Orange-Senqu River Basin

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

UNDP-GEF
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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

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

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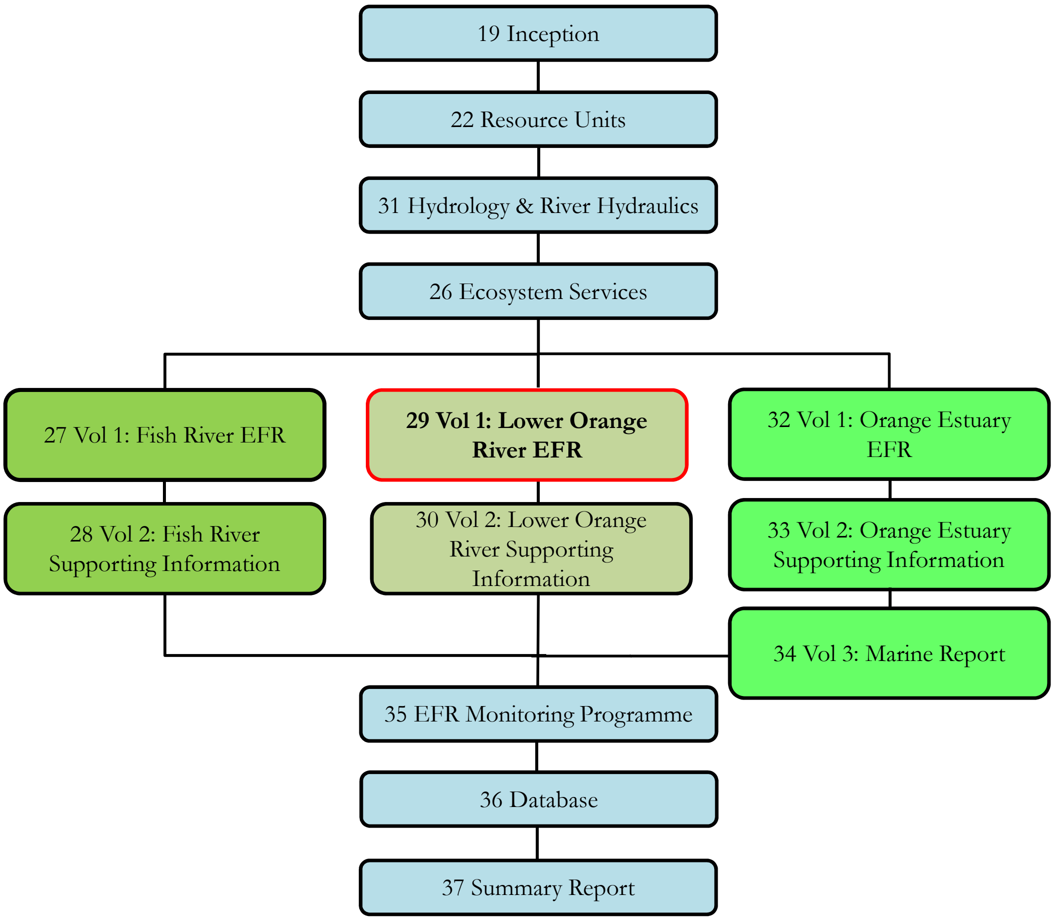
Report list

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

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

Bold indicates current report.



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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 lower Orange River, between the Fish River confluence and the estuary. The objectives of this component of the study were to:

- determine the present ecological state (PES) and describe alternative ecological states;
- set the environmental flow requirement (EFR);
- address scenarios that include future developments and growth, and determine the ecological implications.

Study sites

EFRs are determined 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. One EFR site (EFR O5) was selected in the lower Orange River. It lies approximately 6 km upstream of Sendelingsdrift in the /Ai-/Ais–Richtersveld Transfrontier Park, and is situated in MRU Orange G, the reach between the Fish River confluence and the estuary.

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 ecological classification (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 method that was applied was the Habitat Flow Stressor Response (HFSR) method (Hughes and Louw, 2010). The method consists of a process to determine a flow regime that will result in a range of ecological states. Different flow regimes can then be evaluated and the ecological state determined.

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).

EIS: HIGH
Highest scoring metrics: Rare and endangered instream and riparian species. Unique instream and riparian species. Important migration corridor for various species. Site is situated in the /Ai-/Ais–Richtersveld Transfrontier Park.
PES: B/C
Flow-related impacts: Decreased frequency of small and moderate floods. Agricultural return flows and mining activities cause water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times.
Non-flow-related impacts: Presence of alien fish species and barrier effects of dams. Alien vegetation.
REC: B
Increased (from present) wet season base flows.
Reinstate dry season droughts.

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

Environmental flow requirements

A summary of the flow requirement results for two ecological categories, i.e. B/C for the PES and B for the REC, is provided below.

Hydrology	*B/C PES*	*B REC*
Natural mean annual runoff (nMAR) (Mm^3)	11,373	11,373
Maintenance low flows (%nMAR)	6.35	10.15
Drought low flows (%nMAR)	0.96	1.32
High flows (%nMAR)	4.51	4.51
Long-term mean (%nMAR)	10.85	14.66
Present-day mean annual runoff (pMAR) (Mm^3)	4641	4641
Maintenance low flows (%pMAR)	15.54	24.87
Drought low flows (%pMAR)	2.36	3.22
High flows (%pMAR)	11.05	11.05
Long-term mean (%pMAR)	26.6	35.93

Scenario evaluation

Scenarios (Sc) consist of combinations of different drivers. The various scenarios, their respective combination of drivers, and the likely timeframes are provided below.

Time frame	*Scenario*	*Orange River drivers*	*Fish River drivers*
Present day	Sc OF 1	Modelled present day current releases and use included.	
2013 - 2020	Sc OF 2	Metolong Dam, Tandjieskoppe, acid mine drainage (AMD) treated.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 3	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
	Sc OF 4	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.

Time frame	***Scenario***	***Orange River drivers***	***Fish River drivers***
		Optimised releases from dams.	
2020 - 2040	Sc OF 5	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Post 2040 - maximum foreseeable development	Sc OF 6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 7	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
	Sc OF 8	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (EFR O4 released), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation

Scenarios OF 4, OF 5 and OF 8 were not evaluated as these supply the REC EFR as specified at EFR O4 and, by implication, EFR O5. The river assessment therefore focused on Scenarios OF 2, OF 3, and OF 6 and OF 7. Scenarios OF 2 and OF 3 were sufficiently similar to be combined, as were Sc OF 6 and OF 7.

The evaluation of the scenarios indicated that Sc OF 2 and OF 3 maintained the PES, whereas Sc OF 6 and OF 7 lowered the EC to a D/E for the instream components and resulted in a D EcoStatus. The figure below illustrates the degree to which the ecological objectives are met. The tick and crosses indicate if ecological objectives are met or not and the colour coding indicates the degree to which the ecological objectives are met. Sc OF 2 and Sc OF 3 did not meet the ecological objectives but maintained the PES. Sc OF 6 and OF 7 did not meet the ecological objectives and the instream components would be in an unsustainable state.

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

Conclusions and recommendations

EcoClassification

The confidence in the data availability and information at both EFR sites were evaluated to determine the EcoClassification results. Overall, the confidence in the EcoClassification is moderate. Increased confidence will be achieved through monitoring and no other further work is recommended.

Environmental flow requirements

Confidence in hydrology cannot be improved without improved gauged data. A gauging weir at Sendelingsdrift is currently being constructed and this will result in future in an improved estimation of current day hydrology. The observed data from the gauge will also result in improved predictions on the duration and low flow discharge that will result in the estuary to close.

The biophysical response's confidence was high and no further work would be recommended to improve these requirements. The emphasis of further work should be to test and verify the estimated biophysical responses to a changed flow and potentially quality regime. If steps are taken to implement the EFR, then monitoring to determine whether the ecological objectives are being met is essential. It is therefore recommended that further work should focus on biophysical monitoring within an Adaptive Monitoring Framework. Monitoring recommendations are made in Technical Report 35.

Recommended scenario and further work

Based on the ecological consequences, Sc OF 6 and Sc OF 7 will, from an ecological perspective, not be recommended. Although the consequences associated with Sc OF 2 and OF 3 result in the PES being maintained, this still does not achieve the REC of a B/C. The scenarios which include the EFR, i.e., Sc OF 4, OF 5 and OF 8 will therefore be more acceptable from an ecological perspective.

The above results will be used to design a scenario that will attempt to minimise the impacts and maximise the benefits using the river EFR results and estuarine evaluations and considering the implications on yield. The aim of this scenario would be to achieve the REC at the estuary and the river and minimise the impacts on users. A final recommendation from this project will therefore be made in the summary report (Technical Report 37).

Contents

List of tables

List of figures

Abbreviations

AMD	*Acid mine drainage*
BBM	*Building Block Methodology*
DWA	*Department of Water Affairs*
DRM	*Desktop Reserve Model*
DRIFT	*Downstream Response to Imposed Flow Transformation*
EC	*Ecological category*
EcoClassification	*Ecological classification*
EcoStatus	*Ecological status*
EIS	*Ecological importance and sensitivity*
EcoStatus	*Ecological Status*
EWR	*Ecological water requirement*
EFR	*Environmental flow requirement*
FDI	*Flow dependant macro-invertebrates*
FROC	*Frequency of occurrence*
HFSR	*Habitat Flow Stressor Response*
IHI	*Index of Habitat Integrity*
IWRM	*Integrated water resources management*
IUCN	*International Union for Conservation of Nature*
LSR	*Large semi-rheophilic fish guild*
MCB	*Macro channel bank*
MRU	*Management resource unit*
MAR	*Mean annual runoff*
NASS2	*Namibian Scoring System version 2*
NWA	*National Water Act*
NWRS	*National Water Resources Classification System*
nMAR	*Natural mean annual runoff*
ORASECOM	*Orange-Senqu River Commission*
PAI	*Physico-chemical Driver Assessment Index*
PD	*Present day*
pMAR	*Present day mean annual runoff*
PES	*Present ecological state*
REC	*Recommended ecological category*
RC	*Reference condition*
RDM	*Resource Directed Measures*

Sc	*Scenario*
SAIAB	*South African Institute for Aquatic Biodiversity*
SANBI	*South African National Biodiversity Institute*
SASS5	*South African Scoring System version 5*
WMA	*Water Management Area*
Fish species abbreviations	
ASCL	*Austroglanis sclateri*
BAEN	*Labeobarbus aeneus*
BHOS	*Barbus hospes*
BKIM	*Labeobarbus kimberleyensis*
BPAU	*Barbus paludinosus*
BTRI	*Barbus trimaculatus*
CCAR	*Cyprinus carpio*
CGAR	*Clarias gariepinus*
LCAP	*Labeo capensis*
LUMB	*Labeo umbratus*
MBRE	*Mesobola brevianalis*
OMOS	*Oreochromis mossambicus*
PPHI	*Pseudocrenilabrus philander*
TSPA	*Tilapia sparrmanii*
Velocity Depth Classes: Fish	
SS	*Slow shallow fish habitat*
SD	*Slow deep fish habitat*
FS	*Fast shallow fish habitat*
FI	*Fast intermediate fish habitat*
FD	*Fast deep 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). The focus of this task within the above study and report is the lower Orange River only and the study area is further described below.

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

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

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

The study area is provided in Figure 1.

1.3 Objectives of the study

The objectives of this study for the lower Orange River were to:

- determine the present ecological state (PES) and describe alternative ecological states if relevant;
- set the EFR;
- address scenarios in terms of the existing and new dams in the lower Orange River (also providing input to release specifications).

1.4 Management resource units

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

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

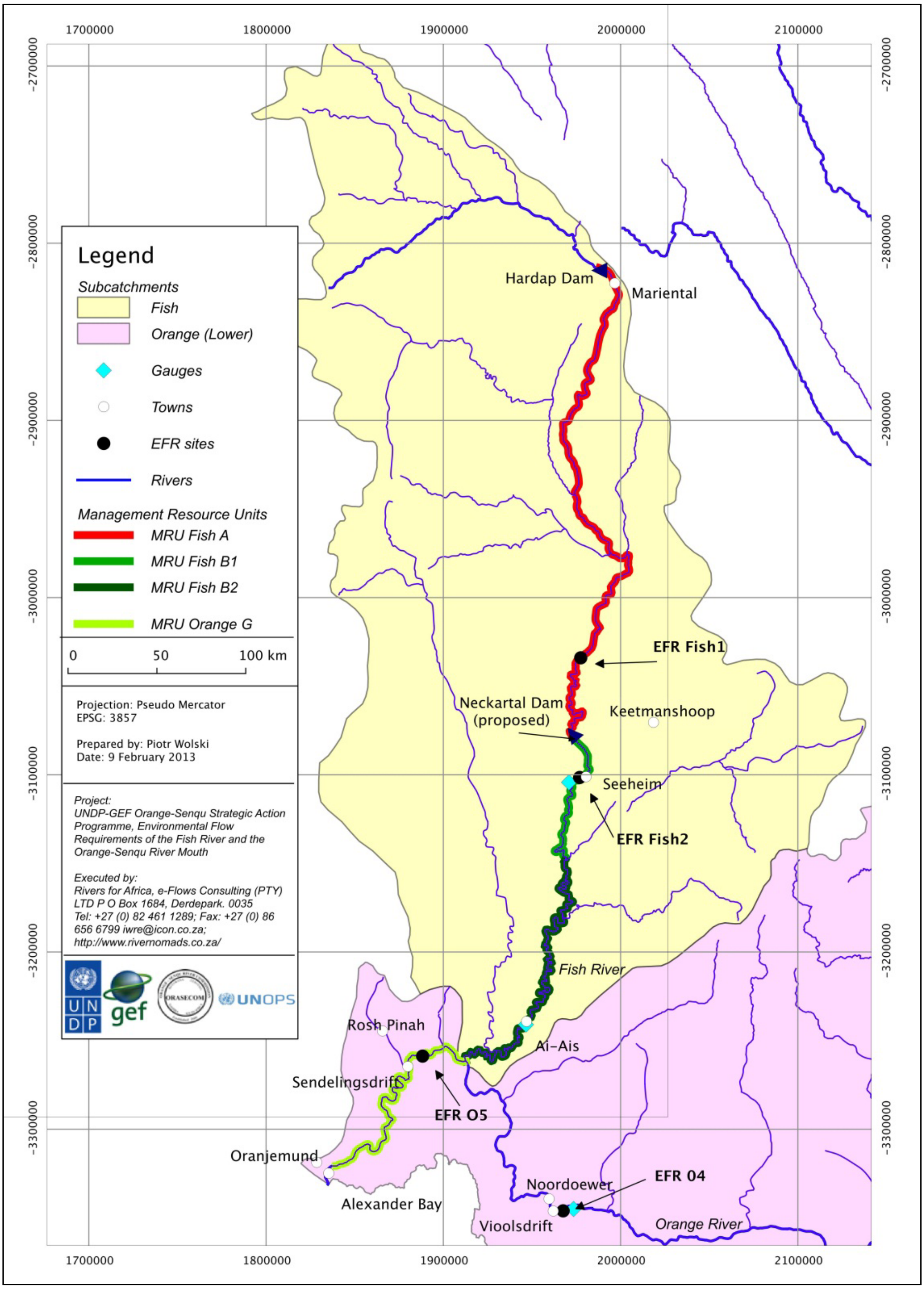


Figure 1. Study area

1.5 EFR sites

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

EFR O5 is situated in a reach which is a mixed alluvial and bedrock controlled system and consists of a weakly braided/multichannel reach (at moderate flows). Although the bar and channel bed consisted of large cobbles with isolated patches of silty fines (lee/slackwater deposits such as in the backwater channel), coarse sands and gravels were largely absent from the site. One area of exception was along a narrow strip immediately adjacent to active channel. This zone of sand and cobbles was probably a consequence of high level energy zone (cobble deposit) and high suspended load arising from the Orange (accounting for the sand) during floods (Figure 2).

Figure 2. EFR O5 located in MRU Orange G

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	
Physico-chemical variables	Confidence: 2
	Data used for the water quality assessment was from Department Water Affairs (DWA) gauging weirs D8H007Q01 at Brandkaros: 414 samples; 1971–2002, for reference condition (RC), and the following for the PES: • Orange River at Oppenheimer Bridge, Alexander Bay (D82L; EcoRegion II: 25.03). • D8H012Q01 (1995–2003; n = 263). • Data from diatom sample collection in 2012 (n = 1).
Geomorphology	Confidence: 3
	The aerial photographic record for the study area began in 1943 (limited coverage) and then full coverage was available on the 15/07/1964, 08/05/2005, 22/11/2006, 07/08/2009 and 14/05/2011. These data sources were used to assess changes in the reach morphology over the historical period. Records of observed and estimated catchment sediment loads were available from a number of sources. Field data were collected during June 2012.
Index of Habitat Integrity (IHI)	Confidence: 3.5
	• Personal ground-based observations, local knowledge and other specialist assessments undertaken as part of this study. • Google Earth (high resolution). The confidence in the data was high due to the detailed ground-based observations and the high quality of Google Earth imagery available for large sections of the study area.
Riparian vegetation	Confidence 3.5
	• Satellite images (Google Earth imagery, 14 May 2011) and historic aerial photos (1943, 15/7/1964, 8/5/2005, 22/11/2006, 7/8/2009 and 14/5/2011) of the respective reach. • EcoRegion class and associated information. • Geomorphic Zone classification. • Biomes and vegetation types of South Africa: (Rutherford and Westfall, 1986; van Wyk and van Wyk, 1997; Mucina and Rutherford, 2006). • Historical botanical descriptions of the area (Skead, compiler 2009). • South African Institute for Aquatic Biodiversity (SANBI, 2009): Plant of Southern Africa online database (based on several herbaria collections). • Data collected during field visit (15 June 2012).
Fish	Confidence: 3
	• Data collected during a single site survey conducted in June 2012. • Various previous fish surveys in region. • Atlas of Southern African Freshwater fishes (Scott et al., 2006). • South African Institute for Aquatic Biodiversity (SAIAB) database (2006). • Reference Fish Frequency of Occurrence Report (Kleynhans and Louw, 2007a)
Macro-invertebrates	Confidence: 2
	The main sources of information on macro-invertebrates in the Orange River that were used in this assessment comprised the following: • Nov 1995: Macro-invertebrates were collected at the confluence with the Boom River, 14.5

Components	
	km upstream of EFR O5, by Mark Chutter, as part of an assessment of environmental flow requirements of the middle and lower Orange River, undertaken by the Orange River Environmental Task Group (Chutter, 1996). • Jan 2004: Macro-invertebrates were collected 10 km downstream of the EFR O5 by Rob Palmer, as part of the Environmental Assessment of irrigation development at Sendelingsdrift (Palmer, 2004). • Nov 2010: Macro-invertebrates were collected at the confluence of the Boom River (OSAEH 28.5), 14.5 km upstream of EFR O5 by Marie Watson, as part of the Orange-Senqu baseline monitoring programme (ORASECOM, 2011b).
Diatoms	Confidence 4
	Diatoms were collected at four sites within this reach during the period 2005-2012 along with measured in situ water quality measurements. The diatom samples taken during 2005 could not be assessed as the valve count was not viable due to high flows experienced during sampling. Site specific diatom data were available from sample collection during 2008–2010 as well as data from sample collected during EFR site visit.
Riverine fauna	Confidence: 3
	• Atlas maps and field guide 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 (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 recommended ecological category (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

EC	*description*
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

1.8 Scenario descriptions

Scenarios consist of combinations of different drivers. The drivers were combined within the likely time-frame that these developments could take place so as to derive plausible development scenarios. The combination of drivers that result in scenarios are illustrated in Table 3. A flow regime for each scenario is produced at the EFR site and then evaluated to predict the consequences on the ecological state. This process forms part of the step 5 of the river EFR methodology.

Table 3. Time lines, scenario and driver combinations

Time frame	*Scenario*	*Orange River drivers*	*Fish River drivers*
Present day	Sc OF 1	Modelled present day current releases and use included.	
2013 - 2020	Sc OF 2	Metolong Dam, Tandjieskoppe, acid mine drainage (AMD) treated.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 3	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
	Sc OF 4	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
2020 - 2040	Sc OF 5	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Post 2040 - maximum foreseeable development	Sc OF 6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 7	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
	Sc OF 8	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (EFR O4 released), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation

1.9 Constraints and limitations

Physico-chemical variables: Due to the dearth of water quality data for this area, the same data record was used as for the upstream EFR site at Vioolsdrift (EFR O4). Diatom data collected during 2012 were also used and the Physico-chemical Driver Assessment Index (PAI) model adapted to allow for changes in land-use and flow pattern at the lower site.

Geomorphology: Although there are annotated maps from the early 1900's (from the Orange River Reconnaissance Study undertaken between 1906 and 1914), there are no data describing in detail the historical morphological condition of the lower Orange River prior to the widespread conversion of the upper catchment for agricultural activities. This has affected some of the confidence in the reference condition assessments; specifically related to sediment characteristics and loads and how the reduced sediment loads together with reduced flows have interacted to change the physical habitat conditions.

Macro-invertebrates: There was limited information on aquatic macro-invertebrates in the study area before impoundment and associated large-scale irrigation development. The only data available on macro-invertebrates in the lower Orange River before the construction of Vanderkloof and Gariep dams in the 1970s was a snap sample collected at Onseepkans in December 1960 (Agnew, 1965). Reference conditions were therefore based almost entirely on information collected after these rivers had been impounded. Considerable changes in the structure and function of the Orange River took place after impoundment, most notably significant increases in the abundance of pest blackflies (Palmer 1997; Palmer et al., 2007). The expected composition of macro-invertebrates used in this study therefore constitute what may be described as ‘best attainable’ rather than ‘reference’ state.

Fish: Very limited fish survey data have been undertaken in this area in the past, or data made available of the present fish assemblage and none available for reference (pre-disturbance) conditions. The setting of reference conditions is therefore based on limited available information and a single survey undertaken in the area as part of the current study. The natural indigenous fish species richness is also relatively low (12 fish species) with only semi-rheophilic and no species intolerant to water quality alteration present. Albeit natural, it reduces the sensitivity of the fish assemblage to detect and reflect changes in the ecosystem.

1.10 Report structure

The report structure is outlined below.

Chapter 1: Introduction

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

Chapter 2: EcoClassification: MRU Orange G - EFR O5

The EcoClassification results are provided for EFR O5. A comparison between EFR O4 and O5 results are provided to ensure the compatibility between recommendations made during a previous study and this study.

Chapter 3: EFR O5 (Sendelingsdrift) - Determination of stress indices
The stress indices for all physical and biological components at EFR O5 are provided.

Chapter 4: EFR O5 (Sendelingsdrift) - Determination of environmental flow requirements
This chapter provide results of different EFR scenarios with respect to low and high flows. Aspects covered in the chapter are component and integrated/stress curves, generating stress requirements, general approach to high flows and final results.

Chapter 5: Description of scenarios
This Chapter provides a summary of the drivers and the resulting scenarios applicable to the lower Orange River.

Chapter 6: Ecological consequences of operational scenarios
The results of the ecological consequences of the operational scenarios are provided for EFR O5.

Chapter 7: Conclusions and recommendations
A summary of the Ecological Consequences are summarised and integrated providing overall consequences. Recommendations are also provided.

Chapter 8: References

Appendix A: 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 O5 is provided in Appendix B.

Appendix B: Environmental flow requirements: Approach and method
Summarised methods are provided for the EFR scenario determination. A short summary of the Habitat Flow Stressor Response method, which was used to determine the low (base) flow Environmental Flow Requirements, is provided.

Appendix C: Environmental flow requirement – Flow duration tables
An EFR rule table as model outputs are provided for EFR O5. These tables provide the recommended EFR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). EFR rules are supplied for total flows as well as for low flows only.

2. EFR O5 (Sendelingsdrift): EcoClassification

A summary of the EcoClassification approach is provided in Appendix A, Technical Report 27. For more detailed specialist information, refer to Technical Report 30.

2.1 Ecological importance and sensitivity results

The EIS results for EFR O5 were **HIGH.** The highest scoring matrices are outlined below.

- Rare and endangered instream and riparian species: *Labeobarbus kimberleyensis* (BKIM - Largemouth yellowfish), *Simulium gariepense, Amaryllis paradisicola* (vulnerable), *Ectadium virgatum* (near threatened), Cape clawless otter (*Aonyx capensis*), pink-backed pelican (*Pelecanus rufescens*) and black stork (*Ciconia nigra*). *Acacia erioloba* (IUCN listed as declining) and *Euclea pseudobenus* (SANBI protected tree). The Lower Gariep Alluvial vegetation type is listed as endangered.
- Unique instream and riparian species: Some fish species are endemic to the Orange System (*Austroglanis sclateri* (ASCL), *Labeobarbus aeneus* (BAEN), and *Labeo capensis* (LCAP)). *Barbus trimaculatus* (BTRI) occurring in lower Orange is possibly unique population. *Barbus hospes* (BHOS) is endemic to lower Orange River and the presence of *Mesobola brevianalis* (MBRE) is an isolated population in Orange River. The Orange River white-eye (*Zosterops pallidus*) is restricted to catchment and six endemic plants are present (*Amaryllis paradisicola*, *Gymnosporia linearis* subsp. *lanceolata*, *Nymania capensis*, *Schotia afra* var. *afra* and *Tamarix usneoides*)
- The important migration corridor for various species and the site is situated in the /Ai-/Ais-Richtersveld Transfrontier Park.

2.2 Reference conditions

The reference conditions for the components in EFR O5 are summarised below in Table 4.

Table 4. EFR O5: Reference conditions

Component	
Hydrology	Confidence: 2
The natural mean annual runoff (nMAR) is 11373 Mm^3. It is possible that under extreme drought conditions, zero discharge occurred for short periods.	
Physico-chemical variables	Confidence: 2.5
Reference conditions were set based on data from Orange River @ Korridor Brandkaros (D82L; EcoRegion II: 25.03) D8H007Q01 (1980; n=35). See Technical Report 30 for RC values on the PES table for water quality. Note that the data record was inadequate for a proper assessment of water quality under a natural state.	

Component

Geomorphology — Confidence: 3

Based on the Orange River Reconnaissance Study undertaken between 1906 and 1914, comments on the sediment distribution through this area noted a variety of sedimentary deposits, from shingly beds (near Vioolsdrift) to further downstream where the Orange River is described as having a very sandy bed. Closer to EFR O5 (around the Richtersveld) the bed is noted as "very rocky" with "rough and stony" banks. Downstream of EFR O5 it was noted that the banks were well-wooded in places "with mimosa and bastard ebony", and general notes indicated that an "abundance of firewood (was) to be had all along the Orange River". Close to the mouth (along the wetland estuary) "great quantities of debris of trees etc. lie on banks". Historical aerial photographs indicate that the channel planform of the river channel is largely unchanged, with the notes the Orange River Reconnaissance Study confirming that a well-wooded riparian zone with a variety of bed sediment types was present. Sediment loads would have been higher than the present day.

Riparian vegetation — Confidence 3.5

The assessed area at EFR O5 is contained within Lower Gariep Alluvial Vegetation. This vegetation type is poorly protected and has 50.3% remaining. Consequently it has a conservation status of "Endangered". Alluvial terraces and banks are dominated by woody riparian thickets (mainly *Acacia karoo, Ziziphus mucronata, Searsia pendulina*) or stands of *Tamarix usneoides* or reeds (*Phragmites australis*). Cobble or boulder features are characterised by a mix of woody species (*T. usneoides, Gomphostigma virgatum*) and sedges (*Cyperus longus,* and *C. marginatus*). Frequently flooded alluvia are open or grassed (mainly *Cynodon dactylon*) and *Salix mucronata* is also common on frequently inundated alluvia.

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 vegetated areas. Vegetation, similarly, should be a mix of woody (*G. virgatum*, *S. mucronata* subsp. *mucronata*) and non-woody (*P. australis*, *C. marginatus*, and *C. longus*) vegetation.

Lower zone: Expect the same as the marginal zone, with the addition of *T. usneoides*.

Upper zone: Terraces should be well vegetated with small percentage of open areas. Vegetation will be a mix of reed beds (*P. australis*) or woody thickets (mainly *A. karoo*, *Z. mucronata*, and *S. pendulina*).

Upper zone macro channel bank (MCB): Banks should be well vegetated and dominated by woody riparian thickets, with dominant species as outlined above. Also expect *Euclea pseudobenus*.

Floodplain: Similar to bank species with some terrestrial woody and shrub species.

Fish — Confidence: 3

Based on the available fish distribution data and expected habitat composition of the river reach of site EFR O5, twelve indigenous fish species (ASCL, BAEN, BKIM, BHOS, BTRI, MBRE, LCAP, *Barbus paludinosus* (BPAU), *Labeo umbratus* (LUMB), *Clarias gariepinus* (CGAR), *Pseudocrenilabrus philander* (PPHI) and *Tilapia sparrmanii* (TSPA)) have a high to definite probability of occurrence under reference conditions in this reach. The expected habitat composition at the site under reference conditions met the requirements of all these fish species. The expected spatial frequency of occurrence (FROC) of most species was relatively high, with the exceptions being ASCL and LUMB which is expected to have been scarce even under natural conditions.

Macro-invertebrates — Confidence: 3

A total of 21 SASS5[1]/NASS2[2] taxa was recorded during the field survey in June 2012 compared to 30 expected under natural conditions. Taxa expected but not recorded included Simuliidae, Tricorythidae, Corbiculidae, Leptoceridae, Gerridae and Veliidae. The suitability of instream habitats was good (61%), but macro-invertebrate populations were generally very low. The life span of most adults was moderate (3 to 6 months), and only one taxon with a long adult life span was recorded. Six of the 21 taxa were air-breathers, indicating well-oxygenated conditions. The most common functional feeding groups were collector/gatherers and predators. Filterers were noticeably rare, and comprised low populations of sponges and hydropsychid caddisflies. The low abundance of filterers was attributed to elevated turbidity and scouring effects of suspended fines associated with recent

Component		
high flows from the Fish River. Most taxa had a preference for slow to moderate current speeds, and only one taxon had a preference for fast current speeds. Four categories of habitat preferences were represented, and the highest number of taxa had a preference for cobble habitats. No taxa with a preference for warmer water were recorded. The diversity of macro-invertebrates sensitive to water quality deterioration was high, with six sensitive taxa recorded, including heptageniid and leptophlebiid mayflies. No alien macro-invertebrates were recorded, but they have been recorded in the reach as a whole.		
Riverine fauna		Confidence: 2
Habitats available: Extensive sand banks, large stretches of exposed shorelines, few patches of reed beds and reed islands, very little grassy edges, moderate continuous riparian corridor, good open water in the form of deep pools and backwaters. A total of 37 riverine animal species are expected in the reach (two mammals, 33 birds and two frogs); four of these species are Special Species (endemic or Red Data). The following habitats would have been expected under reference conditions: • Sluggish in-stream channels and pools habitat (10 species). • Backwater pool habitats (5 species). • Exposed shoreline - shallow edge habitats (14 species). • Floodplain habitats (one species). • Reed bed habitats (5 species). • Grassy bank habitats (one species). • Wooded bank habitats (one species). The diversity of species are currently similar to that was found during reference conditions (i.e., no species lost in the system), but abundances of the more sensitive species are expected. It is expected that these species will react to changes in food and habitat availability due to lack of fluxes in flows and a decrease in riparian vegetation		

1 South African Scoring System version 5 2 Namibian Scoring System version 2

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 5.

Table 5. EFR O5: Present Ecological State

Component		
Hydrology		Confidence: 3
The present day mean annual runoff (pMAR) is 4,641 Mm^3 (41% of the nMAR). Small floods have disappeared, moderate and large floods have significantly decreased and wet season base flows as well. Due to releases for downstream demands, discharge is often higher during drought periods		
Physico-chemical variables	PES: C	Confidence 2.5
Main water quality issues in this section are elevated nutrient loads, elevations in salts and some elevated metals. All issues are exacerbated by fluctuating flows. There have also been reports of health incidents (blisters and skin rashes after rafting in the Orange River) and fish kills in the Richtersveld (De Hoop camp and Grasdrift respectively) during April and May 2008 (Bezuidenhout, SANParks, pers. comm., November 2010). Causes are unknown although fish kills might be related to seasonal temperature changes and human skin conditions due to toxic cyanobacteria or *Schistosome cercarial dermatitis* (Palmer, Nepid Consultants, pers. comm., November 2010). Fish kills were also seen in the Fish River Canyon during 2012.		

Component

Geomorphology — PES B/C — Confidence: 3

This relatively high PES score is due to the resistant nature of the channel form in this reach, as well as to the ameliorating impacts on flow (especially floods) and sediment delivery afforded by the upstream Fish River tributary. The EFR site is within a multichannel anastomosing reach, with backwaters created by seasonal and ephemeral secondary and flood channels. Reduced floods (especially small and moderate events) reduce the potential for scour and the maintenance of channels and pools. The secondary channels are activated by high flows and floods; with very infrequent large floods scouring the channel bed, but this occurs less often under present day condition due to the reduced floods. Sediment delivery to the lower Orange has been reduced relative to natural conditions (Rooseboom, 1992, Bremmer et al, 1990, Basson, 2011), but the gross river morphology at the lower Orange EWR river (and estuary) remains relatively similar to the reference condition. This apparent insensitivity to sediment inputs can be attributed to the simultaneous reduction of floods. There is less sediment flowing through the lower Orange to create and maintain the alluvial beds, banks and bars, but there is a concomitant enormous reduction of floods, such that the reduced delivery of sediment has, to a large extent, been offset by the reduced frequency of erosive events and there is little resultant net change in the morphology.

IHI Instream PES: C — Confidence 2.4 — IHI Riparian PES: C — Confidence 4.2

Instream: The Orange River is impacted mainly by altered flow, specifically reduced flooding regimes due to dams in the upper reaches of the Orange river as well as irrigation and mining activities. The reduced flood impacts have led to bed and bank modification. Salinity and nutrients are elevated due to associated irrigation return flows.

Riparian: The loss of moderate and large floods impacts has an impact while anthropogenic activities (mining activities, roads, camp site, and goats) results in bank modification and loss of vegetation cover and continuity.

Riparian vegetation — PES: B/C — Confidence: 3.7

Marginal zone: Mostly open bedrock with some alluvium. *P. australis* (common and localised), *S. mucronata*, *G. virgatum* (common and widespread) and *C. longus* (common localised) are dominants. The marginal zone, when considered in isolation, is an A/B category, so is close to reference condition, with some reduction in non-woody cover and woody recruitment due to livestock disturbance and grazing.

Lower zone: Similar to marginal zone with the addition of *S. mucronata* in large numbers (especially recruiting saplings) and adults where alluvial bars have formed. The lower zone, when considered in isolation, is a B category, with some reduction in non-woody cover and woody recruitment due to livestock disturbance and browsing and grazing.

Upper zone: Sparse, mostly cobble beds with some back channels where fine alluvia have collected. Back channels support wetland and aquatic species such as *C. longus*, *C. marginatus*, *Bolboschoenus glaucus* and *Potamogeton pectinatus* and *P. schweinfurthii* respectively. The upper zone, when considered in isolation, is a B/C category, with some reduction in non-woody cover and woody recruitment due to livestock disturbance and grazing. A small proportion of the woody vegetation is alien (*Prosopis glandulosa*) which changes the species composition and reduces indigenous woody vegetation cover.

Upper zone MCB: Alluvial and dominated by dense woody vegetation. Mostly *A. karoo*, *Z. mucronata*, *S. pendulina* and *E. pseudobenus*. Some *P. glandulosa* recruitment is evident. The MCB, when considered in isolation, is a C category, with some reduction in non-woody cover and woody recruitment due to livestock disturbance and grazing. A small proportion of the woody vegetation is alien (*P. glandulosa*) which changes the species composition and reduces indigenous woody vegetation cover.

Floodplain: Alluvial, left bank only - continuation of MCB species with the addition of terrestrial species. *Lycium* spp. common. The floodplain, when considered in isolation, is a B/C category, with some reduction in non-woody cover and woody recruitment due to livestock disturbance and grazing and browsing, and some roads. A small proportion of the woody vegetation is alien (*P. glandulosa*) which changes the species composition and reduces indigenous woody vegetation cover.

Component		
Fish	PES: B/C	Confidence: 3
	Eleven of the expected twelve indigenous fish species were sampled in the reach during the June 2012 survey, together with one alien/introduced species (*Oreochromis mossambicus* (OMOS)). The one species not sampled during the survey, namely LUMB, is still expected to occur in this reach in very low FROC. The abundance and spatial FROC of the indigenous species sampled were generally high for most species (LCAP > BAEN > MBRE > BPAU > BHOS), while ASCL, BKIM, CGAR, PPHI and TSPA were relatively scarce during the survey. Based on all considerations of impacts and available fish information, it was estimated that the present FROC of many species were comparable to reference condition, while a few had slightly reduced FROC (BKIM, BPAU, BTRI, LUMB, PPHI and TSPA). The primary impacts include modified flow regimes as well as water quality deterioration. Overall the fish assemblage was therefore estimated to currently still be in a largely natural to slightly modified state.	
Macro-invertebrates	PES: B/C	Confidence: 3
	A total of 21 SASS5 taxa was recorded compared to 30 expected. Taxa expected but not recorded included Simuliidae, Tricorythidae, Corbiculidae, Leptoceridae, Gerridae and Veliidae. The suitability of instream habitats was good (61%), but macro-invertebrate populations were generally very low. The life span of most adults was moderate (three to six months), and only one taxon with a long adult life span was recorded. Six of the 21 NASS2 taxa were air-breathers, indicating well-oxygenated conditions. The most common functional feeding groups were collector/gatherers and predators. Filterers were noticeably rare, and comprised low populations of sponges and hydropsychid caddisflies. Most taxa had a preference for slow to moderate current speeds, and only one taxon had a preference for fast current speeds. Four categories of habitat preferences were represented, and the highest number of taxa was had a preference for cobble habitats. No taxa with a preference for warmer water were recorded. The diversity of macro-invertebrates sensitive to water quality deterioration was high, with six sensitive taxa recorded, including hepatageniid and leptophlebiid mayflies. 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
	Habitats that have changed from reference conditions are: • Marginal biotopes: The presence of in-stream dams results in the loss of moderate and large floods, as well a decrease in flow variation. This condition impacts adversely on the variability in riverine habitats, especially that of floodplain and marginal biotopes. • Water quality: Poor water quality impacts adversely on macro-invertebrate and fish abundance, therefore also influencing the abundance of riverine fauna feeding on these species. • Changing riparian structure: Grazing pressure (goats and cattle) and elevated flows (dam releases) are impacting on riparian woody vegetation, changing riparian structure, ultimately influencing the nesting and sheltering habitat of riverine fauna adversely. The long term impact of reduced habitat diversity in the marginal biotopes (inundated vegetation, marginal overhanging vegetation, and temporary flooded areas), will impact on fish nursery areas and small fish species abundance, subsequently adversely influencing smaller piscivorous animal species. The added impact of poor water quality, also influence the abundance of macro-invertebrate and fish. The change in riparian structure will impact the nesting habitats of larger bird species, and the sheltering habitat of smaller fauna species.	

2.3.1 Causes and sources

The reasons for changes from reference conditions must be identified and understood. These are referred to as causes and sources (EPA, 2012). The causes and sources for the PES are summarised in Table 6.

Table 6. EFR O5: PES causes and sources

Component	Causes	Sources
Hydrology		Confidence 5
	Decrease in flow regime.	Upstream dams and irrigation.
Physico-chemical variables	PES: C	Confidence 3
	Elevated salts and nutrients.	Irrigation return flows from upstream farming activities. (Non-flow-related)
	Some evidence of metal toxicity.	Mining activities in the area could be a potential source. Other expected toxicants include fertilizers etc. from upstream farming activities. (Non-flow-related)
Geomorphology	PES B/ C	Confidence 5
	Small and medium floods have been heavily reduced, with even floods up to the 1:10 year size having been lost/attenuated in the system. This decreases the ability of the river to flush out accumulating sediment.	Large dams in the catchment and these have led to some reduction in sediment and large reductions in floods. (Flow-related)
Riparian vegetation	PES B/C	Confidence 3
	Reduced flooding and elevated dry season base flows.	Dams and abstraction in the catchment. (Flow-related)
	Low occurrence of perennial aliens (*Prosopis glandulosa*) and ruderal weeds.	Reduced flooding and elevated dry season base flows. (Flow-related)
	Overgrazing.	Livestock (mainly goats). (Non-flow-related)
Fish	PES B/C	Confidence 3.5
	Erosion, flow modification and vegetation removal leading to decreased overhanging vegetation as cover (especially for BTRI) and marginal vegetation as feeding and breeding habitat (especially for BPAU).	Upstream dams, overgrazing by livestock, agricultural activities. (Flow-related)
	Increased nutrients leading to excessive algal growth on substrates resulting in decreased substrate quality as cover and habitat for spawning, feeding etc.	Irrigated agriculture and livestock farming. (Non-flow-related)
	Flow modification and increased algal growth favours some species (such as LCAP) and causes ecosystem imbalances (domination by any species result in a shift in the natural equilibrium).	Upstream dams, return flows, irrigated agriculture and livestock farming. (Flow-related and Non-flow-related)

Component	***Causes***	***Sources***
	Flow modification (increased dry season low flows) alters the occurrence of slow habitats (SD and SS) impacting on species with a preference for slow habitat and water column for cover (especially MBRE). Absence or lag effect of spring flushes reduce spawning success - decreased FROC of many species.	Upstream dams. (Flow-related)
	Presence of toxics, altered hydrology and trapping of silt decreased water quality which affects species with requirement for unmodified water quality.	Agriculture, dams and waste water treatment works. (Flow-related and Non-Flow-related)
	Presence of alien predatory species - competition with and predation on indigenous species.	OMOS and possibly others such as *Cyprinus carpio* (CCAR). (Non-Flow-related)
	Increased turbidity and disturbed bottom substrates (impact on LUMB breeding habitats).	Presence of alien CCAR. (Non-Flow-related)
	Reduced migration (breeding, feeding, and dispersal).	Some small dams/weirs. (Non-Flow-related)
Macro-invertebrates	PES B/C	Confidence 3.5
	A-seasonal releases.	Operation of Vanderkloof Dam. (Flow-related)
	Increased woody snags.	Reduced high flows (Flow-related)
	Increased cyanobacteria	Irrigated agriculture; impoundments. (Non-flow-related)
	Increased nutrients.	Irrigated agriculture; livestock. (Non-flow-related)
	Increased salinity.	Irrigated agriculture. (Non-flow-related)
	Competition from alien species.	*Physa acuta*; and *Lymnaea columella*. (Non-flow-related)
Riverine fauna	PES B	Confidence 3
	Lack in flow variation.	Flow regulation by dams. (Flow-related)
	Loss of habitat diversity.	Constant flows due to flow regulation. (Flow-related)
	Deterioration in water quality.	Irrigation return flows, dams. (Flow-related)
	Deteriorated riparian zone structure.	Browsing by goats and elevated low flows; dams. (Non-flow-related)

The major issues that have caused the change from reference conditions are flow-related impacts that included a general increase in low flows and a reduction in small and medium floods caused by the presence of impoundments (i.e. Vanderkloof Dam and other dams in the catchment). Dry season base flows were elevated, especially in the drought periods. Wet season base flows were reduced. Nutrients and salinity were elevated due to the irrigation return flows.

Non-flow-related impacts also impacted on the reach as fairly high grazing and browsing pressure (mainly goats) existed. Alien vegetation, fish and macro-invertebrate species were also present.

2.3.2 Present ecological state EcoStatus

The ecological state (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, the following is required:

- reinstatement of droughts (i.e., lower flows than present during the drought season);
- improved (higher) wet season base flows.

The two points above will not improve water quality which was a concern. However, the deterioration in water quality (specifically salts and nutrients) during the drought season was only for approximately 20% of the time in the dry season. Geomorphology could not improve without reinstating floods.

Each component was adjusted to indicate which metrics would react to the improved scenario. The rule based models are available electronically and summarised in Table 7.

Table 7. EFR O5: Actions required achieving the REC

Component		
Physico-chemical variables	PES: C; REC: C	Confidence 2
The reinstating of droughts, i.e. a reduction in flows about 20% of the time in the dry season, will result in an elevation in nutrients and salts, and an increase in toxics in the system due to lower dilution capacity. However, it seems unlikely that water quality will move out of a C category. Note that only the institution of flushing flows can improve water quality, which is not practically possible at this site with the current infrastructure.		
Geomorphology	PES: B/C; REC: B	Confidence: 3.5
The proposed decrease in dry season low flows and increase in wet season low flows will not have a significant impact on the geomorphology but does change in into a B by 0.4%. The major causes of the current condition are the reduced moderate floods, and these cannot be practicably restored.		
Riparian vegetation	PES: B/C; REC: B	Confidence: 3
Reducing dry season low flows and increasing wet season low flows will improve the degree of seasonality. The response by vegetation is likely to be small, and difficult to quantify, but the change will reduce the risk of deterioration of the riparian vegetation component. A greater portion of the marginal zone vegetation will be inundated during the growing season and this will afford protection from grazing (*C. longus, Cynodon dactylon*) / browsing (*G. virgatum*) from livestock during peak growth and reproduction.		
Fish	PES: B/C; REC: B	Confidence: 3
Increased base flows during the wet season will not make a notable improvement on the fish assemblage, since most of the species with a preference for fast flows and fast flow requirements during the wet season (semi-rheophilic) is presently already in a good condition (high FROC). The species most negatively impacted under present condition is the species with a preference for slow habitats (slow shallow (SS) and slow deep (SD)) and preference for vegetated habitats. Vegetation as		

Component		
cover for fish is currently in a good condition and recommended changes to achieve the REC is not expected to improve the vegetation notably to improve the relevant fish species. It is estimated that the unnatural high flows during the dry season under present condition may be the cause for loss of slow habitats and thus the impact on the relevant species. By reducing the low flows in the dry season, slow habitat suitability will be improved an expected improvement in the FROC of species such as BTRI, PPHI and TSPA are expected, which should improve the overall status of the fish assemblage in an improved status B.		
Macro-invertebrates	PES: B/C; REC: B	Confidence: 3
Lower low flows during the dry season and a wider seasonal range of low flows are expected to increase habitat variability and thereby increase biodiversity, and also reduce the incidence of outbreaks of the pest blackfly *Simulium chutteri*. Higher wet season low flows are expected to benefit taxa sensitive to water quality deterioration, such as Hydropsychidae (>2 spp.), Perlidae and Tricorythidae. The total number of SASS5 taxa is expected to increase to 24. The overall SASS5 score is expected to be 158, and the average score per taxon was 6.6.		

2.5 Summary of EcoClassification results

The EcoClassification results are summarised in Table 8. The colours used are standard colours associated with EcoClassification.

Table 8. EFR O5: Summary of EcoClassification results

Components	***PES***	***REC***
IHI hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B
Fish	B/C	B
Macro-invertebrates	B/C	B
Instream	**B/C**	**B**
Riparian vegetation	B/C	B
Riverine fauna	B	B
EcoStatus	**B/C**	**B**
EIS	HIGH	

In summary, higher low flows in the wet season and lower low flows during the dry season, specifically dryer years and drought periods will achieve the REC.

2.6 Links to EFR O4: Present ecological state and recommended ecological category

To ensure that these recommendations are compatible to recommendations made at upstream sites, the EcoClassification results of EFR O4 (downstream of Vioolsdrift gauge) undertaken as part of the GIZ study during 2010 (Louw and Koekemoer (Eds), 2010) was compared to EFR O5.

At EFR O4, the PES was a C, the importance was HIGH and the REC was set to improve the PES. To achieve the REC, the following was recommended:

- In terms of discharge, higher low flows in summer are required.
- Droughts need to be reinstalled, i.e. lower flows than present day flows from the 80th percentile to 100%.

The objectives to improve EFR O3 (downstream of Augrabies Falls) are similar. The objectives to achieve the REC are therefore similar for all the sites with the main emphasis being the improved wet season base flows and to reinstate droughts during the dry season.

3. EFR O5 (Sendelingsdrift): Determination of stress indices

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

3.1 Indicator species or group

3.1.1 Large semi-rheophilic fish species

As a result of the absence of any true rheophilic fish species in this system, the large semi-rheophilic (LSR) flow guild was selected as indicator group for setting flows with *Labeobarbus kimberleyensis* and *Labeobarbus aeneus* used as indicator species of this guild.

The preferred optimal habitat of *Labeobarbus kimberleyensis* (BKIM) is slow deep (SD), fast intermediate (FI) and fast deep (FD) with suitable cover provided by substrate and water column depth. The spawning habitat requirement of this species is FD and fast shallow (FS) habitats with good quality substrate (gravel and other suitable rocky habitats), flowing water, well oxygenated and low sediments loads. The species requires substrate (gravel/cobbles) in flowing water (FS and FI) to spawn. Flows should last long enough for the embryos to develop and hatch out. The incubation period for BKIM is two to three days and larvae become mobile after a further three to four days. Larvae require SD habitats with substrate, while juveniles prefer FI and SD with substrate.

Labeobarbus aeneus (BAEN) has a maximum size of approximately 50 cm. Its optimal preferred general habitat is SD, FS and FD with suitable cover provided by substrate and water column depth. The spawning habitat requirement of this species is FD and FS habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require FS habitats with substrates, with flows lasting long enough for the eggs to hatch (three to eight days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and slow shallow (SS) with substrate, and seek refuge in SD at night.

Refer to Table 9 for more detail regarding the flow requirements of these species during different life stages.

Table 9. Summarised habitat requirements for different life stage of the LSR indicator group

BAEN life stages	***Description***
Spawning	FS, FI over substrate. Spring to midsummer (September to January). Fast (>0.3 m/s) with substrate (gravel and cobbles). Flowing water, well oxygenated and low sediments loads. BAEN breeds from spring through to mid-summer after the first substantial rains of the season.
Egg & Embryo development	FS with substrate (gravel/cobbles). Flows to last long enough for eggs to hatch and embryos to develop. Sudden pulse after spawning may cause many of the eggs to be washed out of the spawning beds and die in the deeper less oxygenated pools and also be smothered by silt. Also if the flow subsides it could result in higher temperatures and lower oxygen thus killing the developing embryos or leaving them stranded. The fertilised eggs of BAEN incubate for 3 to 8 days at 18–21.5°C, where after the embryos remain in the gravel for a further period.
Larvae	SD with substrate (October to February). Cover, flow, oxygen and low silt loads. They require suitable flows to move them away from the spawning beds to the nursery areas which are usually warmer shallow backwaters. If the backwaters are not there due to too high or too low flows the larval fish will die out as this is a very critical stage where they have to start eating. Larvae are initially inactive and sink to the bottom, not becoming mobile until 4 to 6 days after hatching. At this stage, they begin feeding on microscopic organisms.
Juveniles	FS, FI and SS with substrates and SD at night are required.
Adults	SD, FD, FI and FS with substrates and water column are required.
BKIM life stages	***Description***
Spawning	FS and FD with substrates (gravel, cobbles) flowing water, well oxygenated and low sediments loads. The breeding season extends from mid to late summer. The species requires gravel beds in flowing water to spawn.
Egg & Embryo development	FS and FI with substrate (gravel/cobbles). Flows to last long enough for the embryos to develop and hatch out. The incubation period is 2 to 3 days and larvae become mobile after a further 3 to 4 days at 23–25°C.
Larvae	SD with substrate is required.
Juveniles	FI and SD with substrates are required.
Adults	SD, FD and FI with substrates and water column are required.

3.1.2 *Macro-invertebrate indicator group*

Amphipsyche scottae is a flow-dependent hydropsychid caddisfly that is common in the middle and lower Orange River. This species was chosen as the key indicator for defining low flows because larvae have a strong preference for fast current speeds in deep water, and because it is sensitive to water quality deterioration. Furthermore the larvae are large and easily recognised from the head shape and pattern (Scott, 1983). This species has a preference for fast current speeds (0.6 to 0.8 m/s), but has been recorded at current speeds ranging between 0.3 and >2 m/s (Palmer, 1996). Members of the same genus have been recorded in areas with fast current speeds in the Cunene River (de Moor et al. 2000) and the Volta River (Petr, 1970). The larvae also have a strong preference for deeper water (Chutter, 1969). The larvae spin nets that are used to capture drifting invertebrates, and are important predators of blackflies (Chutter, 1968). Several studies have noted higher larval population densities during summer months and lower densities in winter (Chutter, 1969; de Moor, 1986; Palmer, 1996). The survival strategy of this species during drought periods is unknown, but likely options include diapausing eggs, hyporheic larvae and/or adults resting in shelters (de Moor, pers. comm., 2012).

3.2 Stress flow index

A stress flow index is generated for every component, and describes the progressive consequences to the flow dependent biota of flow reduction. The stress flow index is generated in terms of habitat response and biotic response and is discussed below.

3.2.1 Habitat response

The habitat flow index is described separately for fish and macro-invertebrates as an instantaneous response of habitat to flow in terms of a 0–10 index relevant for the specific site where:

- 0 – optimum habitat (Maximum base flow under natural conditions);
- 10 – zero discharge (Note: Surface water in pools will still be present).

The instantaneous response of fish and macro-invertebrate breeding habitat, abundance, cover, connectivity, and water quality are derived by considering (amongst others) rated velocity depth classes (in terms of abundance) to flow changes based on a 0 (velocity depth class absent) - 5 (velocity depth class very abundant).

3.2.2 Biota response

The biota stress index is the instantaneous response of biota to change in habitat (and therefore flow), based on a scale of 0 – 10 where:

- 0 = optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).
- 10 = zero discharge. The biota response will depend on the indicator groups present, i.e. rheophilics will have left whereas semi-rheophilics will still be present and survive.

The instantaneous response of fish and invertebrate breeding habitat, abundance, cover, connectivity, and water quality are derived by considering (amongst others) rated velocity depth classes (in terms of abundance) to flow changes based on a 0 (velocity depth class absent) – 5 (velocity depth class very abundant). Fish and macro-invertebrate habitat is then rated separately according to a 0 (no habitat) – 5 (optimum occurrence of habitat).

3.2.3 Integrated stress curve

The integrated stress curve represents the highest stress for either fish or macro-invertebrates indicators at a specific flow. The stress index is provided in Figure 3 and Table 10.

In this specific case, the fish stress index represents the integrated stress range 6 – 0. Therefore the blue curve (representing the fish stress index) is lying 'beneath' the integrated stress curve (black). The macro-invertebrate stress index represents the integrated stress range 10 – 7, therefore the red curve (representing the macro-invertebrate/invert stress index) is lying 'beneath' the integrated stress curve (black) (Figure 3).

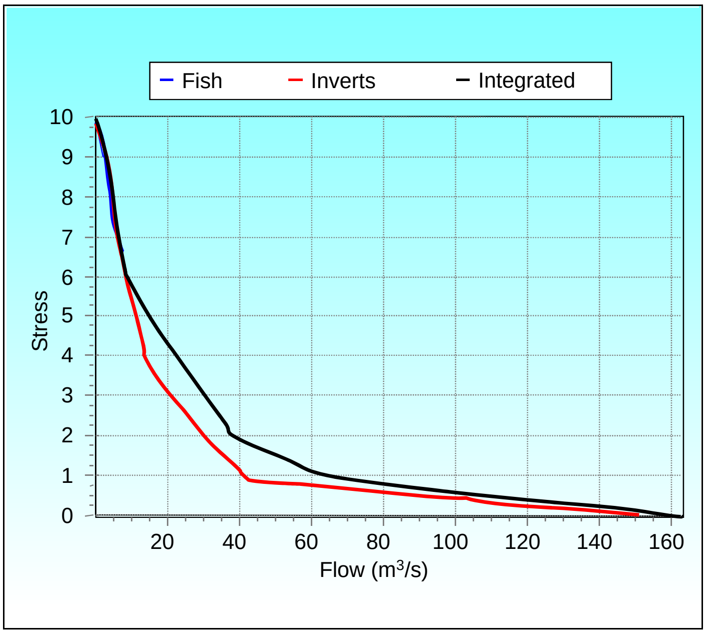


Figure 3. EFR O5: Species stress discharges used to determine biotic stress

Table 10. EFR O5: Species stress discharges used to determine biotic stress

Stress	***Fish flow (m³/s)***	***Inverts flow (m³/s)***	***Integrated flow (m³/s)***
0	**165**	165	**165**
1	**65**	43	**65**
2	**38.6**	31	**38.6**
3	**30.5**	21	**30.5**
4	**22.5**	14	**22.5**
5	**15**	11	**15**
6	**8.8**	8.4	**8.8**
7	5.7	**6.3**	**6.3**
8	4	**4.7**	**4.7**
9	2.4	**2.6**	**2.6**
10	0	0	0

Table 11 provides the summarised habitat and/or biotic response for the integrated stresses.

Table 11. EFR O5: Integrated stress and summarised habitat/biotic responses

Integrated stress	***Flow (m³/s)***	***Habitat and/or biotic responses***
0	165	Optimal habitat (compared to reference conditions).
1	65	The habitat suitability for indicator fish species (and all other species) will still be very good and close to optimal, with an estimated 37% loss of FS, FI and FD habitats. A slight loss in abundance of indicator taxa can be expected.
2	38.6	The habitat suitability for indicator fish guild will still be very good at this flow, although the abundance of fast habitats would have been reduced by almost half of that expected under natural conditions.
3	30.5	Habitat suitability for the indicator fish guild will still be good at these flows, but fast habitats, and especially FD, would have been reduced by more than half of that expected under natural conditions. It can be expected that all aspects considered (spawning and nursery habitats, abundance, cover, connectivity and water quality) of the indicator guild would have been impacted/reduced to some extent at these flows.
4	22.5	Although the overall habitat suitability for the indicator fish guild will still be moderate, the fast habitats would have been reduced by approximately 60% of what can be expected under natural conditions, with an expected overall notable deterioration in the condition of the fish assemblage.
5	15	Spawning habitat suitability becomes low, while the rest of the criteria are still expected to be moderate for the indicator fish guild. The fish assemblage can overall be expected to be exposed to notable stress at this flow.
6	8.8	The habitat suitabilities of most metrics considered for the indicator fish guild are low at this flow, and the indicator guild can be expected to reflect notable stress levels. Fast habitats would have been reduced by approximately 75%, and the reduction of FD habitats is especially of concern at this flow.
7	6.3	Wetted perimeter reduced to 35% compared to zero stress baseline, while absolute availability of very fast flow habitat over course substrate reduced to 18% of base

Integrated stress	***Flow (m^3/s)***	***Habitat and/or biotic responses***
		flow conditions (zero stress). Average depth is 0.28 m, which is on the lower boundary for *A. scottae*. Low turbidity, slow current speeds (0.42 m/s) and limited dilution leads to excessive growth of benthic algae, which limits suitability of instream habitats. These conditions are marginal for the indicator taxon, *A. scottae*, but suitable for filter-feeding midge *Rheotanytarsus fuscus*, the sponge *Ephydatia fluviatilis* and the blackflies *Simulium adersi* and *S. ruficorne*.
8	4.7	Wetted perimeter reduced to 32% compared to zero stress baseline, while absolute availability of very fast flow habitat is reduced to 8% of base flow conditions (zero stress). Some critical habitat for the key indicator *A. scottae* larvae is potentially present, with average current speed still sufficient for food capture (0.38 m/s). However, water quality deterioration and excessive growth of benthic algae is expected at such flows, so critical habitat is effectively absent.
9	2.6	Average current speed very low (0.33 m/s). Some critical habitat is potentially present, but excessive growth of benthic algae is expected at such flows, so critical habitat is effectively absent. Average depth unsuitable for *A. scottae* larvae.
10	0	No flow. Macro-invertebrates diapause phase triggered. Habitat not suitable for any of the criteria assessed (spawning habitat, nursery habitat, and abundance, cover, connectivity and water quality) for the large-semi-rheophilic fish guild.

4. EFR O5 (Sendelingsdrift): Determination of flow requirements

4.1 EcoClassification summary of EFR O5

EIS: HIGH
Highest scoring metrics: Rare and endangered instream and riparian species. Unique instream and riparian species. Important migration corridor for various species. Site is situated in the /Ai-/Ais–Richtersveld Transfrontier Park.
PES: B/C
Decreased frequency of small and moderate floods. Agricultural return flows and mining activities – water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. Presence of alien fish species and barrier effects of dams. Alien vegetation.
REC: B
Increased (from present) wet season base flows.
Reinstate dry season droughts.

Components	*PES*	*REC*
IHI hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B
Fish	B/C	B
Macro-invertebrates	B/C	B
Instream	**B/C**	**B**
Riparian vegetation	B/C	B
Riverine fauna	B	B
EcoStatus	**B/C**	**B**
EIS	HIGH	

4.2 Hydrological considerations

The wettest and driest months were identified as March and September respectively. Droughts were set at 95% exceedance (flow) and 5% exceedance (stress). Maintenance flows were set at 40% exceedance (flow) and at 60% exceedance (stress).

4.3 Low flow requirements (in terms of stress)

EFR O4 flows were extrapolated to EFR O 5 for the PES and the REC. These extrapolated flows were then converted to stress using the EFR O5 stress flow index. These stresses were then evaluated to determine whether the stress regime will maintain and achieve the PES and REC. This approach was followed to ensure that there is no mismatch between the EFRs set at EFR O5 and O4. As the EFR objective to achieve the REC at both sites was the same, the REC EFR should be similar. It is accepted that there could be changes as the indicators and cross-section profile can be different.

The only stresses that changed from the extrapolated EFR O4 requirement were for the REC of a B. This is illustrated on Figure 4 where the purple arrow indicates the change in stress that is required. The flow (and stress) requirements are provided in Table 12 and 13. Comments on each flow are provided in terms of its adequacy to achieve the required ecological objectives for the respective component. The stress and flows were adjusted to meet the requirements and are illustrated as stress in Figure 5.

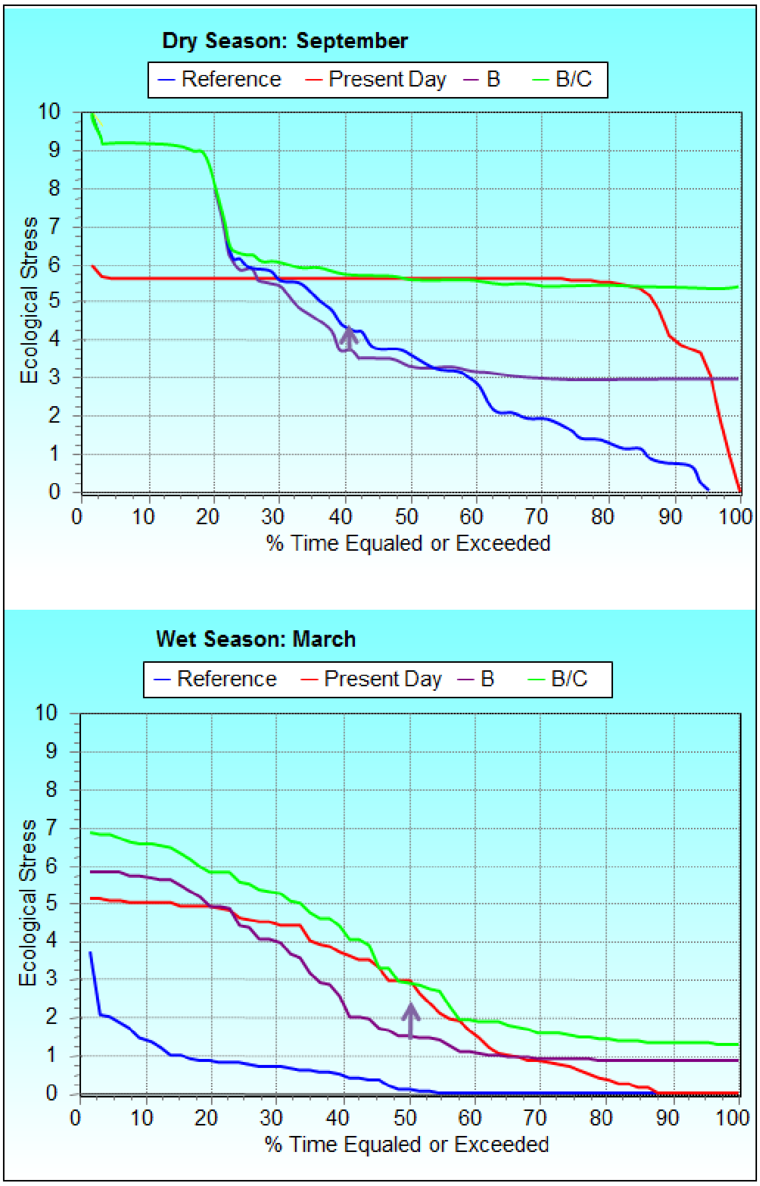


Figure 4. EFR O5: Stress duration curve for the PES and REC indicating the required shift in the B curve required.

Table 12. EFR O5 requirements for the PES (B/C)

Component stress duration,	***Stress (discharge)***	***Response***
Fish 5% Dry season	9.2 (1.9)	Habitat suitability will be very low to unsuitable for the indicator guild in terms of providing cover, maintaining abundance, connectivity and water of acceptable quality, but adequate to allow survival of this fish guild as it is semi-rheophilic and can survive periods without flow in the dry season. It is estimated that zero flows occurred under natural conditions, and hence the low dry season drought flows are reflecting closer to natural conditions. The fact that some flow occurs will ensure that water quality will at least be maintained.
Invert 5% Dry season	9.2 (1.9)	This stress requirement will introduce some of the natural stress into the system to which the biota are adapted, and reduce the risks of outbreaks of pest blackflies. The requested stress duration is similar to the natural stress, and significantly higher than the present day stress. Elevated present day low flows at this time of the year are the main reason leading to outbreaks of pest blackflies.
Fish 60% Dry season	5.5 (11.9)	Habitat suitability will be low in terms of providing cover and maintaining abundance and connectivity, and water of acceptable quality. These flows are however similar to those expected under present conditions and should therefore be able to maintain the fish in its current state.
Invert 60% Dry season	5.8 (8.9)	The flow at this stress is 8.9 m^3/s. Wetted perimeter reduced to 38% compared to zero stress baseline, while absolute availability of very fast flow habitat over course substrate is reduced to 29% of base flow conditions (zero stress). Average depth is 0.3 m, which approaches the lower boundary for the indicator species *A. scottae.*
Fish 5% Wet season	6.9 (6)	Habitat suitability will be very low in terms of providing spawning habitats, but allow spawning to take place during droughts in the wet season. Cover and abundance suitability will also be very low, while nursery areas and water of acceptable quality will be of low suitability. These conditions are however thought to be adequate to maintain the present state of the fish assemblage during drought conditions in the wet season.
Invert 5% Wet season	7 (6.3)	Maintain some of the natural flow variability needed to maintain biodiversity of the PES.
Fish 60% Wet season	2.9 (31.3)	Habitat suitability will be moderate in terms of spawning habitats and in providing cover for maintaining abundance. Nursery habitats, connectivity and water quality can be classified as good for the LSR guild. These flows will therefore be adequate to maintain the fish in its present state.
Invert 60% Wet season	3.2 (9.6)	The flow at this stress is 20 m^3/s, which is slightly lower than the flows measured during the field survey in June 2012 Habitat suitability for invertebrates under these flows are good, and sufficient to maintain the invertebrates in a Category B/C.

Table 13. EFR O5 requirements for the REC (B)

Component stress duration	Stress (discharge)	Response
Fish 5% Dry season	9.2 (1.9)	See B/C in Table 12 above.
Invert 5% Dry season	9.2 (1.9)	See B/C in Table 12 above.
Fish 60% Dry season	4.3 (20.3)	Habitat suitability will be low in terms of providing cover/abundance and moderate in terms of connectivity and water of acceptable quality. This is an improvement (almost double the amount of water) expected under present conditions and an improvement towards the expected natural flows. A slight improvement in the fish assemblage can be expected (it must be emphasized that the LSR guild is already in a very good state under present conditions and increased flows is not expected to result in a significant improvement).
Invert 60% Dry season	5.8 (8.9)	Similar to reference condition.
Fish 5% Wet season	5.8 (10)	Habitat suitability will be very low in terms of providing spawning habitats, but allow spawning to take place during droughts in the wet season. Cover and abundance suitability will also be very low, while nursery areas and water of acceptable quality will be of low suitability. These conditions are however thought to be adequate to maintain the present state of the fish assemblage during drought conditions in the wet season.
Invert 5% Wet season	4.8 (11.6)	Maintain some of the natural flow variability needed to maintain biodiversity of the PES.
Fish 60% Wet season	2.2 (37)	Habitat suitability will be moderate to good in terms of providing spawning habitats, nursery habitats, cover/abundance and water quality. It must again be emphasized that the LSR guild is already in a good condition at the site, and that increased flows in the wet season will most probably result in minimal improvement in this guild. It is estimated that improvement in the dry season (closer to natural flows) will be more important in improving the fish assemblage.
Invert 60% Wet season	1.6 (5.8)	This stress was selected on the basis of providing sufficient current speeds for the target species, *A. scottae.* In addition, this flow will elevate turbidity and provide suitable feeding conditions for filter feeding taxa that need high flows and good quality water. Overall, instream habitats are highly suitable for macro-invertebrates, and the total SASS5 scores are expected to approach 170.

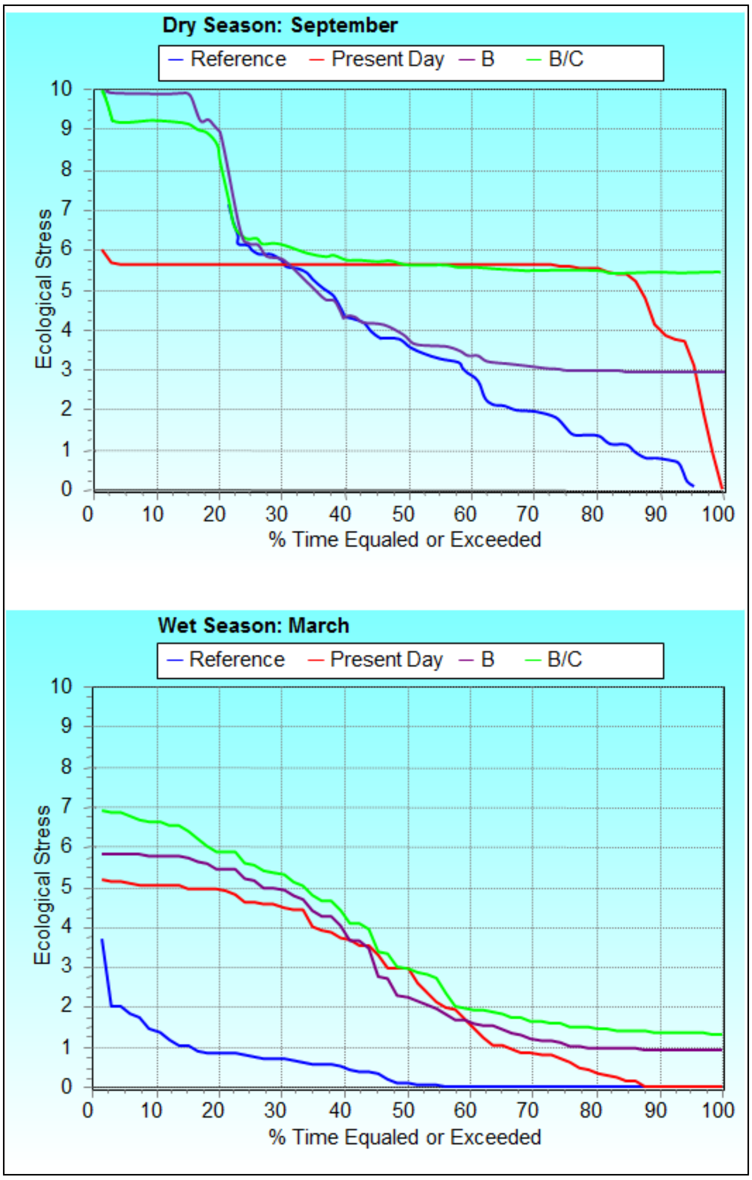


Figure 5. EFR O5: Stress EFR requirements

The low flow requirements was checked (and modified if necessary) to ensure that it achieves the riparian vegetation (specifically marginal) objectives for the PES. The REC was not evaluated as improvement in the vegetation is dependent on non-flow-related mitigation. This verification is summarised in Table 14.

Table 14. EFR O5: Verification of low flow requirements to achieve the riparian vegetation objectives for the PES

Species	***Average inundation height above water level (m)***		***Comment***
	Lower limit	***Upper limit***	
Dry Season Drought			
Cyperus longus	0.37	1.23	Water stress is high, but not higher than would be expected for dry season drought.
Phragmites australis	0.37	0.49	
Gomphostigma virgatum	0.37	0.93	
Salix saplings	1.19		
Salix mucronata (adult)	2.12	2.26	
Tamarix usneoides	2.24	4.24	
Dry Season Maintenance			
C. longus	0.08	0.94	No inundation of vegetation occurs on the transect, but upstream in pool areas there will be inundation of both sedges and reeds. Flow is sufficient to sustain riparian vegetation survival.
P. australis	0.08	0.20	
G. virgatum	0.08	0.64	
Salix saplings	0.90		
S. mucronata (adult)	1.83	1.97	
T. usneoides	1.95	3.95	
Wet Season Drought			
Cyperus longus	0.16	1.02	Water stress is high, but not higher than would be expected for wet season drought. No inundation of vegetation occurs, and some reproductive failure is likely.
Phragmites australis	0.16	0.28	
Gomphostigma virgatum	0.16	0.72	
Salix saplings	0.98		
Salix mucronata (adult)	1.91	2.05	
Tamarix usneoides	2.03	4.03	
Wet Season Maintenance			
Cyperus longus	-0.13	0.73	Significant portions of the reed population remains inundated. Similarly sedges and *G. virgatum* have large portions of the population inundated. Flow is sufficient to sustain growth and reproduction.
Phragmites australis	-0.13	-0.01	
Gomphostigma virgatum	-0.13	0.43	
Salix saplings	0.69		
Salix mucronata (adult)	1.62	1.76	
Tamarix usneoides	1.74	3.74	

The conclusion was that the proposed flows will maintain the PES. Riparian zone structure and functionality will remain unchanged from current as a result of low flow requirements.

4.4 High flow requirements

Detailed motivations are provided in Table 15 and final high flow results are provided in Table 16.

Table 15. EFR O5: Identification of instream functions addressed by the identified floods for geomorphology and riparian vegetation (flood ranges provided as instantaneous peaks)

Flood range (m^3/s)	***Geomorphology and riparian vegetation motivation***	***Fish***	***Macro-invertebrates***	***River fauna***
50 - 60	**Riparian vegetation:** Required to inundate 50% on average, of marginal and lower zone obligates (mainly *Gomphostigma virgatum* and *Cyperus longus* and activates (just reaches the lower limit) the *Salix mucronata* population. Prevents the establishment of terrestrial and alien species (especially *Prosopis glandulosa*) in the marginal and lower zones. At least four events required during growing season (Spring to Summer: Nov - Jan). **Geomorphology:** These very small flushes or high wet season baseflows entrain and remove fines from the bed of the active channel.	This flood caters for: Migration spawning, adequate migration habitat, clean spawning substrate, the creation of nursery areas and inundation of vegetation for spawning.	This flood caters for breeding and hatching cues, clearing of fines, scouring of substrate and inundation of important habitats.	This flood caters for scouring of lower zone habitats, creates floodplain habitats and invigorate riparian vegetation habitats.
190	**Geomorphology:** These regular wet season flushes transport about 20% of the fines at the site and will scour accumulated fines from the active channel bed. Small gravel material will also be activated.	See above and water quality maintenance.	See above.	See above.
300	**Riparian vegetation:** Required to flood marginal (completely inundates *G. virgatum* and *C. longus*) and lower zone riparian species (activates *S. mucronata* adult population but inundates areas with high density of seedlings at the time of the survey). This will facilitate recruitment opportunities at higher levels, but creates flooding disturbance at the lower limits which also maintains open habitats and vegetative patchiness. *Phragmites australis* may be removed in small isolated patches at its lower limits, an important change towards better conditions. Required each year during summer (Nov - Feb). **Geomorphology:** Scouring flood to remove fines and activate gravels. This flow class is important for scouring and fines removal, as well as activating the secondary channels and scouring low bars.	See above.	See above.	See above.

Flood range (m^3/s)	*Geomorphology and riparian vegetation motivation*	*Fish*	*Macro-invertebrates*	*River fauna*
500	**Riparian vegetation:** Activation of the *Tamarix usneoides* population. Important for removing *Prosopis* species, especially on the macro channel floor, and also to scour marginal and lower zone habitats and maintain open patches. Needed in the growing season (Jan to Mar) every two years. **Geomorphology:** Scouring flood to remove fines and gravels. This flow class transports is important to scour and maintain the secondary channels.	See above.		See above.
1000	**Riparian vegetation:** Large and infrequent flood required to inundate about 50% of the *T. usneoides* population. Important to maintain *T. usneoides* recruitment. Also begins inundation of *Searsia pendulina, Acacia karoo* and *Ziziphus mucronata* in the tree line. These floods will facilitate recruitment and vigour of upper zone woody species, but also prevent their encroachment into the lower zone. Similarly, these floods are also useful for preventing terrestrialisation and expansion of alien species such as *P. glandulosa*. Required every 3 to 5 years. **Geomorphology:** This flood class transports acts as the present day effective discharge for fines and small gravels. Gravels and some larger elements will be mobilised and thus inhibit embeddedness. The large bars will also be scoured and bar growth inhibited.	See above		See above.

The number of high flow events required for each EC is provided in Table 16. The availability of high flows was verified using the observed data at gauge D8H003. Theses observed floods were extrapolated to EFR O5 by adding in the time flow series from the Fish River and allowing for losses and water use between the gauge and EFR O5. These high flow events are not expected to be required during dry or drought years.

Table 16. EFR O5: The recommended number of high flow events required for the PES and REC

Flood range (m^3/s)	***Riparian vegetation***	***Geomorphology***	***Final* no of events***	***Months***	***Daily average (m^3/s)***	***Duration (days)***
50 - 60	4	4	4	Dec, Jan, Feb, Mar	60	5
190		3	3	Nov, Dec, Jan	190	7
300	1	1	1	Feb	300	10
500	1:2	1:2	1:2**	Mar	500	12
1,000	1:3-5	1:3	1:3			

* Agreed on number of events considering the individual requirements for each component.
**Refers to frequency of occurrence, i.e. the flood will occur once in two years.

4.5 Final flow requirements

The low and high flows were combined to produce the final flow requirements for each EC as:

- an EFR table, which shows the results for each month for high flows and low flows separately (Table 17 - 18). The very large flood of 1:3 years are not included in the modelled results as they cannot be managed;
- an EFR rule table which provides the recommended EFR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). EFR rules are supplied for total flows as well as for low flows only. These tables as model outputs are provided in Appendix C.

The low flow EFR rule table is useful for operating the system, whereas the EFR table must be used for operation of high flows.

Table 17. EFR O5: EFR table (m^3/s) for PES: B/C

Desktop version: 2 nMAR (Mm^3): 11,373 pMAR (Mm^3): 4,641
BFI index: 0.301 Distribution type: Vaal

Month	***Low flows***		***High flows***	
	Maintenance (m^3/s)	***Drought (m^3/s)***	***Daily average (m^3/s) on top of base flow***	***Duration (days)***
October	13.1	2.1		
November	18.4	2.9	190	7
December	21.5	3.4	60 & 190	5 & 7
January	29.4	4.6	60 & 190	5 & 7
February	43.0	6.7	60 & 300	5 & 10
March	40.4	6.3	60 & 500	5 & 12
April	35.8	5.6		
May	25.08	3.9		
June	16.8	2.7		
July	12.1	1.9		
August	10.6	1.7		
September	10.1	0		
Total Mm^3	721.63	109.42	512.85	
% of virgin MAR	6.35	0.96	4.51	
% of PD MAR	15.54	2.36	11.05	
Total EFR	1,234.48			
% of natural MAR	10.85			
% of PD MAR	26.6			

Table 18. EFR O5: EFR table (m^3/s) for REC: B

Desktop version: 2 | Natural MAR (Mm^3): 11373 | PD MAR (Mm^3): 4641
BFI index: 0.301 | Distribution type: Vaal

Month	***Low flows***		***High flows***	
	Maintenance (m^3/s)	***Drought (m^3/s)***	***Daily average (m^3/s) on top of base flow***	***Duration (days)***
October	22.9	2.6		
November	30.5	3.3	190	7
December	34.5	4.5	60 & 190	5 & 7
January	45.7	5.9	60 & 190	5 & 7
February	65.1	10.0	60 & 300	5 & 10
March	61.0	9.4	60 & 500	5 & 12
April	54.6	6.2		
May	39.5	5.9		
June	28.2	4.0		
July	21.4	2.9		
August	19.3	2.6		
September	18.8	0		
Total Mm^3	1,154.46	149.64	512.85	
% of virgin MAR	10.15	1.32	4.51	
% of PD MAR	24.87	3.22	11.05	
Total EFR	1,667.32			
% of natural MAR	14.66			
% of PD MAR	35.93			

5. Description of scenarios

The scenario development and detail regarding the hydrological and yield modelling are described in Technical Report 31. As explained in this report, scenarios (Sc) consist of combinations of different drivers. The drivers were combined within the likely time-frame that these developments could take place so as to derive plausible development scenarios. The combination of drivers that result in scenarios are illustrated in the two tables below. Table 19 illustrates the time-line and list the drivers, whereas Table 18 shows explicitly which driver is activated in each scenario.

Table 19. Time lines, scenario and driver combinations

Time frame	***Scenario***	***Orange River drivers***	***Fish River drivers***
Present day	Sc OF 1	Modelled present day current releases and use included.	
2013 - 2020	Sc OF 2	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 3	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
	Sc OF 4	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
2020 - 2040	Sc OF 5	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Post 2040 - maximum foreseeable development	Sc OF 6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam. Increase in Naute Dam irrigation.
	Sc OF 7	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
	Sc OF 8	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (EFR O4 released), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation

Table 20. Drivers that are activated or deactivated under different Scenarios

	Orange River drivers										**Fish River drivers**		
Scenario	**Metolong Dam**	**AMD treated**	**EFR flows 2010**	**Optimised releases**	**Tandjieskoppe**	**Additional Namibian irrigation**	**Polihali Dam**	**Vioolsdrift balancing dam**	**Vioolsdrift large dam**	**Boskraai Dam**	**Neckartal Dam**	**Neckartal with REC EFR**	**Increased Naute irrigation**
Sc OF 2	Yes	Yes			Yes						Yes		Yes
Sc OF 3	Yes	Yes			Yes							Yes	Yes
Sc OF 4	Yes	Yes	Yes	Yes	Yes							Yes	Yes
Sc OF 5	Yes	Yes	Yes	Yes	Yes		Yes	Yes				Yes	Yes
Sc OF 6	Yes	Yes		Yes	Yes	Yes	Yes		Yes	Yes	Yes		Yes
Sc OF 7	Yes	Yes		Yes	Yes	Yes	Yes		Yes	Yes		Yes	Yes
Sc OF 8	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes		Yes	Yes

Scenarios OF 4, OF 5 and OF 8 were not evaluated as these supply the EFR as specified at EFR OF 4 and therefore OF 5. The river assessment therefore focussed on evaluating the consequences of Scenarios OF 2, OF 3 and OF 6 and OF 7.

These scenarios were then compared to see how similar they are and whether sufficient resolution exists to differentiate between them. The following was concluded:

- Sc OF 2 (green curve) and Sc OF 3 (purple curve) were virtually the same (Figure 6) for the dry season and was not assessed in terms of low flows. The only difference between these scenarios was the inclusion of the Fish River driver: Neckartal with REC EFR. This does mean that there could be a difference in the flooding regime.
- Scenarios OF 6 (blue curve) and OF 7 (orange curve) are virtually the same.

The only scenarios that were therefore sufficiently different to warrant evaluation was Sc OF 3 (the same as Sc OF 2) and Sc 7 (the same as OF 6).

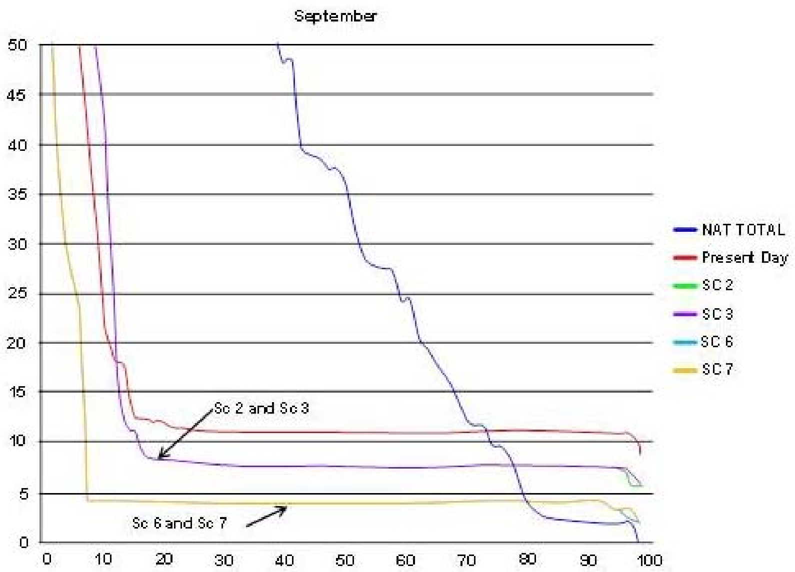


Figure 6. Flow duration graph illustrating similarities of scenarios

6. Ecological consequences of operational scenarios

The time series for each operational scenario was converted to stress and is supplied in Figure 7 below. The changes in stress from the stress regime recommended for a B and B/C could then be used to assess the ecological consequences of each scenario.

Figure 7 illustrates the stress requirements required for a B/C PES (light green curve) and B REC (purple curve). The blue curve illustrates natural stress, the red curve Present Day stress, the yellow curve Sc OF 3 and the black curve Sc OF 7.

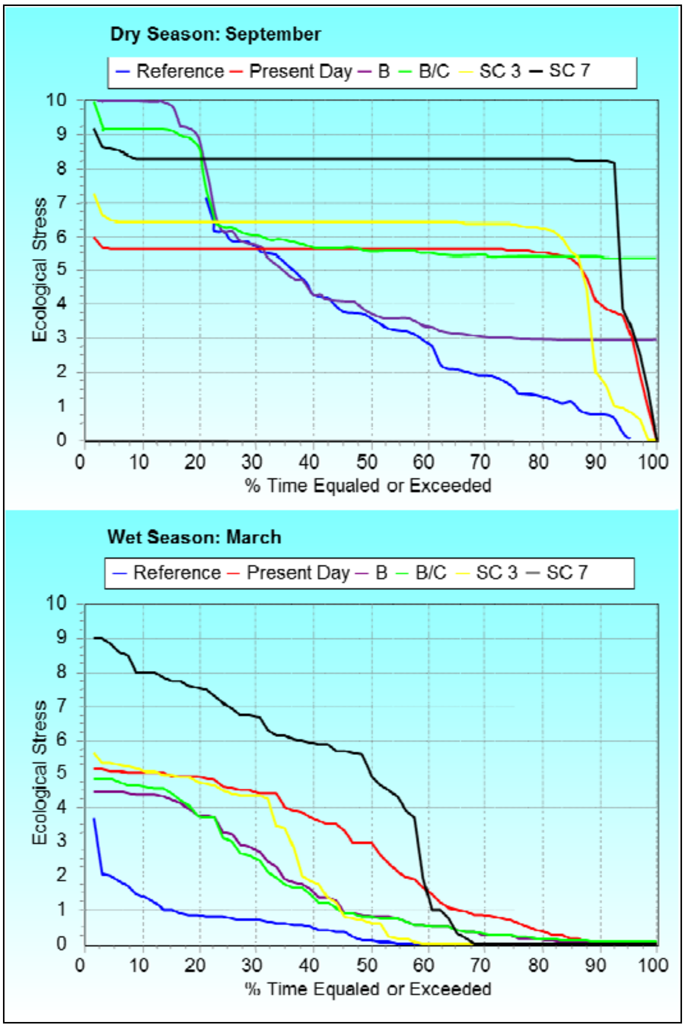


Figure 7. Stress duration for EFR O5: Dry and Wet season

6.1 Physico-chemical and geomorphology consequences

The consequences of the operational scenarios OF 3 and OF 7 are described in Table 21 for the driver components.

Table 21. Physico-chemical and geomorphology consequences of Sc OF 3 and Sc OF 7

Driver component	***Scenario consequences***
Physico-chemical variables	
PES: C (74%) REC: C (68%) Sc 3 C (74%) Sc 7 D/E (49%)	**Sc OF 3:** The scenario flows are similar to present state. Impacts from upstream dams and irrigation are minimal due to the distance from the site. Flows may also be balanced by the treated AMD water available to the system. It is assumed the quality of the treated water is acceptable. **Sc OF 7:** It is expected that most water quality variables will be impacted, particularly salt and nutrient levels. Impacts on temperature and oxygen will also be severe due to the abstraction of flows and impact of upstream dams, and the concentration of any toxics in the system will be increased due to a drop in dilution capacity. Sediment levels will drop as sediments are trapped in upstream dams. The water quality category is expected to change from a C category to a D/E.
Geomorphology	
PES: B/C (79.3%) REC: B (82.4%) Sc 3 B/C (79.3%) Sc 7 C/D (60%)	**Sc OF 3:** Little measureable change in the frequency of the important flood classes. It is not likely that these scenarios will cause a change in the PES. **Sc OF 7:** There is a large reduction in the frequency of floods. The critical flood classes are expected to decrease - moderate floods by between 30 - 50% and large floods (1000 m^3/s and more) by more than two thirds relative to the Present Day conditions. Additionally, the close proximity of the large Vioolsdrift Dam will cut off the supply of coarser sediment to the lower reaches. These combined impacts will cause the PES to deteriorate. **Conclusion:** There will be no measurable change in geomorphology under Sc OF 3. Under Sc OF 7, geomorphology will not be impacted significantly by dry season flows, however during wet season flows there is a large reduction in flood frequency and coarser sediment supply will be cut Vioolsdrift Dam leading to a deteriorated PES.

6.2 Biotic responses

The consequences of the operational scenarios OF 3 and OF 7 are described in Table 22 for the biotic components.

Table 22. Biotic consequences of Sc OF 3 and Sc OF 7

Driver component	***Scenario consequences***
Riparian vegetation	
PES: B/C (81.9%) REC: C (82.5%) Sc 3 B/C (81.9%) Sc 7 D/E (61.9%)	**Sc OF 3:** This scenario will not result in measurable change to the PES. **Sc OF 7:** During the dry season low flows 4 m^3/s occurs at 60%. At this flow the upper limit of marginal/lower zone riparian vegetation is more than 1 m above the water level and some mortality is likely. During the wet season a low flow of 9 m^3/s occurs at 60%. This results in zero inundation of marginal zone vegetation and overall water stress, with some reproductive failure and possible mortality. A severe reduction of all flood classes under Sc 7 reduces the PES. This is due to

Driver component	***Scenario consequences***
	reduced recruitment of indigenous species which will alter population structure over time, promotion of alien species on the macro channel floor, which would be removed by large floods and encroachment by reeds.
Fish PES: B/C (79.9%) REC: B (83.3%) Sc 3 B/C (80.3%) Sc 7 D/E (405%)	**Sc OF 3:** Dry season low flows: Habitat suitability will be very low to low for the LSR guild, while the species preferring slow habitats may be advantaged by the reduced flows and a slight increase in their abundance can be expected. Although the lower dry season flows may be an improvement from present condition (too high flows at present), the notably reduced maintenance flows will result in an overall slight reduction in habitat availability and hence a very slight reduction in abundance of some species. Wet season low flows: Habitat suitability will be low during the droughts, but adequate to maintain all life stages and processes of all species. The maintenance flows will result in optimal habitats for especially the LSR guild. The status of the fish assemblage will be maintained during the wet season, and a slight improvement may even occur as a result of increased abundance of habitats (maintenance and drought periods). **Sc OF 7:** Dry season maintenance flows will be notably lower than the required flows to maintain the PES, and hence habitat suitability and availability will be very low during the dry season. Although the drought flows will be adequate, the overall dry season condition will be deteriorated due to the low maintenance flows (occurring most of the time). It is therefore expected that the PES of the fish will be significantly reduced under this scenario during the dry season. **Conclusion:** The PES of the fish should be maintained under Sc OF 3, and may even slightly improve primarily as a result of increase abundance of habitats in the wet season, and a slight improvement of slow habitats in the dry season. The PES is expected to be significantly reduced under Sc OF 7 because of reduced habitat suitability and availability for fish during both the dry and wet seasons.
Macro-invertebrates PES: B/C (78%) REC: B (82.4%) Sc 3 B/C (79.3%) Sc 7 D/E (40%)	**Sc OF 3:** Dry season drought flows are significantly higher than required to maintain the REC, but similar to present day (PD) hydrology, so the PES is likely to be maintained. Dry season maintenance flows are similar to what is required. Wet season drought and maintenance flows are similar to what is required. **Sc OF 7:** Dry and wet season flows remain very low for most of the time, and this is likely to cause extreme change in the composition and abundance of macro-invertebrates with a preference for fast and very fast flow. Excessive growth of benthic algae is expected at these low flows, and this is likely to have a large impact on taxa with a preference for cobble, boulder and bedrock substrates. Inverts with a preferences for good quality water, such as stoneflies (Perlidae, trichorythid mayflies and Hydropsychidae (>2 spp) caddisflies), as well as species with a preference for high silt levels (*Simulium gariepense*) are expected to disappear. Overall diversity of macro-invertebrates is expected to drop significantly. These flows are also expected to have a large impact on natural seasonal patterns of macro-invertebrate composition and abundance.

6.3 Summary

The responses in terms of impact on Ecological Categories are summarised in Table 23. A scale is also provided that indicates the relative differences between the different scenarios (Figure 8).

Table 23. Summary of biophysical responses at EFR O5

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

Sc OF 3 maintained the PES whereas Sc OF 7 dropped the EC to a D/E for the instream components and resulted in a D EcoStatus. None of the scenarios met the REC, however it must be noted that none of these scenarios included the REC EFR as a demand. Sc OF 2 and Sc OF 3 did not meet the REC but maintained the PES. Sc 6 and 7 did not meet the ecological objectives and the instream components would be in an unsustainable state. It is assumed that Sc OF 4, 5 and 8 will meet the REC as that is included in the scenario as a demand.

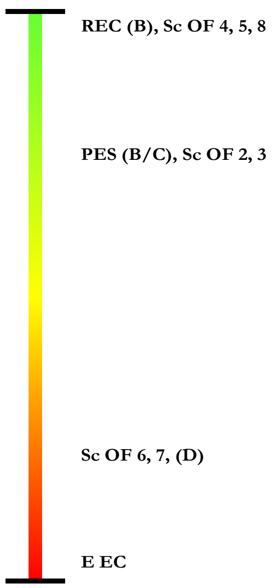
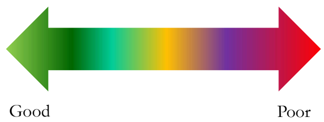


Figure 8. Relative differences between scenarios

A further summary in terms of meeting the ecological objectives are provided in Table 24. 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 24. Degree to which ecological objectives are met at EFR O5 under each flow scenario

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



7. Conclusions and recommendations

7.1 EcoClassification

7.1.1 Summary of EcoClassification results

The EcoClassification results are summarised in Table 25.

Table 25. EcoClassification summary

EIS: HIGH
Highest scoring metrics: Rare and endangered instream and riparian species. Unique instream and riparian species. Important migration corridor for various species. Site is situated in the /Ai-/Ais–Richtersveld Transfrontier Park.
PES: B/C
Decreased frequency of small and moderate floods. Agricultural return flows and mining activities – water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. Presence of alien fish species and barrier effects of dams. Alien vegetation.
REC: B
Increased (from present) wet season base flows.
Reinstate dry season droughts.

Components	*PES*	*REC*
IHI hydrology	C	C
Physico-chemical	C	C
Geomorphology	B/C	B
Fish	B/C	B
Macro-invertebrates	B/C	B
Instream	**B/C**	**B**
Riparian vegetation	B/C	B
Riverine fauna	B	B
EcoStatus	**B/C**	**B**
EIS	HIGH	

7.1.2 Confidence in EcoClassification results

The confidence in the EcoClassification process is provided below (Table 26) and was based on data and information availability and EcoClassification where:

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

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

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

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

Table 26. Confidence in EcoClassification

EFR site	***EFR Fish 1***
Information availability	
Physico-chemical	2
Geomorphology	3
IHI	3.5
Fish	3
Invertebrates	3
Riparian vegetation	3.5
Riverine fauna	3
Average	**3**
Median	**3**
EcoClassification	
Physico-chemical	2.5
Geomorphology	3
IHI	4.3
Fish	3
Macro-invertebrates	3
Riparian vegetation	3.7
Riverine fauna	3
Average	**3.2**
Median	**3**

7.1.3 Recommendations to improve the confidence in the EcoClassification results

The confidence in the data availability and information at both EFR sites were evaluated to determine the EcoClassification results. Overall, the confidence in the EcoClassification is moderate. Increased confidence will be achieved through monitoring and no other further work is recommended.

7.2 Environmental flow requirements

7.2.1 Summary of EFR results

The final flow requirements are expressed as a percentage of the natural MAR (nMAR) and the present MAR (pMAR) and provided in Table 27.

Table 27. Summary of EFR O5 results as a percentage of the present and natural MAR

Hydrology	*B/C PES*	*B REC*
Natural mean annual runoff (nMAR) (Mm^3)	11,373	11,373
Maintenance low flows (%nMAR)	6.35	10.15
Drought low flows (%nMAR)	0.96	1.32
High flows (%nMAR)	4.51	4.51
Long-term mean (%nMAR)	10.85	14.66
Present-day mean annual runoff (pMAR) (Mm^3)	4,641	4,641
Maintenance low flows (%pMAR)	15.54	24.87
Drought low flows (%pMAR)	2.36	3.22
High flows (%pMAR)	11.05	11.05
Long-term mean (%pMAR)	26.6	35.93

7.2.2 Confidence in low flow results

Confidences in the low flow EFR requirements are considered as follows:

'How confident are you that the low flow (with the associated high flows) recommended will achieve the EC?'

To determine the confidence, one should consider:

- the quality of available information;
- whether the component requirement represents the critical requirement. For example, if the macro-invertebrate stress requirement of a 4 at 30% was the final recommendation, and fish was 7 at 30%, then fish should have very high confidence that the recommended flow will achieve the EC. The reasoning behind this is that fish will receive more flow than required. Even if the fish information availability and understanding of habitat requirements are of low confidence, there should be high confidence that the higher flow recommendation will cater for fish requirements and that the EC will be maintained/achieved.

The low flow confidence evaluation is representative of the component's (fish or macro-invertebrates) confidence which drove the flow requirement. If both components drove the flow requirement, then an average of the confidence is provided.

Table 28 provides the confidence for the low flow biotic components (fish, macro-invertebrates, riparian vegetation and riverine fauna). The shaded green columns indicate which of these components dictated the final requirements. The final confidence is representative of these requirements. The confidence scale is as provided in section 7.1.2.

Table 28. EFR O5: Confidence in low flows for biotic responses

Component	Confidence	Comment
Fish	3.5	Presence of two large semi-rheophilic fish species at the site, as well as the availability of adequate flow requirement information regarding these species, in addition to a well selected cross section and EFR site, assisted in the interpretation of data and in setting low flows for the site.
Macro-invertebrates	4	Although drought low flow requirements were driven by macro-invertebrates, there was reliable baseline information and reasonable understanding of macro-invertebrate ecology and key drivers in this management unit, including the key indicator species. Furthermore, the system is naturally resilient, so tolerance ranges are expected to be wide.
Riparian vegetation	4	A rated profile, together with surveyed vegetation and hydraulic look-up table was used to determine whether low flow requirements (as determined by fish and macro-invertebrates) are sufficient to maintain riparian vegetation in its current state. Confidence is high that stipulated flows will maintain the PES for riparian vegetation, provided that flood requirements are met?
Riverine Fauna	3.5	Most of the assessments were done with the combined support from the water quality, fish, macro invertebrates and vegetation response assessments. The riverine fauna are closely connected to these aspects for health, food and habitat.
Final	3.5	

7.2.3 Confidence in high flow results

Confidences in the high flow EFR requirements are considered as follows:

'How confident are you that the recommended high flows (with the associated low flows) will achieve the EC?'

To determine the confidence, one should consider:

- the quality of available data;
- which of the riparian vegetation or geomorphological components required the highest flow.

The high flow confidence (Table 29) represents an average of the riparian vegetation and geomorphology confidence as these two components both determined the flood requirements.

Table 29. EFR O5: Confidence in high flows

Component	***Confidence***	***Comment***
Fish	4	Floods set to meet the vegetation and geomorphological requirements are adequate in terms of duration and extent to meet the requirements of the fish.
Macro-invertebrates	4	High flows requested will provide periodic flushing needed to trigger hatching of macro-invertebrate eggs, such as Caenidae and *Simulium chutteri*. The requested high flows will also provide elevated turbidity needed to create feeding conditions suitable for the threatened blackfly *Simulium gariepense*.
Riverine Fauna	4	Most of the assessments were done using the responses of water quality, fish, macro-invertebrates and vegetation assessments. The riverine fauna is closely connected to these aspects for health, food and habitat.
Riparian vegetation	4	A rated profile, together with surveyed vegetation and hydraulic look-up table was used to determine flood levels that will maintain riparian vegetation in its current state. Confidence is high that stipulated floods will maintain the PES for riparian vegetation, provided that low flow requirements are also met.
Geomorphology	3	The morphological cues are relatively defined, and there was good correlation between the outputs of the potential bed sediment transport modelling. Geomorphological cues and vegetation flood requirements.
Final	3.5	

7.2.4 Confidence in the environmental flow requirement assessment

Hydrology confidence is determined from the perspective of its usefulness to EFR assessment. This will be different than the confidence in the hydrology for water resources management and planning. The scale of requirements is different, and that is why high confidence hydrology for water resource management purposes does not necessarily provide sufficient confidence for EFR assessment. The confidence in hydrology is provided in Table 30.

Table 30. Confidence in hydrology

Component	***Confidence***	***Comment***
Modelled natural hydrology	3.5	Modelled PD hydrology is low due to the mismatch of modelled hydrology and the observed hydrology. There are however also problems with the observed hydrology due the gauge being inaccurate below 40 m^3/s.
Modelled PD hydrology	2	
Observed hydrology	3	
Local knowledge/information	2.5	
Average	2.8	

The overall confidence in the results are linked to the confidence in the hydrology and hydraulics as the hydrology provides the check and balance of the results and the hydraulics convert the requirements in terms of hydraulic parameters to flow. Therefore, the following rationale is applied when determining the overall confidence:

- If the hydraulics confidence is lower than the biological responses column, the hydraulics confidence becomes the overall confidence. Hydrology confidence is also considered, especially if used to guide the requirements.
- If the biological confidence is lower than the hydraulics confidence, the biological confidence becomes the overall confidence. Hydrology confidence is also considered. If hydrology is used to guide requirements, than that confidence will be overriding.

The confidence is supplied in Table 31.

Table 31. Confidence in EFR O5 results

Component	**Confidence**	**Comment**
Low Flows		
Hydrology	2.8	The recommended low flows (drought and maintenance) are in the range 1.9 m^3/s to 37 m^3/s. Although measured rating data include 29.1 m^3 and zero flow depth is expected at the cessation of flow (section lies through a rapid), a non-horizontal cross-channel water surface profile occurs at low to medium flows, thus reducing the accuracy of the hydraulic characterisation.
Biological responses	3.5	
Hydraulics	3	
Final	3	
High Flows		
Hydrology	2.8	Floods range from 70 m^3/s to 1000 m^3/s. The measured rating data include approximately 550 m^3/s. A non-horizontal cross-channel water surface profile occurs at low to medium flows, thus reducing the accuracy of the hydraulic characterisation.
Biophysical responses	3.5	
Hydraulics	3	
Final	3	

7.2.5 Further work required to improve confidence

Confidence in hydrology cannot be improved without improved gauged data. A gauging weir at Sendelingsdrift is currently being constructed and this will result in future in an improved estimation of current day hydrology. The observed data from the gauge will also result in improved predictions on the duration and low flow discharge that will result in the estuary to close.

The biophysical response's confidence was high and no further work would be recommended to improve these requirements. The emphasis of further work should be to test and verify the estimated biophysical responses to a changed flow and potentially quality regime. If steps are taken to implement the EFR, then monitoring to determine whether the ecological objectives are being met is essential. It is therefore recommended that further work should focus on biophysical monitoring within an Adaptive Monitoring Framework. Monitoring recommendations are made in Technical Report 35.

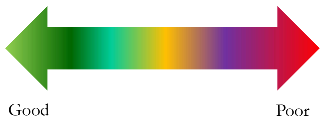
7.3 Recommended scenario and further work

Scenarios OF 4, OF 5 and OF 8 were not evaluated as these supply the REC EFR as specified at EFR O4 and, by implication, EFR O5. The river assessment therefore focussed on Scenarios OF 2, OF 3 and OF 6 and OF 7. Scenarios OF 2 and OF 3 were sufficiently similar to be combined and Sc OF 6a and 6b as well.

The evaluation of the operational scenarios indicated that Sc OF 2 and OF 3 maintained the PES whereas Sc OF 6 and OF 7 dropped the EC to a D/E for the instream components and resulted in a D EcoStatus. Table 32 shows that Sc OF 2 and Sc OF 3 did not meet the ecological objectives but maintained the PES. Sc OF 6 and OF 7 did not meet the ecological objectives and the instream components would be in an unsustainable state.

Table 32 Summary of ecological consequences of Operational Scenarios at EFR O5

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



Based on the above evaluation, Sc OF 6 and Sc OF 7 will, from an ecological perspective, not be recommended. Although the consequences associated with Sc OF 2 and OF 3 result in the PES being maintained, this still does not achieve the REC of a B/C. The scenarios which include the EFR, i.e., Sc OF 4, OF 5 and OF 8 will therefore be more acceptable from an ecological perspective.

The above results will be used to design a scenario that will attempt to minimise the impacts and maximise the benefits using the river EFR results and estuarine evaluations and considering the implications on yield. The aim of this scenario would be to achieve the REC at the estuary and the river and minimise the impacts on users. A final recommendation from this project will therefore be made in the summary report (Technical Report 37).

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Appendix A EcoStatus model output

Table A1. MRU Orange G, EFR O5: EcoStatus - REC

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	3	80
2.What is the natural diversity of fish species with a preference for different cover types	4	100
3.What is the natural diversity of fish species with a preference for different flow depth classes	3.5	90
4. What is the natural diversity of fish species with various tolerances to modified water quality	2.5	70
Macro-invertebrates		
1. What is the natural diversity of macro-invertebrate biotopes	3.5	80
2. What is the natural diversity of macro-invertebrate taxa with different velocity requirements	4	100
3. What is the natural diversity of macro-invertebrate taxa with different tolerances to modified water quality	2	50
Component	PES	Confidence
Fish	B	
Macro-invertebrates	B	
Confidence rating for instream biological information		3
Instream Ecological Category	B	
Riparian vegetation	B	
Confidence rating for riparian vegetation zone information		3
Riparian fauna	B	
ECOSTATUS	B	

Appendix B Environmental flow requirements: Approach and method

The Habitat Flow Stressor Response method (HFSR) (Hughes and Louw, 2010), a modification of the Building Block Methodology (BBM; King and Louw, 1998) was used to determine the low (base) flow EFRs. This method is one of the methods used to determine EFRs at the intermediate level. A short summary of the approach is provided below.

The method that was applied was the Habitat Flow Stressor Response (HFSR) method (Hughes and Louw, 2010). The method consists of a process to determine a flow regime that will result in a range of ecological states. Different flow regimes can then be evaluated and the ecological state determined.

B.1 Low flows

The basic approach is to set stress indices for fish and macro-invertebrates. The stress index describes the consequences of reductions of low flows on flow dependent biota and is determined by first assessing the relationship between habitat availability and quality to flow reduction.

The first step is to determine the habitat flow index, which is described separately for fish and macro-invertebrates as an instantaneous correlation of habitat to flow in terms of a 0 – 10 index relevant for the specific site. The zero stress (best habitat) and 10 stress (worst habitat) is fixed as follows to ensure that the range for fish and macro-invertebrates are the same:

- 0: Optimum habitat represented by the maximum natural base flow. The maximum natural base flow is selected using separated base flows. (Hughes and Louw, 2010)
- 10: No flow.

The second step is to determine the biota stress index which describes the instantaneous response of biota to change in habitat (and therefore flow) in terms of a 0–10 stress index. The description of the changes of habitat at each stress level (as described in the habitat stress index) is then related to the response of the fish and macro-invertebrate indicators. The biotic stress index is described separately for fish and macro-invertebrates. The zero stress, representing optimum habitat, would therefore represent the natural reference condition with the maximum abundance of species present.

The stress index therefore describes the habitat conditions and biota response for fish and macro-invertebrates at a range of low flows. The fish and macro-invertebrate stress-flow relationship will not be the same as the responses to the same flow will/can result in different stress for fish and macro-invertebrates.

The fish and macro-invertebrate stress indices are then used to convert separate natural and present day flow time series to a stress time series. The stress time series is converted to a stress duration graph for the highest and lowest flow months. This then provides the specialist with the information of how much the stress has changed from natural under present conditions due to changes in flow. It would follow that if flow has decreased from natural, the low-flow-related stress would increase, and vice versa. If specialists do not agree with the levels of stress under natural conditions based on their knowledge of the species, the stress indices are refined.

Tools used to determine the stress indices are specialist knowledge and information about the indicator species' habitat requirements, the hydraulics in the specific format required, and the natural hydrology. An example of the habitat stress flow index is provided in Figure A1. Figure A1 illustrates an example of the interpolated individual component stresses as well as the integrated curve. The black curve represents the integrated curve while the other two curves represent the stress flow relationships for the various components. The integrated curve in this case consists of the flow dependant macro-invertebrates (FDI) (red curve) for the stress range 0 to 5, and fish (large semi-rheophilic (LSR) (blue curve) for the stress range 5 to 10.

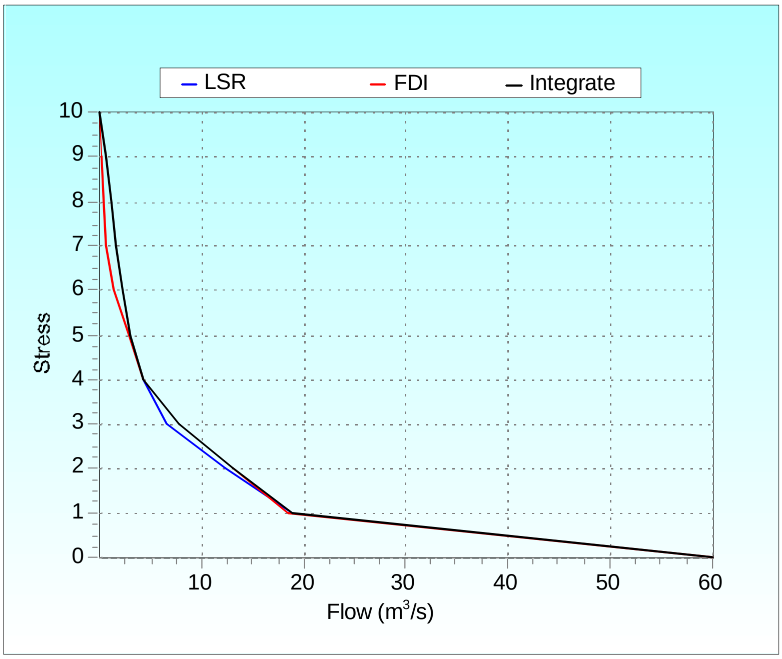

Figure A1. Component and integrated stress curves

At this stage only the instantaneous response of habitat and biota to flow reduction has been assessed. This means that the actual stress requirements FOR SPECIFIC DURATIONS AND DURING SPECIFIC SEASONS to maintain the biota in a certain ecological state has not yet been assessed. The standard process would be to consider the Ecological Category for the instream biota when determining the stress required to maintaining or achieving this ecological state.

For EFR O5, a scenario based approach will however be followed to ensure that synergy with requirements set at EFR O4 (Vioolsdrift) is maintained. The following sequential steps were followed:

EFR O4 results were extrapolated to EFR O5 for the PES and the REC. These flow requirements were converted to stress and the stress index used to interpret whether this stress regime would achieve or maintain the Ecological Categories. Any adjustment in the requirements was recommended and the stress and flow regime adjusted accordingly. These changes were motivated accordingly. The step by step procedure is provided below:

- determine the stress index for fish and invertebrates at EFR O5;
- extrapolate the EFR O4 PES and REC flow requirements to EFR O5;
- use the stress index of EFR O5 and convert the natural, and present day, as well as the EFR O4 PES EFR and EFR O4 REC requirements to stress;
- present to specialists who will determine whether these flows will maintain the PES and whether the identified improvements will achieve the REC;
- if adjustments are to be made, then these will be provided to the HFSR hydrologist to adjust the stress and resulting flow requirements;
- motivate the reasons for the changes;
- consider high flows (see next section).

B.2 High flows

The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and BBM. The high flows determination is outlined below.

- Flood ranges for each flood class and the geomorphology and riparian vegetation functions were identified and tabled by the relevant specialists.
- These were provided to the instream specialists who indicated:
    - which instream function these floods cater for;
    - whether additional instream functions are required;
    - whether any additional flood classes were required.
- The number of floods for each flood class was identified as well as where (early, mid, late) in the season they should occur.
- These numbers of floods were then adjusted for the different Ecological Categories.
- The floods were evaluated by the hydrologist to determine whether they are realistic. A nearby gauge with daily data was used for this assessment. Without this information it is difficult to judge whether floods are realistic.
- The hydrologist then determined the daily average and documented the months in which the floods are spaced.

The floods were entered into the Desktop Reserve Model (DRM) (Hughes and Forsyth, 2006).

For this specific situation, the EFR requirements of EFR O4 were considered in terms of number of events and flood classes as a starting point. The EFR requirements set for the Fish River were also considered and evaluated.

B.3 Final flow requirements

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EFR table, which shows the results of high flows and low flows for each month separately. Floods with a frequency higher than once a year (1:1) are often not included as they cannot be managed.
- An EFR rule table which provides the recommended EFR flows as a duration table, showing flows which should be provided when linked to a natural trigger (modelled natural hydrology in this case). EFR rules are supplied for total flows as well as for low flows only.

The low flow EFR rule table is useful for operating the system, whereas the EFR table must be used for operation of high flows

Appendix C Environmental flow requirement: Flow duration tables

Table C1. EFR O5: Assurance rules (mean monthly m³/s) for PES: B/C

Desktop Version 2, Printed on 2013/02/05 Regional Type: Vaal PES = B/C
Data are given in m³/s mean monthly flow

Month	***% Points***									
	10%	***20%***	***30%***	***40%***	***50%***	***60%***	***70%***	***80%***	***90%***	***99%***
Oct	19.455	19.247	18.863	18.183	17.035	15.214	12.547	9.063	5.254	2.508
Nov	65.21	58.599	52.641	46.787	36.789	31.191	23.927	15.97	9.113	3.306
Dec	80.362	70.539	61.798	53.229	39.833	31.95	22.964	14.652	8.788	6.131
Jan	94.095	82.061	71.105	59.937	43.81	33.27	22.723	14.369	9.357	7.347
Feb	178.144	149.066	123.701	99.227	66.656	48.078	31.695	20.386	14.41	12.192
Mar	156.519	150.135	136.824	115.102	87.354	59.606	37.884	24.573	18.189	15.927
Apr	49.497	47.902	44.586	38.953	31.184	22.568	14.97	9.725	6.954	5.924
May	34.954	34.064	32.237	29.037	24.307	18.497	12.683	8.078	5.316	4.208
Jun	23.824	23.355	22.416	20.741	18.113	14.555	10.5	6.749	4.102	2.903
Jul	17.399	17.143	16.646	15.756	14.295	12.136	9.334	6.265	3.621	2.175
Aug	15.684	15.516	15.207	14.659	13.735	12.269	10.123	7.317	4.251	2.041
Sep	12.512	12.409	12.23	11.922	11.402	10.536	9.134	5.883	2.188	0.555
Reserve flows without High Flows										
Oct	19.455	19.247	18.863	18.183	17.035	15.214	12.547	9.063	5.254	2.508
Nov	26.58	26.188	25.428	24.065	21.828	18.522	14.234	9.536	5.487	3.273
Dec	30.461	29.861	28.659	26.515	23.151	18.597	13.405	8.603	5.216	3.68
Jan	41.14	40.092	37.941	34.172	28.603	21.761	14.916	9.493	6.24	4.935
Feb	59.566	57.645	53.654	46.873	37.522	27.15	18.004	11.691	8.355	7.116
Mar	55.434	53.218	48.599	41.062	31.433	21.804	14.267	9.648	7.432	6.648
Apr	49.497	47.902	44.586	38.953	31.184	22.568	14.97	9.725	6.954	5.924
May	34.954	34.064	32.237	29.037	24.307	18.497	12.683	8.078	5.316	4.208
Jun	23.824	23.355	22.416	20.741	18.113	14.555	10.5	6.749	4.102	2.903
Jul	17.399	17.143	16.646	15.756	14.295	12.136	9.334	6.265	3.621	2.175
Aug	15.684	15.516	15.207	14.659	13.735	12.269	10.123	7.317	4.251	2.041
Sep	12.512	12.409	12.23	11.922	11.402	10.536	9.134	5.883	2.188	0.555
Natural Duration curves										
Oct	706.187	309.569	217.611	156.519	98.212	64.191	44.605	22.252	10.749	2.595
Nov	805.208	601.728	474.263	354.198	245.224	191.331	158.225	114.363	37.176	3.306

Month	***% Points***									
	10%	***20%***	***30%***	***40%***	***50%***	***60%***	***70%***	***80%***	***90%***	***99%***
Dec	994.388	659.939	506.724	396.744	317.003	284.468	223.029	87.582	49.231	21.001
Jan	1403.872	1016.473	786.376	510.682	382.09	257.68	208.964	130.974	72.405	28.129
Feb	2300.566	1709.974	1229.638	824.417	482.684	362.913	285.189	211.959	132.593	25.765
Mar	1869.067	1069.474	744.004	656.25	538.777	350.317	277.666	203.409	148.309	42.832
Apr	962.813	876.034	474.672	353.646	302.431	247.5	193.769	146.231	100.536	26.424
May	367.182	276.96	220.154	157.672	118.492	107.116	79.025	48.596	30.597	6.803
Jun	186.485	141.049	92.886	72.184	57.681	54.414	45.71	30.077	17.662	7.928
Jul	147.991	100.553	80.276	59.054	41.237	33.819	28.342	21.39	14.639	10.055
Aug	158.065	112.351	82.131	53.566	34.476	24.739	20.845	17.365	12.227	7.781
Sep	213.492	130.305	73.453	52.558	37.681	24.41	14.892	5.883	2.188	2.033

Table C2. EFR O5: Assurance rules (mean monthly m³/s) for PES: B

Desktop Version 2, Printed on 2013/02/05 Regional Type: Vaal REC = B
Data are given in m³/s mean monthly flow

Month	***% Points***									
	10%	***20%***	***30%***	***40%***	***50%***	***60%***	***70%***	***80%***	***90%***	***99%***
Oct	35.029	34.703	33.945	32.348	29.346	24.417	17.605	10.149	4.433	2.595
Nov	82.375	75.887	69.985	63.895	52.943	45.132	34.106	21.411	10.558	3.306
Dec	98.92	89.011	79.852	70.14	54.426	42.912	29.59	17.562	9.761	7.119
Jan	110.193	100.083	90.458	79.82	62.561	48.939	33.367	19.61	11.021	8.511
Feb	197.552	171.659	147.54	122.307	86.217	62.628	40.706	25.197	17.344	15.534
Mar	161.171	153.882	138.537	113.892	83.701	55.485	35.368	24.428	19.891	18.947
Apr	71.412	69.309	64.908	57.189	46.005	32.858	20.642	11.999	7.622	6.613
May	52.044	51.22	49.379	45.787	39.768	31.305	21.63	13.082	7.746	6.186
Jun	39.877	39.25	37.858	35.15	30.611	24.191	16.764	10.058	5.709	4.235
Jul	30.665	30.401	29.8	28.559	26.244	22.432	17.051	10.856	5.559	3.096
Aug	29.593	29.322	28.69	27.36	24.859	20.754	15.08	8.87	4.109	2.747
Sep	30.715	30.575	29.966	28.505	25.455	20.092	12.551	4.848	0.192	0.192
Reserve flows without High Flows										
Oct	35.029	34.703	33.945	32.348	29.346	24.417	17.605	10.149	4.433	2.595
Nov	43.614	43.229	42.357	40.553	37.19	31.651	23.833	14.832	7.137	3.306
Dec	48.908	48.131	46.407	43.053	37.43	29.478	20.278	11.972	6.584	4.759
Jan	60.182	59.212	57.043	52.81	45.719	35.746	24.347	14.276	7.988	6.151
Feb	85.176	82.754	77.684	68.791	55.906	40.76	26.686	16.729	11.687	10.524
Mar	69.877	66.8	60.319	49.912	37.162	25.247	16.752	12.132	10.216	9.817
Apr	71.412	69.309	64.908	57.189	46.005	32.858	20.642	11.999	7.622	6.613
May	52.044	51.22	49.379	45.787	39.768	31.305	21.63	13.082	7.746	6.186

Month	***% Points***									
	10%	***20%***	***30%***	***40%***	***50%***	***60%***	***70%***	***80%***	***90%***	***99%***
Jun	39.877	39.25	37.858	35.15	30.611	24.191	16.764	10.058	5.709	4.235
Jul	30.665	30.401	29.8	28.559	26.244	22.432	17.051	10.856	5.559	3.096
Aug	29.593	29.322	28.69	27.36	24.859	20.754	15.08	8.87	4.109	2.747
Sep	30.715	30.575	29.966	28.505	25.455	20.092	12.551	4.848	0.192	0.192
Natural Duration curves										
Oct	706.187	309.569	217.611	156.519	98.212	64.191	44.605	22.252	10.749	2.595
Nov	805.208	601.728	474.263	354.198	245.224	191.331	158.225	114.363	37.176	3.306
Dec	994.388	659.939	506.724	396.744	317.003	284.468	223.029	87.582	49.231	21.001
Jan	403.872 1	16.473	786.376	510.682	382.09	257.68	208.964	130.974	72.405	28.129
Feb	300.566 1	709.974 1	229.638	824.417	482.684	362.913	285.189	211.959	132.593	25.765
Mar	869.067 1	69.474	744.004	656.25	538.777	350.317	277.666	203.409	148.309	42.832
Apr	962.813	876.034	474.672	353.646	302.431	247.5	193.769	146.231	100.536	26.424
May	367.182	276.96	220.154	157.672	118.492	107.116	79.025	48.596	30.597	6.803
Jun	186.485	141.049	92.886	72.184	57.681	54.414	45.71	30.077	17.662	7.928
Jul	147.991	100.553	80.276	59.054	41.237	33.819	28.342	21.39	14.639	10.055
Aug	158.065	112.351	82.131	53.566	34.476	24.739	20.845	17.365	12.227	7.781
Sep	213.492	130.305	73.453	52.558	37.681	24.41	14.892	5.883	2.188	2.033