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Orange-Senqu River Basin

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

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Orange-Senqu Strategic Action Programme
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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

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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

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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
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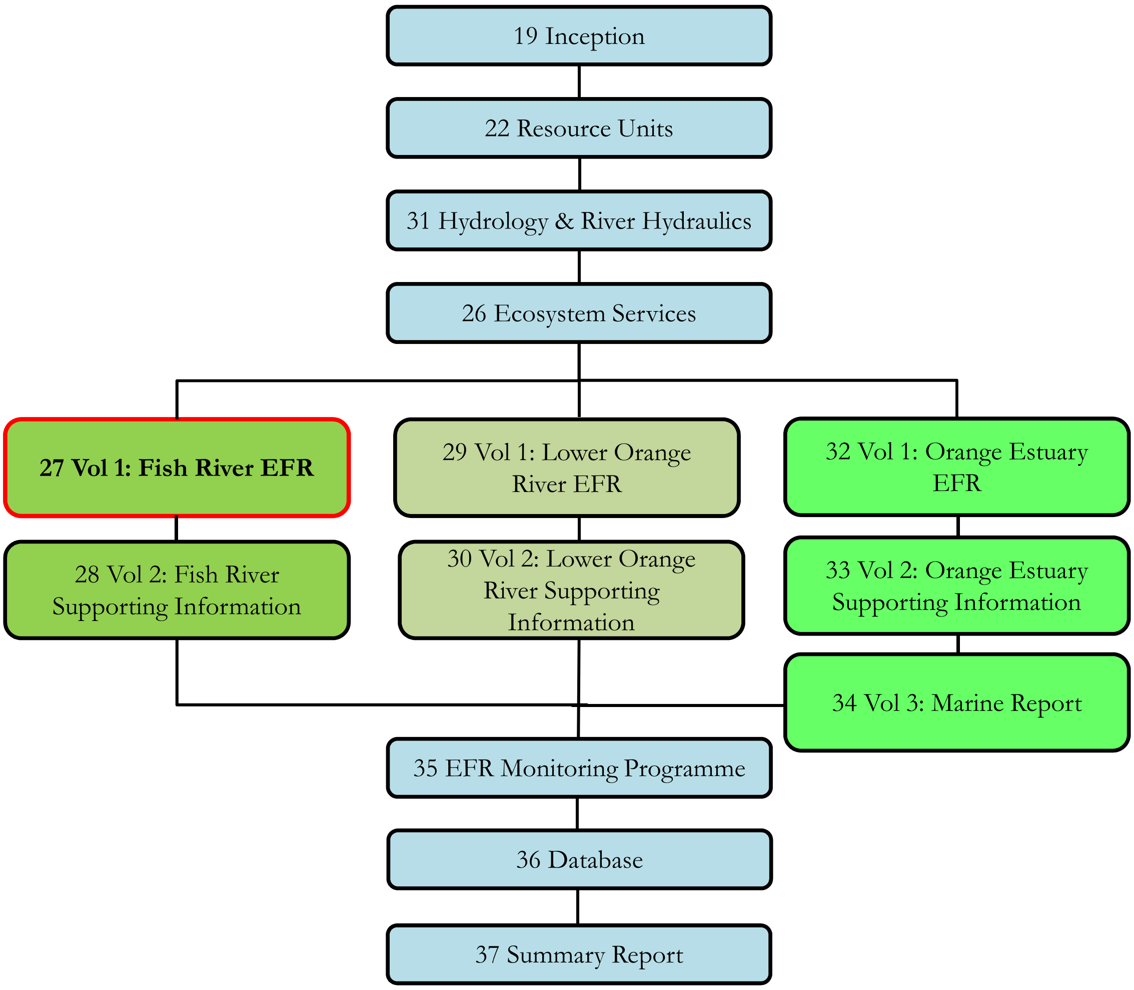
26	Consequences of Scenarios on Ecosystem Services, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
27	**River EFR assessment, Volume 1: Determination of Fish River EFR** **Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth**
28	River EFR assessment, Volume 2: Fish River EFR, supporting information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
29	River EFR assessment, Volume 1: Determination of the lower Orange River EFR Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
30	River EFR assessment, Volume 2: Lower Orange River EFR, supporting information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
31	River and Estuary EFR assessment, Hydrology and River Hydraulics Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
32	Estuary and Marine EFR assessment, Volume 1: Determination of Orange Estuary EFR Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
33	Estuary and Marine EFR assessment, Volume 2: Orange Estuary EFR: Supporting Information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
34	Estuary and Marine EFR assessment, Volume 3: Assessment of the Role of Freshwater Inflows in the Coastal Marine Ecosystem Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
35	EFR monitoring programme, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
36	Database, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth

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

Bold indicates current report.



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Executive summary

Introduction

The Orange-Senqu Strategic Action Programme 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 (Technical Report 22).

This report focuses on the Fish River in Namibia. The objectives of the Fish River component of the 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 recommended ecological category (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.

Study sites

EFRs are undertaken at specific study sites, (EFR sites), which are selected within management resource units (MRUs). The EFRs determined at each 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:

- 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 to the evaluation of different flow regimes, an additional 'site' was selected in the /Ai-/Ais Hot Springs Resort area to represent MRU Fish B.2 (Löwen confluence to the Orange River). This area or 'site' is referred to as EFR Fish Ai-Ais.

Method

Methods to determine the EFR (also called the ecological water requirement (EWR)) of rivers have been in place in South Africa since 1987 and, based on the development and application of the Building Block Methodology (King and Louw, 1998), the concept of EFRs (referred to as the ecological Reserve) was incorporated in the National Water Act (NWA). The methods have been slightly modified in the development and evolution of methods for rivers, estuaries, wetlands and groundwater, but essentially the same generic steps are followed in each:

- Step 1: Initiate the study.
- Step 2: Define the resource units.
- Step 3: Ecological classification (EcoClassification).
- Step 4: Quantify EFR.
- Step 5: Ecological consequences of operational (flow) scenarios.
- Step 6: Decide on management category.
- Step 7: Flow requirement specification.

In essence, the method can be summarised in the determination of the ecological state and importance of the river (part of the EcoClassification process) and the determination of EFR for different ecological states. EcoClassification consists of steps 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 Ecological Status (EcoStatus) (if relevant).

The ecological state of the river is described in terms of ecological categories (EC) A (near natural) to F (critically modified).

The EFR is quantified for different ecological states. This is the most technically demanding of the steps; the rules are rigorous procedures for deriving site-specific numerical objectives which are appropriate for a specific ecological state. The Fish River method was a scenario-based approach, i.e. different flow regimes are evaluated and the ecological states predicted. In this case, different EFR release options from the eminent Neckartal Dam were investigated to provide the decision-maker with sufficient information to decide on a preferred operating rule.

A summary of the different EFR release options (ROs) from the proposed Neckartal Dam which represent a percentage of inflows into the dam are provided below.

- EFR RO 0%
- EFR RO 10%
- EFR RO 20%

- EFR RO 30%
- EFR RO 40%
- EFR RO 50%

Results

EcoClassification

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

EFR Fish 1: EcoClassification description

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

Components	*PES*	*REC*
Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B/C
Fish	B	B
Macro-invertebrates	C	B
Instream	**B/C**	**B**
Riparian vegetation	B/C	B
Riverine fauna	B	B
EcoStatus	**B/C**	**B**
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 provides motivation for improvement of the EcoStatus. However an overall improvement in the EcoStatus could not be achieved by flow related mitigation measures as the instream biota components were already in a B EC. The riparian vegetation could be improved within the C EC by minimizing trampling and grazing pressure of goats.

Ecological Categories

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

EFR Fish 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 Hot Springs Resort resulting in elevated nutrient levels.	***Components***	***PES***
	IHI hydrology	C
	Physico-chemical	C
	Geomorphology	B
	Fish	C
	Macro-invertebrates	B
	Riparian vegetation	B/C
	Riverine fauna	C
	EIS	HIGH

Environmental flow requirement determination

The consequences of the EFR release options at EFR Fish 2 are summarised below.

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

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

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

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

A comparison of the consequences of the ROs at EFR Fish 2 and EFR Fish /Ai-/Ais is provided below.

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

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

Environmental flow requirement release option recommendations

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

As the RO 40 and 50% would have a significant impact on the yield of Neckartal Dam, an optimised RO that will minimise the impacts on both the yield and the ecological status was investigated. Such a RO should be between RO 30 and RO 40% and therefore a combination of the RO 30 and RO 40% was investigated. The optimised RO (RO Opt) entails releasing 40% of the inflow while the storage in the dam is above 60% of its full supply capacity dropping to 30% of the inflow should the storage in the dam drop below 60% of full capacity.

The evaluation of the RO Opt indicated that RO Opt has an even higher risk than RO 40% that the ecological objectives would not be met. However, as the yield was a significant improvement from RO 40%, this release option would represent the recommended EFR from Neckartal Dam.

Recommendations for further work

The evaluation of confidence in available information, EcoClassification and EFR results indicate whether further work is required to improve the predictions regarding EFRs.

Information availability at the EFR sites were generally moderate; although better for EFR Fish 2 due to the recent impact assessment studies undertaken for the Neckartal Dam development.

EcoClassification results for EFR Fish 1 and EFR Fish 2 were of moderate confidence. EcoClassification results for EFR Fish Ai-Ais were the lowest because surveys were less intensive than at the main (key) EFR sites. In general, the main problem with confidence was the lack of historical data on biota (required to determine reference conditions) and measured hydrology (pre Hardap Dam). This will, however, have limited consequences on the ability to evaluate flow regimes, which is mainly dependent on an understanding of the flow requirements of indicator species and their response to an altered flow regime. No further work is therefore required to refine the reference conditions and hence improve the PES as this would be impossible without historical data. Effort should rather be focussed on bio-monitoring to confirm predictions on responses to the altered flow regime from the proposed Neckartal Dam, within an Adaptive Management Framework.

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

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Abbreviations

ASPT	Average score per taxon
BBM	Building Block Methodology
DRIFT	Downstream Response to Imposed Flow Transformations
EC	Ecological category
EcoClassification	Ecological classification
EcoStatus	Ecological Status
EFR	Environmental flow requirement
EIS	Ecological importance and sensitivity
ESIA	Environmental and social impact assessment
EWR	Ecological water requirement
FRAI	Fish Response Assessment Index
FROC	Frequency of occurrence
GAI	Geomorphological Diver Assessment Index
HAI	Hydrological Driver Assessment Index
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HFSR	Habitat Flow Stressor Response
IHI	Index of Habitat Integrity
IUCN	International Union for Conservation of Nature
IWRM	Integrated water resources management
MAR	Mean annual runoff
MCB	Macro channel bank
MIRAI	Macroinvertebrate Response Assessment Index
MRU	Management resource unit
NASS2	Namibian Scoring System version 2
NWA	National Water Act
NWRS	National Water Resources Classification System
ORASECOM	Orange-Senqu River Commission
PAI	Physico-chemical Driver Assessment Index
PD	Present day
PES	Present ecological state
RDM	Resource Directed Measures
REC	Recommended ecological category
RO	Release option
RO Opt	Optimised release option

SANBI	South African National Biodiversity Institute
STW	Sewage treatment works
VEGRAI	Riparian Vegetation Response Assessment Index

Fish species abbreviations

BAEN	Labeobarbus aeneus
BHOS	Barbus hospes
BKIM	Labeobarbus kimberleyensis
BPAU	Barbus paludinosus
CCAR	Cyprinus carpio
CGAR	Clarias gariepinus
LCAP	Labeo capensis
LUMB	Labeo umbratus
MBRE	Mesobola brevianalis
OMOS	Oreochromis mossambicus
TSPA	Tilapia sparrmanii

Velocity Depth Classes: Fish

FD	Fast deep fish habitat
FI	Fast intermediate fish habitat
FS	Fast shallow fish habitat
SD	Slow deep fish habitat
SS	Slow shallow fish habitat

1. Introduction

1.1 Background

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

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

1.2 Study area

The study area is the Orange River downstream of the Fish River confluence (including the estuary and immediate marine environment) and the Fish River (Technical Report 22). This report focuses on the EFR of the Fish River in Namibia.

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

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

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

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

The study area is shown in Figure 1.

1.3 Objectives of the 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 category (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 for more detail regarding the process and methods.

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

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

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

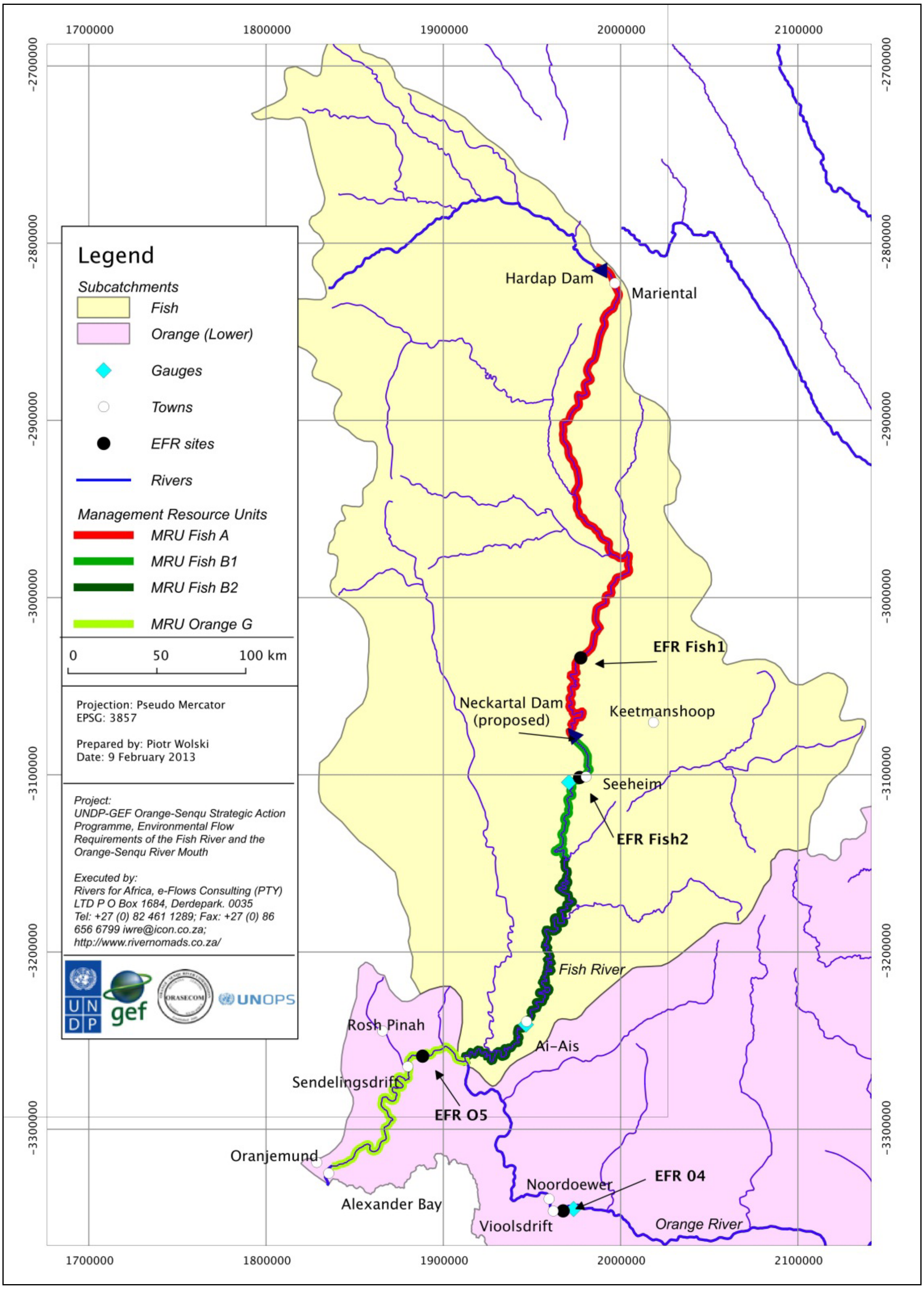


Figure 1. The Fish River basin, Namibia

1.5 Study sites

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

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

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

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

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

- EFR release options (ROs) had to be evaluated in detail at EFR Fish 2. However, due to the significant river losses, potential inflows from tributaries and to take cognisance of the Naute Dam, consequences as identified at EFR Fish 2 had to be verified further downstream;
- due to the presence of a waterfall in the Witputs area (downstream of the Löwen River confluence and upstream of /Ai-/Ais Hot Springs Resort) there is a notable difference in the fish species composition of the lower Fish River (below the waterfall, EFR Fish Ai-Ais) and the upper Fish River reaches (EFR Fish 1 and 2);
- Specific localised water quality issues at and upstream of /Ai-/Ais Hot Springs Resort;
- Changes in operation of Naute Dam.

EFR Fish 1

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

Figure 2. EFR Fish 1 located in MRU Fish A

EFR Fish 2

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

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

EFR Fish Ai-Ais

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

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

1.6 Information availability

Information utilised to assess hydrology, geohydrology and hydraulics are provided in Technical Report 31.

The available information for the biophysical components (i.e. fish, macro-invertebrates and riparian vegetation, water quality, or physico-chemical variables, and fluvial geomorphology) are provided in Table 1. Information consisted of historic information and 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 information

Components	
Information availability	
Physico-chemical variables	Confidence: 2
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 information sources including accessing information from specialists on the study (e.g. Roberts, Koekemoer, Rountree and Bockmühl), literature (see reference list – Technical Report 28), a site visit in June 2012 and correspondence/interviews with Namibian residents.	
Geomorphology	Confidence: 3
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).	
Index of Habitat Integrity (IHI)	Confidence: 3.5
• Personal ground-based observations.	

Components

Information availability

- Local knowledge.
- Hydrological assessments.
- Water quality assessments.
- Land covers assessments.
- Google Earth (high resolution).

The confidence 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.

Riparian vegetation — Confidence: 3

- 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).
- South African National Biodiversity Institute (SANBI, 2009): Plants of Southern Africa online database (based on several herbaria collections).
- Data collected during field visit (18 June 2012).

Fish — Confidence: 2

- 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).
- 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).

Macro-invertebrates — Confidence: 2

- Paper which summarises the distribution of macro-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.

Diatoms — Confidence 2.5

EFR Fish 1: No historic site specific diatom information 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.

Riverine fauna — Confidence: 3

- 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 (International Union for Conservation of Nature

Components	*Information availability*
	(IUCN) and SA Red Data). • Data collected during field visit (June 2012).

1.7 Methodology

South Africa's National Water Act (NWA) (No. 36 of 1998) requires the implementation of regulatory activities in order to make optimal use of the country's water resources while minimising ecological damage. One of which is resource-directed measures, i.e. defining a desired level of protection for a water resource, and on that basis, setting environmental flows and specific goals for the quality of the resource (the resource quality objectives). The objective of Resource Directed Measures (RDM) is to ensure the protection of water resources, in the sense of protecting ecosystem functioning and maintaining a desired state of health (integrity or condition) of aquatic and groundwater-dependent ecosystems. This objective is met through various processes, including the setting of 'environmental flows'.

The development of methods to determine river EFRs (also called the ecological water requirement (EWR) in South Africa) was initiated in South Africa during 1987 when the need for EFRs in the National Kruger Park rivers were identified. The Building Block Methodology (BBM - King and Louw, 1998) was developed and the successful application of these methods to determine EFRs was largely responsible for EFRs to be incorporated in the NWA (No. 36 of 1998). The BBM and methods developed since follow a generic methodology which can be carried out at different levels of effort to determine the desired state or REC and the associated flow allocation (EFR/EWR). The methods have been slightly modified in the development and evolution of methods for rivers, estuaries, wetlands and groundwater, but essentially the same generic steps are followed in each:

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

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

Step 3: EcoClassification
This step entails estimating the reference and present condition and ecological importance in order to determine the REC. The reference condition refers to the natural, un-impacted characteristics of a water resource, and must represent a stable baseline. This usually requires expert judgment in conjunction with local knowledge and historical data. The present ecological status of resource quality (water quantity, water quality, habitat and biota), is assessed in terms of the degree of similarity to reference conditions. This helps to identify what may be desirable or achievable as a REC. The assessment is summarised in terms of the classification system of A to F described in

Table 2. The EcoClassification process (Kleynhans and Louw, 2007) is described in Appendix A and the steps are listed below:

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

Step 4: Quantify EFR

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

- Top-down approach: These are methods such as the Downstream Response to Imposed Flow Transformation (DRIFT) (Brown and King, 2001) and the method developed and used for the Fish River. These methods typically evaluated different flow regimes and predict the resulting Ecological Category.
- Bottom-up approach: These are methods such as the BBM (King and Louw, 1998) and the Habitat Flow Stressor Response (HFSR) method (Hughes and Louw, 2010). Both these methods consist of a process to determine a flow regime that would result in a range of ecological states. Different flow regimes can then be evaluated and the ecological state determined.

Step 5: Ecological consequences of operational (flow) scenarios

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

Step 6: Decide on management category

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

Step 7: Flow requirement specification

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

Table 2. The description of Ecological Categories. Categories A to D are within the desired range, whereas E and F are not (Kleynhans and Louw, 2007)

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

The specific Fish River EFR approach is documented in Appendix C and Technical report 31.

1.8 Release options

The Fish River method as indicated above was a scenario-based approach, i.e. different flow regimes are evaluated and the ecological states predicted. In this case, different EFR release options from the eminent Neckartal Dam were investigated to provide the decision-maker with sufficient information to decide on a preferred operating rule.

A summary of the different EFR release options (ROs) from the proposed Neckartal Dam which represent a percentage of inflows into the dam are provided below.

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

1.9 Report structure

The report details the following two main components of the EFR process:

- Ecological classification (EcoClassification) process – Discussed in Chapter 2 – 5 of this report, and
- EFR determination – Discussed in Chapter 7 - 10 of this report.

The report structure is outlined below.

Chapter 1: Introduction
This chapter provides an overview of the study area, objectives of the study and information availability and approaches are discussed that were applied during the study.

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 - 7: EFR release option evaluation
The results of the ecological consequences of the ROs are provided for EFR Fish 2 and EFR Fish Ai-Ais.

Chapter 8: Environmental flow requirements at EFR Fish 1
As EFR Fish 1 is upstream of Neckartal Dam from which all the ROs originate, flow requirements were set at the site and provided in this chapter.

Chapter 9: 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 RO that will maintain the PES and minimise the impacts on system yield and for users

Chapter 10: 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.

Appendix C: Fish River environmental flow requirement determination - methods
For the evaluation of EFR ROs, 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: EFR Fish 1

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

2.1 Ecological importance and sensitivity results

The EIS results for EFR Fish 1 were **HIGH.** The highest scoring matrices are outlined below.

- 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 3.

Table 3. EFR Fish 1: Reference conditions

Component / ***Reference conditions***	
Hydrology	Confidence: 2
The natural mean annual runoff (MAR) is 420 M^3m.	
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. This information was modified by available information where possible. • Electrical Conductivity: 42.02 mS/m (using the mean of the electrical conductivity 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 basin 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	

Component

Reference conditions

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 basin area as well as inflows from the numerous small tributaries.

Riparian vegetation — Confidence 3:

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 were 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 Technical Report 28:

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).

Component	
	Reference conditions
	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 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

The PES reflects the changes in terms of the ecological category (EC) from reference conditions. The summarised information is provided in Table 4.

Table 4. EFR Fish 1: PES

Component			
PES description			
Hydrology			Confidence: 3
The present day (PD) MAR is 331 M³m. 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 basin 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 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 basin, 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	IHI 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.			

<table>
<tr><th colspan="3">Component</th></tr>
<tr><th colspan="3">PES description</th></tr>
<tr><td colspan="3">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.</td></tr>
<tr><td>Fish</td><td>PES: B</td><td>Confidence: 2</td></tr>
<tr><td colspan="3">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).</td></tr>
<tr><td>Macro-invertebrates</td><td>PES: C</td><td>Confidence: 2</td></tr>
<tr><td colspan="3">A total of 15 NASS2 taxa were 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 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).</td></tr>
<tr><td>Riverine fauna</td><td>PES: B</td><td>Confidence 3.5</td></tr>
<tr><td colspan="3">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 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</td></tr>
</table>

Component   ***PES description***
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).

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 5.

Table 5. 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
	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)

Component	***Causes***	***Sources***
	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.

Present ecological status - EcoStatus

The Ecological status (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

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 PES could be improved by flow-related measures. As the riparian vegetation

PES score was 0.4% below a B EC, minimal improvement would be required to achieve a B REC for riparian vegetation.

2.5 Summary of EcoClassification results

The EcoClassification results are summarised in Table 6. The colours used are standard colours associated with EcoClassification.

Table 6. EFR Fish 1: Summary of EcoClassification results

Components	***PES***	***REC***	***Comment***
Hydrology	C	C	
Physico-chemical	C	C	
Geomorphology	B/C	B/C	
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: EFR Fish 2

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

3.1 Ecological importance and sensitivity results

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

- 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 7.

Table 7. EFR Fish 2: Reference conditions

Component	
Reference conditions	
Hydrology	Confidence: 2
The natural MAR is 504 M^3m.	
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).	

Component / ***Reference conditions***
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 EC from reference conditions. The summarised information is provided in Table 8.

Table 8. EFR Fish 2: Present Ecological State

Component / ***PES description***			
Hydrology			Confidence: 3
The PD MAR is 404 M^3m. 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 basin above Hardap. There is, however, evidence for quite substantial attenuation and loss of flow between Seeheim gauging weir and /Ai-/Ais Hot Spring 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	IHI 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			

Component

PES description

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 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.

Component
PES description
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.

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 9.

Table 9. 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.			

Component	***Causes***	***Sources***
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.

Present EcoStatus

The EcoStatus represents an integrated status as a biological end point (Kleynhans and Louw, 2007). The ECs 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

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 10. The colours used are standard colours associated with EcoClassification.

Table 10. EFR Fish 2: Summary of EcoClassification results

Components	***PES***	***REC***	***Comment***
Hydrology	C	C	
Physico-chemical	C	C	
Geomorphology	B/C	B/C	
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: EFR Fish Ai-Ais

As discussed in section 1.5.3 an additional 'site' was required downstream of the Löwen River confluence due to the existence of migration barriers between EFR Fish 2 and EFR Fish Ai-Ais and to essentially check the ROs 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 Hot Springs 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 scenario evaluation. For more detailed specialist information, refer to Technical Report 28.

A summary of the PES conditions are provided in Table 11.

Table 11. Description of the PES for MRU Fish B.2

Component / ***PES description***	
Hydrology	
The PD MAR is 475 M^{3}m. Any The natural MAR is 613 M^{3}m. 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 Hot Springs 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 Hot Springs 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 Hot Springs 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 Hot Springs Resort	

Component		
	PES description	
	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 Hot Springs Resort). Overall the fish assemblage was therefore estimated to currently be in a slightly to moderately modified state. Refer to Technical Report 28 for more detail.	
Macro-invertebrates		PES: B
	A total of 15 NASS2 taxa were recorded at /Ai-/Ais Hot Springs 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 and species composition is similar to EFR Fish 2. Impacts on the riverine fauna will be a bit more pronounced, however the PES will not deteriorate.	

The EcoClassification results are summarised in Table 12. The colours used are standard colours associated with EcoClassification.

Table 12. MRU Fish B.2 (EFR Fish Ai-Ais): Summary of EcoClassification results

Components	***PES***
Hydrology	C
Physico-chemical	C
Geomorphology	B
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 13.

Table 13. EcoClassification Results summary

EFR Fish 1: EcoClassification description

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

Components	***PES***	***REC***
Hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B/C
Fish	B	B
Macro-invertebrates	C	B
Instream	**B/C**	**B**
Riparian vegetation	B/C	B
Riverine fauna	B	B
EcoStatus	**B/C**	**B**
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 provides motivation for improvement of the EcoStatus. However an overall improvement in the EcoStatus could not be achieved by flow related mitigation measures as the instream biota components were already in a B EC. The riparian vegetation could be improved within the C EC by minimizing trampling and grazing pressure of goats.

Ecological Categories

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

EFR Fish 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 Hot Springs Resort resulting in elevated nutrient levels.	***Components***	***PES***
	IHI hydrology	C
	Physico-chemical	C
	Geomorphology	B
	Fish	C
	Macro-invertebrates	B
	Riparian vegetation	B/C
	Riverine fauna	C
	EIS	HIGH

5.2 Limitations and constraints

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 basin included nutrient elevations and irrigation return flows around Hardap Dam and a number of malfunctioning STWs, e.g. at Gibeon and /Ai-/Ais Hot Springs Resort.

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 Hot Springs Resort) refers to BKIM, BPAU, CGAR, CCAR, *Mesobola brevianalis* (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).

Macro-invertebrates

Reference Conditions: There was limited information on 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 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 14) and was based on information availability and EcoClassification where:

- Information availability: Evaluation based on the adequacy of any available information 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 14. Confidence in EcoClassification process

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

EFR site	***EFR Fish 1***	***EFR Fish 2***	***EFR Fish Ai-Ais***
Median	**3**	**3**	**2.5**

5.4 Conclusions

The confidence in the information availability at both EFR sites were moderate, however 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 5.2. The overall confidence is lower at EFR Fish 2 despite a higher confidence in information availability. 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 information availability and for EFR Fish 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 information regarding the biota and historic measured hydrology (pre Hardap Dam). This will however have limited consequences to the ability of evaluating ROs 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 information. As the construction of Neckartal Dam is imminent, the focus in the future should be on monitoring to verify the predicted responses of the altered flow regime within an adaptive management framework (see following chapters).

6. Environmental flow requirement release option evaluation: EFR Fish 2

6.1 Release options: Flow indicators

For the evaluation of EFR ROs, various flow indicators (Technical Report 31 and Appendix C) were used in determining the ecological consequences. Table 15 provides the flow indicators showing changes from the PD hydrology.

Table 15. Flow indicators showing changes from PD under different EFR ROs

Low flow indicators (% of time)	***Release options***					
	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 m^3/s (wet season)	25	35	37	41	43	56
When flow is >2 m^3/s (all months)	10	15	16	18	19	27
When flow is >10 m^3/s (wet season)	16	20	22	24	26	37
High flow criteria (number of events throughout modeled flow release)						
Events >80 m^3/s (duration of 4 days at 80 or higher)	29	27	27	24	24	36
Events >150 m^3/s (duration of 4 days at 150 or higher)	24	24	25	21	20	28
Events >600 m^3/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).

6.2 Consequences of the release option 0%

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

Table 16. Consequences of RO 0%

Component	***PES***	***EC RO 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.

Component	*PES*	*EC RO 0%*	*Response*
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.
Riverine 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.

6.3 Consequences of release option 20%, 30%, 40% and 50%

Physico-chemical and geomorphological consequences

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

Table 17. Consequences of EFR ROs (20% – 50%) on physico-chemical and geomorphology components

EFR ROs	*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 RO 20% and RO 30%.	C/D (61.8%)
20%	Most parameters deteriorating from present state conditions. There is almost a RO 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%)

Biological response consequences

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

Table 18. Fish: Ecological consequences of the different EFR ROs

EFR ROs	***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 RO 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 RO 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.

EFR ROs	***Flow indicators***	***Response***
% 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 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.
The predicted response of the fish component described in terms of ECs		
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 EFR ROs

EFR ROs	***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 RO 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 RO 30%.
Macro-invertebrate water quality categories		
PES	1	
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 RO 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.
The predicted response of the macro-invertebrate component described in terms of ECs		
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 EFR ROs

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

Flow indicators	*EFR release options*						*Comments*
	0%	*20%*	*30%*	*40%*	*50%*	*PD*	
No of events of <600 m^3/s (duration of 2 days at 600 or higher)	24	24	21	20	20	27	Not significantly altered by any of the ROs.
No of events of <150 m^3/s (duration of 4 days at 150 or higher)	24	24	25	21	20	28	Not significantly altered by any of the ROs.
No of events of <80 m^3/s (duration of 4 days at 80 or higher)	29	28	27	24	24	36	RO 50% and RO 40% result in increased woody cover on the channel floor.
10 m^3/s	16	20	22	24	26	37	
2 m^3/s	10	15	16	18	19	27	
Decrease in % of time that flow occurs in wet season	34	45	47	51	53	65	RO 30%, RO 20% and RO 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**	RO 0%, 20% and 30% is a lower EC than PES

Table 21. Riverine fauna: Ecological consequences of the different EFR ROs

EFR ROs	*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 RO 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

EFR ROs	*Flow indicators*	*Response*
		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 RO 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 RO 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 RO 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 marginal zone species, reduce reproductive success; influence riparian fauna, especially relating to feeding along the riparian corridor.
20%	20	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.

EFR ROs	***Flow indicators***	***Response***
		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 RO 50%.
30%	Medium	This will impact on piscivorous species, invertivores and other aquatic predators.
20%	Medium- High	Same as RO 30%.
The predicted response of the riverine fauna component described in terms of ECs		
PES	B (84%)	
50%	B (83%)	
40%	B (83%)	
30%	C (69.5%)	
20%	C/D (60%)	

6.4 Summary of biophysical responses to different release options 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 EFR ROs (Figure 5).

Table 22. Summary of biophysical responses at EFR Fish 2

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

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

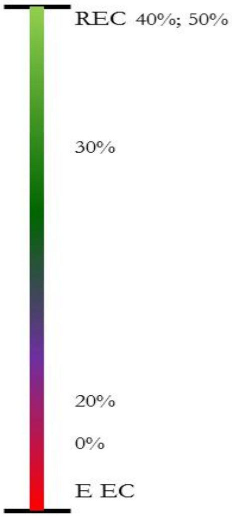


Figure 5. Relative differences between EFR ROs

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 met (red implies all objectives are not met).

Table 23. Degree to which ecological objectives are met at EFR Fish 2 under each EFR RO

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

7. Environmental flow requirement release option evaluation: EFR Fish Ai-Ais

7.1 Release options: Flow indicators

For the evaluation of EFR ROs, various flow indicators (Technical Report 31 and Appendix C) were used in determining the ecological consequences. Table 24 provides the flow indicators used during the evaluation, showing changes from the PD hydrology.

Table 24. Flow indicators evaluation showing changes from PD under different EFR ROs

Low flow indicators (% of time)	***Release options***					
	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 m^3/s (wet season)	27	35	39	42	46	61
When flow is >2 m^3/s (all months)	12	16	17	19	21	30
When flow is >10 m^3/s (wet season)	19	21	23	25	26	37
High flow criteria (number of events throughout modeled flow scenario)						
Events >80 m^3/s (duration of 4 days at 80 or higher)	34	33	32	32	31	50
Events >150 m^3/s (duration of 4 days at 150 or higher)	27	27	26	25	25	36
Events >600 m^3/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 6.1), but the probability (and therefore risk) of pool drying would be greater for the lower ROs (i.e. RO 20% and RO 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.

7.2 Consequences of the release option 0%

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

Table 25. Consequences of RO 0%

Component	***PES***	***EC RO 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.

Component	*PES*	*EC RO 0%*	*Response*
Riverine 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.

7.3 Consequences of the release option 20%, 30%, 40% and 50%

Physico-chemical and geomorphological consequences

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

Table 26. Consequences of EFR ROs (20% – 50%) on physico-chemical and geomorphology components

EFR ROs	*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 ROs 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 basin. 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

Biological response consequences

An analysis was made to determine the responses to the EFR ROs based on the flow, water quality and geomorphological changes associated with each scenario. These consequences are provided in Table 27–30.

Table 27. Fish: Ecological consequences of the different EFR ROs

EFR ROs	***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.
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.

EFR ROs	***Flow indicators***	***Response***
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.
The predicted response of the fish component described in terms of ECs		
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 EFR ROs

EFR ROs	***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 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

EFR ROs	***Ecological traits***	***Response***
		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 RO 50.
30%	2	Gomphid production is expected to drop slightly because of the reduced duration of the wet season.
20%	3	Same as RO 30%.
Macro-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.

EFR ROs	***Ecological traits***	***Response***
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.
The predicted response of the macro-invertebrate component described in terms of ECs		
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 EFR ROs

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

Flow indicators	***EFR release options***						***Comments***
	0%	***20%***	***30%***	***40%***	***50%***	***PD***	
No of events of <600 m^3/s (duration of 2 days at 600 or higher)	25	25	33	32	30	28	Same as PD
No of events of <150 m^3/s (duration of 4 days at 150 or higher)	27	27	26	25	25	36	Same as PD.
No of events of <80 m^3/s (duration of 4 days at 80 or higher)	34	33	32	32	31	50	Minimal increased woody cover at all ROs.
10 m^3/s	19	21	23	25	26	37	
2 m^3/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 RO 20%, RO 10% and RO 0 %,

Flow indicators	*EFR release options*						*Comments*
	0%	*20%*	*30%*	*40%*	*50%*	*PD*	
							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	RO 40% and RO 50%: Localised mortality of non-woody. Rest of ROs extensive mortality.
PES	**D**	**C/D**	**C/D**	**C**	**C**	**C**	

Table 30. Riverine fauna: Ecological consequences of the different EFR ROs

EFR ROs	***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 RO 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 RO 30%. Exposed shoreline - shallow edges: Wetted perimeter declining - impacts on shore species. Wooded bank - shrubs and tall riparian - continuous: Same as RO 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 RO 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 RO 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;

EFR ROs	*Flow indicators*	*Response*
		piscivorous animal species will be impacted accordingly.
% time that 10 m³/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 RO 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 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.
The predicted response of the riverine fauna component described in terms of ECs		
PES	C (73.9%)	
50%	C (70.4%)	
40%	C (62.2%)	
30%	C/D (58.7%)	
20%	D (50.1%)	

7.4 Summary of biophysical responses to different release options at MRU B.2 (EFR Fish 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 ROs (Figure 6).

Table 31. Summary of biophysical responses at EFR Fish Ai-Ais

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

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

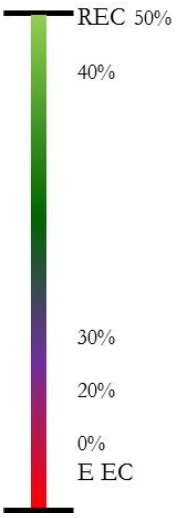
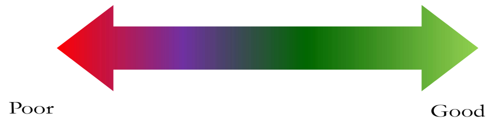


Figure 6. Relative differences between EFR ROs

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 Ai-Ais under each EFR RO

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



8. Environmental flow requirements at EFR Fish 1

No changes in the current operation and release rules from Hardap Dam were identified. As all the EFR ROs are applicable downstream from Neckartal Dam, they were not evaluated at EFR Fish 1. EFR Fish 1 can however play an important role in monitoring and if any future developments are identified which would 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

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

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.

9. Conclusions

9.1 Comparison of the ecological consequences at EFR Fish 2 and EFR Fish Ai-Ais

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

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

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

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

9.2 Optimised release option

As the RO 40 and 50% would have a significant impact on the yield of Neckartal Dam (Table 36), an optimised RO that will minimise the impacts on both the yield and the ecological status was investigated. Such a RO should be between RO 30 and RO 40% and therefore a combination of the RO 30 and RO 40% was investigated. The optimised RO (RO Opt) entails releasing 40% of the inflow while the storage in the dam is above 60% of its full supply capacity dropping to 30% of the inflow should the storage in the dam drop below 60% of full capacity.

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 RO

EFR RO	***Releases (M^3m /a)***	***Yield (M^3m /a)***	***Yield as % of the EFR RO 0%***
0	0	81	100.0
10	27.8	74	91.4
20	40.7	68	84.0

EFR RO	***Releases (M^3m /a)***	***Yield (M^3m /a)***	***Yield as % of the EFR RO 0%***
30	51.3	61	75.3
40	59.8	55	67.9
50	67.1	49	60.5
Opt	56	61	75.3

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

Table 37. Flow indicator analysis for the RO Opt and comparison with RO 30% and RO 40%

Low flow indicators (% of time)	***Release options***			
	30%	***RO Opt***	***40%***	***PD***
Flow: Wet Season	54	56	57	72
Flow: All months	28	29	30	40
When flow is> 2 m^3/s (wet season)	39	41	42	61
When flow is > 2 m^3/s (all months)	17	18	19	30
When flow is > 10 m^3/s (wet season)	23	24	25	37
High flow criteria (number of events throughout modeled flow scenario)				
Events > 80 m^3/s (duration of 4 days at 80 or higher)	34	32	32	50
Events > 150 m^3/s (duration of 4 days at 150 or higher)	26	26	25	36
Events >600 m^3/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 RO Opt lies between the RO 30% and 40% and closer to the RO 40% (Table 38). Specialists did not have the resolution to evaluate this RO and the following statements were made.

- RO 40% has a higher risk than RO 50% that the ecological objectives would not be met.
- RO 30% will not maintain the PES.
- The RO Opt has an even higher risk than the RO 40% that the ecological objectives will not be met. However, as the yield was a significant improvement from the RO 40%, this would be the RO 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.

Table 38. Comparison of ecological consequences at EFR Fish 2 and EFR Fish Ai-Ais including the RO Opt

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

9.3 Confidence in release option 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 ROs was sometimes difficult to distinguish, and a range of variables had to be considered for each of these ROs.
- 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 ROs 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.

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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. Please note that the terminology 'drivers' are used in the following section in the context of the processes that drive the system. Drivers in this sense must not be confused with the term 'drivers' used in the formulation of scenarios. As this is a summary of a published method the terminology cannot be changed.

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

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

- drivers (physico-chemical, geomorphology, hydrology), which provide a particular habitat template;
- biological responses (fish, riparian vegetation and 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 outlined below.

- 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).
- Index of Habitat Integrity (IHI): Kleynhans et al. (2009).

A.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 EIS for the biota and habitat;
- considering the PES and the EIS, suggest a realistic REC for each component, as well as for the EcoStatus;
- determine Alternative Ecological Categories for each component, as well as for the EcoStatus.

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 ECs.

The flow diagram (Kleynhans and Louw, 2007) (Figure A1) illustrates the process.

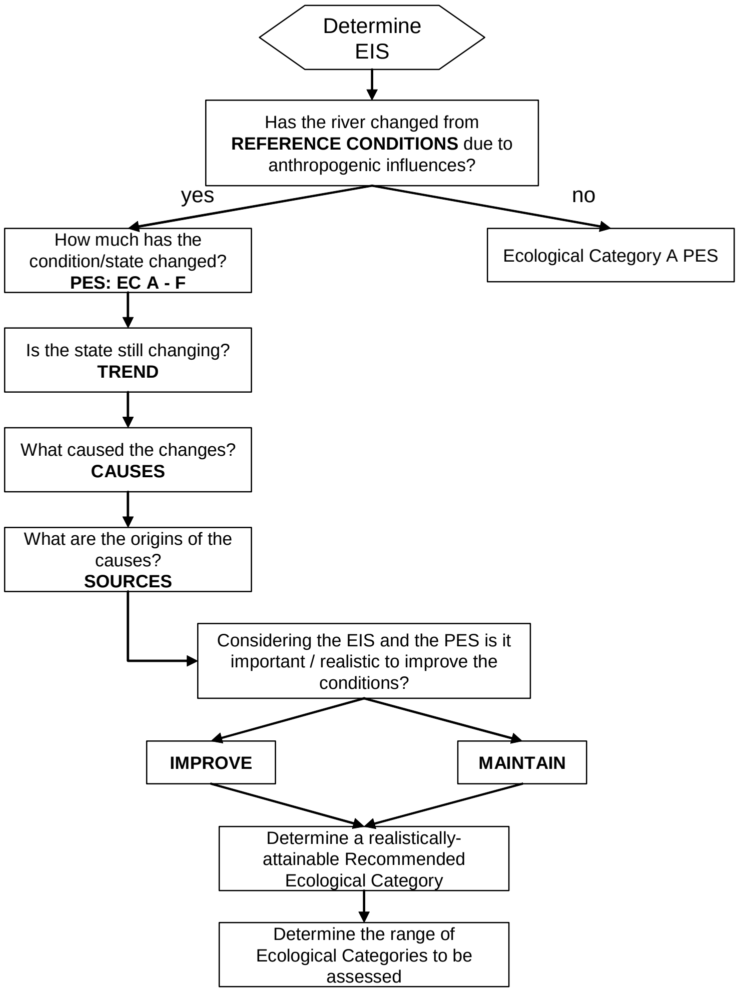

Figure A1. Flow diagram illustrating the information generated to determine the range of ECs for which the EFR will be determined.

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 A2.

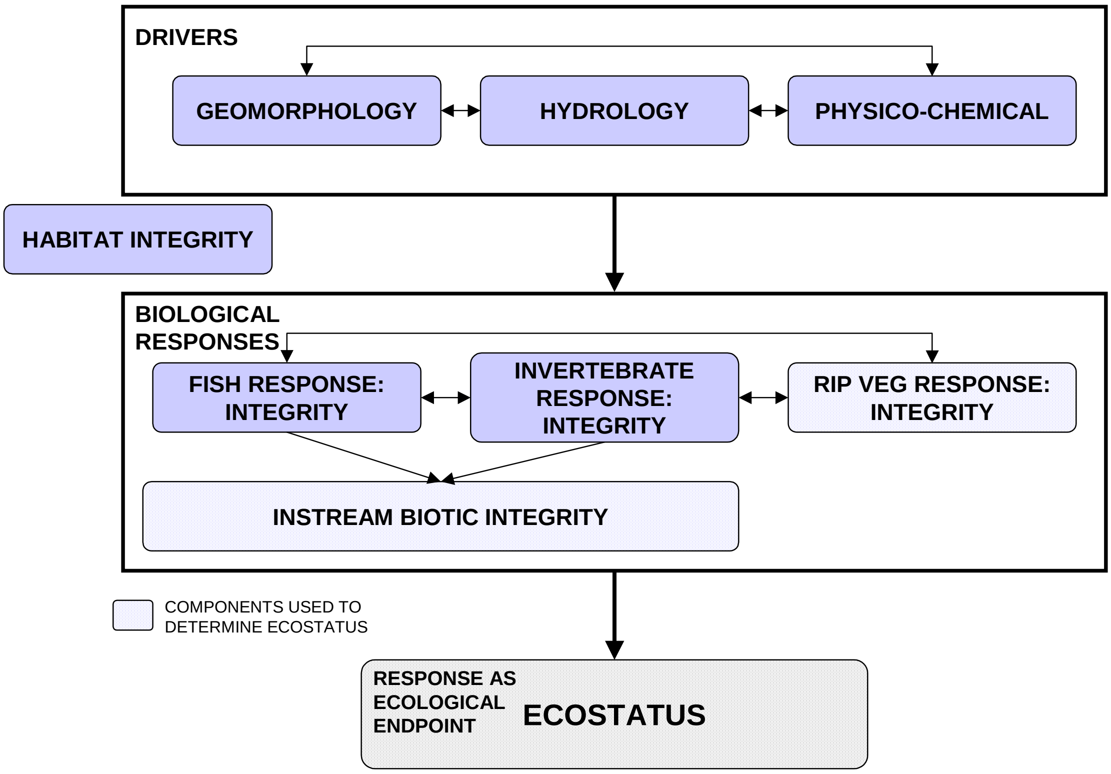

Figure A2 EcoStatus Level 4 determination

A.2 Ecological importance and sensitivity

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 basin 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 A1.

Table A1. 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.

Appendix B EcoStatus model output

B.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	

B.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
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	

Appendix C Fish River environmental flow requirement determination: Methods

C.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 Hydrologic Engineering Centers River Analysis System (HEC-RAS) model.

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

The scenario development and detail regarding the hydrological, yield and HEC-RAS modelling are described in Technical Report 31. The rest of this chapter focusses on the approaches followed for the biophysical components to evaluate the impacts of different EFR ROs from Neckartal Dam.

C.2 Conceptual approach to biophysical responses to different release options

Geomorphological responses to different release options

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 scenarios to evaluate if the future proposed ROs will be able to scour and maintain the pools.

Fish responses to different release options

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 ROs.

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

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.

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 ROs.
- 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 ROs (ideally the water quality specialist estimated ranges (actual values/concentrations) of for instance salinity under different ROs, 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 ROs. Input from the macro-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 ROs.

Macro-invertebrate responses to different release options

The method used to assess macro-invertebrate response to ROs 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 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 PES category (A to F). The macro-invertebrate response to altered ROs was assessed by changing ratings, were applicable, but weightings were kept constant to ensure consistent comparison.

Riparian vegetation responses to release options

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), RO 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.

Riverine fauna (excluding instream) to different release options

- 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 ROs: 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.

C.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 RO 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 EFR ROs which will be assessed. The decision-makers can then make informed decision on which RO they would implement, knowing the resulting ecological consequences. The impact of the different sROs on Ecosystem services as well as stakeholder input will also be evaluated and provided.

C.4 Process to determine ecological consequences of release options

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

- All specialists identified important flow indicators that had to be analysed and compared to PD.
- Motivations and reasoning were provided for each criterion.
- An initial qualitative evaluation was undertaken to determine whether any of the ROs 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 RO was designed and re-tested. The purpose of this is to improve the yield and maintain the ecological state.

Each EFR RO was analysed according to certain parameters and flow indicators. For detail on how the flow indicators were quantified, refer to Technical Report 31. The importance of the specific flow indicators in assessing the biophysical responses are described below.

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 *Barbus hospes* (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 Hot Springs Resort however confirmed that breeding of many species do occur in the Fish River (juveniles sampled).

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).

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 two days at a time at EFR Fish 2. Longer durations than two days will be required for movement between the Orange and Fish River in the Ai-Ais reach.

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.

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. ten 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.

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 two 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).

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.

Time series of modelled present day hydrology and release options

Time series are provided for modelled natural and present day as well as for each RO. 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.

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 ROs. 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 ROs.