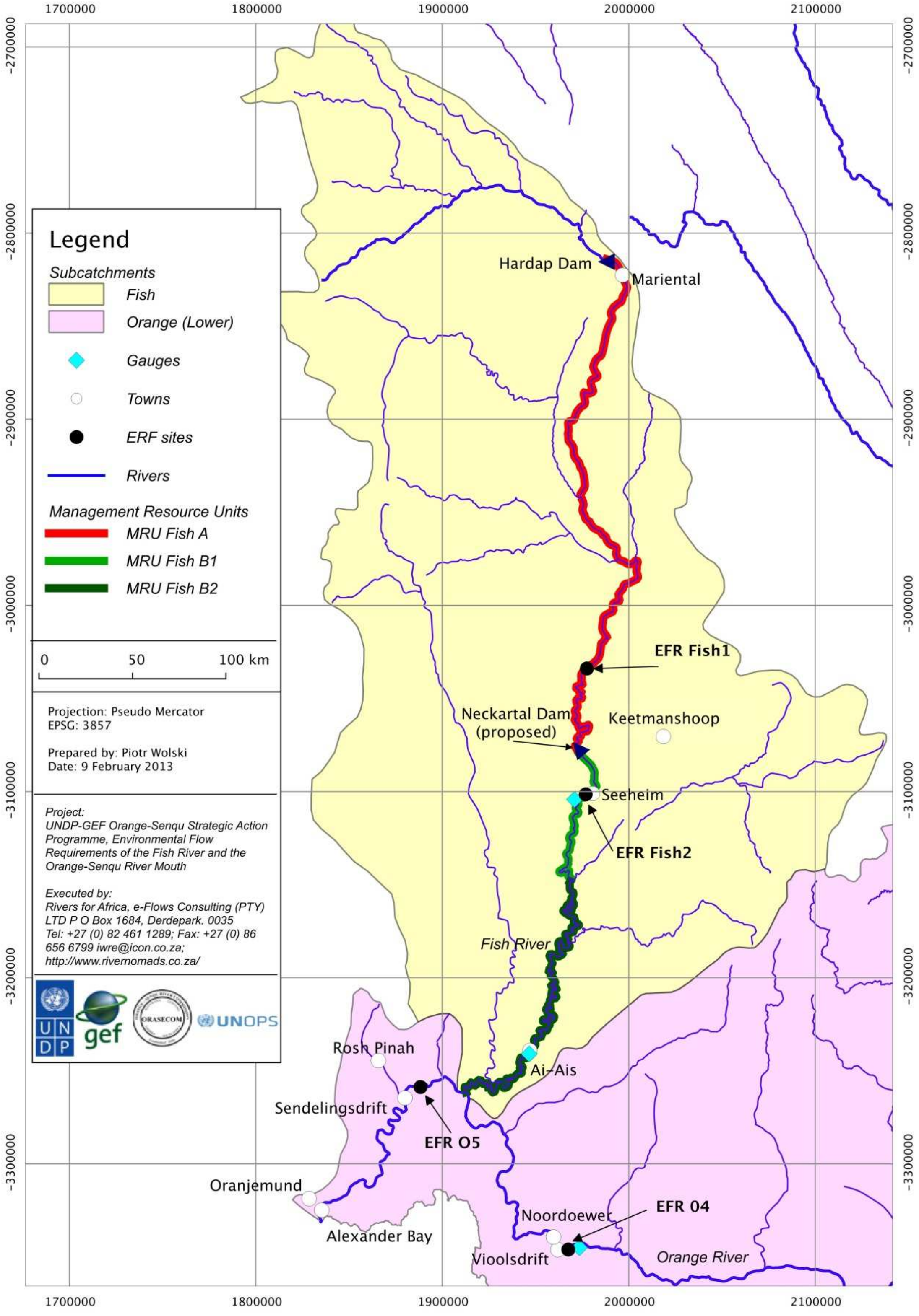


Figure 1. The Fish River basin, Namibia

1.3 Objectives of the Fish River EFR Study

The objectives of this Fish River EFR study were to:

- Develop EFR methodologies with specific emphasis on the ephemeral nature of the Fish River.
- Determine the Present Ecological State (PES), importance and future Recommended Ecological Condition (REC).
- Set the EFR using the approach developed within this study.
- Address scenarios in terms of the existing and new dams in the Fish River.

1.4 Management Resource Units

Two Management Resource Units (MRUs) were delineated in the Fish River (Figure 1). Refer to Technical Report 22 (ORASECOM, 2012) 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: The rest of the river forms one MRU.

During this phase of the study, it was identified that due to the operation of Naute Dam, a MRU break at the confluence of the Naute Dam will 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.

1.5 EFR Sites

EFR sites are selected within MRUs and the EFRs determined at the EFR site, will be 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 photographs from a reconnaissance visit during 2010 (Louw *et al.*, 2010) and was groundtruthed during a field visit undertaken 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 value to the evaluation of operational scenarios, an additional area or 'site' was selected at the Ai-Ais area to represent MRU Fish B.2. This area or 'site' is referred to as EFR Ai-Ais. No cross-sectional surveys were undertaken and the site represents a reach with the focus on the area around Ai-Ais Resort. Limited biological data collection was undertaken at the site.

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

- Operational scenarios 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 Resort) there is a notable difference in the fish species composition of the lower Fish River (below the waterfall, EFR Ai-Ais) and the upper Fish River reaches (EFR Fish 1 and 2).
- Specific localised water quality issues at and upstream of Ai-Ais Resort.
- Changes in operation of Naute Dam.

1.5.1 EFR Fish 1

EFR Fish 1 is situated in the Lower Foothills (ORASECOM, 2012) 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

1.5.2 EFR Fish 2

The site is located within the Upper Canyon, a rift valley formation (ORASECOM, 2013a). 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 Seeheim gauging weir.

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

1.5.3 EFR 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 Ai-Ais located in MRU Fish B.2

1.6 Data and Information Availability

Information utilised to assess hydrology, geohydrology and hydraulics are provided in Volume 5, Technical Report 31 (ORASECOM, 2013b).

The information available for the biological response components (fish, macro-invertebrates and riparian vegetation) and driver components (water quality, or physico-chemical variables, and fluvial geomorphology) are provided in Table 1. Information consisted of historical recently collected data as well as the results of physical surveys (June 2012). Confidence in the information relates to the 'usefulness' of the information in the assessment of EFRs and is rated on a scale of 0 (no confidence) to 5 (very high confidence).

Table 1. Availability of data and information

Components	***Data Availability***
Physico-chemical variables	Data used for the water quality assessment was collected as part of the Knight Piesold study for the Neckartal Dam development Environmental and Social Impact Assessment (ESIA), as no information was available to characterise the baseline. The data record is short, with sampling starting in February 2010 through to April 2012. Other data sources including accessing information from specialists on the study (e.g. Roberts, Koekemoer, Rountree and Bockmühl), literature (see reference list – ORASECOM, 2013a), a site visit in June 2012 and correspondence/interviews with Namibian residents. Confidence: 2
Fluvial Geomorphology	EFR Fish 1: Historical aerial photography and satellite imagery were available from the 1960s until the mid-2000s for this site (24/11/1962, 12/7/1971 and 20/12/2004). EFR Fish 2: Historical aerial photography and satellite imagery were available from the 1960s until the mid-2000s for this site (specifically for the dates of the 16/12/1962; 25/7/1966; 6/8/1978; 8/9/2004; 7/8/2009 and 14/12/2011). Data collected during field visit (18 June 2012). Confidence: 3
Index of Habitat Integrity (IHI)	▪ Personal ground-based observations. ▪ Local knowledge. ▪ Hydrological assessments. ▪ Water quality assessments. ▪ Land covers assessments. ▪ Google Earth (high resolution). The confidence in the data was high due to the detailed ground-based observations and the high quality of Google Earth imagery available for large sections of the study area. The only low confidence issue was the lack of hydrological information in terms of losses, tributary inflows and groundwater interaction. Confidence: 3.5
Riparian vegetation	▪ Satellite images (Google Earth imagery, 8 September 2004) and historic aerial photos. ▪ Hydrology specialist reports. ▪ Geomorphic zone classification. ▪ Biomes and vegetation types of Namibia: (Atlas of Namibia Project, 2002). ▪ SANBI (2009): Plants of Southern Africa online database (based on several herbaria collections). ▪ Data collected during field visit (18 June 2012). Confidence: 3
Fish	▪ Data collected during a site survey conducted in June 2012. ▪ Results of previous fish surveys conducted in the region (Mr J. Koekemoer and Dr C. Hay).

Components	
	Data Availability
	▪ Personal communication with Dr C. Hay (previously from Namibian fisheries). ▪ Various publication, especially Hay (1991), Hay et al. (1997), Hay et al. (1999), Nepid Consultants (2010), Van Vuren et al. (1989). Confidence: 2
Macro-invertebrates	
	▪ Paper that summarises the distribution of aquatic invertebrates in Namibia, based on published data and museum records (Curtis, 1991). ▪ 2009-2010. Macro-invertebrates were collected on two occasions in the vicinity of the proposed Neckartal Dam, including EFR Fish 2 (Seeheim), as part of the environmental and social impact assessment of the proposed Neckartal Dam (Nepid Consultants, 2010). ▪ Data collected during a site survey conducted during June 2012. Confidence: 2
Diatoms	
	EFR Fish 1: No historic site specific diatom data was available for this site or MRU Fish A. Due to the ephemeral nature of the Fish River the confidence in the assessment is low. Confidence: 1.5 EFR Fish 2: Site specific diatom data were available (2009-2010) as well as data from sample collected during EFR site visit. Diatom samples were collected during 2008-2009 across the reach MRU Fish B, along with measured in situ water quality measurements. Confidence 2.5
Riverine fauna (Fauna)	
	▪ Atlas maps and field guides containing faunal distribution: Birds, mammals, reptiles and frogs. ▪ Various field guides containing descriptions of faunal habitat. ▪ Red Data books relating to the riverine fauna (IUCN and SA Red Data). ▪ Data collected during field visit (June 2012). Confidence: 3

1.7 Report Structure

The report details the following two main components of the Reserve Process:

- EcoClassification process – Discussed in Chapter 2 – 5 of this report, and
- EFR scenario determination – Discussed in Chapter 7 - 10 of this report.

The report consists of the following chapters:

Chapter 1: Introduction

This chapter provides an overview of the study area, objectives of the study and data availability.

Chapter 2 - 4: EcoClassification results of the EFR sites of the Fish River

The EcoClassification results are provided for each EFR site.

Chapter 5: EcoClassification: Summary and Conclusions

A summary of the EcoClassification results are summarised and recommendations are provided. The challenges and limitations pertaining to the EcoClassification process are discussed.

Chapter 6: Fish River EFR Assessment: Approach and Operational Scenarios

This Chapter provides a summary of the drivers and the resulting scenarios applicable only for the Fish River.

Chapter 7 – 8: Operational Scenario evaluation

The results of the Ecological Consequences of the Operational Scenarios are provided for EFR Fish 2 and EFR Ai-Ais.

Chapter 9: Environmental Flow Requirements at EFR Fish 1

As EFR Fish 1 is upstream of Neckartal Dam from which all the scenarios originate, flow requirements were set at the site and provided in this chapter.

Chapter 10: Conclusions

A summary of the Ecological Consequences are summarised and integrated providing overall consequences. Recommendations are also provided. This includes an investigation into an optimised scenario that will maintain the PES and minimise the impacts on system yield and for users

Chapter 11: References

Appendix A: EcoClassification Approach and Method

This chapter outlines the methods followed during the EcoClassification process.

Appendix B: EcoStatus Model Output

The Ecological Categories of the biological response components, namely fish, macro-invertebrates and riparian vegetation, have to be combined to determine the EcoStatus. The resulting EcoStatus model output for EFR Fish 1 and Fish 2 is provided in Appendix B.

Appendix C: Fish River EFR Determination Method

For the evaluation of Operational Scenarios, various flow indicators were used in determining the ecological consequences. This chapter outlines the general approach to determining the Ecological Consequences for each component.

2. EcoClassification: MRU Fish A - EFR Fish 1

A summary of the EcoClassification approach is provided in Appendix A. For more detailed specialist information, refer to Technical Report 28 (ORASECOM, 2013a).

2.1 Ecological Importance and Sensitivity (EIS) Results

The EIS results for EFR Fish 1 were **HIGH.** The highest scoring matrices were:

- Rare and Endangered instream and riparian species: *Labeobarbus kimberleyensis*, *Simulium gariepense,* three threatened vegetation species, Cape clawless otter, great white pelican, pink-backed pelican, yellow-billed stork and black stork.
- Critical instream habitat and refugia: Perennial pools are present within the reach which are important as the tributaries have no or limited perennial pools.
- The diversity of riparian habitat types and features: The river valley, with the chain of seasonal pools and the riparian corridor forms a good migration corridor, especially for migrating bird species.

2.2 Reference Conditions

The reference conditions for the components in EFR Fish 1 are summarised in Table 2.

Table 2. EFR Fish 1: Reference conditions

Component / ***Reference conditions***	
Hydrology	Confidence: 2
The natural Mean Annual Runoff (MAR) is 420 Million Cubic Meters (MCM).	
Physico-chemical variables	Confidence: 1.5
▪ No information was available on the expected natural state of the Fish River system and therefore benchmark tables (DWAF, 2008) for an A category or natural/least impacted state were used as a proxy for Reference Conditions (RC). This information was modified by available information where possible. ▪ Electrical Conductivity: 42.02 mS/m (using the mean of EC data from SW2 and Löwen River). Low confidence, as natural levels in the Fish River may be higher than 42.02 mS/m. ▪ The lowest confidence was for nutrients, as phosphate, macro- and benthic algae levels are elevated throughout the catchment although causes are not always evident.	
Geomorphology	Confidence: 3
Historically the river experienced larger and more continuous flows than the present condition. Pools would have been larger, more perennial and more continuous (connected) than the present condition due to the more continuous low and larger flood flows prior to the construction of Hardap Dam. It is likely that most of the pools in this reach were permanent under natural conditions; these being dependent on small and large floods arising from the wetter upper catchment area as well as inflows from the numerous small tributaries.	
Riparian vegetation	Confidence 3:

Component

Reference conditions

The riparian zone should be sparsely vegetated with distinct association of vegetation with pools or riffle areas. Alluvial terraces and banks are likely to be dominated mainly by *A. karoo, Z. mucronata*, or stands of *Tamarix usneoides*. Cobble or riffle features likely to be characterised by a mix of woody species (*T. usneoides, Gomphostigma virgatum*) and sedges (*Cyperus longus,* and *C. marginatus*). Frequently flooded alluvia will be mostly open or sparsely grassed.

The expected reference condition of riparian vegetation for each of the zones is as follows:

- Marginal and Lower zone: Expect a mix of open alluvia or cobble/boulder and sparsely vegetated areas. Vegetation, similarly, should be a mix of woody (*G. virgatum, T. usneoides*) and non-woody (*C. marginatus, and C. longus*) vegetation, although the distribution of sedges is likely to be limited to areas where water availability is longer lasting in the wet season e.g. pools or wet areas upstream of bedrock hydraulic control areas.
- Upper zone: Similar to present state, but expect greater abundance of *Acacia* spp., possibly due to browsing pressure being high.
- Upper zone Macro Channel Bank (MCB): Similar to present state, with the exception of alien weed species and *Prosopis* spp. (which occur in low numbers).
- Floodplain: Similar to present state, with the exception of alien weed species and *Prosopis* spp. (which occur in low numbers).

Fish — Confidence: 1

The expected six indigenous fish species were sampled in the reach during the June 2012 survey, together with two alien/introduced species (*Tilapia sparrmanii* (TSPA) and *Oreochromis mossambicus* (OMOS)). The abundance and spatial Frequency of Occurrence (FROC) of the indigenous species were generally high for most species (*Labeobarbus aeneus* (BAEN), *Barbus paludinosus* (BPAU), *Labeo capensis* (LCAP), and *Clarias gariepinus* (CGAR)), while two species were scarce during the survey. Based on all considerations of impacts and available fish information, it was estimated that the expected reference FROC of BAEN, *Labeobarbus kimberleyensis* (BKIM), CGAR and *Labeo umbratus* (LUMB) was slightly reduced in this reach. Overall the fish assemblage is therefore still in a relatively good condition (largely natural) under present conditions.

Macro-invertebrates — Confidence: 1

For the purposes of this report, three phases of the hydrological cycle were distinguished; Early Dry Season, Late Dry Season and Dry Season. The wet season was not considered because of its short duration and associated rapid successional changes, which makes this an unreliable period for purposes of defining ecological state, or for any long-term monitoring purposes. The expected composition, abundance and FROC of macro-invertebrates in the Fish River was based on information presented in Curtis (1991), and a baseline report on aquatic ecosystems (Nepid Consultants, 2010). Reference Namibian Scoring System version 2 (NASS2) results were based on species with an expected FROC of 3 or higher. The following reference NASS2 scores were obtained for three phases of the hydrological cycle referred to in ORASECOM (2013a):

Hydrological Phase:	Early Dry	Late Dry	Dry
NASS2 Score:	112	84	58
Number of Taxa :	23	18	12
Average Score Per Taxon (ASPT):	4.9	4.7	4.8

Early Dry Season: Characterised by taxa with short to very short life cycles (i.e. early colonisers). The most abundant trophic group expected during the early wet season are filter-feeders, including the blackflies *Simulium chutteri* and *S. gariepense*, freshwater sponges and moss animalcules (Bryozoa). Filter-feeders are likely to form the base of secondary production during this phase, and provide food for predators such as gomphid dragonflies, coenagrionid damselflies, water boatmen (Corixidae), and whirligig beetles (Gyrinidae). Air-breathing taxa are expected to be common during this phase.

Late Dry Season: As the dry season progresses water is expected to become increasingly clear, leading to an increase in primary production and increased importance of scraper-grazers, such as bulinid snails and hydroptilid caddisflies, and collector-gatherers such as caenid mayflies, chironomid midges and seed shrimps (Ostracoda). The abundance of filter-feeders with rapid life cycles, such as *S. chutteri,* are expected to reduce and

Component	
Reference conditions	
be replaced by taxa with longer life-cycles, such as hydropsychid caddisflies, or taxa that prefer slow-flowing water, such as *Simulium ruficorne*. Dry Season: With the cessation of surface flow during the dry season, most filter-feeding macro-invertebrates enter a dormant phase until flows resume, and air-breathing taxa are expected to become more abundant. The dominant trophic group under these conditions are collector-gatherers, such as caenid mayflies and Chironomidae, and predators, such as gomphid dragonflies. Extended duration of the dry season is likely to lead to conditions associated with ephemeral rather than seasonal systems. Taxa indicative of ephemeral systems include mosquitoes (Culicidae) and rat tailed maggots (Syrphidae).	
Riverine fauna	Confidence: 2
Habitats available: Extensive sand banks, large stretches of exposed shorelines, few patches of reed beds, very little grassy edges, moderate continuous riparian corridor, very little seepage wetland, good open water in the form of deep pools. A total of 60 riverine animal species are expected in the reach (two mammals, 51 birds, one reptile and six frogs); five of these species are Species of Special Concern (endemic or Red Data). The following habitats would have been expected under reference conditions: ▪ Sluggish in-stream channels and pools habitat (13 species). ▪ Backwater pool habitats (six species). ▪ Exposed shoreline - shallow edge habitats (23 species). ▪ Seepage wetland habitats (six species). ▪ Reed bed habitats (seven species). ▪ Grassy bank habitats (two species). ▪ Wooded bank habitats (two species). ▪ Tall riparian habitats (one species).	

2.3 Present Ecological State (PES)

The PES reflects the changes in terms of the Ecological Category (EC) from reference conditions. The summarised information is provided in Table 3.

Table 3. EFR Fish 1: Present Ecological State

Component		
PES Description		
Hydrology		Confidence: 3
The PD MAR is 331 MCM. Any changes in the flow regime will be a decreased number of events or decreased size of events due to the presence of Hardap Dam. There are strong similarities in the shapes of the observed hydrographs at Hardap (inflows) and Seeheim gauging weir, despite the fact that no releases were made from Hardap Dam in most years (only nine in the years between 1963 and 2006). This suggests that the flows at Seeheim are not totally dependent upon flows from the upper parts of the catchment above Hardap.		
Physico-chemical variables	PES: C	Confidence 2.5
The abstractions, upstream dams and extensive irrigation scheme around Hardap Dam, result in the major water quality issues being highly elevated salts and nutrients from irrigation return flows. Low flows result in exacerbated poor water quality conditions for much of the year. It is expected that at times the flow will consist largely of irrigation return flows, as well as untreated sewage discharges around towns due to malfunctioning Sewage Treatment Works (STWs). A number of metal ions were elevated above available guidelines, suggesting toxics present in the water column.		
Geomorphology	PES B/C	Confidence: 3
▪ Aerial photographs showed that the pools at the site are far more extensive, more continuous and wider in		

Component				
	PES Description			
	November 1962 (during which a 800 m^3/s flood peak occurred) in comparison to the pool sizes in July 1971 and December 2004, (a 400 m^3/s flood peak occurred in both years). ▪ Despite the reduction in flows following the closure of Hardap Dam in 1963, the gross channel morphology appears relatively stable. ▪ Pool sizes (length and width) appear to adjust in the short term to the volume of water, but over the long term large floods would be necessary to scour and enlarge pools. From the historical record there is no evidence of a progressive reduction in the pools due to reduced flows at this site. This is possibly due to: o Sufficient flood flows still coming down the system, providing for sufficient (albeit less frequent) maintenance of the pools. o The sediment load of the river is likely to be relatively low due to the age and gentle slopes across much of the catchment, so the rate of sedimentation of the pools is less than the frequency of large scouring flood events.			
IHI	Instream PES: C	Confidence 3.3	Riparian PES: B/C	Confidence 3.1
	The Fish River is impacted mainly by altered flow, specifically reduced flooding regimes due to Hardap Dam and irrigation. The reduced floods impacts lateral channel connectivity. Salinity and nutrients are elevated and problematic due to associated irrigation return flows as well as malfunctioning STWs. The loss of moderate and large floods impacts the Riparian IHI to some extent while grazing results in bank modification and altered bank structure.			
Riparian vegetation		PES: B/C		Confidence: 3.6
	Marginal and Lower zone: Marginal and lower zone similar (as would be expected in ephemeral systems) mostly with open sand and cobble/bedrock areas. Vegetation is sparse with a notable absence of sedges and woody species represented by *G. virgatum* and *T. usneoides*. Although overgrazing was not evident at the time of the site assessment, the absence of sedges and woody rheophytic shrubs, which would be present under reference conditions, suggests a greater that expected grazing / browsing pressure. Upper zone: Mostly open sand with cobble and bedrock. Vegetation is sparse and mostly dominated by woody species (especially *T. usneoides*), but also with some sparsely grassed areas (*Stipagrostis namaquensis*) higher up the bank and the MCB. Upper zone MCB: Alluvial (or in some places a cliff) and dominated by sparse mixed woody and non-woody vegetation. Mostly *S. namaquensis*, *T. usneoides* and some *Acacia karoo*. The abundance and population structure of *A. karoo* specifically is different from reference conditions since this species is targeted for firewood, hence lower abundances in general and also a younger population. Floodplain: Alluvial, left bank only; dominated by *T. usneoides*, *S. namaquensis*, some A. *karoo* and *A. erioloba* higher up. Data indicates that the floodplain was wetter in the past, but this is obscured by large floods in last decade. The comment above for *A. karoo* also applies to the floodplain.			
Fish		PES: B		Confidence: 2
	The expected six indigenous fish species were sampled in the reach during the June 2012 survey, together with two alien/introduced species (TSPA and OMOS). The abundance and spatial FROC of the indigenous species were generally high for most species (BAEN, BPAU, LCAP, and CGAR), while two species were scarce during the survey. Based on all considerations of impacts and available fish information, it was estimated that the expected reference FROC of BAEN, BKIM, CGAR and LUMB was slightly reduced in this reach. Overall the fish assemblage is therefore still in a relatively good condition (largely natural).			
Macro-invertebrates		PES: C		Confidence: 2
	A total of 15 NASS2 taxa was recorded at EFR Fish 1, compared to 23 expected. Taxa expected but not recorded included sponges, crabs, Bryozoa, Ecnomidae, Dytiscidae, Oligochaeta, Gerridae and Veliidae. The suitability of instream habitats was poor (47%), and this could partially explain the low diversity. The fauna was characterised by high numbers of baetid mayflies, and moderate numbers of Caenidae, Simuliidae, and Chironomidae. These taxa all have very short adult life spans (<one week). No taxa with long adults life spans (>six months) were recorded, apart from a single empty thiarid shell. Five of the 15 NASS2 taxa were air-breathers, indicating well-oxygenated conditions. The most common functional feeding groups were collector/gatherers and predators. Two filter-feeding taxa only were recorded: Simuliidae in moderate			

Component		
PES Description		
abundance and hydropsychid caddisflies in low abundance. Three species of blackflies were recorded, including the threatened *Simulium gariepense*, which is restricted to large, turbid rivers and is endemic to the Orange River Basin. The blackfly *S. ruficorne* was also recorded. This species is typically associated with slow-flowing water (<0.1 m/s) and high salinity, and is widely distributed throughout Africa and the Arabian Peninsula. All four categories of flow preferences were represented, indicating that current speeds were not limiting. Four categories of habitat preferences were represented. Taxa with a preference for warmer water comprised 13% of the taxa, which is considered low. The diversity of macro-invertebrates sensitive to water quality deterioration was low, with only two sensitive taxa recorded: Naucoridae and Baetidae >2spp. No alien macro-invertebrates were recorded during baseline surveys for this study, but the alien invasive species *Physa acuta* is likely to be present as it was recorded in the Fish River by Curtis (1991).		
Riverine Fauna	PES: B	Confidence 3.5
Habitats that have changed from reference conditions were: ▪ The open water habitats are smaller, more seasonal and less connected. ▪ The vegetation (sedges) of the lower and marginal zones does not last as long during the wet season, and the extent of marginal habitats diminish during lower flows. There is a lower abundance in Acacia species in the upper zone, and an increase in alien *Prosopis*. As the populations of certain fish species were slightly reduced in the pool habitats of this reach due to altered flow, the piscivorous (fish-eating) animals are affected accordingly. The abundances of certain open water piscivores, such as Cape clawless otter, pink-backed pelican, white-breasted cormorant, African darter, osprey, African fish eagle and great white pelican, would have been affected. A combination of the deterioration of marginal zone vegetation and reduced marginal habitats, reduced backwater habitats, and a lower abundance of tall riparian trees (*Acacia*) as nesting areas, will concurrently impact adversely on herons (two species), storks (two species) and egrets (two species).		

2.3.1 Causes and Sources

The reasons for changes from reference conditions must be identified and understood. These are referred to as causes and sources (EPA, 2012). The causes and sources for the PES are summarised in Table 4.

Table 4. EFR Fish 1: PES causes and sources

Component		
Causes	***Sources***	
Hydrology		Confidence 5
Changes in flow regime and reduction of runoff.	Hardap Dam and associated operational rules. (Flow related)	
Physico-chemical variables	PES: C	Confidence 3
Changes in flow regime and reduction of runoff.	Hardap Dam. (Flow related)	
Elevated salts and nutrients.	Irrigation return flows. (Non-flow related) Sewage discharges due to malfunctioning/non-existent STWs. (Non-flow related)	
Suspected metal toxicity.	Possible natural geological input of copper; discharges around urban areas. Confidence in metal toxicity is low, as sources not easily identifiable. (Non-flow related)	
Geomorphology	PES B/C	Confidence 5

Component			
	Causes	***Sources***	
	Changes in flow regime and reduction of runoff have reduced flushing events and pool filling frequencies.	Hardap Dam. (Flow-related)	
Riparian vegetation	PES B/C		Confidence 3
	Reduction of floods generally favours woody vegetation and facilitates their encroachment into lower zones and pool margins.	Hardap Dam. (Flow related)	
	Decrease in woody seedlings (notably *Acacia* species).	Grazing and browsing pressure (mainly goats). Alien species invasion. (Non-flow related)	
Fish	PES B		Confidence 4
	Presence of alien or introduced fish species (OMOS, TSPA and possibly *Cyprinus carpio* (CCAR)).	Stocking of species alien to Fish River in Hardap Dam and escape of alien fish from Hardap hatchery. (Non-flow related)	
	Decreased dispersal and breeding success (reaching optimal spawning habitats).	Artificial migration barriers (Hardap Dam, farm dams and weirs). (Non-flow related)	
	Potential slight increase in turbidity at times.	Overgrazing (mostly goats) and potential presence of bottom feeding alien fish species (CCAR). (Non-flow related)	
	Flow modification - slight decrease in condition and availability of pools (slow-deep habitats).	Hardap Dam. (Flow-related)	
Macro-invertebrates	PES C		Confidence 3
	Increased nutrients, salinity and cyanobacteria.	Livestock, irrigated agriculture, impoundments, *Prosopis* leaf litter. (Non-flow related)	
	Competition from alien species.	*Physa acuta*. (Non-flow related)	
	Reduced duration of flow.	Hardap Dam (Flow related)	
Riverine Fauna	PES B		Confidence 5
	Slight decrease in fish abundance and condition of pools (slow-deep habitats) impacts on the abundance of the piscivorous fauna.	Flow modification caused by Hardap Dam and abstraction. (Flow related)	
	Deterioration in marginal habitats (extent of wetted perimeter and vegetation presence-sedges).	Flow modification caused by Hardap Dam and abstraction. (Flow related)	
	Lower abundance in *Acacia* species in the upper zone as nesting and migration corridor habitat, and an increase in alien *Prosopis*.	Some grazing and browsing pressure (mainly goats). Alien species invasion. (Non-Flow related)	

The major issues that have caused the change from reference conditions were flow related impacts that included abstraction and flow reduction caused by the presence of impoundments (i.e. Hardap Dam and various farm dams).

Non-flow related impacts also impacted the reach as fairly high grazing and browsing pressure (mainly goats) existed. Irrigation return flows causes nutrient and salinity elevations. Vegetation removal occurred at Gideon and other settlements. Sewage discharges into the Fish River occurred due to malfunctioning/non-existent STWs at surrounding towns and settlements.

2.3.2 PES EcoStatus

The EcoStatus represents an integrated status as a biological end point (Kleynhans and Louw, 2007). The Ecological Categories of the biological response components, namely fish, macro-invertebrates and riparian vegetation, must therefore be combined to determine the EcoStatus. The resulting EcoStatus was a B/C. The model output is provided in Appendix B.

2.4 Recommended Ecological Category (REC)

The REC is determined based on ecological criteria only and considered the EIS (HIGH or VERY HIGH scoring provides motivation for improvement), the restoration potential and attainability thereof. The EIS is HIGH, therefore the REC was an improvement of the PES of a B/C to at least a B EcoStatus. To achieve the REC, macro-invertebrates and riparian vegetation must be improved as fish is already in a B PES. The macro-invertebrate improvement can only be achieved by addressing the water quality problems (nutrients) (non-flow related measures). Therefore, only the riparian vegetation EC could be improved by flow-related measures. As the riparian vegetation EC score was 0.4% below a B EC, minimal improvement would be required to achieve a B EC for riparian vegetation.

2.5 Summary of EcoClassification Results

The EcoClassification results are summarised in Table 5. The colours used are standard colours associated with EcoClassification.

Table 5. EFR Fish 1: Summary of EcoClassification results

Driver Components	***PES***	***REC***	***Comment***
IHI Hydrology	C	C	
Physico-chemical	C	C	
Geomorphology	B/C	B/C	
Response Components	***PES***	***REC***	
Fish	B	B	No improvement will be required to achieve the REC as the fish is already in a B PES.
Macro-invertebrates	C	B	Improvement in terms of water quality (improvement nutrient loads) will be required.
Instream	**B/C**	**B**	Improvement based on invertebrate improvement by means of non-flow-related water quality improvements.
Riparian Vegetation	B/C	B	Minor improvement will be required, mostly by means of increased floods.
Riverine Fauna	B	B	No improvement will be required to achieve the REC as the fauna is already in a B PES.
EcoStatus	**B/C**	**B**	Improvement based on riparian vegetation and invertebrate improvement
EIS	HIGH		

3. EcoClassification: MRU Fish B.1 - EFR Fish 2

A summary of the EcoClassification approach is provided in Appendix A. For more detailed specialist information, refer to Technical Report 28 (ORASECOM, 2013a).

3.1 Ecological Importance and Sensitivity (EIS) Results

The EIS results for EFR Fish 2 were **HIGH.** The highest scoring matrices were:

- Rare and Endangered instream and riparian species: Included *Labeobarbus kimberleyensis*, *Simulium gariepense,* one threatened vegetation species, Cape clawless otter, Great white pelican, Pink-backed pelican, Yellow-billed stork, and Black stork.
- Critical instream habitat and refugia: Perennial pools are present and are important as the tributaries have no refugia.
- The diversity of riparian habitat types and features: Semi-permanent pools and a good riparian corridor are favourable refugia. The river valley, with the chain of seasonal pools and the riparian corridor forms a good migration corridor, especially for migrating bird species.

3.2 Reference Conditions

The reference conditions are similar to EFR Fish 1 except for minor differences in riparian vegetation described in Table 6.

Table 6. EFR Fish 2: Reference conditions

Component	
Reference conditions	
Hydrology	Confidence: 2
The natural MAR is 504 MCM.	
Riparian vegetation	Confidence 3
The expected reference condition of riparian vegetation for each of the zones is as follows: ▪ Marginal zone: Expect a mix of open alluvia or cobble/boulder and sparsely vegetated areas. Vegetation, similarly, should be a mix of woody (*G. virgatum*, *T. usneoides*) and non-woody (*C. marginatus*, and *C. longus*) vegetation, although the distribution of sedges is likely to be limited to areas where water availability is longer lasting in the wet season e.g. pools or wet areas upstream of bedrock hydraulic control areas. ▪ Lower zone: Similar to marginal zone, with reeds around deep permanent pool areas. ▪ Upper zone: Similar to present state, but expect greater abundance of *Acacia* spp., possibly due to browsing pressure being high. ▪ Upper zone MCB: Similar to present state, with the exception of alien weed species and *Prosopis* spp. (which occur in low numbers). Floodplain: Similar to present state, with the exception of alien weed species and *Prosopis* spp. (which occur in low numbers). Woody density would be less under reference and not likely to have palm trees.	

3.3 Present Ecological State

The PES reflects the changes in terms of the Ecological Category (EC) from reference conditions. The summarised information is provided in Table 7.

Table 7. EFR Fish 2: Present Ecological State

Component / ***PES Description***				
Hydrology				Confidence: 3
The PD MAR is 404MCM. Any changes in the flow regime will be a decreased number of events or decreased size of events due to the presence of Hardap Dam. There are strong similarities in the shapes of the observed hydrographs at Hardap (inflows) and Seeheim gauging weir, despite the fact that no releases were made from Hardap Dam in most years (only nine in the years between 1963 and 2006). This suggests that the flows at Seeheim are not totally dependent upon flows from the upper parts of the catchment above Hardap. There is, however, evidence for quite substantial attenuation and loss of flow between Seeheim gauging weir and Ai-Ais Resort in most years, partly influenced by the limited number (and magnitude) of spills and releases from Naute Dam. These patterns of attenuation and loss are difficult to generalize and it is clear that the contribution of the lower and western tributaries is highly variable.				
Physico-chemical variables		PES: C		Confidence 2.5
Conditions are slightly improved as compared to EFR Fish 1, but water quality appears to be driven by similar variables, i.e. elevated salt and nutrient levels from the upstream area being exacerbated at times of low flow.				
Geomorphology		PES B/C		Confidence: 3
As with the upstream EFR site, morphological impacts appear to be limited and are likely to be less in this downstream reach (further from Hardap Dam) due to the ameliorating impacts of tributaries. The pools are however more strongly seasonal than at EFR Fish 1. In December 1962 and 2011, despite there having been large (>800 m^3/s) floods in the preceding wet season, the pools are very reduced and isolated in comparison to the winter condition of other years associated with much smaller floods. The duration since the last flow period is thus more important than the flood peak size in the short term maintenance of pools.				
IHI	Instream PES: C	Confidence 2.9	Riparian PES: C	Confidence 4.2
Similar to EFR Fish 1, however tributaries contribute to the mainstem flow to a greater extent than at EFR Fish 1. Deteriorated water quality (nutrients and salts) are still problematic. Periods of zero flow has resulted in bank and structure exposure. Increased pressure has also led to bank modification and altered bank structure.				
Riparian vegetation		PES: B/C		Confidence: 3.6
Marginal zone: Marginal and lower zones similar (as would be expected in ephemeral systems) mostly with open sand and cobble/bedrock areas. Vegetation is sparse with mainly *G. virgatum, C. longus* and some *P. australis* around deep pools. The aerial cover of sedges and abundance of woody rheopytes is less that would be expected under reference conditions. This is due to heavy grazing and trampling pressure by goats especially. Lower zone: Similar to marginal zone, but also with *T. usneoides*, especially *T. usneoides* overhang around deep pools. There is also lower cover of sedges in this zone, compared to what is expected, also due to grazing. Upper zone: Mostly open sand with cobble and bedrock. Vegetation is mostly sparse and dominated by woody species (especially *T. usneoides*), but also with some sparsely grassed areas (*Stipagrostis namaquensis*) higher up the bank and the MCB and some *A. karoo*. Some densely wooded areas exist around permanent pool areas, mainly dominated by *T. usneoides* thicket (although this is also associated with the dry tributary). An increase in this species is likely the result of reduced flooding and increased herbivory. Upper zone MCB: Alluvial (or in some places a cliff) and dominated by sparse mixed woody and non-woody vegetation. Mostly *S. namaquensis, T. usneoides* and some *A. karoo*. Floodplain: Alluvial and extensive: dominated by *T. usneoides, S. namaquensis*, some *A. karoo* and *Z. mucronata.* Some palm trees in places are likely planted or originate from planted stock. The upper zone and floodplain area both differ from the reference conditions in that the abundance (and aerial cover) of *T. usneoides* has increased				

Component	***PES Description***		
	markedly. This is a frequent response by this species when overgrazing is prevalent. Also, the abundance of *A karoo* is less than expected, and the population structure younger due to the collection of mature individuals for wood.		
Fish		PES: B	Confidence: 2
	The expected six indigenous fish species were sampled in the reach during the June 2012 survey, together with one alien species (OMOS). The abundance and spatial FROC of the indigenous species were generally high for most species (BAEN, BKIM, BPAU, LCAP, and CGAR), while LUMB were very scarce during the survey. Based on all considerations of impacts and available fish information, it was estimated that the expected reference FROC of BAEN, BKIM and LUMB was slightly reduced from reference condition in this reach. Overall the fish assemblage is however still in a relatively good condition (largely natural) under present conditions.		
Macro-invertebrates		PES: B	Confidence: 2
	A total of 20 NASS2 taxa were recorded at EFR Fish 2, despite limited suitability of instream habitats, which was rated as *Poor* (42%). Taxa expected but not recorded were Oligochaeta, Libellulidae and Dytiscidae. The fauna was characterised by high numbers of blackflies comprising four species, dominated by the pest species *Simulium chutteri*. Two taxa with long adult life spans (>six months) were recorded, but in low numbers only (crabs and thiarid snails). The proportion of air-breathing taxa was low (30%), indicating well-oxygenated conditions. The most abundant functional feeding group was filterers (*S. chutteri*). All four categories of flow preferences were represented, indicating that current speeds were not limiting. Four categories of habitat preferences were represented. Taxa with a preference for warm water comprised <10% of the taxa, which is considered low. The diversity of macro-invertebrates sensitive to water quality deterioration was moderate, with four sensitive taxa recorded: Aeshnidae, Hydracarina, Naucoridae and Baetidae >2spp. No alien macro-invertebrates were recorded during baseline surveys for this study, but the alien invasive species *Physa acuta* is likely to be present as it was recorded in the Fish River by Curtis (1991).		
Riverine Fauna		PES: B	Confidence 3.5
	Habitats that have changed from reference conditions were: ▪ Pools are more strongly seasonal and water quality deteriorated. ▪ Periods of zero flow has resulted in bank and structure exposure, as well as a decrease in the exposed shoreline and shallow edges habitats. ▪ Lower abundance of *Acacia* trees in the upper zone, possibly due to browsing pressure being high, and the encroachment of the alien weed *Prosopis*; woody density is lower in the floodplain. As the populations of certain fish species were slightly reduced in the pool habitats of this reach due to altered flow, the piscivorous (fish-eating) animals are affected accordingly. The abundances of certain open water piscivores, such as cape clawless otter, pink-backed pelican, white-breasted cormorant, African darter, osprey, African fish eagle and great white pelican, would have been affected. A combination of the deterioration of marginal zone vegetation and reduced marginal habitats, reduced backwater habitats, and a lower abundance of tall riparian trees (*Acacia*) as nesting areas, will concurrently impact adversely on herons (two species), storks (two species) and egrets (two species). The decrease in the exposed shoreline and shallow edges habitats will impact on the abundance of three duck species, three plover species and two waders.		

3.3.1 Causes and sources

The reasons for changes from reference conditions must be identified and understood. These are referred to as causes and sources (EPA, 2012). The causes and sources for the PES are summarised in Table 8.

Table 8. EFR Fish 2: PES causes and sources

Component	***Causes***	***Sources***
Hydrology		Confidence 4
	Changes in flow regime and reduction of runoff.	Hardap Dam and associated operational rules. (Flow related)
Physico-chemical variables	PES: C	Confidence 3
	Changes in flow regime and reduction of runoff.	Hardap Dam. (Flow related)
	Elevated salts and nutrients and subsequence lower oxygen levels (resulting in fish kills and development of blue-green algae.	Irrigation return flows. (Non-flow related) Sewage discharges due to malfunctioning STWs. (Non-flow related)
	Suspected metal toxicity.	Possible natural geological input of copper; discharges around urban areas. Confidence in metal toxicity is low, as sources not easily identifiable. (Non-flow related)
Geomorphology	PES B/C	Confidence 5
	Changes in flow regime and reduction of runoff have reduced flushing events and pool filling frequencies.	Hardap Dam. (Flow related)
Riparian vegetation	PES C	Confidence 4
	Reduction of floods generally favours woody vegetation and facilitates their encroachment into lower zones and pool margins.	Hardap Dam. (Flow related)
	Decrease in woody seedlings (notably *Acacia* species).	High grazing and browsing pressure (mainly goats). Alien species invasion. (Non-flow related)
	Reduced cover of palatable species and increased cover of *T. usneoides*, thereby also altering species composition.	
Fish	PES B	Confidence 3
	Presence of alien or introduced fish species (OMOS, and possibly CCAR).	Stocking of species alien to Fish River in Hardap Dam and escape of alien fish from Hardap hatchery. (Non-flow related)
	Decreased dispersal and breeding success (reaching optimal spawning habitats).	Artificial migration barriers (Hardap Dam, farm dams and weirs). (Non-flow related)
	Potential slight increase in turbidity at times.	Overgrazing (mostly goats) and potential presence of bottom feeding alien fish species (CCAR). (Non-flow related)
	Flow modification - slight decrease in condition and availability of pools (slow-deep habitats).	Hardap Dam. (Flow related)
	Reduced breeding success of semi-rheophilic species requiring extended flow over rocky substrates (riffles/rapids).	Decrease in occurrence and duration of flowing conditions as result of flow modification by upstream dams. (Flow related)
Macro-invertebrates	PES B	Confidence 2.2
	Increased nutrients, salinity and Cyanobacteria.	Livestock, irrigated agriculture, impoundments, *Prosopis* leaf litter. (Non-flow related)
	Competition from alien species.	*Physa acuta*. (Non-flow related)
	Reduced duration of flow.	Hardap Dam (Flow related)

Riverine Fauna	PES B	Confidence 4
	Slight decrease in fish abundance and condition of pools (slow-deep habitats) impacts on the abundance of the piscivorous fauna.	Flow modification caused by Hardap Dam and abstraction. (Flow related)
	Deterioration in marginal habitats (extent of wetted perimeter and vegetation presence-sedges).	Flow modification caused by Hardap Dam and abstraction. (Flow related)
	Lower abundance in *Acacia* species in the upper zone as nesting and migration corridor habitat, and an increase in alien *Prosopis*.	Grazing and browsing pressure (mainly goats). Alien species invasion. (Non-Flow related)

The major impacts that have caused the change from reference conditions were flow related impacts caused by the operation of Hardap Dam as well as irrigation return flows. It should be noted that the impacts of dams on the hydrology in this reach was less pronounced at EFR Fish 2 as there were more tributaries that contribute lateral inflow. Nutrients and salinity were elevated due to the irrigation return flows.

Non-flow related impacts included fairly high grazing and browsing pressure (mainly goats) and the extent of this impact was greater than at EFR Fish 1. Elevated nutrient levels were present due to upstream activities. The exact sources of elevated nutrients were unknown, although malfunctioning/non-existent STWs at upstream towns and settlements were considered a contributing factor.

3.3.2 PES EcoStatus

The EcoStatus represents an integrated status as a biological end point (Kleynhans and Louw, 2007). The Ecological Categories of the biological response components, namely fish, macro-invertebrates and riparian vegetation, must therefore be combined to determine the EcoStatus. The resultant EcoStatus was a C. The model output is provided in Appendix B.

3.4 Recommended Ecological Category (REC)

The REC is determined based on ecological criteria only and considered the EIS (HIGH or VERY HIGH scoring provides motivation for improvement), the restoration potential and attainability thereof. The EIS is HIGH, therefore the REC requires improvement of the C PES to a B EcoStatus. However an overall improvement in the EcoStatus could not be achieved by flow related mitigation measures as the instream biota components were already in a B EC. The riparian vegetation could be improved within the C EC by minimizing trampling and grazing pressure of goats.

3.5 Summary of EcoClassification Results

The EcoClassification results are summarised in Table 9. The colours used are standard colours associated with EcoClassification.

Table 9. EFR Fish 2: Summary of EcoClassification results

Driver Components	***PES***	***REC***	***Comment***
IHI Hydrology	C	C	
Physico-chemical	C	C	
Geomorphology	B/C	B/C	
Response Components	***PES***	***REC***	
Fish	B	B	No improvement will be required to achieve the REC as the fish is already in a B PES.
Macro-invertebrates	B	B	No improvement will be required to achieve the REC as the macro-invertebrates are already in a B PES.
Instream	**B**	**B**	No improvement will be required to achieve the REC as the instream components are already in a B PES.
Riparian Vegetation	C	C+[1]	Improvement requires addressing overgrazing. Restoration will not be possible to a B REC.
Riverine Fauna	B	B	No improvement will be required to achieve the REC as the fauna is already in a B PES.
EcoStatus	**C**	**C+**	Due to the difficulties of addressing grazing issues, improvement in the vegetation is unlikely to happen, and the REC of a B cannot be achieved.
EIS	HIGH		

1 The C+ indicates an improvement within the C percentage range.

4. EcoClassification: MRU Fish B.2 – EFR Ai-Ais

As discussed in section 1.3.2 an additional 'site' was required downstream of the Löwen River confluence due to the existence of migration barriers between EFR Fish 2 and EFR Ai-Ais and to essentially check the flow scenarios and its impact further downstream of EFR Fish 2.

The site effectively refers to a reach located in MRU Fish B.2 representing the Fish River from the Löwen River to the Orange River confluence with the focus on the area around Ai-Ais Resort. Although no cross-sectional surveys were undertaken, limited field work was undertaken to determine the PES. Less detailed information was therefore available for this reach, but it will be sufficient for determining the PES and for operational scenario evaluation. For more detailed specialist information, refer to Technical Report 28 (ORASECOM, 2013a).

A summary of the PES conditions are provided in Table 10.

Table 10. Description of the PES for MRU Fish B.2

Component PES Description	
Hydrology	
The PD MAR is 475 MCM. Any The natural MAR is 613 MCM. The patterns of flow are also likely to be relatively natural, but it is distinctly possible that the attenuation and channel loss effects may be exaggerated by the loss of some inflows from the Löwen tributary (due to Naute Dam) as well as somewhat reduced flow magnitudes at Seeheim gauging weir. There is, evidence for quite substantial attenuation and loss of flow between Seeheim gauging weir and Ai-Ais gauging weir in most years, partly influenced by the limited number (and magnitude) of spills and seepage (leak) from Naute Dam. These patterns of attenuation and loss are difficult to generalize and it is clear that the contribution of the lower and western tributaries is highly variable.	
Physico-chemical variables	PES: C
Although nutrient levels are expected to be elevated due to the sewage discharges at Ai-Ais Resort and the water quality category is expected to drop, it should stay within a C category, largely due to the position of Ai-Ais Resort in the lower section of the reach	
Geomorphology	PES B
Although the reduced flows from Hardap and Naute Dams remain the major problem for geomorphology, flows from tributaries and sediment introduced in the gorge progressively offset the morphological impacts of Hardap Dam in this lowest reach of the river.	
Riparian vegetation	PES:B/C
A large portion of this reach is inside conservation areas so non-flow related impacts, such as herbivory by livestock will be absent in the Transfrontier Park (Hendley, 2012 pers. comm.) and vegetation clearing will be mitigated, and similar to those assessed at EFR Fish 1 (low). There will still be a response to altered flow as some reduced flooding will still exist due to upstream dams, but tributary contribution will mitigate this impact to some degree. Also, species composition of riparian vegetation has changed from Ai-Ais Resort downstream as species such as the fever tree (*A. xanthophloea*) has been planted at the Resort and has spread downstream all the way to the confluence with the Orange River. *P. australis* (reeds) is also abundant at Ai-Ais Resort due to the	

	presence of springs and nutrient enrichment, but the effect downstream is likely to not be extensive, and the impact does not occur upstream.
Fish	PES: C
	Six of the expected eight indigenous fish species were sampled in the reach during the June 2012 survey, together with one alien/introduced species (OMOS). Two species not sampled during the survey, namely BKIM and BPAU, are still expected to occur in this reach. The abundance and spatial FROC of the indigenous species sampled were generally high for most species (BAEN > LCAP > MBRE > BHOS), while BTRI and CGAR were relatively scarce during the survey. Based on all considerations of impacts and available fish information, it was estimated that the expected reference FROC of BAEN, BKIM, CGAR and LUMB was reduced in this reach due to the impact of various human induced activities. The primary impacts includes modified flow regimes (especially related to large dams such as Hardap and Naute), as well as localized water quality deterioration (Ai-Ais Resort). Overall the fish assemblage was therefore estimated to currently be in a slightly to moderately modified state. Refer to the (ORASECOM, 2013a) for detail regarding the estimated present status of each fish species.
Macro-invertebrates	PES: B
	A total of 15 NASS2 taxa were recorded at Ai-Ais Resort in June 2012. The same weighting of ecological traits used for EFR Fish 1 was applied. Habitat suitability was rated as Moderate (60%). The macro-invertebrate composition was dominated by the pest blackfly *S. chutteri*, which was the only species of blackfly recorded at this site. The proportion of air-breathing taxa was low (25%), indicating well-oxygenated conditions. Two warm stenothermal taxa were recorded: Thiaridae and Tricorythidae, and this constituted 12% of the NASS2 taxa. The diversity of macro-invertebrates sensitive to water quality deterioration was low, with only two sensitive taxa recorded: Tricorythidae and Baetidae >2spp. No alien macro-invertebrates were recorded.
Riverine Fauna	PES: C
	The PES is similar to EFR Fish 2, with the species composition being similar. Impacts on the riverine fauna will be a bit more pronounced, however not to such an extent that the PES would deteriorate.

The EcoClassification results are summarised in Table 11. The colours used are standard colours associated with EcoClassification.

Table 11. MRU Fish B.2 (EFR Ai-Ais): Summary of EcoClassification results

Driver Components	***PES***
IHI Hydrology	C
Physico-chemical	C
Geomorphology	B
Response Components	***PES***
Fish	C
Macro-invertebrates	B
Riparian Vegetation	B/C
Riverine Fauna	C
EIS	HIGH

5. EcoClassification: Summary and Conclusions

5.1 Summary of EcoClassification Results

The EcoClassification results are summarised in Table 12.

Table 12. EcoClassification Results summary

EFR Fish 1: EcoClassification description	***Ecological Categories***		
EIS: HIGH Highest scoring metrics: Rare and endangered instream and riparian species, critical instream habitat, refugia and diversity of riparian habitat types and features. **PES: B/C** Flow-related impacts: Abstraction and flow reduction caused by dams, e.g. Hardap Dam, Irrigation return flows. Localised impacts closer to the Hardap Dam due to irrigation. Non-flow related impacts: Nutrients and salinity elevated due to the irrigation return flows. Grazing and browsing pressure (mainly goats), vegetation removal at settlements, sewage discharges into the Fish River. **REC: B** HIGH EIS 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).	***Driver Components***	***PES***	***REC***
	IHI Hydrology	C	C
	Physico-chemical	C	C
	Geomorphology	B/C	B/C
	Response Components	***PES***	***REC***
	Fish	B	B
	Macro-invertebrates	C	B
	Instream	**B/C**	**B**
	Riparian Vegetation	B/C	B
	Riverine Fauna	B	B
	EcoStatus	**B/C**	**B**
	EIS	HIGH	
EFR Fish 2: EcoClassification description	***Ecological Categories***		
EIS: 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 EIS was motivation for improvement of the EcoStatus. This can however not be achieved as the grazing impacts are the main impacts to be addressed. The riparian vegetation can only be improved within the C and this improvement would be insufficient to achieve a B EC for riparian vegetation.	***Driver Components***	***PES***	***REC***
	IHI Hydrology	C	C
	Physico-chemical	C	C
	Geomorphology	B/C	B/C
	Response Components	***PES***	***REC***
	Fish	B	B
	Macro-invertebrates	B	B
	Instream	**B**	**B**
	Riparian Vegetation	C	C+[1]
	Riverine Fauna	B	B
	EcoStatus	**C**	**C+**
	EIS	HIGH	

EFR Fish Ai-Ais: EcoClassification description

EIS: 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 EIS.
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 Resort resulting in elevated nutrient levels.

Ecological Categories

Driver Components	***PES***
IHI Hydrology	C
Physico-Chemical	C
Geomorphology	B
Response Components	***PES***
Fish	C
Macro-invertebrates	B
Riparian Vegetation	B/C
Riverine Fauna	C
EIS	HIGH

5.2 Limitations and Constraints

5.2.1 Physico-chemical variables - Uncertainty of the source of apparent nutrient problems

Nutrient elevations were evident in the Fish River system, although the source(s) could not be easily determined. Due to the lack of water quality data, particularly upstream of the Hardap irrigation area, a reference state for nutrients could not be established. Consultation with the geohydrologist on the study confirmed that a natural geological source was unlikely. Possible nutrient sources in the catchment included nutrient elevations and irrigation return flows around Hardap Dam and a number of malfunctioning Sewage Treatment Works (STWs), e.g. at Gibeon and Ai-Ais Resort.

5.2.2 Fish

Hybridization of fish species: Hybridization among the two *Labeo,* and among the two *Labeobarbus* species in the Fish River has been recorded (Van Vuren *et al*, 1989; Hay, 1991 etc.). Nepid Consultants (2010) indicated the presence of a potentially undescribed *Labeo* species in the Löwen River (DNA analysis was not yet available to confirm this). Hybridization complicates the identification of these species.

A fish survey conducted in 1971 in the Fish River (Hardap Dam, Seeheim settlement, Sunnyside farm and Ai-Ais Resort) refers to BKIM, BPAU, CGAR, CCAR, MBRE, LCAP, LUMB, OMOS, and TSPA. The absence (no mention) of BAEN indicated that there could already at that stage have been confusion regarding BAEN and BKIM as a result of hybridization. This may be an indication that the hybridization between these species may not be the result of manmade barriers (Hardap Dam) but rather natural conditions (ephemeral system with isolated pools that create natural barriers for long periods creating a situation similar to many dams in a system). Hybridization may therefore be a strongly/unique natural phenomenon in the Fish River.

The question also arises whether there may have been a different species or isolated population of a yellowfish species in the Fish River above the Witputs Waterfall, and through human activities the two yellowfishes (BAEN and BKIM) were introduced, which led to hybridization.

Reference Conditions: One of the main challenges of this component of the study was the description of the reference condition of the fish assemblages of each reach/Resource Unit. This process was limited by the lack of historical information and the current flow alteration (especially modified flow regime as a result of Hardap Dam) that may have altered the fish population to some extent and especially by introduction of fish species into Hardap Dam, and also keeping and escapees of various fish species from the Hardap Dam hatchery. This is furthermore complicated by the hybridisation between indigenous species, as well as the presence of fish species alien to the system (see above).

5.2.3 Macro-invertebrates

Reference Conditions: There was limited information on aquatic macro-invertebrates in the study area before impoundment and associated large-scale irrigation development. The only data available on macro-invertebrates in the Fish River before the construction of Hardap Dam was limited to collections of specific taxa (Curtis, 1991). No data were collected upstream of Hardap Dam during this study because of logistical constraints. Reference conditions were therefore based almost entirely on information collected after these rivers had been impounded. The expected composition of aquatic macro-invertebrates used in this study therefore constitute what may be described as “best attainable” rather than “reference” state.

EcoClassification: The composition and abundance of macro-invertebrate taxa in non-perennial systems, such as the Fish River, is driven mainly by the hydrological phase, and this presented a particular challenge of using macro-invertebrates as indicators of ecological state. Furthermore, the ecological traits that characterise macro-invertebrates inhabiting non-perennial systems are also typically associated with human impacts and disturbance, and include small size, rapid life cycles, multiple generations, high fecundity, and tolerance of water quality deterioration. This makes it difficult to distinguish between natural variation and human impacts. In this study the assessment of the PES in the Fish River was restricted to conditions during the early dry season only, as this is when data are likely to be most reliable. There was no method available to quantify the PES of macro-invertebrates in non-perennial systems, so the method applied in this report for the Fish River is new and has not been tested or undergone any peer review process. The ecological traits that were used were limited to those for which data were available, or could be assumed with reasonable confidence. These factors have a significant influence on reducing the confidence in the assessment of PES in the Fish River.

MIRAI: The weightings and ratings applied to Macro Invertebrate Response Assessment Index (MIRAI) metrics at a particular site should remain constant, so for consistency the same or similar values used for the ORASECOM baseline monitoring conducted at the confluence of the Boom River (Site OHAEH 28.5), should have been applied in this study (ORASECOM, 2011b). However, there were differences in opinion in ranking and weighting metrics. In particular, the ORASECOM monitoring report ranked the "presence of taxa with a preference for very fast-flowing water" as the most important factor for assessing modified flows at OHAEH 28.5. Geomorphologically this section of river is classified as Lower Foothill, and therefore has a comparatively gentle gradient, so it is unlikely that the macro-invertebrate fauna would comprise many taxa with a preference for very high water velocities.

5.3 Confidence

The confidence in the EcoClassification process is provided below (Table 13) and was based on data and information availability and EcoClassification where:

- Data and information availability: Evaluation based on the adequacy of any available data for interpretation of the Ecological Category.
- EcoClassification: Evaluation based on the confidence in the Present Ecological State category.

The confidence score is based on a scale of 0–5 and colour coded where:

0–1.9: Low 2–3.4: Moderate 3.5–5: High

These confidence ratings are applicable to all scoring provided in this chapter.

Table 13. Confidence in EcoClassification

EFR site	Data and information availability									EcoClassification								
	Physico-chemical	*Geomorphology*	*IHI*	*Fish*	*Invertebrates*	*Riparian vegetation*	*Fauna*	*Average*	*Median*	*Physico-chemical*	*Geomorphology*	*IHI*	*Fish*	*Macro-invertebrates*	*Riparian vegetation*	*Fauna*	*Average*	*Median*
EFR Fish 1	1.5	3	3.5	2	1	3	3	**2.43**	**3**	2.5	3	3.2	2	2	3.6	3.5	**2.83**	**3.00**
EFR Fish 2	2	3	3.5	2	2	3	3	**2.64**	**3**	2.5	3	3.6	2	2	3.1	3.5	**2.81**	**3.00**
EFR Ai-Ais	2	3	3.5	2	2	3	3	**2.64**	**3**	2.5	3	3.6	2	2	2.5	3.5	**2.73**	**2.50**

5.4 Conclusions

The confidence in the data availability and information at both EFR sites were moderate, however data availability and information was better for EFR Fish 2 due to the recent ESIA undertaken in the reach.

EcoClassification results for both EFR sites were moderate. Reasons for this are described in section 5.4. The overall confidence is lower at EFR Fish 2 despite a higher confidence in data availability and information. This was due to lower confidence in riparian vegetation due to high grazing pressure at the site which made assessment more difficult. The confidence in data availability and information for EFR Ai-Ais was similar to EFR Fish 2 and the confidence in the EcoClassification was the lowest because surveys were less intensive than at the main (key) EFR sites. In general the biggest problem with the confidences was the lack of historical data regarding the biota and historic measured hydrology data (pre-Hardap Dam). This will however have limited consequences to the ability of evaluating operational flow scenarios which is more dependent on an understanding of the flow requirements of indicator species and how they will respond to a different flow regime than present.

No further work is therefore required to refine the reference conditions and therefore improving the PES as this would be impossible without historical data, and effort should rather be focussed on biomonitoring to confirm predictions on responses to the altered flow regime from the proposed Neckartal Dam within an Adaptive Management Framework (see following chapters).

6. Fish River EFR Assessment: Approach and Operational Scenarios

All hydrological and hydraulic information and approaches are provided in Technical report 31 (ORASECOM, 2013b) including the operational scenarios, and therefore summarised in this chapter. The biophysical components' approach is provided in Appendix C.

Scenarios include specific development or operational options which are referred to as drivers while the combination of drivers is referred to as a Scenario (Sc). Timing is also attached to the drivers and scenarios. The possible/likely drivers and scenarios as modelled were derived from two meetings; the first held in Pretoria on 31 August 2012 and the second held in Windhoek on 21 September 2012. The drivers and scenarios forthcoming from the first meeting related to developments envisaged by South Africa and Lesotho, while drivers and scenarios from the second meeting related to developments envisaged by Namibia.

Table 14 illustrates the drivers and the resulting scenarios applicable only for the Fish River. Note, no timing is coupled specifically to the driver developments as the construction of Neckartal Dam and the increase in irrigation is imminent.

Table 14. Fish River scenarios

Scenario	Fish River Drivers						
	Naute Dam:	Neckartal Dam EFR release scenarios as % of inflow					
	Increased irrigation	0%	10%	20%	30%	40%	50%
Sc 0%	Yes	Yes					
Sc 10%	Yes		Yes				
Sc 20%	Yes			Yes			
Sc 30%	Yes				Yes		
Sc 40%	Yes					Yes	
Sc 50%	Yes						Yes

7. Operational Scenario Evaluation: MRU B.1 - EFR Fish 2

7.1 Operational Scenarios

For the evaluation of Operational Scenarios, various flow indicators (ORASECOM, 2013b and Appendix C) were used in determining the ecological consequences. Table 15 provides the flow indicators used during the evaluation, showing changes from the present day flow (PD)

Table 15. Flow indicators used during the Scenario evaluation showing changes from PD under different Operational Scenarios

Low flow indicators (% of time)	***Operational scenario***					
	0%	***20%***	***30%***	***40%***	***50%***	***PD***
Flow: Wet Season	34	45	47	51	53	65
Flow: All months	19	24	25	27	28	36
When flow is> 2 m³/s (wet season)	25	35	37	41	43	56
When flow is > 2 m³/s (all months)	10	15	16	18	19	27
When flow is > 10 m³/s (wet season)	16	20	22	24	26	37
High flow criteria (number of events throughout modeled flow scenario)						
Events > 80 m³/s (duration of 4 days at 80 or higher)	29	27	27	24	24	36
Events > 150 m³/s (duration of 4 days at 150 or higher)	24	24	25	21	20	28
Events >600 m³/s (duration of 2 days at 600 or higher)	24	24	21	20	20	27
Impact on pools						
Risk of all pools drying out 1 or more years in 10 years [1]	VH	H	M	L	VL	Rarely

1 Risk is evaluated in terms of VH (Very High), H (High), M (Moderate), L (Low) and VH (Very Low).

7.2 Consequences of the Neckartal Dam with no EFR Releases (0%) Scenario

Initial screening indicated that the impacts of Sc 0% and Sc 20% would be significant. The impacts related to the Sc 0% are just broadly described whereas all the other scenarios will be discussed in more detail in the following sections. Sc 0% resulted in the following impacts provided in Table 16.

Table 16. Consequences of Sc 0%

Component	***PES***	***EC Sc 0%***	***Response***
Physico-chemical	C	D	Deteriorating conditions for salts, nutrients, temperature, oxygen and turbidity. Toxics will drop by at least half a category (low confidence). It is expected that there is a high risk of surface water-fed pools drying up frequently under these release conditions.
Geomorphology	B/C	C/D	Decrease of scouring potential by 60% and a very high risk of all surface water fed pools drying out every few years.
Riparian vegetation	C	D	Reproductive failure for large proportions of most marginal zone vegetation populations.
Macro-invertebrates	B	D	Macro-invertebrate composition is expected to be dominated by taxa with short and very short adult life spans. Hydrological modeling indicates that there will be a very high risk that all surface driven pools will dry up under this scenario, but this assumes that there will be no leakage from Neckartal Dam. It is likely that there will be some leakage and this will likely maintain permanent pools, at least in the upper portion of this MRU. Further downstream the river is expected to comprise isolated pools for 90% of the time, compared to 70% under PD. Taxa with longer life spans, such as Thiaridae and crabs, are likely to be sustained closer to the dam because of normal leakage from the dam, but these taxa are expected to become increasingly rare further downstream, but are likely to be maintained in pools that remain permanent because of groundwater inflows. Air-breathers: Air breathing taxa, such as many bugs and beetles, are likely to dominate because of reduced oxygen expected with increased duration of flow cessation. Filter-Feeders: Functional feeding is expected to be dominated by scraper-grazers and predators. Filter-feeders, such as *Simulium* and Bryozoa, are expected to be negatively affected because of reduced flow durations. Currents: Gomphid production is expected to drop significantly because of the reduced duration of the wet season, but sufficient wet season duration will remain to allow some egg and larval development. Habitats: Reduced frequency and duration of flows under this scenario is expected to lead to reduced flushing (cleaning) of substrates and this will reduce the suitability of bed substrates for macro-invertebrates. Thermophily: Wet season water temperatures are expected to increase significantly because of reduced duration of flows, and this is expected to favour warm stenothermal taxa, such as Bulininae, Thiaridae and Belostomatidae, and be negative for cold stenothermal taxa, such as Lymnaeidae. Water Quality: Sensitive taxa are expected to become rare because of water quality deterioration, particularly elevated nutrients. Sensitive taxa include Hydropsychidae, Ecnomidae, Tricorythidae and Elmidae.
Fish	B	D	Spawning will occur, but low survival rate. Intolerant species to water quality such as BKIM will become rare. Dispersal of species will be limited. The risk of pools drying up will have a significant impact on the fish species as recolonisation from the other reaches will be required which could be prevented by migration barriers and lack of flow.

Component	***PES***	***EC Sc 0%***	***Response***
Fauna	B	D	Open water - deep for hunting and shelter: Impact on larger fish species spawning survival rate and therefore piscivorous animal species (especially larger species such as pelicans and otters) will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: Reduced flow - water stress for most marginal zone species, and a high proportion of mortality; influence riparian fauna, especially relating to shelter, feeding and migration along the riparian corridor.

7.3 Consequences of the Neckartal Dam with the 20, 30, 40 and 50% EFR Release Scenarios

7.3.1 Driver consequences

The consequences of the Sc 20%, Sc 30%, Sc 40% and Sc 50% are provided in Table 17.

Table 17. Consequences of Scenarios (20% – 50%) on the physico-chemical and geomorphology drivers

Release Scenarios	***Response description***	***Response EC***
Physico-chemical (C PES, 70%)		
50%	Conditions are not expected to change greatly from present state, with a small insignificant risk of pools drying out.	C (69%)
40%	Temperature, oxygen, turbidity and salt levels deteriorating slightly.	C (65%)
30%	Insufficient resolution to distinguish between 20% and 30%.	C/D (61.8%)
20%	Most parameters deteriorating from present state conditions. There is almost a 10% drop in PAI %, as the impact on pools will be significant and a concurrent deterioration in salts, nutrients, oxygen and temperature conditions is expected.	C/D (61.8%)
Geomorphology (B/C PES, 82%)		
50%	Water quality state is governed largely by nutrient status, and to a lesser degree, salt levels. Reductions in flow and potential drying out of pools result in an increase in salt levels and higher nutrient concentrations. Impacts on temperature and oxygen will also be experienced. The overriding factor is considered the increase in nutrients, and although the reference condition concentrations for all these variables are unknown, the highest confidence is in the nutrient state of the system. Some increase in toxics is expected due to lower dilution levels, but confidence is low as there is uncertainty around the sources of the metal ion elevations seen in the data.	C (64%)
40%		C (64%)
30%		C (64%)
20%		C (64%)

7.3.2 Biological response consequences

An analysis was made to assess the biotic responses to the scenarios based on the flow, water quality and geomorphological changes associated with each operational flow scenario. These consequences are provided in Table 18–21.

Table 18. Fish: Ecological consequences of the different scenarios

Release Scenarios	***Flow Indicators***	***Response***
% time that the river flows during the wet season and (all months)		
PES	65 (36)	
50%	53 (28)	Breeding success rate of especially intolerant species (BKIM) to be reduced very slightly. This will have some impact on water quality and more intolerant fish species may be reduced.
40%	51 (27)	Conditions very similar to the Sc 50%, with expected small impact on intolerant species, while water quality expected to remain fairly similar than under PD with small change in some fish species abundances.
30%	47 (25)	Decrease in the breeding success rate of some species (especially BKIM, BAEN, and LCAP) and the decrease in FROC of all species may start to occur. Increase in lotic conditions over lentic condition may also favour the alien/introduced species (OMOS, CCAR and TSPA), leading to a further deterioration in the status of the fish assemblage. Overall increase in no flow conditions will lead to decrease in water quality (especially in the dry season) with a resultant decrease in the FROC of most species. An impact on the survival of fish in the pools (especially early life stages) is expected.
20%	45 (24)	Breeding success rate to be reduced for most species, but significantly for BKIM, BAEN, and LCAP. A decrease in water quality (especially in the dry season) with a resultant decrease in the FROC of most species. An impact on the survival of fish in the pools (especially early life stages) is expected.
% time that 2 m^3/s occurs during the wet season and (all months)		
PES	56 (27)	
50%	43 (19)	Although a slight reduction in adequate connectivity, most potamodromous species will be maintained in close to PD status.
40%	41 (18)	Connectivity frequency similar to Sc 50% with only a small impact on some species expected due to a slight reduction in migratory success of some species (especially other than breeding migrations).
30%	37 (16)	The occurrence of flows to maintain adequate depth for connectivity is decreasing notably from PD. This will start impacting on the ability of some species to migrate and disperse successfully between pools, and result in a slight decrease in FROC of especially species such as BKIM.
20%	35 (15)	Approximately half of the PD opportunities for some larger species to migrate successfully are available. Although it may still be adequate to allow movement, a negative impact can be expected in the more rare species (such as BKIM and LUMB). Slight decrease in FROC of some species due to the inability of some species to disperse successfully at times.
% time that 10 m^3/s occurs during the wet season		
PES	37	
50%	26	Some loss in inundated vegetation will occur (11%), with a slight potential reduction in breeding success of relevant species.
40%	24	The reduction in inundated vegetation results in small potential reduction in some species' (LUMB, BPAU) breeding success.
30%	22	Some potential loss in flooded (inundated) vegetation may occur reducing the breeding success of species such as LUMB, BPAU and to lesser degree CGAR.
20%	20	Only 50% of the inundated vegetation will be available and a slight deterioration in

Release Scenarios	***Flow Indicators***	***Response***
		LUMB and BPAU is expected.
Risk of all surface fed pools drying up		
PES	Rarely dry	
50%	Very Low	Very low risk that pools will dry up completely. No significant impact on the survival of pools expected.
40%	Low	No significant impact on survival of pools expected.
30%	Medium	There is a definite increase in the risk (moderate) that all pools within the reach may dry up at some stage. Should this occur, it will result in a significant decrease in the FROC of all species, since recolonisation from other remaining perennial pools in other reaches will be required
20%	Medium-High	The risk that pools will dry up completely is very high under this scenario, and this is likely to occur at some stage. It will have a significant impact on the fish assemblage of the reach, since recolonisation will be required from other reaches, which could be prevented by migration barriers and lack of flow. There is a definite risk that intolerant species such as BKIM may be lost from reach.
Fish response Ecological Categories		
PES	B (85%)	
50%	B (85%)	
40%	B (84%)	
30%	C (68%)	
20%	C/D (61%)	

Table 19. Macro-invertebrates: Ecological consequences of the different scenarios

Release Scenarios	***Ecological traits***	***Response***
Macro-invertebrate life span categories		
PES	1*	
50%	1	No change from PD.
40%	1	No change from PD.
30%	1.5	Macro-invertebrate with long adult life spans, such as crabs and thiarid snails, are expected to be negatively impacted and disappear (i.e. three of the four categories).
20%	1.5	Same as for Sc 30%.
Velocity Preference Categories		
PES	0	
50%	0	No change from PD.
40%	0	No change from PD.
30%	1	Gomphid production is expected to drop slightly because of the reduced duration of the wet season.
20%	1	Same as for Sc 30%.
Macro-invertebrate water quality categories		
PES	1	

Release Scenarios	*Ecological traits*	*Response*
50%	1	No significant change from PD. However, wet season (summer) water temperatures are expected to increase slightly and this is expected to favour warm stenothermal taxa, such as Bulininae, Thiaridae and Belostomatidae. Furthermore, the abundance of filter-feeding macro-invertebrates is expected to increase because of phytoplankton discharged from the impoundment is expected.
40%	1	Same as for Sc 50%.
30%	1.5	A slight reduction in the abundance and diversity of sensitive taxa, mainly because of expected elevation in nutrients.
20%	2	No more than two sensitive taxa are expected under this scenario.
Macro-invertebrate response Ecological Categories		
PES	B (86%)	
50%	B (85%)	
40%	B (85%)	
30%	B/C (80%)	
20%	B/C (79%)	

*: A six-point rating system was used, as follows:
0 = No change from reference; 1 = Small change from reference; 2 = Moderate change from reference
3 = Large change from reference; 4 = Serious change from reference. 5 = Extreme change from reference.

Table 20. Riparian vegetation: Ecological consequences of the different scenarios

No change to PES | Decrease to PES within EC | Decrease to EC below PES

Flow Indicators	Scenarios						*Comments*
	0%	**20%**	**30%**	**40%**	**50%**	**PD**	
No of events of < 600 m³/s (duration of 2 days at 600 or higher)	24	24	21	20	20	27	Not significantly altered by any of the scenarios.
No of events of < 150 m3/s (duration of 4 days at 150 or higher)	24	24	25	21	20	28	Not significantly altered by any of the scenarios.
No of events of < 80 m3/s (duration of 4 days at 80 or higher)	29	28	27	24	24	36	Sc 50% and Sc 40% result in increased woody cover on the channel floor.
10 m³/s	16	20	22	24	26	37	
2 m³/s	10	15	16	18	19	27	
Decrease in % of time that flow occurs in wet season	34	45	47	51	53	65	Sc 30%, Sc 20% and Sc 0% indicate water stress for most marginal species.
Decrease in % of time that flow occurs in all months)	19	24	25	27	28	36	
PES	**D**	**C/D**	**C/D**	**C**	**C**	**C**	Sc 0%, 20% and 30% is a lower EC than PES

Table 21. Riverine fauna: Ecological consequences of the different scenarios

Release Scenarios	***Flow Indicators***	***Response***
% time that the river flows during the wet season		
PES	65	
50%	53	Open water - deep for hunting and shelter: Little impact on piscivorous fauna. Wooded bank - shrubs and tall riparian - continuous.
40%	51	Same as Sc 50%.
30%	47	Open water - deep for hunting and shelter: A decrease in the breeding success rate of some fish species results in lower fish numbers, thus piscivorous animal species (especially larger species) will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: A reduction in flows - moderate reproductive failure for proportions of marginal zone vegetation populations. This will slightly impact on riparian fauna, especially relating to feeding.
20%	45	Open water - deep for hunting and shelter: Lower fish numbers, thus piscivorous animal species (especially larger species) will be impacted accordingly. Exposed shoreline - shallow edges: Wetted perimeter declining - impacts on shore species. Wooded bank - shrubs and tall riparian - continuous: A reduction in flows - reproductive failure for proportions of marginal zone vegetation populations. This will impact on riparian fauna, especially relating to shelter, feeding and migration along the riparian corridor.
% time that the river flows during all months		
PES	36	
50%	28	Open water - deep for hunting and shelter: Little impact on piscivorous fauna.
40%	27	Open water - deep for hunting and shelter: Same as Sc 50%.
30%	25	Open water - deep for hunting and shelter: Decreased water quality (especially in the dry season and impact on the survival of fish in the pools, thus piscivorous animal species will be impacted accordingly.
20%	24	Open water - deep for hunting and shelter: Lower fish numbers, thus piscivorous animal species (especially larger species) will be impacted accordingly.
% time that 2 m^3/s occurs during the wet season and (all months)		
PES	56 (27)	
50%	43 (19)	Open water - deep for hunting and shelter: Slight reduction in adequate connectivity, fish not influenced - no impact on piscivorous fauna.
40%	41 (18)	Open water - deep for hunting and shelter: Same as Sc 50%.
30%	37 (16)	Open water - deep for hunting and shelter: Lower flows, impacts on fish movement, and result in a slight decrease in fish populations - piscivorous animal species (especially larger species) will be impacted accordingly.
20%	35 (15)	Open water - deep for hunting and shelter: Slightly lower fish abundance; piscivorous animal species will be impacted accordingly.
% time that 10 m^3/s occurs during the wet season		
PES	37	
50%	26	Open water - deep for hunting and shelter: Slight deterioration in larger fish species reproduction - piscivorous animal species will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: Unlikely to affect vegetation and the associated riparian fauna.
40%	24	Same as Sc 50%.
30%	22	Open water - deep for hunting and shelter: Some deterioration in larger fish species reproduction - piscivorous animal species will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: Reduced flow - water stress for

20%	20	marginal zone species, reduce reproductive success; influence riparian fauna, especially relating to feeding along the riparian corridor. Open water - deep for hunting and shelter: Exposed shoreline - shallow edges. Deterioration in larger fish species reproduction - piscivorous animal species (especially larger species such as pelicans and otters) will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: Reduced flow - water stress for marginal zone species, and a low proportion of mortality; influence riparian fauna, especially relating to feeding along the riparian corridor.
Risk of all surface fed pools drying up		
PES	Rarely dry	
50%	Very Low	No significant impact on piscivorous species, invertivores and other aquatic predators.
40%	Low	Same as Sc 50%.
30%	Medium	This will impact on piscivorous species, invertivores and other aquatic predators.
20%	Medium-High	Same as Sc 30%.
Fauna response Ecological Categories		
PES	B (84%)	
50%	B (83%)	
40%	B (83%)	
30%	C (69.5%)	
20%	C/D (60%)	

7.4 Summary of Biophysical Responses to Operational Flow Scenarios at EFR Fish 2

The responses in terms of impact on Ecological Categories are summarised in Table 22. A scale is also provided that indicates the relative differences between the different scenarios (Figure 5).

Table 22. Summary of biophysical responses at EFR Fish 2

Driver Components	***PES (REC)***	***Sc 0%***	***Sc 20%***	***Sc 30%***	***Sc 40%***	***Sc 50%***
Physico-chemical	C	D	C/D	C/D	C	C
Geomorphology	B/C	C/D	C	C	C	C
Response Components						
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 the 40% and 50% scenarios would meet the ecological objectives, i.e. for the PES to be maintained. Under the Sc 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 scenario does not meet the ecological objectives. Sc 20% and Sc 0% results in a worse deterioration in all the components than Sc 30% and the ecological objectives are not met for any of the components.

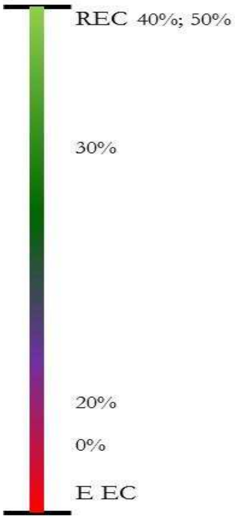


Figure 5 Relative differences between scenarios

A further summary in terms of meeting the ecological objectives are provided in Table 23. 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 23. Degree to which ecological objectives are met at EFR Fish 2 under each flow scenario

Scenario	***Sc 0%***	***Sc 20%***	***Sc 30%***	***Sc 40%***	***Sc 50%***
EFR Fish 2	×	×	×	✓	✓

8. Operational Scenario Evaluation: MRU B.2 (EFR Ai-Ais)

8.1 Operational Scenarios

For the evaluation of Operational Scenarios, various flow indicators (ORASECOM, 2013b and Appendix C) were used in determining the ecological consequences. Table 24 provides the flow indicators used during the evaluation, showing changes from the present day flow (PD)

Table 24. Flow indicators used during the Scenario evaluation showing changes from PD under different Operational Scenarios

Low flow indicators (% of time)	***Operational scenario***					
	0	***20%***	***30%***	***40%***	***50%***	***PD***
Flow: Wet Season	42	51	54	57	60	72
Flow: All months	22	26	28	30	31	40
When flow is> 2 m³/s (wet season)	27	35	39	42	46	61
When flow is > 2 m³/s (all months)	12	16	17	19	21	30
When flow is > 10 m³/s (wet season)	19	21	23	25	26	37
High flow criteria (number of events throughout modeled flow scenario)						
Events > 80 m³/s (duration of 4 days at 80 or higher)	34	33	32	32	31	50
Events > 150 m³/s (duration of 4 days at 150 or higher)	27	27	26	25	25	36
Events >600 m³/s (duration of 2 days at 600 or higher)	25	25	22	21	20	28
Impact on pools						
Risk of all pools drying out 1 or more years in 10 years [1]	VH	H	M	L	VL	Rarely

1 Risk is evaluated in terms of VH (Very High), H (High), M (Moderate), L (Low) and VH (Very Low).

The results showed a similar trend to EFR Fish 2 (refer to section 7.1), but the probability (and therefore risk) of pool drying would be greater for the lower release scenarios (i.e. Sc 20% and Sc 30%). This was associated with the longer distance from the Neckartal Dam release point, the lower tributary inflows in this drier part of the basin and therefore the greater attenuation effects on the releases.

8.2 Consequences of the Neckartal Dam with no EFR Releases (0%) Scenario

Initial screening indicated that the impacts of Sc 0% and Sc 20% would be significant. The impacts related to Sc 0% is just broadly described whereas the other scenario will be discussed in more detail in the following sections. Sc 0% resulted in the following impacts provided in Table 25.

Table 25. Ecological consequences of Sc 0%

Component	***PES***	***EC Sc 0%***	***Response***
Physico-chemical	C	E	Very poor conditions for all variables. Note that the threshold for oxygen is expected to be exceeded, and unacceptable impacts will be experienced for both ecological and anthropogenic users.
Geomorphology	B/C	C	Similar impacts as at EFR Fish 2.
Riparian vegetation	B/C	D	Reproductive failure for large proportions of most marginal zone vegetation populations.
Macro-invertebrates	B	E	Life Span: Macro-invertebrate composition is expected to be restricted to those with short (<one month) and very short (<one week) adult life spans (i.e. two of the four categories). Taxa with long adult life spans, such as crabs and thiarid snails, are expected to disappear. Air-Breathers: Air breathing taxa, such as many bugs and beetles, are likely to dominate because of reduced oxygen expected with increased flow cessation. Filter-Feeding: Filter-feeders are expected to be rare under this scenario. Currents: Gomphid production is expected to drop significantly because of the reduced duration of the wet season, but sufficient wet season duration will remain to allow some egg and larval development. Habitats: Habitat suitability is likely to be significantly reduced compared to reference conditions because of high probability of surface-driven pools drying out. Thermophily: Wet season (summer) water temperatures are expected to increase significantly because of reduced duration of flows, and this is expected to favour warm stenothermal taxa, such as Bulininae, Thiaridae and Belostomatidae, and be negative for cold stenothermal taxa, such as Lymnaeidae. Water Quality: Water quality deterioration is expected to impact negatively on taxa sensitive to water quality deterioration, which are expected to become rare (e.g. Hydropsychidae; Ecnomidae, Tricorythidae, Elmidae).
Fish	C	D/E	Spawning will occur, but low survival rate. Intolerant species to water quality such as BKIM will become rare. Dispersal of species will be limited. The risk of pools drying up will have a significant impact on the fish species as recolonisation from the Orange River (especially due to overall decrease in connectivity as a result of decreased flows) will be low.
Fauna	B	D	Open water - deep for hunting and shelter: A significant impact on fish species, therefore piscivorous fauna (especially larger animal species) will be impacted accordingly. Exposed shoreline - shallow edges: Wetted perimeter declining - impacts on shore species. Wooded bank - shrubs and tall riparian - continuous: A reduction flows will lead to reproductive failure for large proportions of marginal zone vegetation populations. This will impact on riparian fauna, especially relating to shelter, feeding and migration along the riparian corridor.

8.3 Consequences of the Neckartal Dam with the 20, 30, 40 and 50% EFR Release Scenarios

8.3.1 Driver consequences

The consequences of the Sc 20%, Sc 30%, Sc 40% and Sc 50% are provided in Table 26.

Table 26. Consequences of Scenarios (20% – 50%) on the physico-chemical and geomorphology drivers

Release Scenarios	***Response description***	***Response EC***
Physico-chemical (C PES, 67%)		
50%	Impacts on temperature, oxygen, nutrients and salts	C/D (62%)
40%	Impacts on temperature, oxygen, nutrients and salts	C/D (62%)
30%	Most variables deteriorating significantly	D (45%)
20%	Most variables deteriorating significantly	D (45%)
Geomorphology (B/C PES, 82.1%)		
50% 40% 30% 20%	The flow reductions associated with the proposed scenarios show the same patterns as seen at EFR Fish 2. No hydraulic surveys were undertaken at this site, and an analysis of sediment transport potential (as an indication of maintenance of pool scouring) could therefore not be undertaken, but due to the similarity of the flow changes, it can be assumed that changes to the potential for pool scour will be similar to those at EFR Fish 2. The expected reduction in scour potential, mitigated at EFR Fish 2 due to the proximity to the dam and clear water releases, will contrastingly be exacerbated at the MRU B.2 due to sediment inputs from upstream bank erosion and occasional inputs from tributaries. The risk of short term sedimentation of pools is likely to be higher at MRU B.2 than that at EFR Fish 2 due to reduced flows compounded by episodic sediment inputs from tributaries arising in this very sparsely vegetated, arid zone of the catchment. However overall this risk remains low because the large and extreme flood events are not significantly reduced, and sediment inputs from above the dam are cut off.	C C C C

8.3.2 Biological response consequences

An analysis was made to determine the responses to the scenarios based on the flow, water quality and geomorphological changes associated with each operational flow scenario. These consequences are provided in Table 27–33.

Table 27. Fish: Ecological consequences of the different scenarios

Release Scenarios	***Flow Indicators***	***Response***
% time that the river flows during the wet season and (all months)		
PES	72 (40)	
50%	60 (31)	Some decrease in the breeding success rate of BKIM, BAEN, LCAP and probably BHOS. Increased drying up during dry season will have impact on water quality and a very slight impact on especially more intolerant fish species can be expected.
40%	57 (30)	This will have a definite impact on breeding success of many species. Although some recolonisation will occur from the Orange River, reduced FROC still expected.

Release Scenarios	***Flow Indicators***	***Response***
30%	54 (28)	Further decrease in breeding success. Notable change from PD. Overall increase in lotic conditions may favour alien species (OMOS) and impact on FROC of indigenous species.
20%	51 (26)	Significant negative impact on most species. Apart from reduced breeding success rate of some species, the survival rate of early life stages of most species will be reduced. Overall notable decrease in FROC of all species expected. Overall increase in lotic conditions may favour alien species (OMOS).
% time that 2 m^3/s occurs during the wet season and (all months)		
PES	61 (30)	
50%	46 (21)	Slight reduction in adequate connectivity (especially with Orange River) can be expected to have slight decrease in FROC of some potamodromous species. Slight impact on movements in dry season.
40%	42 (19)	Decrease of connectivity for some species between pools and with Orange River. This is expected to have a notable impact on FROC of some species. Slight impact on movements in dry season.
30%	30 (17)	Further slight decrease in the occurrence of adequate connectivity expected to further impact FROC of potamodromous species. Major impact on movement in dry season between pools and Orange River.
20%	35 (16)	A definite decrease in connectivity is expected under this scenario, and a reduced FROC of most species expected (due to decreased connectivity between pools and Orange River).
% time that 10 m^3/s occurs during the wet season		
PES	37	
50%	26	Some loss in inundated vegetation with a slight potential reduction in breeding success of relevant species.
40%	25	Similar to 50% scenario. Slight reduction in breeding success.
30%	23	Increased loss in especially inundated vegetation may reduce the breeding success and impact overall FROC of relevant species
20%	21	Further loss in this habitat type will result in decreased breeding success and reduced overall FROC of relevant species.
Risk of all surface fed pools drying up		
PES	Rarely dry	
50%	Medium Low	No significant impact (more natural occurrence in this reach).
40%	Medium	No significant impact (more natural occurrence in this reach).
30%	High	A significant decrease in the FROC of all species as all fish will be eradicated and recolonisation from the Orange River will take a considerable time.
20%	Very High	A notable impact on the fish assemblages of the reach. Should this occur, it will result in a significant decrease in the FROC of all species as all fish will be eradicated and recolonisation from the Orange River will take a considerable time.
Fish response Ecological Categories		
PES	C (76%)	
50%	C (76%)	
40%	C (68%)	
30%	C/D (62%)	
20%	D (44%)	

Table 28 Macro-invertebrates: Ecological consequences of the different scenarios

Release Scenarios	***Ecological traits***	***Response***
Invertebrate life span categories		
PES	1*	
50%	1	No change from PD.
40%	1	No change from PD.
30%	1.5	Macro-invertebrate with long adult life spans, such as crabs and thiarid snails, are expected to be negatively impacted because of high risks of pools drying out
20%	2	Macro-invertebrate with long adult life spans, such as crabs and thiarid snails, are expected to be negatively impacted and disappear (i.e. three of the four categories).
Air-breathers		
PES	0	
50%	0	No change from PD.
40%	1	A slight increase in the proportion of air-breathing taxa is expected because of reduced oxygen caused by reduced duration of the wet season.
30%	2	A further increase in the proportion of air-breathing taxa is expected because of reduced oxygen caused by reduced duration of the wet season.
20%	3	Air breathing taxa, such as many Hemiptera and Coleoptera, are likely to be abundant because of reduced oxygen expected with increased flow cessation.
Filter feeders		
PES	1	
50%	2	Filter-feeders that prefer high flows, such as *S. gariepense* and *S. chutteri*, are expected to significantly less abundant because of reduced high flows.
40%	2	Same as 50%.
30%	2	Same as 50%.
20%	3	Filter-feeders, such as *Simulium* and Bryozoa, are expected to be negatively affected because of reduced duration of flows. Functional feeding is expected to be dominated by scraper-grazers and predators because of increased duration of flow cessation.
Velocity Preference Categories		
PES	0	
50%	1	Taxa with a preference for high current speeds are expected to reduce because of the lower duration of high flows (10 m^3/s).
40%	1	Same as Sc 50.
30%	2	Gomphid production is expected to drop slightly because of the reduced duration of the wet season.
20%	3	Same as Sc 30%.
Invertebrate water quality categories		
PES	3	
50%	3	No change from present because existing taxa are already hardy.

40%	3	No change from present because existing taxa are already hardy.
30%	3.5	-
20%	4	Water quality deterioration is expected to impact negatively on taxa sensitive to water quality deterioration, which are expected to become rare (e.g. Hydropsychidae, Ecnomidae, Tricorythidae and Elmidae).
Habitat		
PES	1	
50%	1	No change from PD.
40%	1	No change from PD.
30%	2	Warm stenothermal taxa are expected to be common because of the high probability of pools drying.
20%	2	Reduced frequency and duration of flows under this scenario is expected to lead to reduced flushing (cleaning) of substrates and this will reduce the suitability of bed substrates for macro-invertebrates.
Thermophily		
PES	1	
50%	1.5	Wet season (summer) water temperatures are expected to increase slightly, and this is expected to favour warm stenothermal taxa, such as Bulininae, Thiaridae and Belostomatidae.
40%	2	Wet season (summer) water temperatures are expected to increase and this is expected to favour warm stenothermal taxa, such as Bulininae, Thiaridae and Belostomatidae.
30%	3	-
20%	4	Wet season (summer) water temperatures are expected to increase significantly because of reduced duration of flows, and this is expected to favour warm stenothermal taxa, such as Bulininae, Thiaridae and Belostomatidae, and be negative for cold stenothermal taxa, such as Lymnaeidae.
Macro-invertebrate response Ecological Categories		
PES	B (85%)	
50%	B/C (78%)	
40%	C (73%)	
30%	C/D (61%)	
20%	D (49%)	

*: A six-point rating system was used, as follows:
0 = No change from reference; 1 = Small change from reference; 2 = Moderate change from reference
3 = Large change from reference; 4 = Serious change from reference.; 5 = Extreme change from reference

Table 29. Riparian vegetation: Ecological consequences of the different scenarios

No change to PES | Decrease to PES within EC | Decrease to EC below PES

Flow Indicators	**Scenarios**						***Comments***
	0%	**20%**	**30%**	**40%**	**50%**	**PD**	
No of events of < 600 m³/s	25	25	33	32	30	28	Same as PD

Flow Indicators	**Scenarios**						***Comments***
	0%	**20%**	**30%**	**40%**	**50%**	**PD**	
(duration of 2 days at 600 or higher)							
No of events of < 150 m3/s (duration of 4 days at 150 or higher)	27	27	26	25	25	36	Same as PD.
No of events of < 80 m3/s (duration of 4 days at 80 or higher)	34	33	32	32	31	50	Minimal increased woody cover at all scenarios.
10 m³/s	19	21	23	25	26	37	
2 m³/s	12	16	17	29	21	30	
Decrease in % of time that flow occurs in wet season	42	51	54	57	60	72	Water stress for most marginal zone - under Sc 20%, Sc 10% and Sc 0 %, mortality of some species.
Decrease in % of time that flow occurs in all months)	22	26	28	30	31	40	
Risk of pools drying out	VVH	VH	H	M	LM	Rarely	Sc 40% and Sc 50%: Localised mortality of non-woody. Rest of scenarios extensive mortality.
PES	**D**	**C/D**	**C/D**	**C**	**C**	**C**	

Table 30. Riverine fauna: Ecological consequences of the different scenarios

Release Scenarios	***Flow Indicators***	***Response***
% time that the river flows during the wet season		
PES	72	
50%	60	Open water - deep for hunting and shelter: Breeding success rate of especially intolerant fish species may be reduced very slightly - thus little impact on piscivorous fauna. Wooded bank - shrubs and tall riparian - continuous: Riparian vegetation structure still intact, fauna not influenced significantly.
40%	57	Open water – See Sc 50%. Wooded bank - shrubs and tall riparian - continuous: A reduction in flows - moderate reproductive failure for proportions of marginal zone vegetation populations. This will slightly impact on riparian fauna, especially relating to feeding.
30%	54	Open water - deep for hunting and shelter: A decrease in the breeding success rate of some fish species results in lower fish numbers, thus piscivorous animal species (especially larger species) will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: A reduction in flows - reproductive failure for proportions of marginal zone vegetation populations. This will impact on riparian fauna, especially relating to shelter, feeding and migration along the riparian corridor.
20%	51	Open water - deep for hunting and shelter: Same as Sc 30%. Exposed

Release Scenarios	***Flow Indicators***	***Response***
		shoreline - shallow edges: Wetted perimeter declining - impacts on shore species. Wooded bank - shrubs and tall riparian - continuous: Same as Sc 30%.
% time that the river flows during all months		
PES	40	.
50%	31	Open water - deep for hunting and shelter: Increased drying up will have some impact on water quality. More intolerant fish species may be reduced - but little impact on piscivorous fauna
40%	30	See Sc 50%.
30%	28	Open water - deep for hunting and shelter: Impact on the survival of fish in the pools, thus piscivorous animal species will be impacted accordingly.
20%	26	Open water - deep for hunting and shelter: Lower fish numbers, thus piscivorous animal species (especially larger species) will be impacted accordingly.
% time that 2 m^3/s occurs during the wet season all months		
PES	61	
50%	46)	Open water - deep for hunting and shelter: No impact on piscivorous fauna.
40%	42	Same as Sc 50%.
30%	39	Open water - deep for hunting and shelter: Lower flows, impacts on fish movement, and results in a slight decrease in fish populations - piscivorous animal species (especially larger species) will be impacted accordingly.
20%	35	Open water - deep for hunting and shelter: Slightly lower fish abundance; piscivorous animal species will be impacted accordingly.
% time that 10 m^3/s occurs during the wet season		
PES	30	
50%	21	Open water - deep for hunting and shelter: Some loss in inundated vegetation with a slight potential reduction in breeding success of larger fish species - piscivorous animal species will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: Unlikely to affect vegetation and the associated riparian fauna.
40%	19	Open water - deep for hunting and shelter: Same as Sc 50%. Wooded bank - shrubs and tall riparian - continuous: Reduced flow - water stress for marginal zone species, reduced reproductive success; influence riparian fauna, especially relating to feeding along the riparian corridor
30%	17	Open water - deep for hunting and shelter: A loss in this habitat type will result in decreased breeding success and reduced larger fish species reproduction - piscivorous animal species (especially larger species such as pelicans and otters) will be impacted accordingly. Wooded bank - shrubs and tall riparian - continuous: Reduced flow - water stress for marginal zone species, and a low proportion of mortality; influence riparian fauna, especially relating to feeding along the riparian corridor.
20%	16	Open water - deep for hunting and shelter: Further impact on piscivorous animal species (especially larger species such as pelicans and otters). Wooded bank - shrubs and tall riparian - continuous: Reduced flow - water stress for most marginal zone species, and a high proportion of mortality; influence riparian fauna, especially relating to shelter, feeding and migration

Release Scenarios	***Flow Indicators***	***Response***
		along the riparian corridor.
Risk of all surface fed pools drying up		
PES	Rarely dry	
50%	Low Medium	No significant impact on piscivorous species, invertivores and other aquatic predators.
40%	Medium	This will impact on piscivorous species, invertivores and other aquatic predators.
30%	High	This will impact on piscivorous species, invertivores and other aquatic predators.
20%	Very High	This will seriously impact on piscivorous species, invertivores and other aquatic predators.
Fauna response Ecological Categories		
PES	C (73.9%)	
50%	C (70.4%)	
40%	C (62.2%)	
30%	C/D (58.7%)	
20%	D (50.1%)	

8.4 Summary of Biophysical Responses to Operational Flow Scenarios at MRU B.2 (EFR Ai-Ais)

The responses in terms of impact on Ecological Categories are summarised in Table 31. A scale is also provided that indicates the relative differences between the different scenarios (Figure 6).

Table 31. Summary of biophysical responses at EFR Fish 2

Driver Components	***PES (REC)***	***Sc 0%***	***Sc 20%***	***Sc 30%***	***Sc 40%***	***Sc 50%***
Physico-Chemical	C	E	D	D	C/D	C/D
Geomorphology	B	C	C	C	C	C
Response Components						
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 the 50% Scenario would meet the ecological objectives, i.e. for the PES to be maintained. Sc 40% results in the deterioration of the macro-invertebrates by one

Ecological Category but maintains the EcoStatus. Sc 30%, Sc 20% and Sc 0% do not meet the ecological objectives for any of the components. Sc 0% has the potential to fall below a D EC.

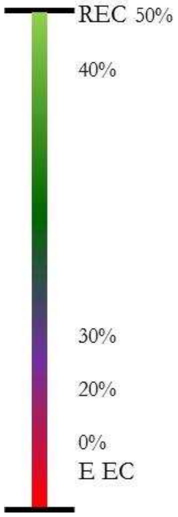
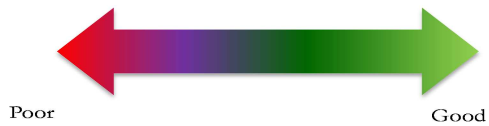


Figure 6 Relative differences between scenarios

A further summary in terms of meeting the ecological objectives are provided in Table 32. 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 32. Degree to which ecological objectives are met at EFR Fish 2 under each flow scenario

Scenario	***0% Sc***	***20% Sc***	***30% Sc***	***40% Sc***	***50% Sc***
EFR Ai-Ais	×	×	×	✓	✓



9. Environmental Flow Requirements at EFR Fish 1

No operational scenarios from Hardap Dam were identified. As all the Scenarios are applicable downstream from Neckartal Dam, they were not evaluated at EFR Fish 1. EFR Fish 1 will however play an important role in monitoring and if any future Scenario is identified that will impact on EFR Fish 1, the information can be used to evaluate the impact.

The EcoClassification resulted in a B/C PES with a HIGH importance (See Table 33). This indicated that improvement would be required to achieve a B REC. The following is required to achieve the B REC:

- Address water quality problems to improve the macro-invertebrates to a B EC (non-flow related).
- Improve floods and other non-flow related measures to improve Riparian vegetation to a B/C EC.

Table 33. EFR Fish 1: Summary of EcoClassification results

Driver Components	***PES***	***REC***
IHI Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B/C
Response Components	***PES***	***REC***
Fish	B	B
Macro-invertebrates	C	B
Instream	**B/C**	**B**
Riparian Vegetation	B/C	B
Riverine Fauna	B	B
EcoStatus	**B/C**	**B**
EIS	HIGH	

The flooding requirements needed to improve riparian vegetation are provided in Table 34. This would therefore require that an operating rule be applied to Hardap Dam to release these floods during 'normal' and wet years when it is not supplied by downstream flows or Hardap Dam releases to prevent spilling.

Table 34. Floods required to improve the riparian vegetation at EFR Fish 1

Floods (m^3/s)	***Reasoning***
2 - 10	Flows within a range of 2 – 10 m^3/s are needed to activate and maintain the marginal zone. This discharge activates the lower limit of the sedge (*C. longus*) and woody rheophyte (*G. virgatum*) populations on the marginal zone while a discharge of 10 m^3/s floods the same populations. At least four events in the wet season are required; a reduction of these flows in the wet season (also the growing season) will result in progressively more stress on successful completion of the reproductive process for most marginal zone vegetation (notably *C. longus* and *G. virgatum*).
30 - 50	The function of this flood is to inundate the seasonal zone, which includes the upper limit of sedges (*C. longus* mainly), a large portion of the *T. usneoides* population and also activates some of the *A. karoo*/*Z. mucronata* tree line. A reduction in this flood class can result in increased woody cover and abundance below the tree line and in the lower zone. This flood is required at least every year, in the wet season.
150	The 150 m^3/s flood inundates the *Dichanthium annulatum* population (where it occurs), most of the *T. usneoides* population and activates the tree line (*A. karoo* and *Z. mucronata* mainly*)*. Its function is to create recruitment opportunities for upper zone vegetation communities, but at the same time reduce woody vegetation cover and density on the channel floor to some extent. This flood is required at least once every two years, in the wet season.
600	The 600 m^3/s flood inundates the macro channel and floods into the tree line where it occurs. It inundates all marginal and lower zone vegetation and will scour some vegetation. Large proportions of the upper zone are also inundated, which creates recruitment opportunities for upper zone vegetation communities, but at the same time reduces woody vegetation cover and density on the channel floor (maintains tree line integrity). This flood is not significantly altered in its functionality under current flows.
flow (% time)	The percentage of time that surface flow occurs is important in the wet season for growth, reproduction and recruitment, and in the dry season for survival. Reduced flow (% time for all months) will result in increased water stress for most marginal zone species and can result in mortality, depending on severity of the reduction. Reduced flow (% time wet season) in the wet season will reduce reproductive and recruitment success for vegetation. To achieve the REC it is estimated that surface flow should occur for at least 50% of the time in the wet season, and for at least 30% of the time each year.

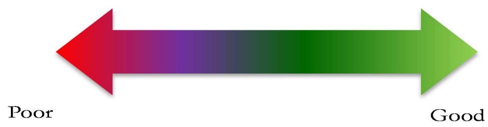
10. Conclusions

10.1 Comparison of the Ecological Consequences at EFR Fish 2 and EFR Ai-Ais

A comparison of the consequences of the scenarios at EFR Fish 2 and EFR Ai-Ais are provided in Table 35.

Table 35. Comparison of ecological consequences at EFR Fish 2 and EFR Ai-Ais

Scenario	*Sc 0%*	*Sc 20%*	*Sc 30%*	*Sc 40%*	*Sc 50%*
EFR Fish 2	×	×	×	✓	✓
EFR Fish 2	×	×	×	✓	✓



This analysis shows that only the 50% Scenario will fully meet the ecological objectives. The 40% Scenario has the potential of meeting all the ecological objectives, albeit with a higher risk of failure than the 50% Scenario.

10.2 Optimised Scenarios

As the 40 and 50% Scenario would have a significant impact on the yield of Neckartal Dam (Table 36), an optimised scenario that will minimise the impacts on both the yield and the ecological status was investigated. Such a scenario should be between Sc 30 and Sc 40% and therefore a combination of the Sc 30 and Sc 40% was investigated. The optimised scenario (Sc 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.

Table 36 summarises the impact of all the possible EFR options on the yield of the Neckartal Dam. Yield in this context refers to the average historical yield.

Table 36. Yield response of the Neckartal Dam given various EFR options

EFR Option as % of inflow released	*Releases (million m³/a)*	*Yield (million m³/a)*	*Yield as % of no EFR option*
0	0	81	100.0
10	27.8	74	91.4
20	40.7	68	84.0
30	51.3	61	75.3

EFR Option as % of inflow released	*Releases (million m³/a)*	*Yield (million m³/a)*	*Yield as % of no EFR option*
40	59.8	55	67.9
50	67.1	49	60.5
Optimum	56	61	75.3

The analysis of the Optimised Scenario in terms of flow indicators and how it changes from PD is provided in Table 37.

Table 37. Flow indicator analysis for the Optimised Scenario and comparison with Sc 30% and Sc 40%

Low flow indicators (% of time)	*Operational scenario*			
	30%	*Sc Opt*	*40%*	*PD*
Flow: Wet Season	54	56	57	72
Flow: All months	28	29	30	40
When flow is> 2 m³/s (wet season)	39	41	42	61
When flow is > 2 m³/s (all months)	17	18	19	30
When flow is > 10 m³/s (wet season)	23	24	25	37
High flow criteria (number of events throughout modeled flow scenario)				
Events > 80 m³/s (duration of 4 days at 80 or higher)	34	32	32	50
Events > 150 m³/s (duration of 4 days at 150 or higher)	26	26	25	36
Events >600 m³/s (duration of 2 days at 600 or higher)	22	21	21	28
Impact on pools				
Risk of all pools drying out	H[1]	M[2]-H	M	Rarely

1 High 2: Moderate

The results of the analysis in terms of ecological consequences indicated that the Optimised Scenario lies between the 30% and 40% and closer to the 40 % Scenario. Specialists did not have the resolution to evaluate this scenario and the following statements were made:

- Sc 40% has a higher risk than Sc 50% that the ecological objectives would not be met.
- Sc 30% will not maintain the PES.
- The Sc Opt has an even higher risk than the Sc 40% that the ecological objectives will not be met. However, as the yield was a significant improvement from the Sc 40%, this would be the scenario that would be included for further analysis below the confluence with the Orange River.

More information on the yield is supplied in Technical Report 31 (ORASECOM, 2013b).

10.3 Confidence in Scenario Evaluation and Recommendations

The confidences in the evaluation were generally MODERATE. Some of the problems are highlighted below:

- Fish: The potential difference in impact on the fish assemblage for some variables/metrics between scenarios was sometimes difficult to distinguish, and a range of variables had to be considered for each scenario.
- Macro-invertebrates: The following contributes to a low to moderate confidence:
    - Coarse resolution of low-flow hydrology in particular;
    - limited information available globally on macro-invertebrates in naturally seasonal systems, as most river research is concentrated on perennial systems;
    - the method used to evaluate responses of macro-invertebrates to flow scenarios is new, unpublished and untested.
- Riparian vegetation: The confidence at EFR Fish 2 was high because several cross sections were done at the site with vegetation surveyed and hydraulic rating curves available. The confidence in the assessment for the Ai-Ais reach was low as no cross sections were done for the reach, although a site visit was conducted, so inference was made from analyses at EFR Fish 2.

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 directed on monitoring to test the hypotheses in predicting the consequences of the altered flow regime. Recommendations regarding monitoring will be made in Technical Report 35 (ORASECOM, 2013c).

11. References

Atlas of Namibia Project. 2002. Directorate of Environmental Affairs, Ministry of Environment and Tourism (http://209.88.21.36/Atlas/Atlas_web.htm).

Brown, C. and King, J. 2001. Environmental flow assessment for rivers. A summary of the DRIFT process. Southern Waters information Report No 01/00.

Crerar, S. and *Mare, M. 2005*. Pre-feasibility study into measures to improve the management of the lower Orange River and to provide for future developments along the border between Namibia and South Africa. Hydrology, Water Quality and Systems Analysis. Volume B: Hydrology. Report prepared for the Permanent Water Commission.

Curtis, B.A. 1991. Freshwater macro invertebrates of Namibia. Madoqua 17(2): 163 187.

Department of Water Affairs and Forestry, South Africa (DWAF). 1999. Resource directed measures for the protection of water resources. Volume 3: River Ecosystems, version 1.0.

Department of Water Affairs and Forestry, South Africa (DWAF). 2008. Methods for determining the Water Quality component of the Ecological Reserve. Prepared by Scherman Consulting.

Dollar, E.S.J and Rowntree, K.M. 2003. Geomorphological Research for the Conservation and Management of Southern African Rivers. Volume 2: Managing Flow Variability: the geomorphological response. Water Research Commission Report No. 849/2/04, Pretoria.

*United States Environmental Protection Agency (EPA). 2012. C*ausal Analysis/Diagnosis Decision Information System (CADDIS). [Web:] http://cfpub.epa.gov/caddis /.

Hay, C.J. 1991. The distribution of fish in the Fish River, Namibia. *Madoqua* 17(2):211-215.

Hay, C.J., Van der Bank, F.H. and Ferreira, J.T. 1997. Aspects of the ecology of Barbus hospes from the Fish River, Namibia. Madoqua 19(2):95-97.

Hay, C.J., Van Zyl, B.J., Van der Bank, F.H., Ferreira, J.T. and Steyn, G.J. 1999. The distribution of freshwater fish in Namibia. Cimbebasia 15:41-63.

Hughes, D.A. and Louw, D. 2010. Integrating hydrology, hydraulics and ecological response into a flexible approach to the determination of environmental water requirements for rivers. Environ. Model. Software 25(8): 910-918.

Iversen, T.M., Madsen, B.L. and Bøgestrand, J. 2000. River conservation in the European Community, including Scandinavia.In: "Global Perspectives on River Conservation: Science Policy and Practice", Edited by P.J. Boon, B.R. Davies and G.E. Petts, John Wiley & Sons Ltd.

Kleynhans, C.J. 2007. Module D: Fish Response Assessment Index. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Kleynhans, C.J., Louw, M.D., Thirion, C., Rossouw, N. and Rowntree, K. 2005. River EcoClassification: Manual for EcoStatus determination (Version 1). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

Kleynhans, C.J. and Louw, M.D. 2007. Module A: EcoClassification and EcoStatus determination. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Kleynhans, C.J., Mackenzie, J and Louw, M.D. 2007. Module F: Riparian Vegetation Response Index. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Kleynhans C.J., Louw, M.D. and Graham, M. 2009. Module G: Index of Habitat Integrity (Section 1, Technical manual). In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Louw, M.D., Kotze, P., and Mackenzie, J. 2010. Desktop EcoClassification Assessment. Report 5: Assessment of Environmental Flow Requirements. Support to Phase 2 of the ORASECOM basin-wide Integrated Water Resources Management Plan.

Nepid Consultants. 2010. Aquatic Ecosystems. Specialist Study for the Environmental and Social Impact Assessment for the Neckartal Dam Project. Prepared for Knight Piésold (Pty) Limited, for submission to the Ministry of Agriculture, Water and Forestry, Directorate Rural Water Supply, Government of Namibia, Windhoek.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-364.

ORASECOM. 2011a. Scoping Paper and Terms of Reference. Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. UNDP-GEF: Orange-

Senqu Strategic Action Programme (Atlas Project ID 71598). Orange Senqu River Commission Report No. TR10.

ORASECOM. 2011b. Baseline monitoring of Aquatic Ecosystem Health in the Orange-Senqu River Basin: Final Report: Part 1 – Main Report. Southern African Development Community: Water Sector Support Unit – Gaborone. European Development Fund. African Transboundary River Basin Support Programme. Global Financial Commitment No. 9 ACP RPR 53. Orange Senqu River Commission Report No. 015/2011.

ORASECOM. 2012. Delineation of Management Resource Units. Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. UNDP-GEF: Orange-Senqu Strategic Action Programme (Atlas Project ID 71598). Orange Senqu River Commission Report No. TR22.

ORASECOM. 2013a. 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. UNDP-GEF: Orange-Senqu Strategic Action Programme (Atlas Project ID 71598). Orange Senqu River Commission Report No. TR28.

ORASECOM. 2013b. River and Estuary EFR assessment, Volume 5: Hydrology and River Hydraulics. Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. UNDP-GEF: Orange-Senqu Strategic Action Programme (Atlas Project ID 71598). Orange Senqu River Commission Report No. TR31.

ORASECOM. 2013c. EFR Monitoring Programme. Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth. UNDP-GEF: Orange-Senqu Strategic Action Programme (Atlas Project ID 71598). Orange Senqu River Commission Report No. TR35.

Parsons, M., Mcloughlin, C.A., Kotschy, K.A., Rogers, K.H. and Rountree, M.W. 2005. The effects of extreme floods on the biophysical heterogeneity of river landscapes. Frontiers in Ecology and the Environment 3: 487-494.

Rountree, M.W., Rogers, K.H. and Heritage, G.L, 2000. Landscape state change in the Semi-arid Sabie River, Kruger National Park, in response to flood and drought, Southern African Geographical Journal 82, 173−181.

Rowntree, K. and du Preez, L. (in prep). Geomorphology Driver Assessment Index. Joint Water Research Commission and Department of Water Affairs and Forestry report. Water Research Commission, Pretoria, South Africa.

SANBI. 2009. Biodiversity data provided by: South African National Biodiversity Institute (Accessed through the SIBIS portal, sibis.sanbi.org, 2009-06-01).

Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index. In River EcoClassification: Manual for Ecostatus Determination (version 2). Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Van Vuren, N.G., Mulder, P.F.S., Ferreira, J.T. and Van der Bank, F.H. 1989. The identification of hybrids of Barbus aeneus X B. Kimberleyensis and Labeo capensis X L. umbratus in Hardap Dam, SWA/Namibia. Madoqua 16(1):27 – 34.

12. Appendix A: EcoClassification: Approach and Method

The EcoClassification process was followed according to the methods of Kleynhans and Louw (2007). Below follows a summary of the EcoClassification approach.

EcoClassification refers to the determination and categorisation of the Present Ecological State (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 the river is expressed in terms of biophysical components:

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

Different processes are followed to assign an Ecological Category (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 river. Thus, the EcoStatus can be defined as the totality of the features and characteristics of the river and its riparian areas 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.

For more detailed information on the approach and suite of EcoStatus methods and models, refer to a suite of manuals:

- Hydrological Driver Assessment Index (HAI): Kleynhans *et al.* (2005).
- Physico-chemical Driver Assessment Index (PAI): Kleynhans *et al.* (2005) and DWAF (2008).
- Geomorphological Driver Assessment Index (GAI): Rountree and du Preez (in prep).
- Fish Response Assessment Index (FRAI): Kleynhans (2007).
- Macroinvertebrate Response Assessment Index (MIRAI): Thirion (2007).
- Riparian Vegetation Response Assessment index (VEGRAI): Kleynhans *et al.* (2007).

- Instream Habitat integrity (IHI): Kleynhans *et al.* (2009).

12.1 Process

The steps followed in EcoClassification are as follows:

- 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 Sensitivity (EIS) for the biota and habitat.
- Considering the PES and the EIS, suggest a realistic Recommended Ecological Category (REC) for each component, as well as for the EcoStatus.
- Determine Alternative Ecological Categories for each component, as well as for the EcoStatus.

Note: As the approach for the Fish River followed a scenario based approach, Alternative Ecological Categories were not modelled as EFRs will not be set for the different Ecological Categories (ECs).

The flow diagram (Kleynhans and Louw, 2007) (Figure 7) illustrates the process.

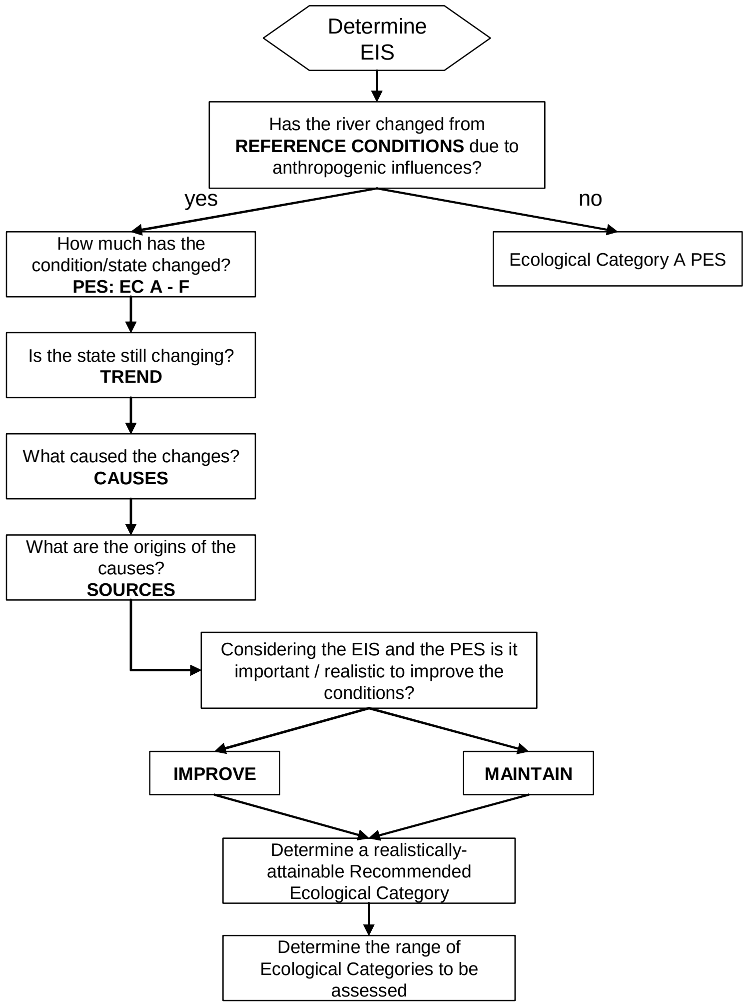


Figure 7. Flow diagram illustrating the information generated to determine the range of ECs for which the EFR will be determined

Different levels of EcoClassification exist, each using a range of tools varying in complexity. The Level 4 EcoStatus assessment is the most comprehensive and therefore uses the most complex and detailed set of EcoClassification tools. This level has been applied and is illustrated in Figure 8.

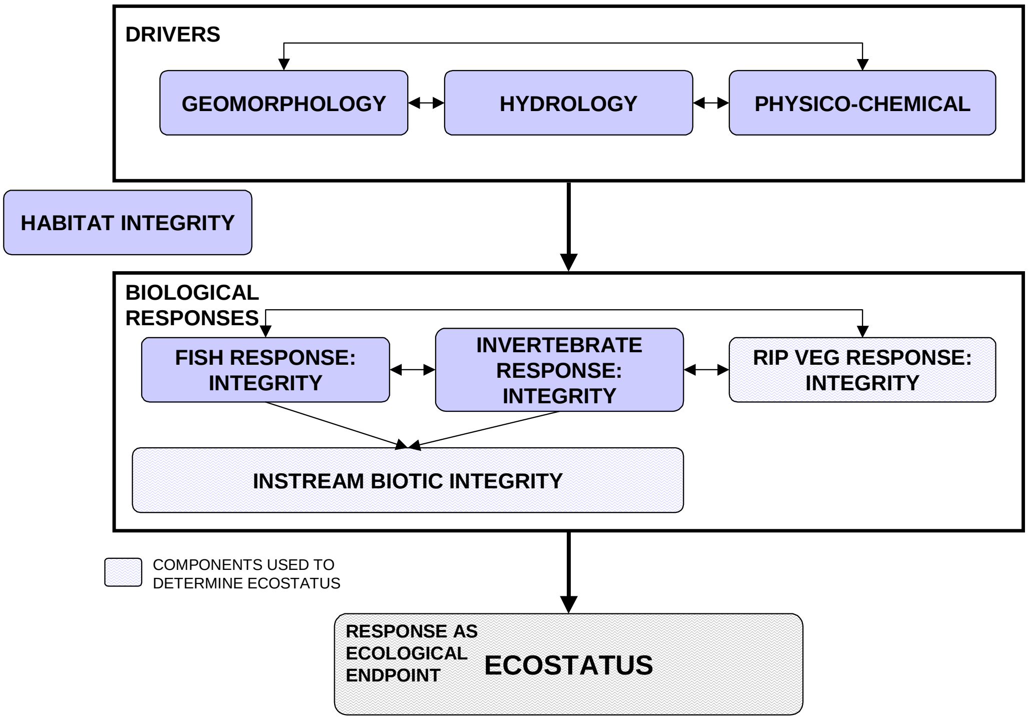


Figure 8. EcoStatus Level 4 determination

12.1.1 Ecological Importance and Sensitivity (EIS)

An updated EIS Model, developed by Dr CJ Kleynhans (DWAF, 1999) and updated during 2010 was used for this study. This approach estimates and classifies the EIS of the streams in a catchment 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 EIS:

- 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.

With reference to the bullets above, biodiversity in its general form (i.e. Noss, 1990) was taken into account as far as the available information allowed:

- The importance of a particular river or stretch of river in providing connectivity between different sections of the river, i.e., whether it provided a migration route or corridor for species, was considered.
- The presence of conservation or relatively natural areas along the river section also served as an indication of ecological importance and sensitivity.
- The sensitivity (or fragility) of the system and its resilience (i.e., the ability to recover following disturbance) of the system to environmental changes was also considered. Consideration of both the biotic and abiotic components was included here.

The EIS results are summarised in this report and the models are provided electronically. EIS categories are summarised in Table 38.

Table 38. EIS categories (Modified from DWAF, 1999)

EIS 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.

13. Appendix B: EcoStatus Model Output

13.1 EFR Fish 1

Instream biota importance as a weight in EcoStatus determination	*Importance Score*	*Weight*
Fish		
1.What is the natural diversity of fish species with different flow requirements	1	70
2.What is the natural diversity of fish species with a preference for different cover types	3	100
3.What is the natural diversity of fish species with a preference for different flow depth classes	2	90
4. What is the natural diversity of fish species with various tolerances to modified water quality	1	70
Macro-invertebrates		
1. What is the natural diversity of macro-invertebrate biotopes	1	40
2. What is the natural diversity of macro-invertebrate taxa with different velocity requirements	2	60
3. What is the natural diversity of macro-invertebrate taxa with different tolerances to modified water quality	3	100
Component	PES	Confidence
Fish	B	
Macro-invertebrates	C	
Confidence rating for instream biological information		2
Instream Ecological Category	B/C	
Riparian vegetation	B/C	
Confidence rating for riparian vegetation zone information		3.6
Riparian fauna	B	
ECOSTATUS	B/C	

13.2 EFR Fish 2

Instream biota importance as a weight in EcoStatus determination	*Importance Score*	*Weight*
Fish		
1.What is the natural diversity of fish species with different flow requirements	1	70
2.What is the natural diversity of fish species with a preference for different cover types	3	100
3.What is the natural diversity of fish species with a preference for different flow depth classes	2	90
4. What is the natural diversity of fish species with various tolerances to modified water quality	1	70

Instream biota importance as a weight in EcoStatus determination	***Importance Score***	***Weight***
Macro-invertebrates		
1. What is the natural diversity of macro-invertebrate biotopes	1	40
2. What is the natural diversity of macro-invertebrate taxa with different velocity requirements	2	60
3. What is the natural diversity of macro-invertebrate taxa with different tolerances to modified water quality	3	100
Component	PES	Confidence
Fish	B	
Macro-invertebrates	B	
Confidence rating for instream biological information		2
Instream Ecological Category	B	
Riparian vegetation	C	
Confidence rating for riparian vegetation zone information		3.6
Riparian fauna	B	
ECOSTATUS	C	

14. Appendix C: Fish River EFR Determination- Methods

14.1 Introduction

The standard processes to determine flow requirements in Southern Africa follow the Habitat Flow Stressor Response (HFSR) method (Hughes and Louw, 2010) and the Downstream Response to Imposed Flow Transformations (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 base flows.

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 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.

The scenario development and detail regarding the hydrological, yield and HEC-RAS modelling are described in Technical Report 31 (ORASECOM, 2013B). The rest of this chapter focusses on the approaches followed for the biophysical components to evaluate the impacts of different flow scenarios from Neckartal Dam. Determination of Biophysical Responses to Different Flow/Release Scenarios

14.2 Conceptual Approach to Biophysical Responses to Different Flow Scenarios

14.2.1 Geomorphological responses to different flow scenarios

Maintenance of pools within the ephemeral Fish River is critical for instream and riparian biota. A typing or classification of pool types was undertaken to identify and describe different pool types. It was expected that whilst springs and/or baseflows provide water for the pools during low flow periods, large infrequent floods scour the pool, thus removing accumulated sediment and preventing sediment from infilling the pools.

Sediment transport modelling was undertaken to identify the floods required to scour these pool types. Daily flow duration curves and site hydraulics were used to undertake potential bed material transport modelling (Dollar and Rowntree, 2003) at the EFR site/s. Present day sediment transport patterns were compared with those expected under alternative flow scenarios to evaluate if the future proposed flow scenarios will be able to scour and maintain the pools.

14.2.2 Fish responses to different flow scenarios

The use of existing approaches such as the fish model within the HFSR method was investigated and alterations made in an attempt to apply this to the Fish River ecosystem. Should this approach have been found to not be applicable in altered format, a more qualitative approach was followed. This followed the use of the fish index to determine the expected change in EC under different scenarios.

Driving factors that determined the status of the fish in the Fish River ecosystem was expected to be the following:

a) Wet season/flood events:

Connectivity/continuity in the system: Adequate depth and duration in flows connecting pools was required during the wet season/flooding events to allow dispersal of fish. This was especially of importance in the lower reaches of the Fish River where connectivity with the Orange River seemed to be a crucial component for semi-rheophilic fish species (yellowfish and *Labeos*). An effort was made to determine whether the semi-rheophilic fish guild in the lower Fish River breed/spawn in the Fish River itself, or whether they breed in the Orange River and colonise the Fish River. If it was found that if they did breed in the Fish River (unlikely), flows should be adequate in duration and timing to allow successful spawning. If they bred in the Orange River and then colonised the Fish River, flows should be adequate in duration and frequency and volume to allow dispersal. The driver information requirements/determinants were frequency, timing and extent of high flows (depth in channel connecting pools).

Pool habitat composition/condition: The pool habitats (cover, substrate, water quality, and depth) were evaluated in terms of the requirements of the different fish species during the wet/summer season. Adequate habitats should be available for breeding and early life stages of fish species utilising pools for breeding activity (limnophilic species). The driver information requirements/determinants were pool depth – habitat suitability and availability and water quality.

b) Dry season/low (or in this case no) surface flow:

Pool habitat composition/condition: Survival of all fish species in the pools would depend on the availability of habitat (physical habitat determined by cover, depth, and substrate quality), food source, as well as water quality (physico-chemical habitat). The requirements and level of intolerance to changes differ between fish species. These differences were considered and indicator species of different types of change (habitat, water quality, specific food sources) were identified (if adequate information were available).

The driver information requirements/determinants were:

- Habitat suitability and availability: Determined by pool level, frequency of flushing and flooding under different scenarios.
- Water quality: The water quality played a critical determining role in the survival of fish in the pools. It was essential to gain an understanding of the change in water quality over time (as pool volumes decrease). Salinity seemed to be one of the primary variables of concern. Other variables that played an important role for the survival of fish were oxygen and temperature. Extreme diurnal fluctuations in any variables could furthermore contribute to stress on fish. It was therefore important to gain an understanding, and possibly quantify, the expected change in water quality in the pools under different scenarios (ideally the water quality specialist estimated ranges (actual values/concentrations) of for instance salinity under different scenarios, to allow the translation of water quality changes into stress levels on fish).
- Availability of food sources: Estimation was made of change in food availability under different scenarios. Input from the invertebrate specialist on the team was used, together with estimation on expected change in other available food sources (algae, etc.).

Other secondary aspects that were considered included changes in level of predation and competition, as well as impact by alien or introduced fish species under different scenarios.

14.2.3 Macro-invertebrate responses to different flow scenarios

The method used to assess macro-invertebrate response to alternative flow scenarios was based on a number of key ecological traits that were rated and weighted in terms of their importance in defining the PES of benthic macro-invertebrates, and by implication, the river health. Each taxon (identified mainly to family level, was allocated one category for each of the following ecological traits as follows:

- Adult Life Span: A = Very Short (<1 week); B = Short (<1 month); C = Moderate (>3 - 6 months); D = Long (>6 months).

- Air-Breathing Taxa: (Yes or No).
- Functional Feeding Groups: CG = Collector/Gatherers; S = Shredders; F = Filterers; SG = Scraper/Grazers; P = Predators; - = Other/unknown.
- Current Speed Preferences: A = Fast Flow (<0.6 m/s); B = Moderate Flow (0.3 - 0.6 m/s); C = Slow Flow (0.1 - 0.3 m/s); D = Zero to Very Slow (<0.1 m/s).
- Habitat Preferences: A = Bedrock and Boulders; B = Cobbles; C = Vegetation; D = Gravel, Sand, Mud; E = Water Column.
- Thermophily: A = Cold Stenothermal; B = Eurythermal; C = Warm Stenothermal.
- Water Quality Preferences: A = Highly Sensitive; B = Sensitive; C = Tolerant; D = Highly Tolerant.

Each trait was classified into one of six Ecological State categories, ranging from *Natural* (0) to *Critically Modified* (5). Each trait was then rated separately for each site or management unit under consideration. Each trait was also weighted in terms of its percentage importance for defining the ecological state of aquatic macro-invertebrates within each management zone under consideration. Highest weightings were allocated to life-history traits that are expected to respond strongly to anthropogenic impacts. The output of the weighted traits analysis was expressed as a percentage, which was converted to a Present Ecological State Category (A to F). The macro-invertebrate response to altered flow scenarios was assessed by changing ratings, were applicable, but weightings were kept constant to ensure consistent comparison.

14.2.4 Riparian vegetation responses to different flow scenarios

The first step in this process was to describe current riparian vegetation communities that were essentially a response to the current hydrological setting. It was expected that there would be pool and non-pool communities (which had different water requirements) and even though species composition might have been similar for the two communities they would be different in structure and vigour. Some important species differences were also likely to occur, and quantifying these differences in riparian indicators would help determine water requirements for each community since these could be different for different species (and may have varied within species in different habitat types).

The purpose of quantifying these communities, other than classifying the PES, together with literature, was to improve understanding of the nature of vegetation dependency on various sources of soil moisture: surface flow, pool level (retention, which was likely to have a water quality component), rainfall, soil moisture in the vadose zone or groundwater. Dependency on different sources of moisture (and disturbance) would vary seasonally and would operate variously for different population processes such as survival, fecundity, dispersal, recruitment and density.

Key population processes in ephemeral systems such as the Fish River are recruitment and survival (or the lack thereof e.g. where floods were required to clear woody vegetation). The frequency of recruitment required to maintain population viability varied for each riparian indicator and was usually event driven in such systems i.e. flooding or rainfall events and more importantly their sequencing. Survival probability was a function of the age of individuals, amongst other limitations, and was dependent on more reliable sources of moisture e.g. ground water or pool level/perenniality/frequency of recharge. Once the general water requirement was defined (based on species characteristics), scenario assessment involved describing likely responses at the population scale and incorporating such responses into an assessment of altered present ecological state.

If aquatic species existed (could occur in more permanent pools), salinity likely affected population dynamics and water quality modelling as a response to pool level and recharge needed to be incorporated for a response by this vegetation unit.

14.2.5 Riverine fauna (excluding instream) to different flow scenarios

- Identify faunal species depending on the riverine ecosystem: Riverine species refer to animal species where their dependency can be related directly to the aquatic habitats for shelter, breeding and food, or to the riparian vegetation for these services. Since many riverine species are relatively mobile (birds and larger mammal species), they can migrate whenever circumstances become harsh. However, certain animal species are less mobile and will thus be influenced more by local environmental changes. These species can be used as key or indicator species.
- Obtain distribution data of these riverine animals: By making use of species distribution maps and atlas data, it can be established which animals should be present in the areas of concern. With detailed distribution records available, the probability of occurrence and even the abundance can be determined.
- Verify the habitat requirements of these assemblages (aquatic, semi-aquatic and riparian): Habitat requirements per animal species can be obtained from a wide spectrum of literature and expert knowledge.
- Map the habitat types at the EFR sites: During the field surveys, different habitat types were delineated on Google Maps and any other aerial maps available. Views of different water levels per site enhanced the effectiveness of the maps for scenario evaluations.
- Model habitat change with changing water levels: By linking the mapped habitats and their positions relating to water levels, changes in habitat extent and functionality was modelled relating to altering water levels. Links with the fish, macro-invertebrate and riparian vegetation evaluation was essential as these groups determine food availability, and presence of shelter and nesting habitats.
- Establish species change (diversity and abundance) for the riverine fauna reacting to flow scenarios: Whenever the habitat integrity of the site was established, the reaction of the riverine fauna to changes in habitat composition was determined, signifying the presence or absence of species, or a level of abundance relating to habitat quality.

14.3 Integration of Results into a Flow Requirement

The process was different from the normal flow requirement processes where an actual flow requirement as an EFR rule (a flow duration table) is provided. The process followed for the Fish River was more scenario based and focussed on determining how the scenarios impacted on the current ecological state (or health) of the system and the degree to which the current state would change. For example, the current state is described as being in a C Ecological Category (i.e. moderately modified). The resulting state is predicted for each of the flow scenarios which will be assessed. The decision-makers can then make informed decision on which scenarios they would implement, knowing the resulting ecological consequences. The impact of the different scenarios on Ecosystem services as well as stakeholder input will also be evaluated and provided.

14.4 Process to Determine Ecological Consequences of Operational Flow Scenarios

The objective of this assessment was to determine the ecological consequences in terms of changes in the PES for each scenario. The evaluation was undertaken at EFR Fish 2 (MRU B.1) and EFR Ai-Ais (MRU B.2). The approach for scenario evaluation is described in the following steps.

- All specialists identified important flow indicators that had to be analysed and compared to Present Day (PD).
- Motivations and reasoning were provided for each criterion.
- An initial qualitative evaluation was undertaken to determine whether any of the scenarios had severe implications and therefore required more detailed analysis.
- The flow indicators were then evaluated as well as additional aspects as required to provide specialists with sufficient information to predict whether the PES would change. A comparison of the evaluations was provided in table format.
- The impacts at both sites where then compared to provide an overall evaluation.
- If necessary, an optimised scenario was designed and re-tested. The purpose of this is to improve the yield and maintain the ecological state.

Each Operational Scenario was analysed according to certain parameters and flow indicators. For detail on how the flow indicators were quantified, refer to Technical Report 31 (ORASECOM, 2013b). The importance of the specific flow indicators in assessing the biophysical responses are described below.

14.4.1 Percentage of time that the river flows during the wet season (Jan, Feb and Mar)

Most fish species will only breed during flowing conditions, especially BKIM, BAEN, LCAP and probably also BHOS in the Ai-Ais reach. Water quality in the pools will also be much improved during flowing conditions, and a reduction in flow will result in deteriorated water quality. Deteriorated water quality will impact on especially early life stages (egg development, and larvae) of fish. Although breeding may not be required every season, a reduction in the duration of flow will reduce the opportunity of species to breed successfully and hence result in a deterioration in the overall fish assemblage. Increased lotic conditions over lentic conditions will favour alien species (i.e. OMOS, and TSPA/CCAR) over indigenous species. Loss of breeding may not be as critical in the lower Fish River since fish may be able breed in the Orange River and recolonise this section from there and from Naute Dam. The June 2012 survey at Ai-Ais Resort however confirmed that breeding of many species do occur in the Fish River (juveniles sampled).

14.4.2 Percentage of time that the river flows during all months

Although flow during the wet season will be important in providing breeding opportunity for fish, flow overall (all year) will be important to maintain water quality (especially in pools during the drier season). An overall flow reduction could result in deteriorated water quality and impact fish (especially early life stages, and health).

14.4.3 Percentage of time that 2 m^3/s occurs during the wet season

This flow is important in terms of connectivity between pools to allow fish migration between pools. The biggest potamodromous species (BKIM) was used as guide, and a depth of 150 mm taken as cut-off. It was estimated (based on transect data) that approximately 2 m^3/s should be adequate to achieve the required depth, at a required duration of approximately 2 days at a time at EFR Fish 2. Longer durations than 2 days will be required for movement between the Orange and Fish River in the Ai-Ais reach.

14.4.4 Percentage of time that 2 m^3/s occurs during all months

Connectivity is important for fish migration between pools. This will be most important during the wet season (especially for breeding), but feeding migrations may also occur and become especially important when food sources diminish and become scarce in some pools. Connectivity between pools during other periods therefore is also important.

14.4.5 Percentage of time that 10 m^3/s occurs during the wet season

At this flow some inundated vegetation will become available. Although this may be a very scarce habitat in the Fish River, various fish species have a requirement for this as spawning habitat (EFR Fish 2: LUMB; although it can also spawn over gravel beds, BPAU, and CGAR; Ai-Ais reach: BTRI, BPAU, and CGAR). A decline in the occurrence of this habitat type will therefore decrease the potential breeding success of these species. The duration of vegetated inundation is also important (not provided by this criteria) to sustain habitats for long enough period to allow successful development of eggs, and larvae (approx. 10 days).

Flows within a range of 2 to 10 m^3/s are needed to activate and maintain the marginal vegetation zone. A discharge of 2 m^3/s activates the lower limit of the sedge (*C. longus*) population in the marginal zone while a discharge of 10 m^3/s floods the same population.

14.4.6 Flow Indicator: High flow event frequency

- Importance for predicting the response of fish: Floods play an important role to stimulate fish migration, drown out barriers in order that fish may pass, reset water quality and flush sediment from pools substrates and maintain depth. Reduced flooding can therefore have a significant impact on fish assemblages. Generally smaller floods are more important than the large floods for fish. Too many or unseasonal floods on the other hand can also be negative as a result of continuous habitat changes, flushing of eggs and larvae, false cues for breeding and migration. The flood indicators specified for riparian vegetation investigation and the evaluation thereof will cater for the fish flooding requirements.

- Importance for predicting the response of riparian vegetation:
  - No of events of > 80 m^3/s (duration of 4 days at 80 m^3/s or higher): Inundation of the seasonal zone, which includes the upper limit of sedges (*C. longus* mainly), the lower portion of the *Tamarix usneoides* population and also activates some of the *A. karoo* / *Z. mucronata* tree line.
  - No of events of > 150 m^3/s (duration of 4 days at 150 m^3/s or higher): Inundates the *Dichanthium annulatum* population (where it occurs), a large proportion of the *T. usneoides* population and activates the tree line in a few places (*A. karoo* and *Z. mucronata* mainly).
  - No of events of > 600 m^3/s (duration of 2 days at 600 m^3/s or higher): Inundates the macro channel and floods into the tree line where it occurs. It inundates all marginal and lower zone vegetation and will scour some vegetation. Large proportions of the upper zone are also inundated, which creates recruitment opportunities for upper zone vegetation communities, but at the same time reduces woody vegetation cover and density on the channel floor (maintains tree line integrity).

14.4.7 Flow indicator: Pool storage conditions (risk of pools drying out)

Pools serve as refuge (survival) areas during dry season, and the most important habitat during the wet season (connecting flowing sections between pools provide limited short duration habitats). Decreasing water levels is also an indicator of water quality deterioration since water quality will be directly correlated with pool stage. If all perennial pools in the EFR Fish 2 reach would dry up this would have a significant impact on the fish assemblage, since all fish would have to recolonise the reach from other perennial pools. This could be hampered or prevented by the presence of natural and artificial migration barriers. In MRU B.2 the desiccation of all perennial pools will not have as significant impact on the fish assemblage as in the upper reaches (EFR Fish 1 and 2)due to the connection between the lower Fish River and the Orange River (no migration barriers present). It will however still result in significant reduction in FROC of all species as it will take time for them to recolonise from the Orange River. This could be hampered or prevented by the presence of artificial barriers and modified flows.

14.4.8 Time series of modelled Present Day and operational scenarios

Time series are provided for modelled natural and present day as well as for each operational scenario. Discharge is obviously the most important indicator for determining the condition of riverine habitat conditions. The numerous pools along the Fish River provide the most permanent riverine habitat. Very large floods (1:10 year and longer return periods) are required to scour the bed and banks of the river, remove encroaching vegetation and scouring these pools of accumulated fine sediment. More regular annual flows are required to fill and maintain the pools and alluvial aquifer along the river so that biota can persist.

14.4.9 Scour Potential in the pools

Bed load is a significant part of the sediment load of the Fish River. Maintenance of the bed habitats, particularly the pools, is important for biota. Potential Bed Material Transport, the modelling of fine sands, the dominant mobile component of the bed material, was undertaken at the pool at EFR Fish 2 to assess the changes in scouring potential of the pools associated with the various flow scenarios. This approach to estimating flow impacts has been undertaken for various regional and international environmental flow studies. A full, detailed description of the technique can be found in Dollar and Rowntree (2003).

Analysis focussed on the mid to high range of flows and floods (30 - 1% of the average daily flow duration curve for the record) but excluded the very large extreme floods. Large extreme floods, whilst they are important ecological reset events for southern African rivers (Rountree et al, 2000; Parsons et al, 2005) are beyond the control of any management actions, as is indicated by the fact that these extreme floods still occur under all scenarios.