Annex J

Environmental Flow Report

BATOKA GORGE HYDRO-ELECTRIC SCHEME

ENVIRONMENTAL FLOW ASSESSMENT

VOLUME 1 (of 2): UPDATED MAIN REPORT (FINAL)

For

ERM Southern Africa

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This report was edited by

Brown, Cate (Southern Waters)

With input from (in alphabetical order):

Birkhead, Andrew (Streamflow Solutions)
Brown, Cate (Southern Waters)
Ewart-Smith, Justine (Freshwater Consulting Group)
Joubert, Alison (Southern Waters)
Reinecke, Karl (Southern Waters)
Rountree, Mark (Fluvius Environmental Consultants)
Tweddle, Denis (SAIAB)

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LIST OF ACRONYMS

Acronym	Description
AddPM	Additional Scenarios, Post Meeting
BGHES	Batoka Gorge Hydro-Electric Scheme
DO	Dissolved Oxygen
DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
EF	Environmental Flow(s)
ERM	Environmental Resources Management Southern Africa (Pty) Ltd.
ESIA	Environmental and Social Impact Assessment
FSL	Full Supply Level
GAI	Geomorphological Assessment Index
HPP	Hydropower Project
IUCN	International Union for Conservation of Nature
km	Kilometer(s)
m	Meter(s)
mamsl	Meters Above Mean Sea Level
masl	Meters Above Sea Level
Mm	Megameters
MW	Megawatt
PES	Present Ecological State
SAIAB	South African Institute for Aquatic Biodiversity
SASS5	South African Scoring System Version 5
Sc	Scenario
SP	Studio Pietrangeli
VEGRAI	Vegetation Response Assessment Index
ZISS	Zambian Scoring System
ZRA	Zambezi River Authority

1 INTRODUCTION

1.1 BACKGROUND

The Inception Report for the ESIA (ERM et al. 2014) provides a comprehensive summary of the historical background to the Batoka Gorge Hydro-Electric Scheme (BGHES).

Zambezi River Authority (ZRA) has commissioned Environmental Resources Management (ERM), in association with Kaizen Consulting (Zambia) and Black Crystal Consulting (Zimbabwe) to produce an updated Environmental and Social Impact Assessment (ESIA) to inform the Governments of Zambia and Zimbabwe, the ZRA, national power utilities, interested and affected parties and other stakeholders about potential environmental and social impacts associated with development of the BGHES. These will include evaluation of potential impacts at the dam site and surrounding areas, the reservoir inundation area, any upstream and or downstream impacts, as well as those from associated infrastructure, such as transmission lines, and operations infrastructure.

As part of the ESIA, Southern Waters was commissioned by ERM to undertake an Environmental Flows (EF) assessment for the downstream riverine ecosystem between the BGHES and Kariba Dam.

This report (Volume 1 of 2) summarises the outcome of the EF assessment. Additional details are available in the specialist reports (Volume 2) and in the DRIFT (Downstream Response to Imposed Flow Transformations) DSS (Decision Support System) populated for this project (see Section 1.4). The main body of the report was completed as part of the ESIA in December 2014. The outcome of a subsequent process to refine and agree on operating rules for the proposed BGHES is presented in Appendix A.

1.2 THE PROPOSED BATOKA GORGE HYDRO-ELECTRIC SCHEME

The proposed BGHES is located on the middle Zambezi River (Figure 1.1) at 18º1'S ; 26º 34' E, in the central portion of the Zambezi River Basin, c. 47 km downstream of Victoria Falls. It will be positioned in a steep-sided gorge, with the inundated area of the reservoir contained within the gorge, stopping just short of the falls themselves. The development will extend across the international boundary between Zambia and Zimbabwe, with a power house and tailrace on each bank. The proposed high-arch gravity dam wall will be 177 m high (SP 2014). The full supply level (FSL) of the reservoir is tentatively set at 757 masl. After impoundment to the FSL, the reservoir surface area will cover approximately 23 km^2. The most recent principal data for the scheme are provided in Table 1.1.

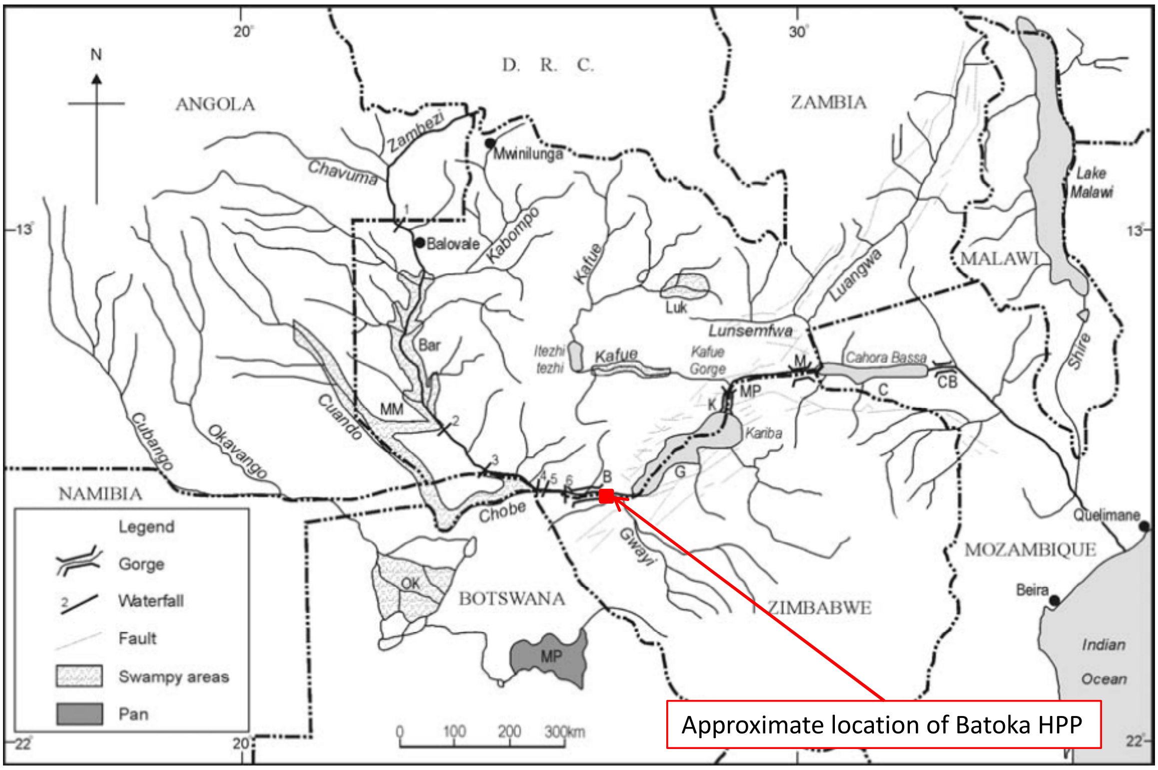

Figure 1.1 **Zambezi River basin (Source: Moore *et al.* 2007).**

Table 1.1 **Principal data for the recommended design proposed for the BGHES on the Zambezi River (SP 2014)**

Reservoir	Catchment area	508 000 km^2
	Full supply level	757 masl
	Minimum operation level	746 masl
	Total storage	1392 Mm^3
	Surface area at FSL	23 km^2
	Volume at FSL	1392 Mm^3
Spillway	Located at about two kilometres from the dam site, at the end of a canal about 2.5 km long, which will link the reservoir with a gorge parallel to the Zambezi river on the south side.	
Dam	Type	Roller Compacted Concrete Gravity Arch
	Height	177 m
	Crest length	720 m
	Crest elevation	762 mamsl
Power Station	Type	Two outdoor and above-ground power stations, located at the dam toe, one on north and one on south bank.
	Installed capacity	2400 MW
	Turbines	12 Francis turbines each with 200 MW of installed capacity

The design of the BGHES is still being finalized. The summary characteristics provided in Table 1.1 are the latest proposals for design (SP 2014), and we developed after the EF assessment was well underway. They include an adjustment to the spillway design that may affect the downstream river, *viz*: *the spillway will be located at about two kilometres from the dam site, at the end of a canal about 2.5 km long, which will link the reservoir with a gorge parallel to the Zambezi River on the south side*. This new spillway design was not evaluated as part of this EF study. However, it will be evaluated the overall assessment should it remain a preferred engineering option.

1.3 THE ENVIRONMENTAL FLOW ASSESSMENT

1.3.1 Objectives

The objectives of the EF assessment were:

- To evaluate location, design criteria and proposed operating procedures for the BGHES to assess any impacts associated with potential changes to the natural flow regimes of the Zambezi River from upstream of the BGHES to Lake Kariba.
- To evaluate how the condition of the river could change under different operational scenarios for the proposed BGHES, and define the environmental boundary conditions downstream of the BGHES, and recommend required water release during reservoir filling and operation of the BGHES.

1.3.2 Scope of Work

Southern Waters' Scope of Work was to:

- Delineate the river within the study area and select representative sites for the EF assessment.
- Provide input to the selection of scenarios for the EF assessment.
- Collect/collate primary and secondary data for the configuration of the Downstream Response to Imposed Flow Transformations (DRIFT) EFs assessment model.
- Incorporate the hydrological data provided by ERM into the DRIFT model and select ecologically-relevant flow indicators.
- Model and incorporate the ecohydraulic relationships based on survey data from EF Sites 1 and 2 into the DRIFT model.
- Select discipline indicators for the DRIFT model.
- Set up, populate and calibrate the DRIFT Decision Support System.
- Simulate scenarios.
- Present results in a report.

The Scope of Work was restricted to an assessment of the riverine biophysical aspects within the direct influence of the BGHES, and did not include an assessment of the consequent social and economic impacts of the project.

All of the local and international EF team members visited the Zambezi River upstream and downstream of the proposed BGHES between the 1st and 5th of September 2014. Thereafter (27th -31st October 2014), the population and calibration of the DRIFT Decision Support System was completed in a workshop situation in Cape Town.

1.3.3 The EF assessment process

DRIFT is a holistic EF assessment approach (Brown *et al.* 2013) that, in this project, was applied at the level of the direct influence of the proposed BGHES. This is essentially the Zambezi River from the location of the proposed BGHES dam wall to Kariba Dam. The objective was to describe the present condition of the river ecosystem and then, through scenarios, to predict how this could change with different design and operation of the BGHES.

Changes in the hydrological regime drive the assessment process. Each scenario would change flow conditions along the river in a different way, with possible different repercussions for the river system. Once these hydrological changes have been simulated, then the DRIFT software provides predictions of the consequent changes in the biotic and abiotic aspects of the river.

1.3.4 Team

The EF team members are listed in Table 1.2.

Table 1.2 EF team members

Name	Organisation	Position on team
Mr Tim Smith	ERM	ERM Task Leader
Dr Cate Brown	Southern Waters	EF Task Leader
Dr Alison Joubert	Southern Waters	DRIFT DSS
Dr Ed Buchak	ERM	Hydrology/Scenarios
Dr George Krallis	ERM	Water Quality
Dr Andrew Birkhead	Streamflow Solutions	Ecohydraulic modeling
Dr Denis Tweddle	SAIAB	Fish ecology
Mr Mark Rountree	Fluvius Consultants	Geomorphology
Dr Justine Ewart-Smith	Freshwater Consulting Group	Macroinvertebrates
Dr Karl Reinecke	Southern Waters	Riparian vegetation

1.4 THIS REPORT

This report is Volume 1 of two volumes:
Volume 1: Environmental Flow Assessment: Main Report (*this report*)
Volume 2: Specialists' Report (*due February 2015*).

Volume 1 provides the results for a suite of scenarios that reflect potential operation of BGHES, and were selected in discussion with the ERM and the Client. Each scenario comprises of a different permutation of design and operation options for BGHES. The report is intended to provide information on the ecological response to each of these for consideration during discussion and eventual setting for the EF releases for the proposed BGHES and informing the ESIA.

The layout of this report is as follows:

Section 0: Background to the river, study objectives and Scope of Work.
Section 2: Summary of Zambezi River to provide the geographic context of the proposed BGHES.
Section 3: The location and Present Ecological Status of the EF sites.
Section 4: DRIFT biophysical indicators.
Section 5: Scenarios assessed and the hydrological data on which the assessment was based.
Section 6: Rules for defining the four ecological seasons in the Zambezi River and other considerations that apply to the scenarios, such as sediment, connectivity, the concept of minimum degradation and uncertainty.
Section 7: The predicted changes in individual biophysical indicators and overall ecosystem integrity for the reach of the Zambezi River represented by each EF site.
Section 8: Summary of the results for all sites and all scenarios.
Section 10: Conclusions.
Section 12: References.

Appendix A: Additional analyses for the refinement of operating rules
Appendix B: An overview of DRIFT

2 THE ZAMBEZI RIVER

The Zambezi River (Figure 2.1) is the fourth largest floodplain river in Africa. It rises in north-west Zambia close to the border between Zambia, Angola and Democratic Republic of the Congo, and flows to the Indian Ocean in Mozambique some 2 700 km downstream. The river enters the sea through a mosaic of alluvial grassland and swamp forest (the Marromeu Complex) some 100 km inland from the coast, and a mangrove–deltaic system with a sea frontage of about 290 km (Tinley and Sousa Dias 1973). Its basin covers about 1,390,000 km² and drains the land of eight countries: Angola; Namibia; Zambia; Botswana; Zimbabwe; Malawi; Tanzania, and; Mozambique (Figure 2.1).

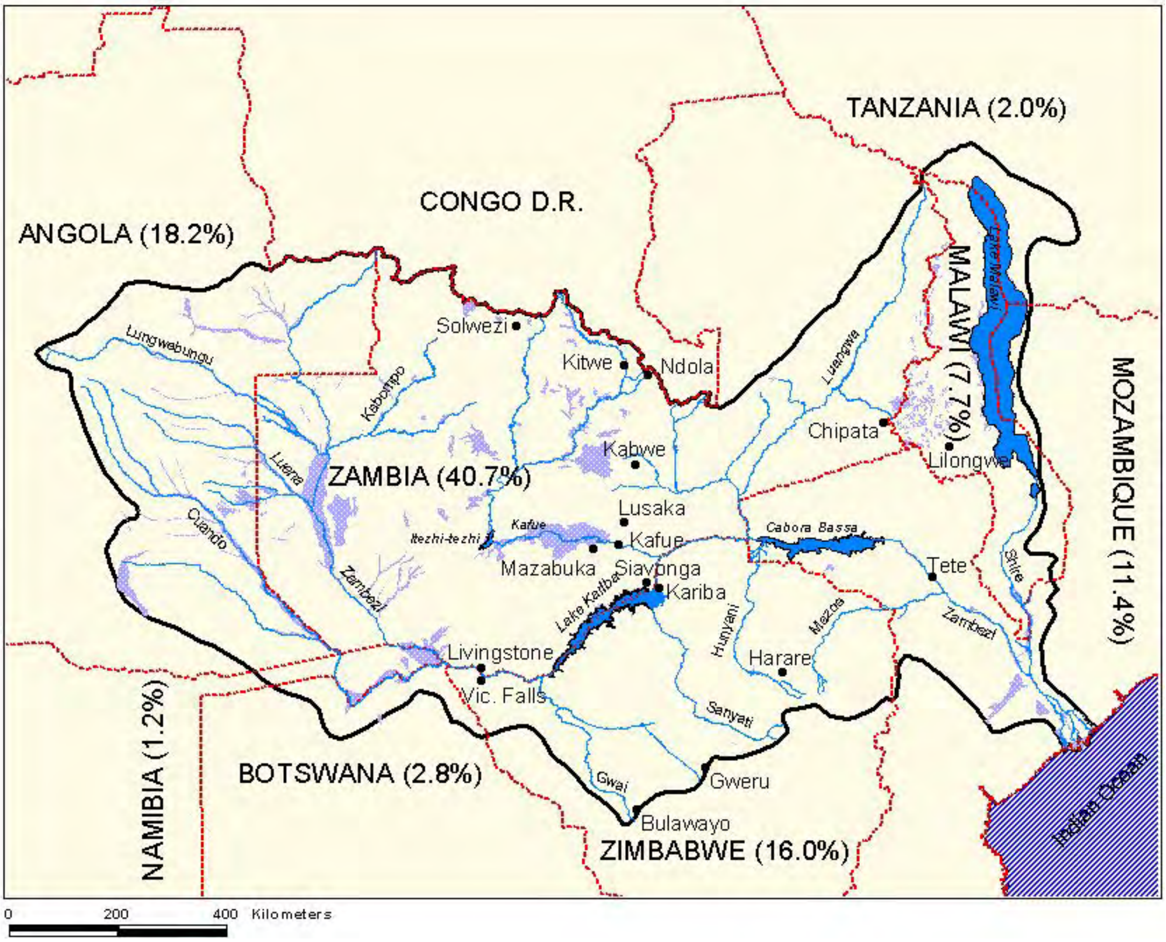

Figure 2.1 The Zambezi River Basin (Zambezi River Authority)

The River carries more than 75% of the mean annual runoff of the region's interior, and drains more than 40% of the landmass. Almost 33% of the total population of the riparian countries lives in the basin (ZRA 2008). Demand for water is increasing with population and economic growth. The Zambezi is not only an area of astounding natural beauty and biodiversity, but also a source of water, food, electricity, transport, communication and recreation for millions of people (ZRA 2008).

There are several major tributaries along the course of the Zambezi River, which contribute towards an average annual runoff of 107.6 km^3 (Table 2.1).

Table 2.1 Estimated mean annual runoff for Zambezi sub-basins (after Beilfuss et al. 2001).

Sub-Basin	Catchment Area (km2)	Mean Annual Discharge ± 95% C.I. (m^3/s)	Mean Annual Runoff ± 95% C.I. (km^3)
Upper Zambezi	507,200	1046 ± 815	32.9 ± 25.7
Gwembe Valley	156,600	222 ± 196	7.2 ± 6.2
Total to Kariba Gorge	**663,800**	**1268 ± 997**	**40.1 ± 31.4**
		Volume of Kariba Reservoir	*180 km^3*
Kafue River	154,200	285 ± 279	9.0 ± 8.8
Luangwa River and others	232,000	888 ± 818	28.0 ± 25.8
Total to Cahora Bassa Gorge	**1,050,000**	**2442 ± 1917**	**77.1 ± 60.4**
		Volume of Cahora Bassa	*52 km^3*
Plateau Tributaries	177,500	412 ± 365	13.0 ± 11.5
Shire Basin	154,000	539 ± 422	17.0 ± 13.3
Zangue Basin	8,500	16 ± 14	0.5 ± 0.4
Total to Zambezi Delta	**1,390,000**	**3424 ± 2675**	**107.6 ± 84.4**

An extensive review of the ecological setting of the Zambezi River can be found in Davies (1986).

2.1 *DELINEATION OF THE ZAMBEZI RIVER*

The physical structure of a river ecosystem is determined by geomorphological processes which shape the channel. These processes determine the material from which the channel is formed, the shape of the channel and the stability of its bed and banks. The channel geomorphology in turn determines the substrate conditions for the riverine fauna and flora and the hydraulic conditions for any given flow. Structural changes to the river channel may be caused by changes in the riparian area, sediment inputs from catchment erosion or reservoir induced changes in the flow regime, all of which can cause long-term irreversible effects for biota (Kochel 1988; O'Keeffe 2000). Geomorphology thus provides an appropriate basis to classify the physical habitat of riparian and aquatic ecosystems.

The aim of geomorphological classification is to subdivide the river's longitudinal profile into morphologically uniform units, so that sites may be selected within these uniform units to facilitate predictions of expected changes. Channel slope is well correlated with many physical habitat descriptors including channel planform, bed material and assemblages of morphological units (Rowntree et al. 2000). Changes in slope down the longitudinal profile are usually correlated with morphological changes and these provide the basis for the zone delineation. These breaks are usually due to changes in lithology, but can also be as a result of tectonic activity or the upstream migration of 'knick' points (Dollar 1998). Rowntree et al. (2000) presented a hierarchical classification system for South African rivers based partly on slope characteristics. This scale-based framework links various components of the river system, ranging from the catchment to the instream habitat (Table 2.2). The classification system describes six hierarchical levels:

- the catchment,
- the segment,
- the zone,
- the reach,
- the morphological unit and
- the hydraulic biotope.

Table 2.2 Definition of geomorphological classification levels (after Rowntree et al. 2000)

Hierarchical unit	Description	Scale
Catchment	The catchment is the land surface which contributes water and sediment to any given stream network.	Can be the whole river system, from source to mouth, or a lower order catchment above a specified point of interest.
Segment	A segment is a length of channel along which there is no significant change in the flow discharge or sediment load.	Segment boundaries will tend to be co-incident with major tributary junctions.
Longitudinal zone	A zone is a sector of the river long profile which has a distinct valley form and valley slope.	Sectors of the river long profile.
Reach	The reach is a length of channel characterised by a particular channel pattern and morphology that results from a uniform set of local constraints on channel form.	100s of meters.
Morphological Unit	The morphological units are the basic structures recognised by fluvial geomorphologists as comprising the channel morphology and may be either erosional or depositional features.	Morphological units occur at a scale of an order similar to that of the channel width.
Hydraulic biotope	Hydraulic biotopes are spatially distinct instream flow environments with characteristic hydraulic attributes.	Hydraulic biotopes occur at a spatial scale of the order of 1 m^2 to 100 m^2 and are discharge dependent.

This classification system was used to describe the macro- and regional scale characteristics of the study area in the middle Zambezi River segment. Reach, morphological unit and hydraulic biotope classifications may be applied to the two EF Sites, based largely on field assessment backed up by reference to available satellite imagery such as Google Earth.

The geomorphological segments and zones were used to guide the spatial framework for the study, the location of the two EF Sites, the site visits for detailed study and the determination of habitat integrity at the EF Sites. Information derived from the field study at the EF Sites may be scaled up to the zone to obtain a broad overview of likely condition and impacts for the entire study area.

2.1.1 Geomorphological zones of the Upper Zambezi River and the study area

The longitudinal zonation of southern African rivers reflects regional geology, tectonic events and long term fluvial action, which together have affected the shape of their long profiles. The classic concave long profile may be disrupted by a number of features including outcrops of more resistant rock and rejuvenation due to tectonic uplift or a fall in sea-level, river capture or the presence of a highly resistant lithology.

The Zambezi River flows over a distance of 3000 km from its source in the Kalene Hills in Zambia at 1585 m above sea level down to the delta at the Indian Ocean in Mozambique (ZRA 1998). The Upper Zambezi River segment drains south-eastern Angola and northern Zambia into the Barotse Floodplain, an extensive floodplain over a distance of 500 km that ends at Ngonye Falls (Figure 2.2). Downstream of this, the river gradient begins to steepen culminating in the dramatic Victoria Falls. The study area, situated in the Middle Zambezi River segment, is from Victoria Falls to the full supply level of Lake Kariba (Figure 2.3). Below the falls, the gradient steepens and the river flows over cascades and rapids through Batoka Gorge. After the gorge, the valley widens and the river consists of wide/deep pools that flow around vegetated islands before the impoundment of Lake Kariba backs the water up.

The study area, downstream of Victoria Falls, was divided into three geomorphological zones based on slope, valley width and confinement, the presence and diversity of morphological units, and tributary inflows as these bring in both flow events and sediment loads to the gorge area (Figure 2.4). These are the Upper Gorge, the Lower Gorge and the Rejuvenated Cascades zones. A description of the river through these three zones is provided in Table 2.3.

The BGHES (Figure 2.5) and EF Site 1 (Figure 2.6) are situated in the Upper Gorge zone, which is characterised by a confined channel (maximum width 180 m) with a moderate to steep gradient and limited development of lateral alluvial features. The reaches of this zone comprise combinations of bedrock falls, cascades and pool-rapid morphological units. There are few sandy alluvial deposits since there are few tributary inputs. Due to this there are few/no marginal graminoids present. The riparian area is narrow and patchy and comprises riparian trees along the channel situated at elevations above the median flood stage. This zone is approximately 100 km long.

The river channel through the Lower Gorge (Figure 2.7) is similar to that of the Upper Gorge in being a confined channel with a moderate to steep gradient and with limited lateral alluvial features. It differs in being wider (maximum width 250 m) and with an increase in the frequency of alluvial sandy deposits due to the presence of a number of tributary junctions. The reaches of this zone comprise combinations of bedrock falls, cascades and pool-rapid morphological units.

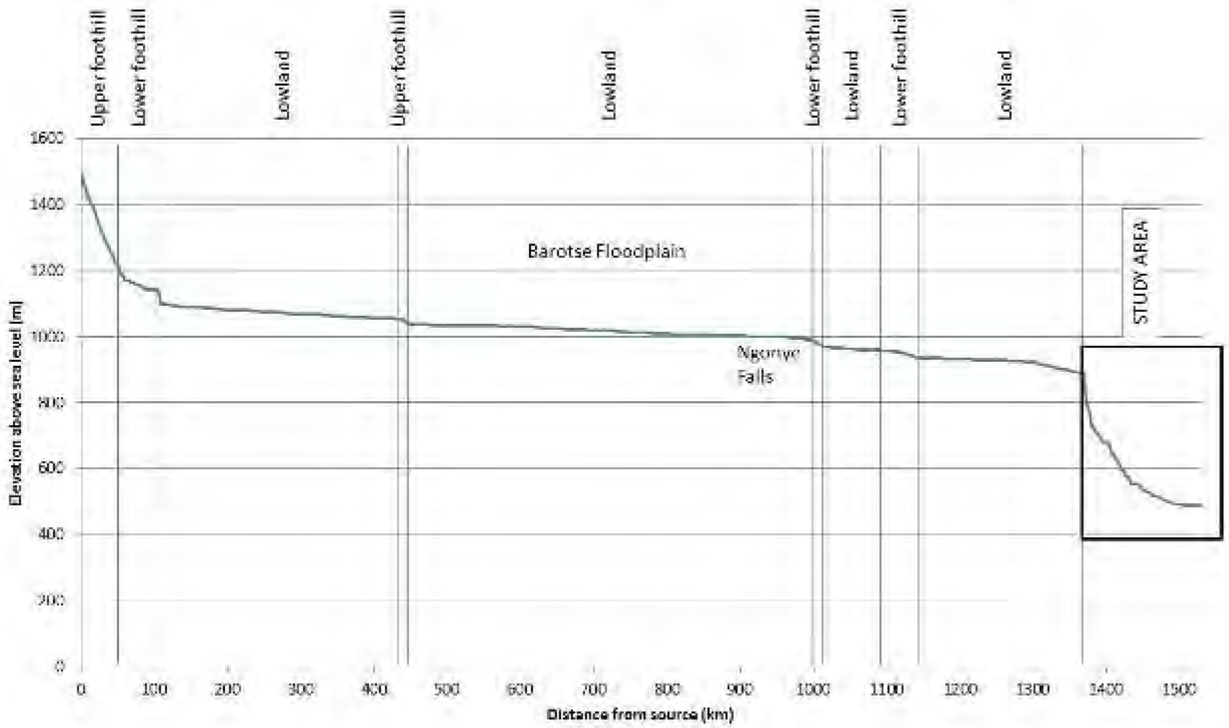

Figure 2.2 **Longitudinal profile of the Upper Zambezi River with geomorphological zones (Rowntree et al. 2000) from its source to Victoria Falls, the upper limit of the study area.**

Figure 2.3 Overview of the study area and location of the EF Sites in relation to Victoria Falls, BGHES, the end of the gorge and Lake Kariba.

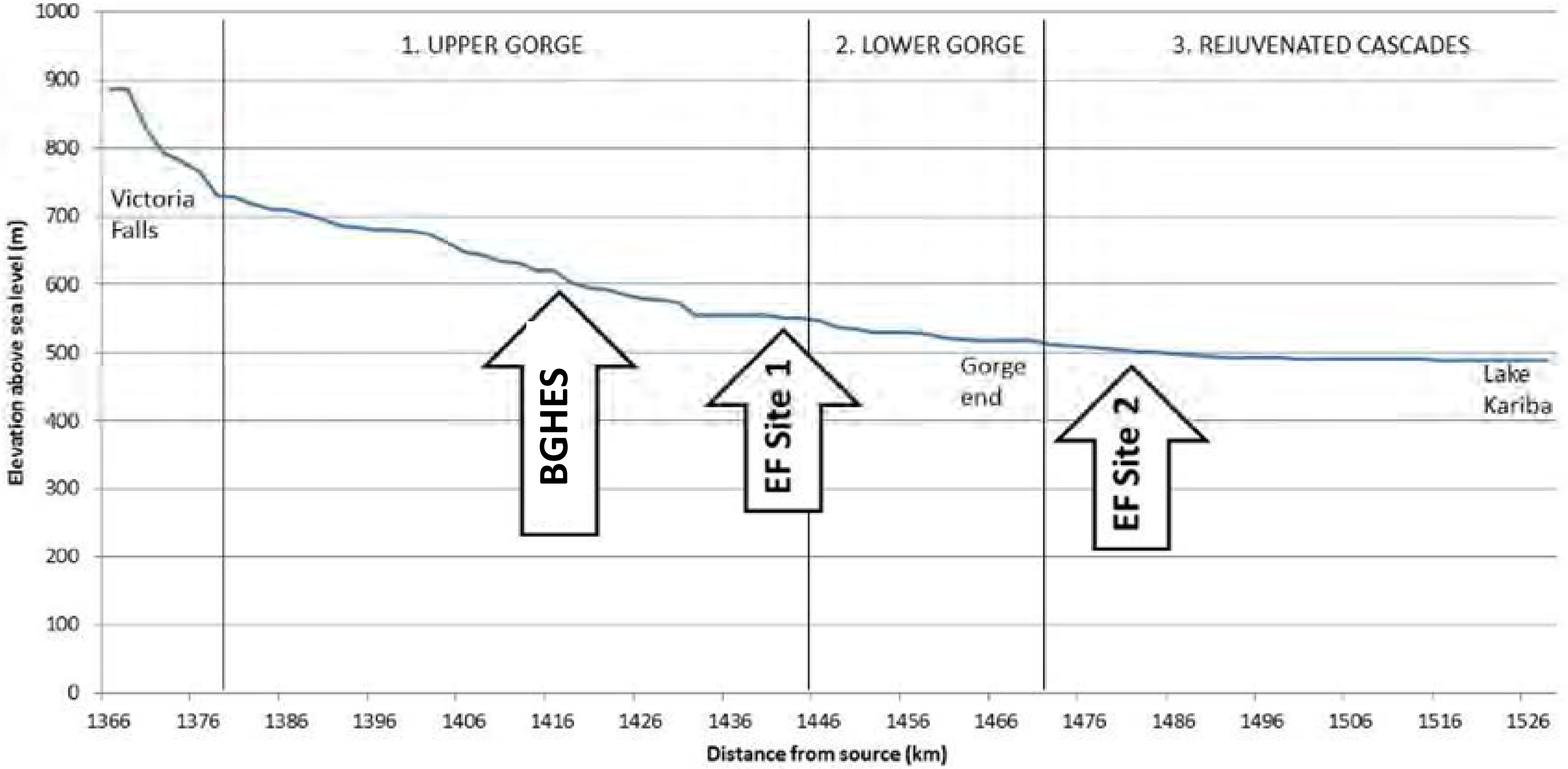

Figure 2.4 **Longitudinal profile of the study area with geomorphological zones (Rowntree et al. 2000) in relation to the location of Victoria Falls, the BGHES, EF Sites 1 and 2 and Lake Kariba.**

Table 2.3 **Descriptions of zones in the study area (Rowntree et al. 2000), river slopes and approximate width/length**

No	Zone name and description	Slope	Maximum channel width (m)	Zone length (km)
1	*Upper Gorge - no tributary inputs: BGHES and EF Site 1* Moderate to steep gradient, confined channel (gorge) with limited lateral development of alluvial features. Morphological units include bedrock fall, cascades and pool-rapid. There are few sandy alluvial deposits but no riparian plants establish there. A narrow riparian area consists of trees in patches along the channel but no reeds at the channel edge.	0.0021	180	100
2	*Lower Gorge - some tributary inputs* Moderate gradient with a wider yet still confined channel (gorge) with limited lateral development of alluvial features. Morphological units include bedrock fall, cascades and pool-rapid. Alluvial sand deposits provide some habitat for riparian trees and there are likely to be some marginal graminoids present[1]. The riparian area is narrow.	0.0016	250	24
3	*Rejuvenated cascades - widened river valley: EF Site 2* Moderate gradient, still within a confined channel, but wider and less steeply sloping banks. Limited lateral development of alluvial features. Morphological units include cascades, pool-rapid, gravel bars, sand bars and vegetated islands. The riparian area remains narrow and consists of a fringing zone of marginal graminoids (reeds) and a narrow band of riparian trees along the channel.	0.0010	550	24

Alluvial sandy deposits provide some habitat for riparian trees and it is likely that there are a greater abundance of marginal graminoids here. The overall extent of the riparian area remains narrow and patchy with the majority of species being found at elevations higher than the median flood stage. This zone is shorter and occurs over a distance of 24 km ending where the gorge ends and the valley widens.

EF Site 2 is located in the Rejuvenated Cascades zone (Figure 2.8) in a widened river valley. The river flows within a confined channel over a moderate gradient but with wider and less sloping banks. This zone, like the two upstream, is also characterised by limited

[1] The extent to which marginal graminoids were present in this zone could not be determined accurately due to the poor image quality available of Google Earth.

development of alluvial features and combinations of cascades and pool-rapids morphological units. It differs with the presence of gravel bars, sand bars and vegetated islands that provide a greater variety of riparian habitats for reeds, shrubs and trees. Marginal graminoids comprise a far greater proportion of the riparian area when compared to the gorge upstream.

Figure 2.5 Zone 1: Upper Gorge at BGHES.

Figure 2.6 Zone 1: Upper Gorge with EF Site 1.

Figure 2.7 Zone 2: Lower Gorge with tributary inputs.

Figure 2.8 Zone 3: EF Site 2.

3 *THE EF SITES*

3.1 *INFLUENCE OF THE BGHES ON FLOWS IN THE ZAMBEZI RIVER*

The design and location of the BGHES means that its potential impacts on the flow and sediment regime in the downstream Zambezi River will limited to the river reach between the BGHES and Lake Kariba, where after any changes in the daily or monthly distribution of flows will be absorbed by the Kariba impoundment. Flow in the river downstream of Kariba Dam will be influenced by the operating rules of Kariba rather than those of the proposed BGHES. It is however possible that operation of Kariba Dam will change as a result of the construction of BGHES (see comment in Section 10).

3.2 *LOCATION OF EF SITES*

The BGHES EF assessment concentrated on two sites on the Zambezi River between the proposed BGHES and Kariba Dam (Table 3.1; Figure 3.1; Figure 3.2; Figure 3.3). The sites were selected considering:

- geomorphologically different river reaches (See Section 2.1);
- biological variations along the length of the river;
- different types and levels of impacts likely to be incurred as a result of the BGHES location and operation;
- access and safety.

Table 3.1 EF sites for the BGHES EF assessment.

Site No.	Site	Description	Coordinates[2]
1	EF Site 1	Represents the Zambezi River in Batoka Gorge from downstream of the tailrace of the proposed BGHES to the end of the gorge	17°56'17.45"S 26°18'34.37"E
2	EF Site 2	Represents the Zambezi River from the end of Batoka Gorge to Lake Kariba.	18° 3'21.62"S 26°38'33.05"E

The flow regimes at the EF sites will be affected by BGHES in three main ways (see also Section 5).

- EF Site 1 (Figure 3.2) represents the Zambezi River within Batoka Gorge. It will be affected by releases from the BGHES tailrace. It will also be affected by the barrier

[2] Coordinate System WGS 84.

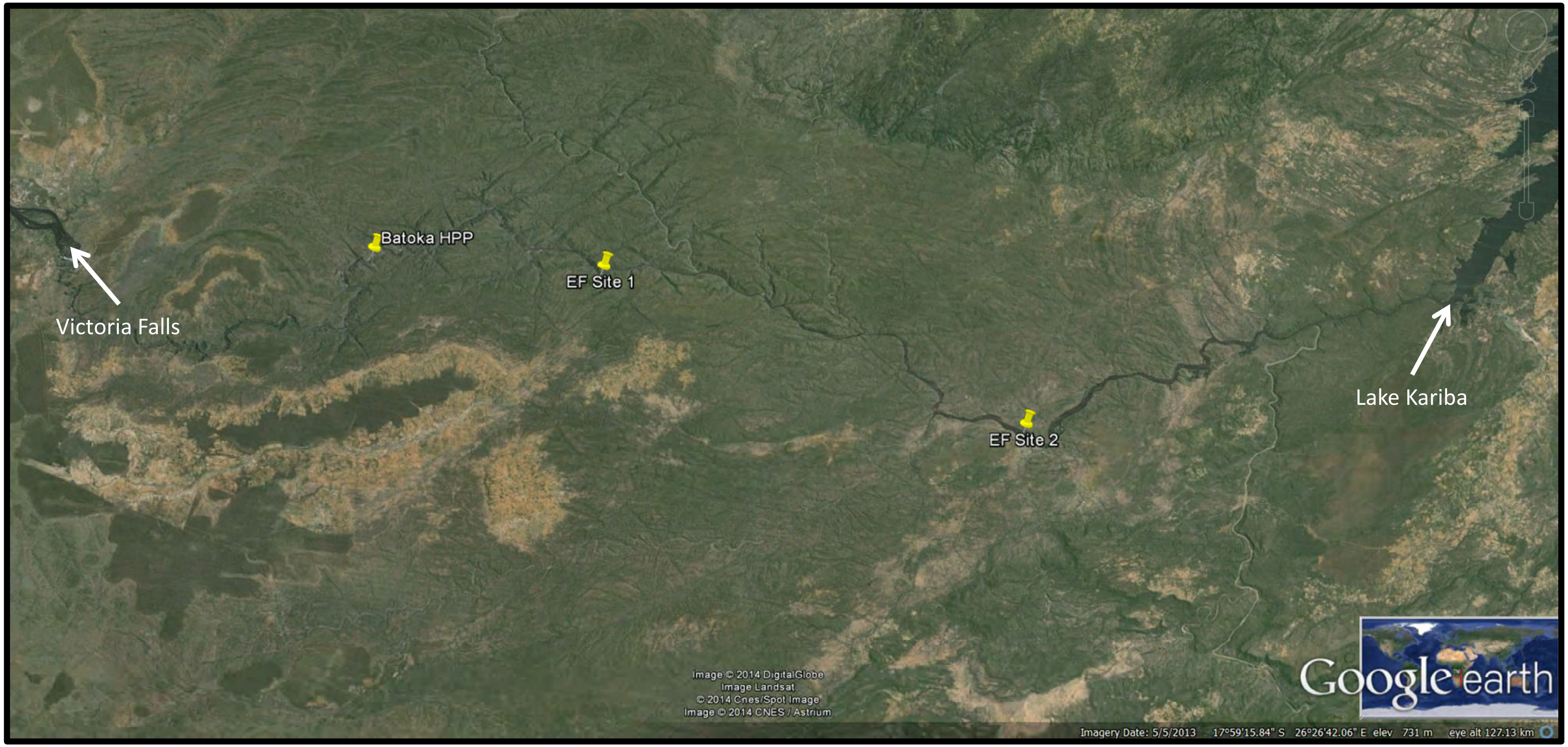

Figure 3.1 The Zambezi River between Victoria Falls and Lake Kariba, showing the approximate position of the BGHES, and EF Sites 1 and 2.

effect of the BGHES dam wall, which will have consequences as mentioned above and will also alter the thermal, sediment and physicochemical regimes along the river downstream of the dam.

- EF Site 2 (Figure 3.3) represents the Zambezi River between Batoka Gorge and Lake Kariba. It will be affected by releases from the BGHES tailrace and by the barrier effect of BGHES dam wall and will be used to predict any anticipated recovery of the river ecosystem with distance downstream of the BGHES.

Figure 3.2 **EF Site 1 in the Batoka Gorge at the site of the BGHES dam wall**

Figure 3.3 **EF Site 2, c. 46 km downstream of BGHES and 3 km upstream of the full supply level of Kariba Dam.**

The data collected for EF Site 1 were in fact collected at the location of the proposed BGHES dam wall. However, the EF Site represents the Batoka Gorge from downstream of BGHES to the end of the gorge and, as such, is shown some distance downstream of the tailrace in (Figure 3.2).

In addition, although not evident in Figure 3.1, on occasion, the backup of water from Kariba Dam extends to the Hwange Fishing and Boating Club, which is located c. 3 km downstream of EF Site 2.

Additional detail on the discipline-specific aspects of the EF sites is given in Volume 2.

3.3 PRESENT DAY ECOLOGICAL CONDITION OF THE EF SITES

Definitions of the Present Ecological State (PES) categories are given in Table 3.2.

Table 3.2 Definitions of the Present Ecological State (PES) categories (after Kleynhans 1996)

Ecological category	Description of the habitat
A	Unmodified. Still in a natural condition.
B	Near natural. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Critically modified. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.

The Present Ecological Status of the sites is provided in Table 3.3, with discipline specific details available in Volume 2 of this report. In summary, the Present Ecological State of the Zambezi River within the study area is Category B (slightly modified from natural condition).

Table 3.3 Present Ecological Status for the BGHES EF sites

Discipline	EF Site 1	EF Site 2
Hydrology	A/B	B
Geomorphology	A	A
Vegetation	A/B	B
Aquatic macroinvertebrates	A/B	A/B
Fish	A/B	B
Crocodiles	B	B/C
TOTAL	A/B	B

3.3.1 Hydrology

There are currently no artificial obstructions such as dams or weirs on the Zambezi River above the gorge and no major water abstraction. The Victoria Falls hydroelectric turbines operate as run-of-the-river with no storage; therefore water flows either over the falls or through the turbines with no effect on river level downstream. The flow regime is therefore close to pristine at EF Site 1.

At EF Site 2, there is some abstraction for water to Hwange and surrounding areas, but there are no available river data to assess the extent of the impact of this abstraction. Presumably its biggest effect is on the dry season flows, particularly in dry years, in the reach represented by EF Site 2. For this reason the present status of the hydrology at EF Site 2 was set at a B-category.

3.3.2 Geomorphology

The present ecological condition of the geomorphology at each EF site was assessed using the South African Department of Water Affairs' Geomorphological Assessment Index (GAI) Level 4 EcoStatus assessment tool (Rowntree and du Preez In press).

EF Site 1: The geomorphology at EF Site 1 is a Category A. This very high score is due to the fact that there are no large dams and thus relatively minor changes to flow upstream of Victoria Falls (i.e. upstream of the site), any changes in sediment loads are also similarly relatively small and, moreover, are attenuated in the large wetlands and slow flowing depositional areas of the upper Zambezi. Furthermore, the gorge in which EF Site 1 is located is insensitive to small-scale changes in sediment and flow due to its resistant, bedrock dominated morphology.

EF Site 2: The geomorphology at EF Site 2 is a Category A. This high score is due to the fact that there are relatively minor changes to flow upstream of the site through the gorge or above Victoria Falls; any changes in sediment loads are similarly relatively small and are attenuated in the large wetlands and slow flowing depositional areas of the upper Zambezi. The reach where EF Site 2 is located is only moderately sensitive to changes in sediment and flow due to the widespread resistant bedrock outcrops alongside and within the channel. There is a small degree of degradation to the geomorphology at EF Site 2, but this is from on-site (non-flow related) bank disturbances associated with land use activities. The small pockets of riparian agriculture on the Zambian side and recreational/residential encroachment into the upper riparian areas on the Zimbabwean side would have very slightly reduced the integrity of the riparian vegetation and bank stability.

3.3.3 Vegetation

The Vegetation Response Assessment Index (VEGRAI) (Kleynhans *et al.* 2007) was used to assess the condition of the riparian vegetation at each EF Site[3]. The method compares the present day condition to that which would be expected under natural (reference) conditions, and considers how past impacts may have influenced the ecological condition over time. The reference condition was taken from ZRA (1998).

EF Site 1: There were no obvious disturbances to the ecological condition of the riparian area at EF Site 1, which scored an Ecological Category A/B. At this EF Site the riparian area was narrow and patchily distributed along the edge of the gorge. The marginal zone normally comprises a mixture of graminoids (such as reeds and sedges) and small trees (such as figs or willows) but here the marginal zone was sparse. There were some marginal graminoids present on lateral bars (of alluvial sand) downstream of this EF Site but overall these constitute a small proportion of the gorges riparian flora. The non-marginal zone was narrow and comprised a mixture of trees, shrubs and their saplings, indicative of healthy relationship between the natural flow regime and the life histories of the plants.

EF Site 2: There were few disturbances to the ecological condition of the riparian area at EF Site 2, which an Ecological Category of B. In contrast to EF Site 1, both the marginal and non-marginal zones of the riparian area were well established. The marginal zone comprised a mixture of marginal graminoids (such as reeds and sedges) and small trees (such as figs or willows). The population of trees and shrubs of the non-marginal zone comprised a mixture of adults and saplings, indicative of a healthy relationship between the natural flow regime and the life histories of these plants. The only visible impacts were related to use of woody plants for firewood or construction material; grazing of saplings or reeds in the marginal area; and the presence of one alien species (*Sesbania sesban*).

[3] Please note: this method does not take plants of the aquatic zone into account.

3.3.4 Aquatic macroinvertebrates

Aquatic macroinvertebrates were collected at EF Sites 1 and 2, and identified to family level according to the Zambian Scoring System (ZISS) biomonitoring method (Lowe 2012). The ZISS method was developed for aquatic macroinvertebrates expected in streams and rivers in Zambia. The ZISS is similar to the South African Scoring System version 5 (SASS5) (Dickens and Graham 2002), but the sensitivity scores have been adjusted and taxa added to account for the regional differences.

At both EF Site 1 and EF Site 2, many sensitive taxa were recorded. The diversity and the average sensitivity score per taxon were high, although slightly lower than expected under undisturbed conditions. No single taxon was dominant. Therefore, the PES was rated as Category A/B (very slightly impaired).

3.3.5 Fish

The fish fauna in the Middle Zambezi River between Victoria Falls and Lake Kariba is naturally depauperate (Jackson 1961; Minshull 2010; Marshall 2011) because of the character of the river. The river flows through the steep-sided rocky Batoka Gorge, and below that it is a ‘sandbank’ river with marked seasonal flow and a resulting paucity of weed cover. Sampling in the Middle Zambezi River before and during the construction of Kariba Dam yielded only 22 species (Jackson 1961), in marked contrast to the 80+ species found in the ‘reservoir’ type Upper Zambezi River above Victoria Falls (Tweddle 2014). The very limited sampling in the current field survey yielded 19 species, <u>one of which, a species of *Cyphomyrus*, is a new record for the Middle Zambezi and is currently under taxonomic/genetic investigation</u>.

EF Site 1: Minshull (2010) recorded 29 fish species in Batoka Gorge, including small numbers of juveniles of Upper Zambezi species. Of the 29 recorded species, only 12 can be regarded as common ‘permanent residents’. Some Upper Zambezi species have become established in the more complex habitats of Lake Kariba, but in general such species can only be regarded as temporary inhabitants in the gorge.

The health of the fish population in Batoka Gorge has to be assessed in terms of the naturally hostile environment in the gorge. Anthropogenic effects are very low. Fishing is restricted to hook and line for predatory fish, tigerfish (*Hydrocynus vittatus*) and vundu (*Heterobranchus longifilis*). Access points are limited and thus fishing mortality is small. Some nutrient enrichment and presence of raised *E. coli* levels are reported from the gorge below the towns of Victoria Falls and Livingstone but at low levels, and thus the fish populations in the gorge can be regarded as near pristine, Category A-B.

EF Site 2: Anthropogenic impacts are much more evident at EF Site 2. Villages border the river and the banks are heavily grazed, either by hippos, cows, or both. Numerous, but small, sand beaches occur wherever there is human habitation, with such sites cleared for water collection and/or washing. Water quality, however, appears to remain healthy.

Fishing activity is evident everywhere, particularly on the Zambian bank. Numerous makoros (dugout canoes) were seen and many monofilament gillnets were observed in makoros, on the river banks and in the water. These monofilament nets are a recent addition to the fishery, and have resulted in serious adverse effects on fish biomass in the Upper Zambezi above Victoria Falls. They are also much more damaging to other fauna than older multifilament nets because (a) they are cheap, easily damaged, not easily repairable, and are thus discarded after use, and (b) they are made of a material that does not lie limply on the ground but instead forms springy bunches of material in which animals of all varieties are trapped and die.

Anthropogenic impacts are not on a scale that impacts on fish diversity, but probably sufficient to lead to changed species abundance ratios. Large cichlids, mainly tilapiines in this area, in particular are most reduced by targeted fishing, while *Labeo altivelis* abundance may be negatively affected by heavy exploitation during breeding migrations (Skelton et al. 1991). Thus, the fish populations in the reach represented by EF Site 2 can be regarded as Category B (slightly modified from natural condition).

3.3.6 Crocodiles

The crocodile populations in the middle Zambezi River were near extinction in the 1950s, but concerned protection resulted in a considerable recovery (IUCN 1989). Nonetheless, it is likely that wild populations at EF Site 1 and 2 are depressed relative to natural levels as a result of conflict between humans and crocodiles and (at EF Site 2) direct pressure from egg collections to stock the nearby crocodile farm[4]. Thus, the condition of the crocodile populations in the reach represented by EF Site 1 was assigned a Category B and that at EF Site 2, a Category B/C.

[4] Under its current operation (September 2014), the farm does not return juveniles to river to compensate for egg removal.

4 INDICATORS USED TO DESCRIBE THE RIVER ECOSYSTEM

In the DRIFT process, the hydrological simulations form the foundation upon which the biophysical and social predictions of change are built. The EF team chose a range of hydrological indicators, and biophysical indicators that they believe will best illustrate the river's response to the flow and other changes likely to result from the BGHES (Table 4.1).

Table 4.1 Discipline indicators used in the DSS

Discipline	Indicators	EF site
Examples of hydrology indicators	Mean annual runoff	1 and 2
	Dry season onset	1 and 2
	Dry season minimum 5-day discharge	1 and 2
	Dry season duration	1 and 2
	Dry season average daily volume	1 and 2
	Dry season within day range in discharge	1 and 2
	Dry season maximum instantaneous discharge	1 and 2
	Dry season minimum instantaneous discharge	1 and 2
	Wet season onset	1 and 2
	Wet season maximum 5-day discharge	1 and 2
	Wet season duration	1 and 2
	Wet season flood volume	1 and 2
	Wet season within day range in discharge	1 and 2
	Wet season maximum instantaneous discharge	1 and 2
	Wet season minimum instantaneous discharge	1 and 2
	Transition 1 within day range in discharge	1 and 2
	Transition 1 maximum instantaneous discharge	1 and 2
	Transition 1 minimum instantaneous discharge	1 and 2
	Transition 2 average daily volume	1 and 2
	Transition 2 within day range in discharge	1 and 2
	Transition 2 maximum instantaneous discharge	1 and 2
	Transition 2 minimum instantaneous discharge	1 and 2
	Transition 2 recession shape (slope of decrease in flow)	1 and 2
Hydraulics	Width/wetted perimeter	1 and 2
	Depth	1 and 2
	Mean velocity (across the cross-section)	1 and 2

Discipline	Indicators	EF site
Suspended sediments	Dry: min Coarse suspended sediment	1 and 2
	Dry: mean Coarse suspended sediment	1 and 2
	Dry: max Coarse suspended sediment	1 and 2
	Dry: min Fine suspended sediment	1 and 2
	Dry: mean Fine suspended sediment	1 and 2
	Dry: max Fine suspended sediment	1 and 2
	Wet: min Coarse suspended sediment	1 and 2
	Wet: mean Coarse suspended sediment	1 and 2
	Wet: max Coarse suspended sediment	1 and 2
	Wet: min Fine suspended sediment	1 and 2
	Wet: mean Fine suspended sediment	1 and 2
	Wet: max Fine suspended sediment	1 and 2
Geomorphology	Low mid-channel rock exposures	1 and 2
	Lengths of cut marginal banks	2
	Backwater bed sediment (fine to coarse)	1 and 2
	Area of backwaters and secondary channels	2
	Vegetated mid-channel bars	1 and 2
	Channel bed sediment (fine to coarse)	1 and 2
	Depth of pools	1 and 2
	Sand bars	1 and 2
Water quality (see below)	*Nutrient concentration*	*1 and 2*
	Temperature	*1 and 2*
Vegetation	Single-celled diatoms	1 and 2
	Filamentous green algae	1 and 2
	Bryophyta	1 and 2
	Marginal Graminoids	1 and 2
	Marginal Shrubs	1 and 2
	Lower Trees	1 and 2
	Upper Trees	1 and 2
	Organic detritus	1 and 2
Macroinvertebrates	Species richness	1 and 2
	Ephemeroptera	1 and 2
	Bivalves	2
	Oligoneuridae	1 and 2
	Chironomidae	1 and 2
	Shrimps	2
	Ceratopogonidae	1 and 2
	Simulidae	1 and 2

Discipline	**Indicators**	**EF site**
Fish	Tigerfish, *Hydrocynus vittatus*	1 and 2
	Cornish jack, *Mormyrops anguilloides*	1 and 2
	Redeye labeo, *Labeo cylindricus*	1 and 2
	Alestids, i.e. *Brycinus imberi, B. lateralis and Micralestes acutidens*	1 and 2
	Cichlids	1 and 2
	Chessa and Nkupe, *Distichodus* spp	2
	Labeo altivelis	2
	Barbus spp.	2
	Vundu, *Heterobranchus longifilis*	1 and 2
	Squeaker, *Synodontis zambezensis*	1 and 2
Crocodiles	Nile Crocodile, *Crocodylus niloticus*	1 and 2

Please note: Water quality was not included in the DRIFT assessment, which concentrates on the effects of potential flow and sediment changes, and barrier effects, as a result of the BGHES. The water quality variables listed in Table 4.1 were switched off for the scenarios assessments. However, the additional effects on the downstream environment as a result of expected changes in water quality, were assessed qualitatively base on the outcome the water quality modelling undertaken by ERM (Section 9).

5 SCENARIOS EVALUATED

The EFs assessment included consideration of twelve flow scenarios. The hydrological modeling underlying the generation of flow scenarios is explained in ERM (2014).

Operation of the BGHES will result in releases down the Zambezi River from the reservoir at the dam via the tailrace[5]. Thus, the EF sites are each affected in different ways by the BGHES:

U/s BGHES:	Situated upstream of the full supply level of the reservoir. BGHES releases will not have any effect on flows at this site. Biotic communities between the full supply level of the BGHES and Victoria Falls may be affected by the barrier effect of the dam itself, which could halt or reduce the upstream movement of aquatic animals. However, this EF study focuses on the river downstream of the BGHES and so these effects were not considered further in the EF study.
EF Site 1 (Batoka Gorge):	Situated downstream of the tailrace. This site will be affected by releases down the tailrace and by releases/spills down the river from the reservoir.
EF Site 2 (Upstream Kariba):	As for EF Site 1 but probably less affected as impact of the dam should decrease with distance downstream

The scenarios differ from one another in terms of the pattern of releases (peaking versus non-peaking) and the minimum dry season releases from the reservoir. Additionally:

- one scenario incorporates a hypothetical sediment flushing operating rule.

5.1 SCENARIO EVALUATED

The scenarios evaluated for the BGHES were:

Scenario 1 (Sc1): "Base" case of straight-through, run-of-river design with no defined flow conditions (minimum or otherwise) other than to match outflows to inflows at all times throughout the day. Sc1 has no sediment flushing.

Sc1Fl: Sediment flushing in the wet season (see Section 6.4.1).

Scenario 2 (Sc2): Outflows peak over a three-hour period every morning and evening with reservoir storage being balanced over a 24-hour period to achieve this. Outflows are managed so that there is no net change in storage over this period. Scenario 2 was run with four variations in the minimum release during the dry season.

a: Minimum release = 94 m^3s^{-1}.

b: Minimum release = 180 m^3s^{-1}.

c: Minimum release = 216 m^3s^{-1}.

d: Minimum release = 255 m^3s^{-1}.

[5] The outlet back into the river after power generation.

Scenario 3 (Sc3): Outflows peak over a three-hour period every morning and evening during ***weekdays*** with reservoir storage being balanced over the weekly period to achieve this. Weekends revert to straight-through, run-of-river, as in Scenario 1. Scenario 3 was run with four variations in the minimum release during the dry season.

a: Minimum release = 94 m^3s^{-1}.

b: Minimum release = 180 m^3s^{-1}.

c: Minimum release = 216 m^3s^{-1}.

d: Minimum release = 255 m^3s^{-1}.

5.2 NOTES ON THE COMPUTATION OF THE SCENARIOS (FROM ERM)

5.2.1 Assumptions

The assumptions used for modelling by ERM can be summarized as follows:

- Began with full pool on 1 October 1924 (elevation = 752 [m ASL], spillway elevation).
- Volume in = volume out ***over each day.***
- Peak flow 6-9 AM and 6-9 PM is the maximum turbine flow of 2550 m^3s^{-1}, whenever there is sufficient volume to achieve this rate.

5.2.2 Computations

The computations conducted by ERM can be summarized as follows:

- Minimum flow is met regardless of inflow, and drawn from storage if necessary.
- Additional available volume first used to fill a less-than-full pool.
- Additional available volume then used to increase flow beyond the requested minimum value.

In all cases for all time, reduction in storage was able to maintain the requested minimum flow.

5.3 EXAMPLES OF SCENARIO FLOW REGIMES

Figure 5.1 shows the baseline (no dam) flow regime at EF Site 1 for the first seven years of the period (1924-1931). The flows for Scenario 1 are identical to those of the baseline because, under Scenario 1, BGHES is operated as a true run-of-river project, i.e., instantaneous inflow = instantaneous outflow.

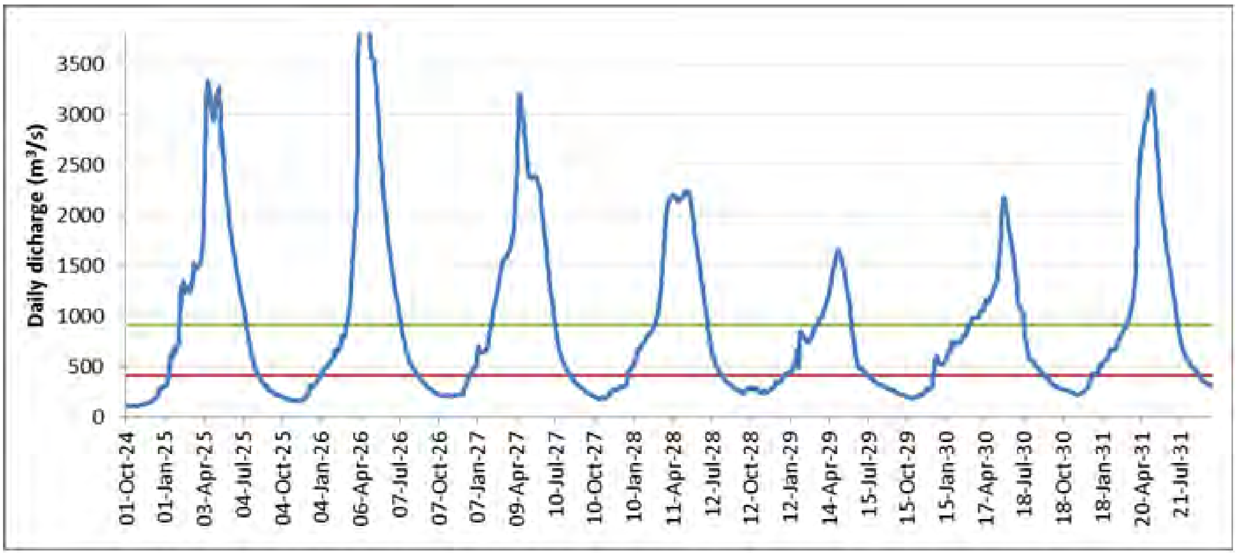

Figure 5.1 **Baseline flows at EF Site 1 with no dam in place, with the average T1/Wet season threshold (green line) and average Dry/T1 threshold (orange). Flows for Scenario 1 are identical to these flows.**

Figure 5.2 shows the flow regime at EF Site 1 for Scenario 2, with minimum releases of A = 94 m^3s^{-1}; B = 180 m^3s^{-1}; C = 216 m^3s^{-1}; D = 255 m^3s^{-1}. The four images show the pattern of flows for increasing time periods: a few days, to 14 years.

Figure 5.3 shows the flow regime at EF Site 1 for Scenario 3, with minimum releases of A = 94 m^3s^{-1}; B = 180 m^3s^{-1}; C = 216 m^3s^{-1}; D = 255 m^3s^{-1}. The four images show the pattern of flows for increasing time periods: a few days, to 14 years.

Please note the scenarios have an increased minimum release moving from dry season to wet season, i.e., through transition 1, and a gradually reducing minimum release from wet season to dry, i.e., transition 2. This is a more environmentally friendly option than fixing the minimum releases, which would allow peaking for longer. In reality what could happen is that, as the flow increases into the wet season, the dam will be operated to peak longer until it there is sufficient water to operate at full capacity for 24 hrs. This possibility was not modelled.

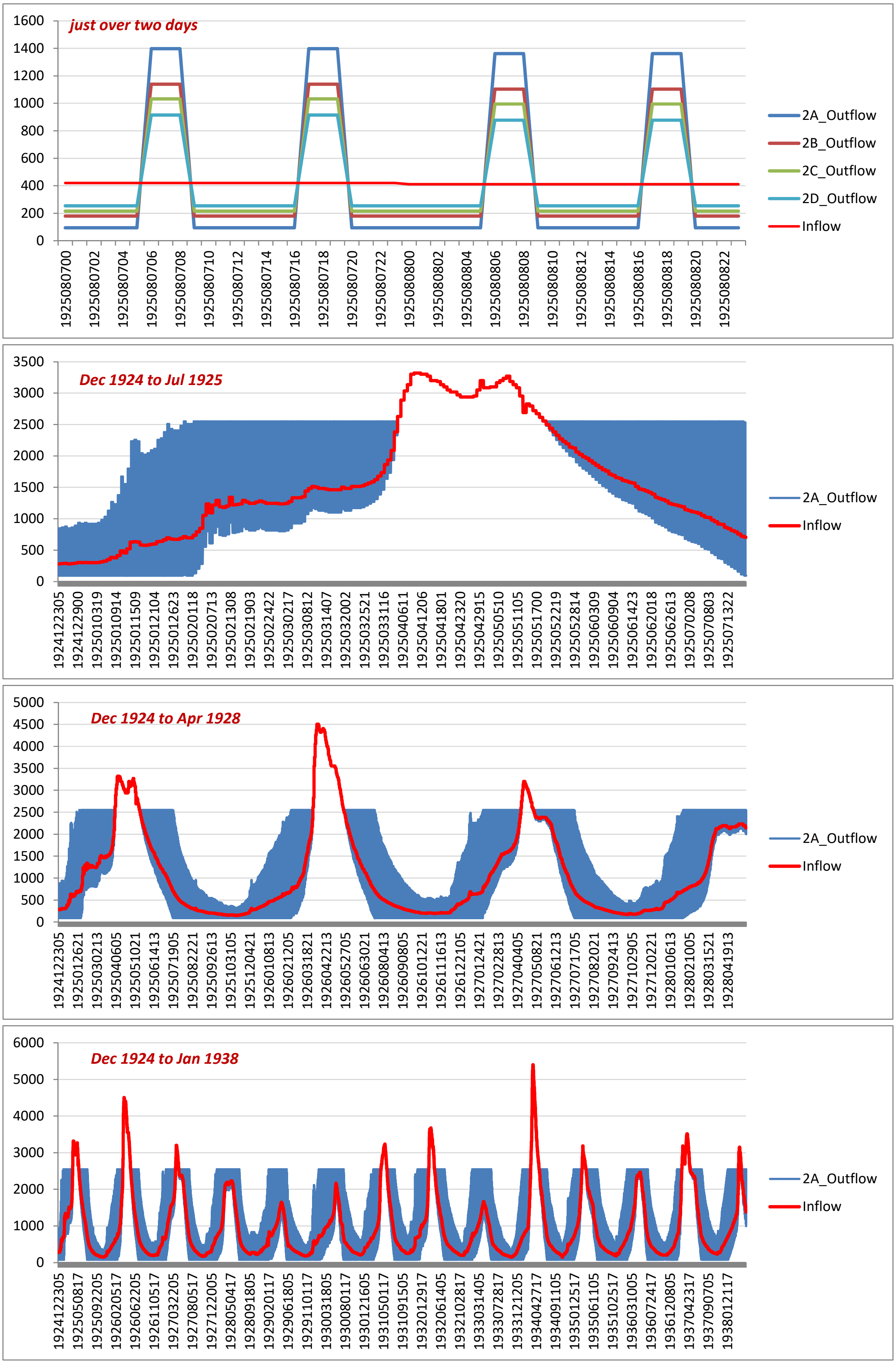

Figure 5.2 **Examples of the pattern of flow for Scenario 2 at EF Site 1 (units on Y axis are in cumecs)**

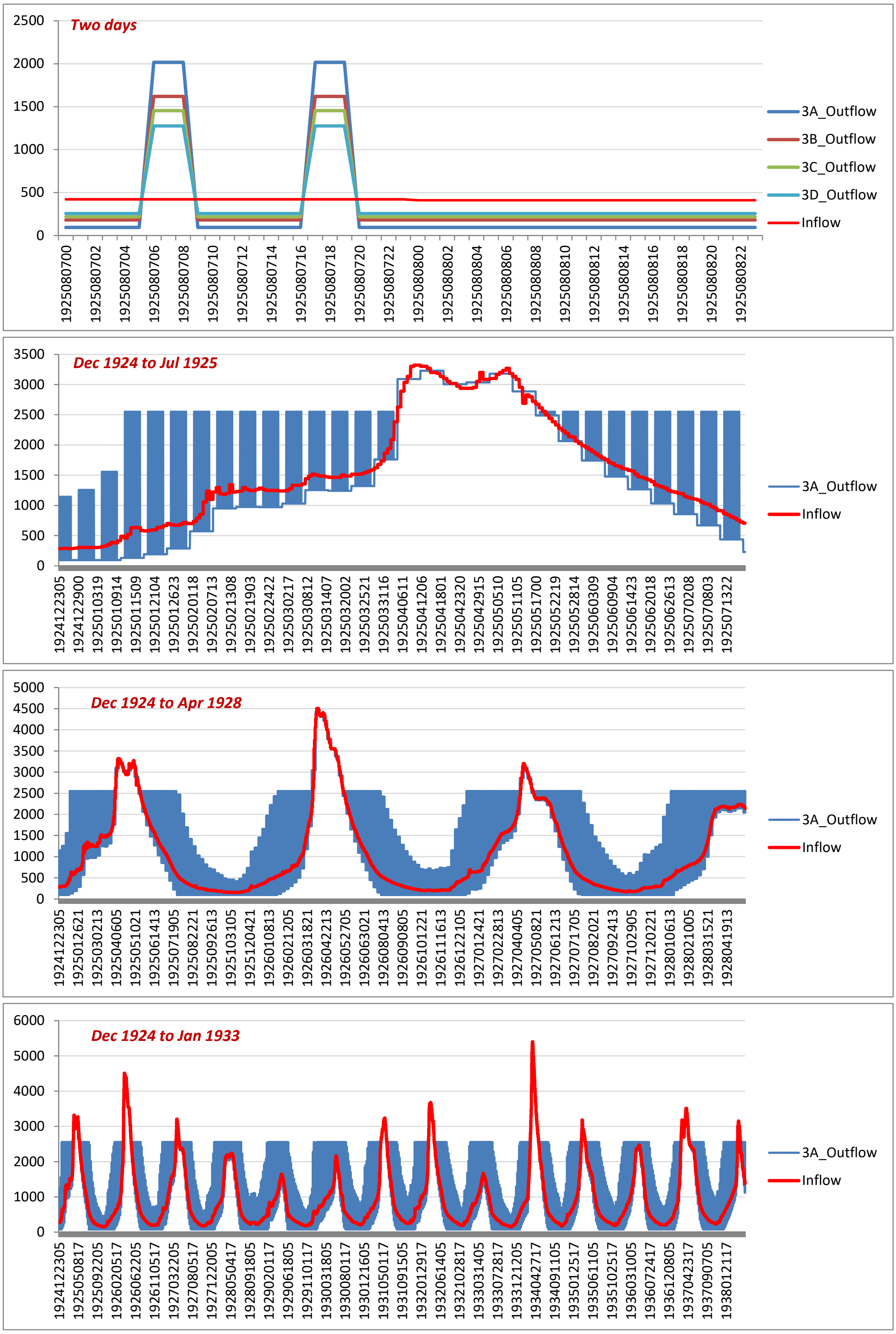

Figure 5.3 Examples of the patterns of flow for Scenario 3 at EF Site 1. (units on Y axis are in cumecs)

6 USE OF DATA FOR THE SCENARIOS

6.1 ANALYSIS OF THE FLOW REGIME

The hydrological record for the Zambezi River suggests that this is a flood pulse system. The seasons for the EF assessment were:

- Dry season
- Transitional season 1.
- Wet season.
- Transitional season 2.

The rules for defining the seasons for the Zambezi River are provided in Table 6.1. The start and end dates of each season are defined for every year of the hydrological time-series. Examples of seasonal divisions for two years are shown in Figure 6.1.

Table 6.1 Rules for defining the four ecological seasons in the Zambezi River.

Transition	Rule for transition from season to season
Dry Season to Transition 1 threshold	Up-crossing over 4.35 x minimum 5-day dry-season discharge
Transition 1 to Wet season threshold	Up-crossing over 0.8 x mean annual discharge
End of Wet Season	Down-crossing below 1 x mean annual discharge
Transition 2 to Dry season	Average recession rate over 14 days >-0.7 m3 s-1 d-1

6.2 DRIFT SCORING

With contemporary understanding of how river ecosystems function, it has become easier to predict WHAT will change and the DIRECTION of change. It is less easy to predict by HOW MUCH ecosystem components will change and HOW LONG it will take. Recognising this, the indicators are chosen as the WHAT, and the response curves show in which DIRECTION they are expected to change. Predictions of by HOW MUCH each indicator might change are less certain and so are captured using severity ratings; these are broad ranges of change from baseline, which is the 2014 condition (Table 3.6).

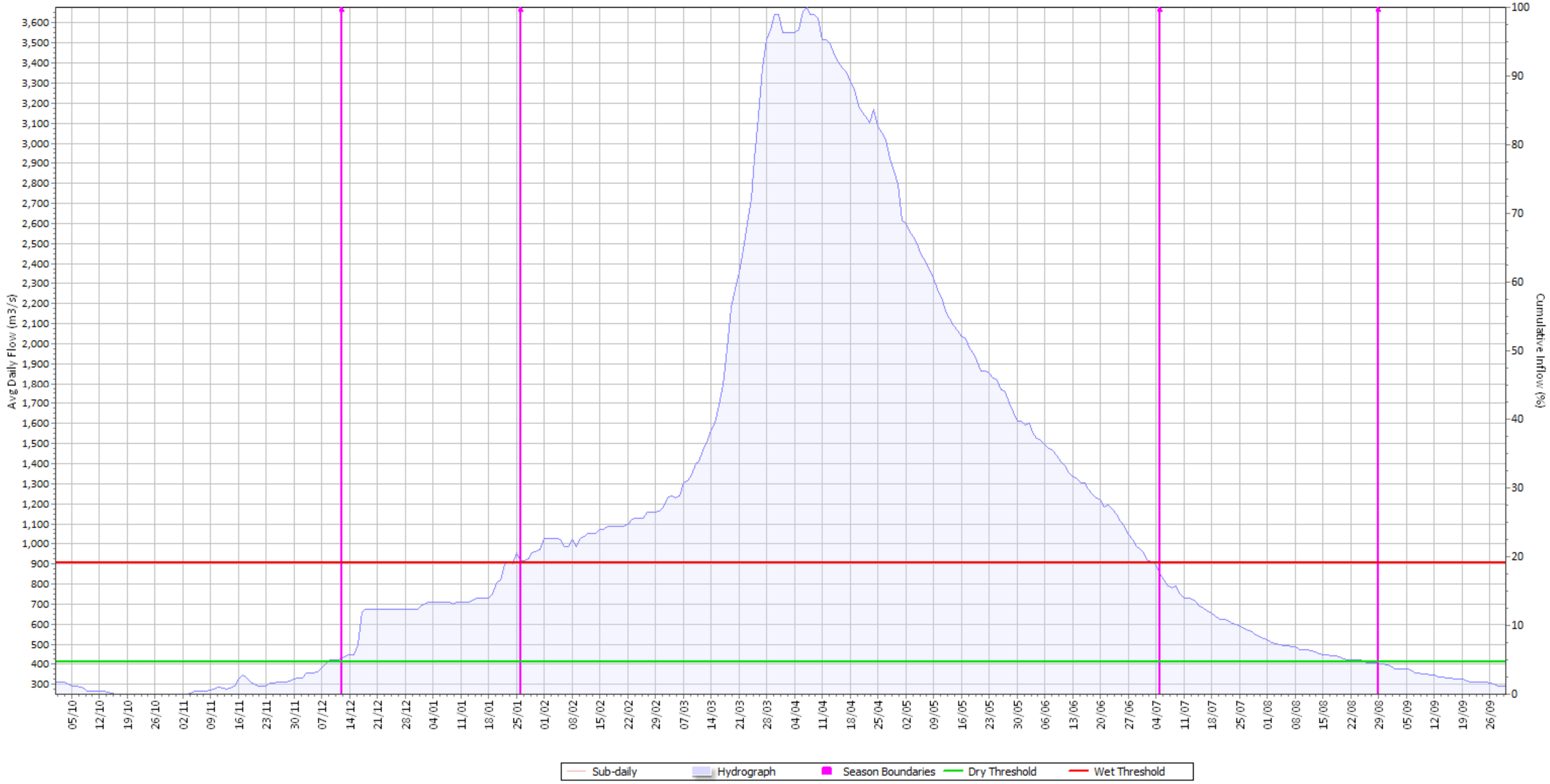

Figure 6.1 Printscreen from the DRIFT-DSS showing examples of seasonal divisions.

Table 3.6 DRIFT severity ratings and their associated abundances and losses (King and Brown 2010)

Severity rating[1]	Severity of change	% abundance change
5	Critically severe	501% gain to ∞ up to pest proportions
4	Severe	251-500% gain
3	Moderate	68-250% gain
2	Low	26-67% gain
1	Negligible	1-25% gain
0	None	no change (represents Baseline)
-1	Negligible	80-100% retained
-2	Low	60-79% retained
-3	Moderate	40-59% retained
-4	Severe	20-39% retained
-5	Critically severe	0-19% retained includes local extinction

The incoming flow regime for any chosen scenario/site accesses the response curves and produces a prediction of change for each indicator and for the ecosystem as a whole. Although these are given by the DSS as precise numbers, they are best interpreted through a search for broad trends of change. In Table 3.7, for instance, one would expect: all but indicator 2 to decrease in abundance from the 2014 condition; indicators 1, 6, 7 and 8 to show more change than the others; and Scenarios 1 and 2 to have the most impact on the river while Scenario 3 has the least impact.

Table 3.7 Example of depicting trends: the mean percentage changes, relative to 2014, of eight ecosystem indicators under four hypothetical development scenarios.

Indicator	Baseline	Hypothetical scenario 1	Hypothetical scenario 2	Hypothetical scenario 3	Hypothetical scenario 4
	Percentage change				
1	0	-50	-50	-33	-33
2	0	19.0	19.0	6.1	14.2
3	0	-21.2	-20.0	-2.3	-6.4
4	0	-15.1	-15.0	1.0	0
5	0	-2.3	-3.3	0	-1.6
6	0	-49.7	-48.2	-7.2	-17.8
7	0	-79.5	-78.2	-13.6	-35.9
8	0	-65.5	-62.8	-9.4	-28.4

Change: 0-20% %-40% > %

HOW LONG BEFORE CHANGE STARTS is addressed through the DRIFT time-series, which depict baseline conditions and future change over the span of years used in the hydrological simulations (in the case of the Zambezi River, the 52 years from 1960 to 2012).

[1] A negative score is a loss in abundance relative to Baseline, a positive is a gain. Zero severity is the Baseline situation.

These prediction of onset of change are based on past climate conditions, and so may differ in reality, depending on future climatic conditions.

6.2.1 Description of percentage of 2014 conditions for changes in bed conditions

The bed sediment conditions linked to the DRIFT severity ratings for the Zambezi River within the study area are provided in Table 6.2.

Table 6.2 Bed sediment condition descriptions linked as percentage of 2014 conditions for the Zambezi River within the study area

% of PD condition	Description of the active channel bed condition
0	Surface is dominated by sand and silts, almost all cobbles are embedded
25	50% more embeddedness than the PD condition, extensive fine deposits
50	25% more embeddedness than the PD condition
75	10% more embeddedness than the PD condition
100	Conditions of the river bed as observed in September, 2014
150	Doubling of the cobble bars with more, larger interstitial spaces, fewer fines.
200	The channel bed is dominated by boulders, cobbles and bedrock (no fines, very few, very small gravel deposits).
250	The active channel has a bedrock/large boulder bed.

6.3 Discipline-specific Response Curves

Response curves were compiled that described the relationships between the driving (flow) and responding (biophysical) indicators. In some cases, indicators responded indirectly to flow changes through an intermediary influence. Fish, for instance, might be responding directly to pool depth or nutrient levels, which in turn might be driven by flow changes. These intermediaries reflect that flow may not be the only driver used in a response curve. The full system of links between driver and responding indicators is a complex web of response curves within the DRIFT DSS.

Each response curve describes the expected impact of a single type of flow or other driving change on the abundance of a single responding biophysical indicator, on a response scale of 0 (no response) to 5 (critically high response). A change in flow could thus be followed through various linked indicators to a change in river condition. The ratings of change were also converted to percentages for use in some meetings and reports. In total, about 240 response curves were created per site for the project and housed in the DRIFT DSS.

In the DSS, for each site and scenario, each year's value for a driving indicator is linked with each response curve that employs that driver and the corresponding value of the responding indicator is recorded. An indicator such as Dry Season Onset, for instance, would have 90 values from a 90-year simulated flow regime of the calendar week in which the onset occurred. Through a response curve, this would produce 90 annual values for the predicted abundance of, for instance, the indicator 'Tigerfish, *Hydrocynus vittatus*'.

The scores from all the response curves for any one indicator were combined in various ways, so that measures of change could be expressed as time-series per indicator, per discipline, or as overall ecosystem integrity. For the latter, results were provided on a scale of A to E, where A represented a pristine ecosystem and E a critically modified one with few, if any, intact ecosystem functions and thus of little value to people (King and Brown 2010).

The DRIFT DSS and process are described in more detail in Appendix A. The links for each indicator and the resultant response curves are provided in Volume 2 of this report (Specialist Reports). For each curve detailed reasoning and relevant scientific references are also provided.

6.4 CONSIDERATION OF BARRIER EFFECTS AS A RESULT OF BGHES DAM WALL

At 180 m, the BGHES dam wall will present an unsurpassable barrier to in-channel movement of abiotic and biotic components of the river ecosystem. Apart from water, the most significant other abiotic component is sediment of different sizes (boulders, cobbles, gravel, sand, mud and silt). However, the impact of these barriers on the functioning of the Zambezi ecosystem is considerably reduced by the siting of the BGHES directly downstream of Victoria Falls.

6.4.1 Trapping and flushing of suspended sediments

The Upper Zambezi River has a low sediment load in comparison with many other large rivers, largely because of the low gradient and extensive wetlands in the upper catchment.

Estimates of the reduced sediment load (relative to baseline of 100%; Table 6.3) were developed based on the design and operation of, and catchment area affected by, the BGHES, together with consideration of the siting of the BGHES, the sediment inflows from tributaries and the availability of sediment which could be reworked and entrained from the bed and banks.

The basic assumptions were:

- Sand and larger calibre sediments will settle out in the reservoir
- Clays, silts and organics will stay in suspension.
- Sediment flushing from the reservoir if it is applied will occur in the wet season[6].

Trapping of (and therefore possible reductions in bedload) was not considered. Bedload is low as a result of Victoria Falls.

[6] Wet-season flushing is the most ecologically friendly option. Flushing in the dry season would have considerably greater ecological impacts, and was not considered here.

Table 6.3 Estimates of changes in suspended sediment delivery to the EF sites

	Fine suspended sediments (silts and clays)				Coarse suspended sediments (sands and larger)			
	Median		Maximum		Median		Maximum	
Flow season:	Flood	Dry	Flood	Dry	Flood	Dry	Flood	Dry
EF 1: Baseline	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***
EF 1: Dam, no flushing	30	20	40	20	15	10	15	10
EF 1: Dam with flushing	40	30	120	30	15	10	15	10
EWR 2: Baseline	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***
EF 2: Dam, no flushing	40	20	40	20	20	15	20	15
EF 2: Dam with flushing	50	30	100	30	20	15	20	15

6.4.2 Barrier to fish movement

At the scale of the Zambezi River, the influence of the BGHES dam wall and reservoir on the upstream and downstream movement of fish is expected to be negligible. This is because the dam wall will be situated on c. 50km downstream of Victoria Falls, which represents a significant natural barrier. There is some evidence that juveniles from upstream are flushed downstream of the falls, possibly through the turbines. Some of these have established in Lake Kariba, but there is little evidence that they can survive to adulthood in the river (see Volume 2). These incidental downstream migrations were not considered further in the EF assessment.

6.5 CONSIDERATION OF IMPACTS IN OTHER PARTS OF THE BASIN

The scenarios EXCLUDE consideration of possible cumulative impacts on riverine habitats and biota resulting from developments in other parts of the Zambezi Basin or degradation of the surrounding landscape. However, fishing pressure was considered because fishing pressure creates an obvious and likely confounding factor when evaluating the effects of reduced lowflows on the system: pressure (fishing success) on fish stocks increases when flows in the river are low because fish are confined to a smaller area.

6.6 INCORPORATION OF HYDRAULIC DATA

Survey data of cross-sections at the BGHES EF sites 1 and 2 (Table 3.1) were used to model the hydraulics of the sites and the fish hydraulic habitat available over a range of flows (specialist report on hydraulics). The hydraulic modelling enabled hydraulic indicators (Table 4.1) to be inserted into the DSS and used to estimate flow and sediment-driven changes in habitat. The data used to calculate the hydraulic indicators are presented in the Hydraulics Report (Volume 2).

6.7 INDIVIDUAL INDICATOR SCORES DENOTING MINIMUM DEGRADATION

The 'minimum degradation' designation refers to a scenario(s) that is expected to result in a small change in river condition. It is defined as follows:

If the overall CHANGE in the Integrity Score of a scenario at a site is a drop of less than 0.5 from baseline (2014) conditions, then the flow change represented by the scenario is deemed to have had a minimal negative impact on the existing ecosystem condition at that site, that is, there will be minimal additional degradation.

The drop of 0.5 in the Integrity score can keep the river in the same condition category or drop it a lower one, in both cases still representing minimum degradation:

- if the condition of an ecosystem is in the upper or middle part of a category, a drop of 0.5 in the Integrity Score could be insufficient to result in a drop to a lower ecological category (for instance, an upper B category condition could drop to a lower B condition).
- if an ecosystem is already in the lower part of a category, a drop of 0.5 in the Integrity Score from Baseline could result in a drop to the next lower category (for instance, a lower B category condition could drop to an upper C condition).

According to this definition 'minimum degradation' does not equate with 'no impact', as some impact has been allowed for.

7 RESULTS FOR THE SCENARIOS

For each scenario, the predicted changes in the study river a represented by the EF Sites are evaluated per site as:

1. estimated mean percentage change from baseline[7] in the abundance, area or concentration of key indicators;
2. time-series of abundance, area or concentration of key indicators under the flow regime resulting from each scenario
3. Overall Ecosystem Integrity.

For comparison purposes, the predicted change in Overall Ecosystem Integrity, relative to baseline, associated with each scenario at both EF sites is provided in Section 8.

7.1 BGHES EF SITE 1

EF Site 1 is located immediately downstream of the BGHES tailrace in Batoka Gorge. As such it is directly affected by EF releases made at the dam. It is also affected by the barrier that BGHES dam wall poses to sediments and fish, and by any limnological changes that may take place in the BGHES reservoir, such as an increase in phyto- and zooplankton, a decrease in oxygen or a change in water temperature.

7.1.1 Characteristics of the flow regime of each scenario at BGHES EF Site 1

The main characteristics of the flow regimes at BGHES EF Site 1 associated with each of the scenarios are summarised in Table 7.1

7.1.2 Mean percentage changes

The mean percentage changes (relative to baseline) for the indicators for the scenarios at BGHES EF Site 1 are given in Table 7.2.

In Table 7.2, baseline, by definition, equals 100%.

[7] Baseline ecological conditions are taken as those measured in 2014.

Table 7.1 Characteristics of the flow regime of each scenario at BGHES EF Site 1. Median values are given for the flow indicators

Indicators	Units	Scenarios										
		Baseline	Sc1	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d
Mean annual runoff	m^3/s	1101.72	1101.72	1101.72	1098.27	1098.27	1098.27	1098.27	1098.53	1098.39	1098.33	1098.27
Dry season Min 5d Q	m^3s^{-1}	220.59	220.59	220.59	220.59	220.59	220.66	255.00	202.65	216.21	221.97	255.00
Dry season onset	weeks	35.00	35.00	35.00	35.00	35.00	35.00	35.00	33.00	33.50	34.00	34.00
Dry season duration	weeks	110.50	110.50	110.50	110.50	110.50	110.50	110.50	115.00	117.50	117.00	117.00
Dry season ave daily vol	m^3	25.730	25.730	25.73	25.73	25.73	25.73	26.08	26.46	26.21	26.14	26.55
Wet season Max 5d Q	m^3s^{-1}	3309.19	3309.19	3309.19	3294.47	3294.47	3294.47	3294.47	3256.58	3256.58	3256.58	3256.58
Wet season onset	weeks	7.00	7.00	7.00	7.00	8.00	8.00	8.00	6.00	6.00	6.00	7.00
Wet season duration	weeks	147.00	147.00	147.00	145.00	145.00	142.50	135.50	156.50	156.00	151.00	143.50
Wet season ave daily vol	m^3	169.63	169.63	169.63	167.53	169.61	172.28	176.91	164.94	164.94	165.95	170.25
Flood volume	MCM	26798.04	26798.04	26798.04	26501.99	26437.15	26161.32	25658.37	26834.26	26834.26	26704.62	26332.99
T1 ave daily vol	m^3	56.56	56.56	56.56	56.56	56.56	56.60	57.87	46.69	48.83	49.65	51.22
T2 ave daily vol	m^3	48.31	48.31	48.31	48.34	48.31	48.31	48.31	53.21	52.28	51.99	51.34
Dry within day range	m^3s^{-1}	0.00	0.00	0.00	745.98	401.98	257.98	101.98	906.54	419.40	217.80	4.94
Wet within day range	m^3s^{-1}	0.00	0.00	0.00	823.09	823.09	816.89	714.88	319.20	319.20	319.20	311.93
T1 within day range	m^3s^{-1}	0.00	0.00	0.00	2165.98	1894.25	1750.25	1644.18	1920.97	1663.89	1536.75	1446.60
T2 within day range	m^3s^{-1}	0.00	0.00	0.00	1733.71	1386.84	1242.84	1086.84	2192.34	1874.74	1639.48	1365.44
T2 max rate of change	m^3s^{-1}	0.00	0.00	0.00	2450.84	2362.48	2325.16	2278.07	2429.94	2335.29	2287.45	2252.50
T2 max instantaneous Q	m^3s^{-1}	844.62	844.62	844.62	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00
T2 min instantaneous Q	m^3s^{-1}	402.25	402.25	402.25	94.00	180.00	216.00	255.00	94.00	180.00	216.00	255.00
Wet season max rate of change	m^3s^{-1}	7.20	7.20	7.20	2248.00	2248.00	2248.00	2248.00	2152.11	2152.04	2144.75	2082.91
Wet season max instantaneous Q	m^3s^{-1}	3321.25	3321.25	3321.25	3321.26	3321.26	3321.26	3321.26	3256.58	3256.58	3256.58	3256.58
Wet season min instantaneous Q	m^3s^{-1}	864.00	864.00	864.00	282.39	281.02	281.02	281.02	393.28	393.69	396.75	401.77
T1 max rate of change	m^3s^{-1}	2.01	2.01	2.01	2443.44	2363.12	2332.31	2295.00	2419.83	2338.96	2325.73	2295.00
T1 max instantaneous Q	m^3s^{-1}	924.41	924.41	924.41	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00
T1 min instantaneous Q	m^3s^{-1}	429.47	429.47	429.47	94.00	180.00	216.00	255.00	94.00	180.00	216.00	255.00
Dry season max rate of change	m^3s^{-1}	1.28	1.28	1.28	1322.90	978.90	834.90	678.90	2010.34	1453.02	1199.64	958.32
Dry season max instantaneous Q	m^3s^{-1}	424.72	424.72	424.72	1416.90	1158.90	1050.90	933.90	2104.34	1633.02	1415.64	1213.32
Dry season min instantaneous Q	m^3s^{-1}	218.39	218.39	218.39	94.00	180.00	216.00	255.00	94.00	180.00	216.00	255.00

Table 7.2 BGHES EF Site 1: The mean percentage changes in abundance (relative to baseline) for the indicators for the scenarios.

Disciplines	Indicators	Scenario									
		Sc1	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d
Geomorphology	Low mid-channel rock exposures	0.3	0.3	-69.6	-57.6	-52.0	-47.6	-73.2	-58.5	-52.2	-46.4
	Backwater bed sediment (fine to coarse)	101.7	101.7	114.1	112.6	111.7	111.0	115.0	113.1	112.3	111.6
	Area of backwaters and secondary channels	0.3	1.1	-37.2	-30.1	-26.8	-23.1	-37.5	-29.4	-25.1	-20.6
	Channel bed sediment (fine to coarse)	101.3	101.3	113.9	112.4	111.5	110.7	114.7	112.8	112.0	111.3
	Depth of pools	-2.6	-0.5	5.9	3.7	2.8	2.0	6.9	4.2	3.1	2.1
	Sand bars	-65.4	-47.5	-79.9	-77.4	-76.4	-75.2	-80.7	-78.7	-77.3	-75.7
Vegetation	Single-celled diatoms	17.6	15.4	-25.5	-15.3	-10.1	-4.9	-29.2	-17.0	-10.9	-4.2
	Filamentous green algae	19.1	17.4	-41.3	-29.8	-23.6	-17.3	-44.0	-31.4	-24.2	-16.0
	Bryophyta	25.2	19.0	91.7	76.8	70.9	69.3	99.2	81.9	74.0	70.3
	Marginal Graminoids	-18.8	-14.2	-6.0	-5.6	-4.9	-4.4	-7.5	-6.7	-6.0	-5.4
	Marginal Shrubs	-9.0	-9.0	26.0	26.7	26.9	21.8	26.0	26.8	27.6	28.6
	Lower Trees	-5.9	-5.9	8.3	6.4	5.6	4.6	13.3	10.0	8.6	7.3
	Upper Trees	0.4	0.4	0.4	0.4	0.4	0.3	1.0	1.0	1.0	0.8
	Organic detritus	-11.8	-11.8	-42.9	-40.3	-38.2	-36.0	-44.9	-40.3	-37.3	-34.5
Macro-invertebrates	Species richness	-31.6	-29.5	-45.9	-45.0	-44.9	-44.2	-45.7	-44.6	-44.3	-43.6
	Ephemeroptera	-0.9	-0.9	-61.0	-50.9	-45.5	-39.7	-66.9	-54.2	-47.0	-39.5
	Oligoneuridae	-3.0	-3.0	-64.7	-49.1	-41.4	-35.5	-72.8	-54.3	-45.2	-37.3
	Chironomidae	-1.6	-1.6	-54.9	-43.4	-39.8	-36.6	-60.6	-48.1	-43.0	-38.2
	Ceratopogonidae	-24.6	-24.6	-30.9	-29.6	-30.1	-29.3	-37.2	-35.1	-34.6	-33.2
	Simulidae	0.1	0.1	-69.0	-52.2	-44.6	-38.2	-74.8	-55.1	-45.9	-37.5
	Gastropods	2.4	2.5	2.0	2.0	1.9	1.7	1.2	1.8	1.9	1.7
Fish	Redeye labeo, *Labeo cylindricus*	0.5	0.5	-37.8	-37.3	-36.7	-36.3	-36.8	-35.7	-35.2	-34.3
	Cichlids	-7.0	-6.8	-47.6	-45.1	-42.2	-33.1	-48.0	-45.8	-40.7	-29.1
	Synodontis zambezensis	-1.3	-1.3	-23.5	-17.3	-9.8	-1.8	-26.4	-19.6	-10.3	-0.5
	Alestids	-2.9	-2.9	-18.5	-12.9	-8.0	-4.8	-23.0	-13.2	-7.3	-3.1
	Cornish jack, *Mormyrops anguilloides*	-9.6	-9.2	-49.5	-48.8	-48.0	-46.1	-49.4	-48.6	-47.7	-43.3
	Vundu, *Heterobranchus longifilis*	-2.0	-1.8	-10.1	-8.1	-5.5	-1.6	-10.6	-6.8	-4.0	0.2
	Tigerfish, *Hydrocynus vittatus*	-1.9	-1.8	-43.0	-37.7	-32.9	-27.2	-43.6	-36.7	-30.6	-22.8
Crocodiles	Nile Crocodile, *Crocodylus niloticus*	0.0	0.0	-34.3	-29.5	-27.5	-25.8	-42.5	-34.4	-31.1	-28.9

7.1.3 Time-series

The time-series for the scenarios for the biophysical indicators (Figure 7.1 to Figure 7.4) show the annual changes in abundance behind the mean values given in Table 7.4. The period simulated is 1924-2014. These show the year-on-year changes in each indicator in response to the prevailing conditions. These conditions, derived using the historical flow records (1924-2014), show the predicted response for each indicator, under the condition specified in each scenario, should the same flow conditions be replicated into the future. In the plots, some scenario lines are hidden underneath others. Where the visible scenarios are quite different, the location of the hidden scenario(s) is given in the text.

7.1.3.1 Geomorphology

The overall predictions (Figure 7.1), relative to the baseline scenario, are that in-channel habitats would change slightly under Scenario 1 and 1F (the effects of the flushing scenario are negligible).

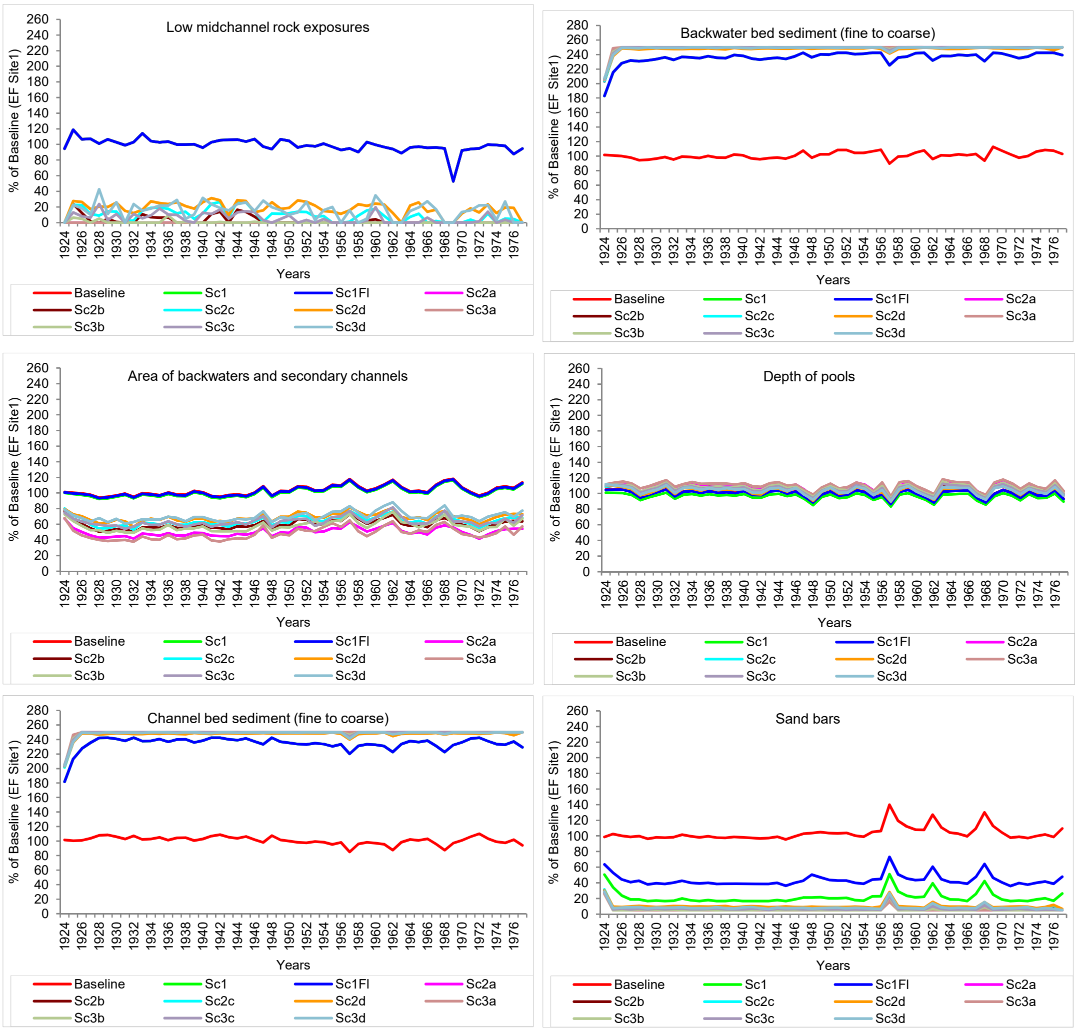

Figure 7.1 Time-series of predicted changes in geomorphological indicators at EF Site 1. Scenario lines not visible are hidden by those showing.

Under run-of-river operation, a general coarsening of the bed sediments is expected, with the most significant change expected being a reduction in sand bars. These are fairly uncommon but important habitats in the gorge, and are expected to be negatively affected by the capture, by the BGHES, of sediments travelling down the river. This is expected to be somewhat offset, but not completely mitigated, by sediment flushing from the dam in the wet season.

If peak power releases are implemented at the BGHES, they would increase sediment movement through the reach represented by EF Site 1, and the bed sediments will coarsen and the sand bars will be removed. A reduction in backwater areas is also predicted. As mentioned above, the sandbars and backwater areas, although uncommon in Batoka Gorge represent valuable habitat for several species in that reach. There is a chance that peaking releases will result in increased bank slumping, but given the steep and rocky nature of the Zambezi River in Batoka Gorge, this is likely to be limited.

7.1.3.2 Vegetation

The time series of the effect of the BGHES scenarios on vegetation at EF Site 1 are shown in Figure 7.2.

Peaking releases are expected to be far more damaging. Peaking at 2 500 m^3s^{-1} will inundate the entire marginal zone. Continuous inundation of the marginal zone is expected to flush any settled organic particulate matter, algae and diatoms leaving little available as a food source for biota. On the other hand, the moss Bryopyta is expected to increase under peaking, mainly because there will be less abrasion by sediments (as these will be trapped in the upstream impoundment) and because peaking flows are sufficiently large to inundate the rocks used by moss but are insufficient to effect scouring. Continual wetting will favour growth of the rock moss. Similarly the marginal vegetation (shrubs and graminoids) is expected to increase slightly as peaking flows will inundate the marginal zone, stimulating growth but are not sufficiently large to cause stem snap to wash plants away. Riparian trees are unlikely to be affected by flows from the BGHES.

Figure 7.2 **Time-series of predicted changes in vegetation indicators at EF Site 1. Scenario lines not visible are hidden by those showing.**

7.1.3.3 Macroinvertebrates

The overall predictions for macroinvertebrates relative to the baseline scenario (Figure 7.3)

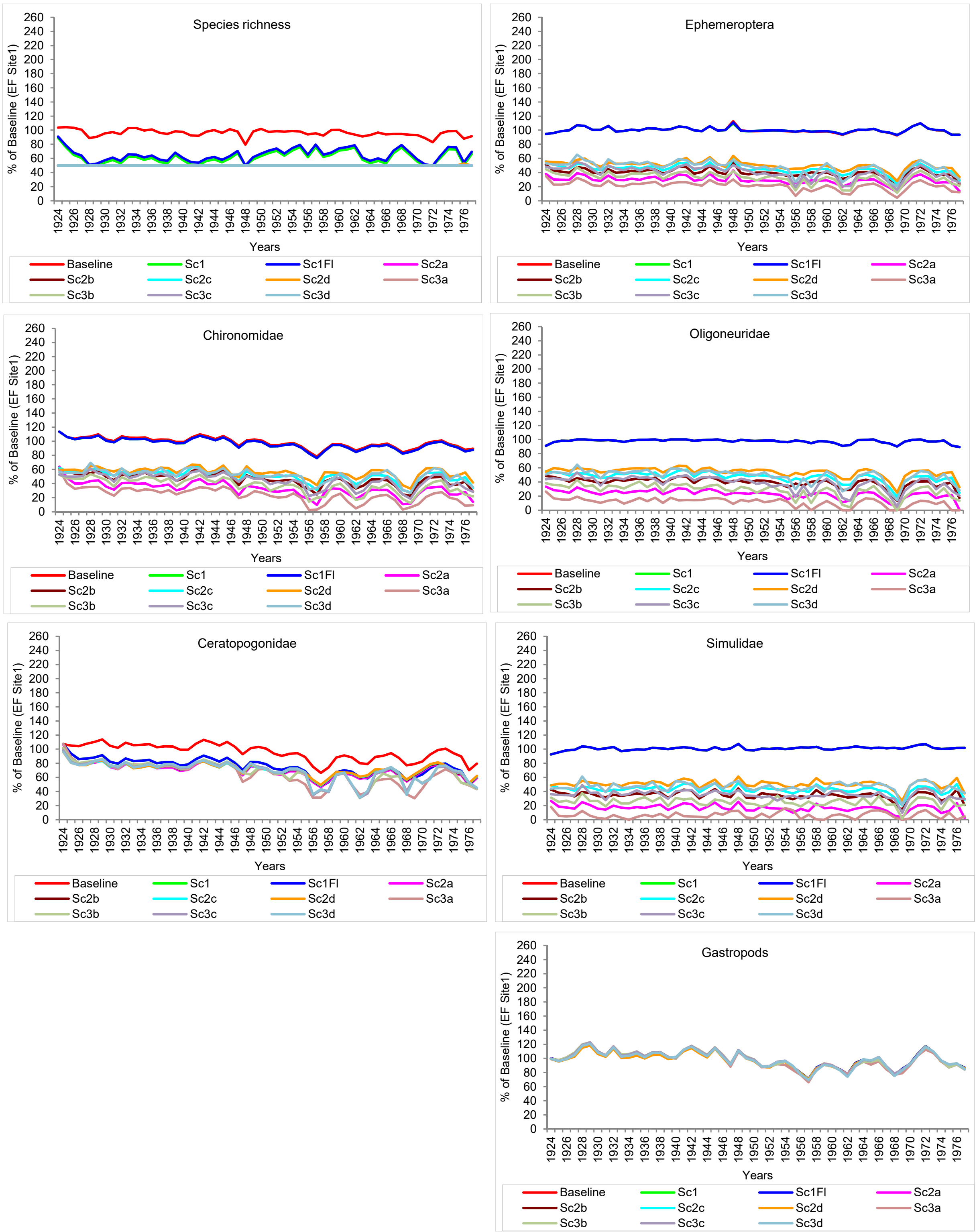

Figure 7.3 **Time-series of predicted changes in invertebrate indicators at EF Site 1. Scenario lines not visible are hidden by those showing, i.e., baseline and Sc1 are under Sc1Fl for several indicators.**

showed minimal change under Scenario 1 and 1F (the effects of the flushing scenario are negligible). Simuliids could also increase in abundance with the expected decline in fine sediments and armouring of the river bed (Berry et al 2003), plus some plankton from the reservoir. There are some slight reductions in sediment-loving species such as Ceratopogonidae, whereas the expected decline in suspended sediments will favour other invertebrates as there will be reduced abrasion. However, under peaking releases, all of these effects will be offset by a disturbance from a fluctuating flow regime and a reduction in the amount and quality of available habitat and food (Figure 7.3).

7.1.3.4 Fish

The effect of the BGHES (Figure 7.4) on fish abundance in the gorge is related to:

- peaking flows that considerably disrupt spawning behavior, survival of eggs and survival of juveniles;
- reduction in algae and macroinvertebrates, which are a food source for some of the fish.

Peaking flows, particularly at the time of the beginning of the rains and during the naturally rising flood waters will have a deleterious effect the spawning of several species as eggs laid in the river margins will be alternately dried out and inundated and potentially washed away. Peaking flows may also will reduce (or render unsafe) the availability of juvenile habitat such as in rocky areas where the juveniles hide beneath and between the rocks. In addition, the peaking may have a serious impact on breeding success of cichlids as the male cichlids establish breeding territories known as nests (Tweddle et al. 1997) in the shallows where they court females, and fluctuating water levels will interfere with this courting behaviour. For some species, the effect on the overall abundance of fish in the gorge may be mitigated to some extent by migration into the area from downstream. This is particularly the case for tigerfish, which have been shown to range more widely in the Zambezi system than other fish species (Okland et al. 2005).

7.1.3.5 Crocodiles

In the DRIFT DSS, Crocodiles at EF Site 1 are only linked to the fluctuating flows with peaking releases. Thus, the predicted responses with Scenarios 2 and 3 are as a result of daily fluctuating flows disrupting nests (Dry Season) and washing out the young (Transition Season 1; Figure 7.11; Swanepoel et al. 2000).

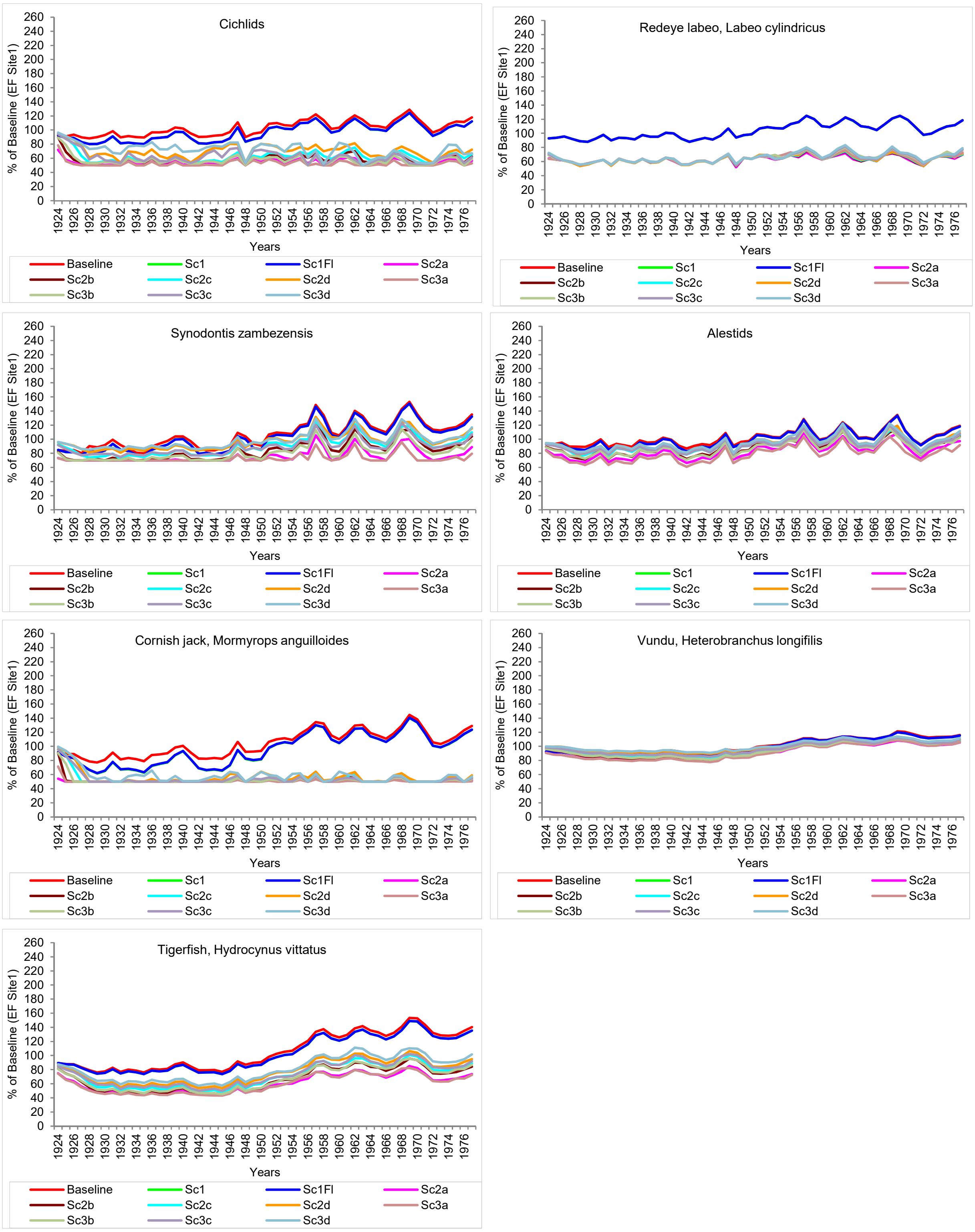

Figure 7.4 **Time-series of predicted changes in fish indicators at EF Site 1. Scenario lines not visible are hidden by those showing.**

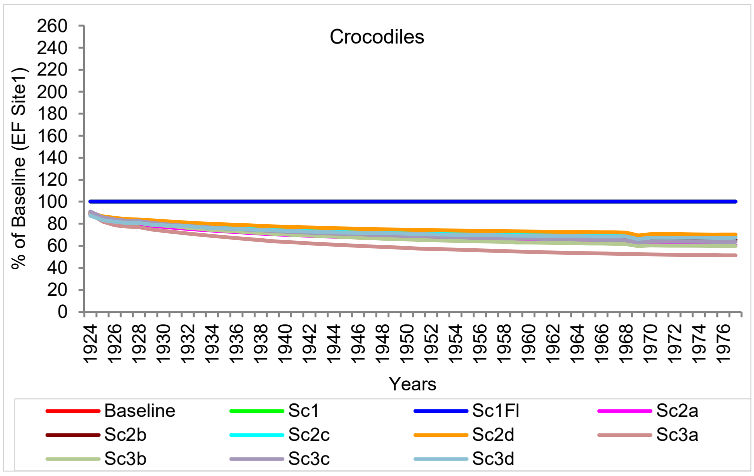

Figure 7.5 **Time-series of predicted changes in crocodiles at EF Site 1. Scenario lines not visible are hidden by those showing.**

7.1.4 Overall Ecosystem Integrity

The Overall Integrity for each the scenarios at BGHES EF Site 1 are illustrated in Figure 7.6. Comments are provided in Section 8.

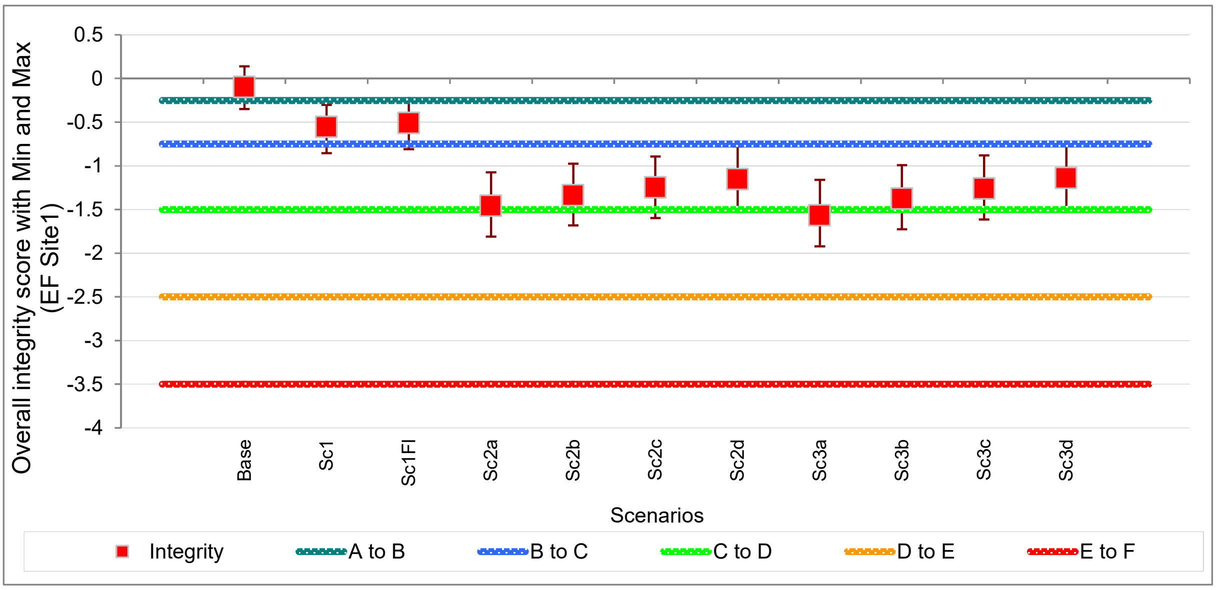

Figure 7.6 **Overall ecosystem integrity scores for the scenarios at BGHES EF Site 1 (Batoka Gorge).**

7.2 *BGHES SITE 2*

EF Site 2 is downstream of the BGHES tailrace and so receives the flow returning to the river after passage through the power house. As modelled, the flow at EF Site 2 is essentially the same as at EF Site 1.

As with the other sites, EF Site 2 is also affected by the barrier that the BGHES dam wall poses to sediments and fish, and by any limnological changes that may take place in the BGHES reservoir, such as an increase in zooplankton or a decrease in oxygen.

7.2.1 Characteristics of the flow regime of each scenario at BGHES EF Site 2

The main characteristics of the flow regimes at BGHES EF Site 2 associated with each of the scenarios are summarised in Table 7.3.

7.2.2 Mean percentage changes

The mean percentage changes (relative to baseline) for the indicators for the scenarios at BGHES EF Site 2 are given in Table 7.4.

In Table 7.4, baseline, by definition, equals 100%.

7.2.3 Time-series

The time-series for the scenarios for the biophysical indicators (Figure 7.7 to Figure 7.11) show the annual changes in abundance encapsulated in the mean values given in Table 7.4.

The period simulated is 1924-2014. The plots show the year-on-year changes in each indicator in response to the prevailing conditions. These conditions, derived using the historical flow records, show the predicted response for each indicator, under the condition specified in each scenario, should the same climatic conditions be replicated into the future. In the plots, some scenario lines are hidden underneath others. Where the visible scenarios are quite different, the location of the hidden scenario(s) is given in the text.

Table 7.3 Characteristics of the flow regime of each scenario at BGHES EF Site 2. Median values are given for the flow indicators.

Indicator	Units	Scenarios										
		Base	Sc1	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d
Mean annual runoff	MCM	1101.72	1101.72	1101.72	1098.27	1098.27	1098.27	1098.27	1098.53	1098.39	1098.33	1098.27
Dry season Min 5d Q	m^3s^{-1}	220.59	220.59	220.59	220.59	220.59	220.66	255.00	202.65	216.21	221.97	255.00
Dry season onset	weeks	35	35	35.00	35.00	35.00	35.00	35.00	33.00	33.50	34.00	34.00
Dry season duration	weeks	111	111	110.50	110.50	110.50	110.50	110.50	115.00	117.50	117.00	117.00
Dry season ave daily vol	m^3	25.730	25.730	25.73	25.73	25.73	25.73	26.08	26.46	26.21	26.14	26.55
Wet season Max 5d Q	m^3s^{-1}	3309.19	3309.19	3309.19	3294.47	3294.47	3294.47	3294.47	3256.58	3256.58	3256.58	3256.58
Wet season onset	weeks	7.00	7.00	7.00	7.00	8.00	8.00	8.00	6.00	6.00	6.00	7.00
Wet season duration	weeks	147.00	147.00	147.00	145.00	145.00	142.50	135.50	156.50	156.00	151.00	143.50
Wet season ave daily vol	m^3	169.63	169.63	169.63	167.53	169.61	172.28	176.91	164.94	164.94	165.95	170.25
Flood volume	MCM	26798.04	26798.04	26798.04	26501.99	26437.15	26161.32	25658.37	26834.26	26834.26	26704.62	26332.99
T1 ave daily vol	m^3	56.56	56.56	56.56	56.56	56.56	56.60	57.87	46.69	48.83	49.65	51.22
T2 ave daily vol	m^3	48.31	48.31	48.31	48.34	48.31	48.31	48.31	53.21	52.28	51.99	51.34
Dry within day range	m^3s^{-1}	0.00	0.00	0.00	745.98	401.98	257.98	101.98	906.54	419.40	217.80	4.94
Wet within day range	m^3s^{-1}	0.00	0.00	0.00	823.09	823.09	816.89	714.88	319.20	319.20	319.20	311.93
T1 within day range	m^3s^{-1}	0.00	0.00	0.00	2165.98	1894.25	1750.25	1644.18	1920.97	1663.89	1536.75	1446.60
T2 within day range	m^3s^{-1}	0.00	0.00	0.00	1733.71	1386.84	1242.84	1086.84	2192.34	1874.74	1639.48	1365.44
T2 max rate of change	m^3s^{-1}	0.00	0.00	0.00	2450.84	2362.48	2325.16	2278.07	2429.94	2335.29	2287.45	2252.50
T2 max instantaneous Q	m^3s^{-1}	844.62	844.62	844.62	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00
T2 min instantaneous Q	m^3s^{-1}	402.25	402.25	402.25	94.00	180.00	216.00	255.00	94.00	180.00	216.00	255.00
Wet season max rate of change	m^3s^{-1}	7.20	7.20	7.20	2248.00	2248.00	2248.00	2248.00	2152.11	2152.04	2144.75	2082.91
Wet season max instantaneous Q	m^3s^{-1}	3321.25	3321.25	3321.25	3321.26	3321.26	3321.26	3321.26	3256.58	3256.58	3256.58	3256.58
Wet season min instantaneous Q	m^3s^{-1}	864.00	864.00	864.00	282.39	281.02	281.02	281.02	393.28	393.69	396.75	401.77
T1 max rate of change	m^3s^{-1}	2.01	2.01	2.01	2443.44	2363.12	2332.31	2295.00	2419.83	2338.96	2325.73	2295.00
T1 max instantaneous Q	m^3s^{-1}	924.41	924.41	924.41	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00	2550.00
T1 min instantaneous Q	m^3s^{-1}	429.47	429.47	429.47	94.00	180.00	216.00	255.00	94.00	180.00	216.00	255.00
Dry season max rate of change	m^3s^{-1}	1.28	1.28	1.28	1322.90	978.90	834.90	678.90	2010.34	1453.02	1199.64	958.32
Dry season max instantaneous Q	m^3s^{-1}	424.72	424.72	424.72	1416.90	1158.90	1050.90	933.90	2104.34	1633.02	1415.64	1213.32
Dry season min instantaneous Q	m^3s^{-1}	218.39	218.39	218.39	94.00	180.00	216.00	255.00	94.00	180.00	216.00	255.00

Table 7.4 BGHES Site 2: The mean percentage changes (relative to 2014) for the indicators under the scenarios.

Discipline	Indicator	Scenarios									
		Sc1	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d
Geomorphology	Low mid-channel rock exposures	1.0	1.0	-70.4	-57.8	-50.6	-43.9	-69.9	-54.6	-47.5	-39.5
	Lengths of cut marginal banks	26.0	14.1	93.3	78.0	71.8	66.6	97.8	80.7	73.1	65.9
	Backwater bed sediment (fine to coarse)	105.1	105.1	116.8	116.9	116.2	114.1	115.9	116.3	115.2	113.2
	Area of backwaters and secondary channels	2.5	2.8	-44.5	-35.1	-31.0	-27.3	-45.5	-34.9	-30.0	-25.3
	Vegetated mid-channel bars	-40.8	-31.7	-72.5	-70.5	-69.7	-69.0	-72.9	-70.3	-69.3	-68.4
	Channel bed sediment (fine to coarse)	80.6	80.6	86.7	83.8	82.7	81.9	90.3	85.5	83.7	82.8
	Depth of pools	6.9	5.1	16.3	14.1	13.1	12.3	17.4	14.5	13.4	12.3
	Sand bars	-20.4	-15.2	-45.7	-40.5	-38.2	-36.1	-46.7	-39.9	-37.1	-34.6
Vegetation	Single-celled diatoms	14.4	12.3	-28.4	-18.4	-13.3	-8.2	-31.7	-19.9	-13.9	-7.3
	Filamentous green algae	-12.2	-10.8	-38.1	-28.2	-23.7	-20.3	-42.3	-30.3	-24.8	-20.4
	Marginal Graminoids	-11.5	-10.1	-27.3	-17.0	-12.4	-9.4	-30.2	-18.6	-13.1	-8.2
	Marginal Shrubs	-4.5	-4.5	24.4	22.0	21.0	19.8	30.5	26.4	24.5	23.0
	Lower Trees	0.3	0.3	0.3	0.3	0.3	0.2	0.7	0.7	0.7	0.6
	Upper Trees	-9.6	-9.6	-43.0	-40.5	-38.3	-36.1	-45.1	-40.4	-37.3	-34.3
	Organic detritus	-12.2	-10.8	-38.1	-28.2	-23.7	-20.3	-42.3	-30.3	-24.8	-20.4
Macro-invertebrates	Species richness	-17.4	-10.1	-41.7	-34.8	-30.7	-27.1	-44.1	-38.5	-33.4	-28.4
	Ephemeroptera	-2.3	-2.1	-42.7	-31.6	-26.3	-22.2	-47.5	-33.7	-27.3	-21.9
	Bivalves	-18.9	-14.8	-43.8	-36.1	-31.3	-26.6	-46.2	-35.3	-30.0	-25.0
	Oligoneuridae	-2.3	-2.3	-57.8	-43.5	-37.3	-32.1	-65.0	-47.5	-39.9	-32.9
	Chironomidae	-2.6	-2.6	-49.2	-39.7	-36.3	-32.4	-52.0	-41.5	-36.9	-31.7
	Shrimps	-5.5	-4.9	-16.2	-11.4	-9.2	-7.2	-18.2	-11.9	-9.3	-6.9
	Ceratopogonidae	-24.1	-24.1	-30.8	-30.0	-29.4	-28.4	-33.2	-31.7	-30.5	-29.3
	Simulidae	-0.8	-0.7	-3.0	-1.5	-0.2	0.9	-3.3	-1.0	0.4	1.5
	Gastropods	1.4	1.4	0.7	1.0	0.9	0.8	-0.5	0.2	0.4	0.5

Discipline	Indicator	Scenarios									
		Sc1	**Sc1Fl**	**Sc2a**	**Sc2b**	**Sc2c**	**Sc2d**	**Sc3a**	**Sc3b**	**Sc3c**	**Sc3d**
Fish	Labeo altivelis	13.6	8.8	-40.7	-56.2	-57.2	-59.6	58.5	-25.0	-38.4	-42.1
	Redeye labeo, Labeo cylindricus	1.3	1.3	-33.5	-32.5	-31.5	-30.6	-32.1	-30.7	-29.7	-28.2
	Cichlids	-6.1	-5.2	-18.3	-25.1	-25.5	-26.0	57.0	-12.6	-20.3	-21.5
	Chessa and Nkupe, *Distichodus* spp	-4.2	-5.0	-10.6	-15.7	-14.0	-14.6	-1.7	-9.5	-9.8	-9.7
	Synodontis zambezensis	-1.4	-1.1	-3.0	-3.4	2.3	6.7	-1.3	2.5	7.9	13.4
	Alestids	-2.5	-2.3	-14.0	-14.0	-13.6	-13.4	-13.8	-13.6	-13.3	-13.0
	Barbus spp	-7.2	-6.0	-52.5	-51.4	-50.0	-46.7	-52.4	-51.0	-48.6	-43.1
	Cornish jack, *Mormyrops anguilloides*	-11.3	-11.2	-37.2	-33.7	-25.8	-14.0	-21.1	-23.6	-15.6	-2.2
	Vundu, *Heterobranchus longifilis*	2.1	1.3	24.6	13.3	15.0	16.9	78.3	40.0	29.3	29.5
	Tigerfish, *Hydrocynus vittatus*	-7.8	-8.3	-34.1	-44.5	-44.6	-45.5	46.0	5.5	-9.1	-11.7
Crocodiles	Nile Crocodile, *Crocodylus niloticus*	0.0	0.0	-34.3	-29.5	-27.5	-25.8	-42.5	-34.4	-31.1	-28.9

7.2.3.1 *Geomorphology*

There is very little effect expected at EF Site 2 as a result of flow changes if the BGHES is operated as a genuine run-of-river plant. However, there is a possibility of a slight coarsening of the river bed and backwater habitats as a result of reduced sediment supply (Figure 7.7).

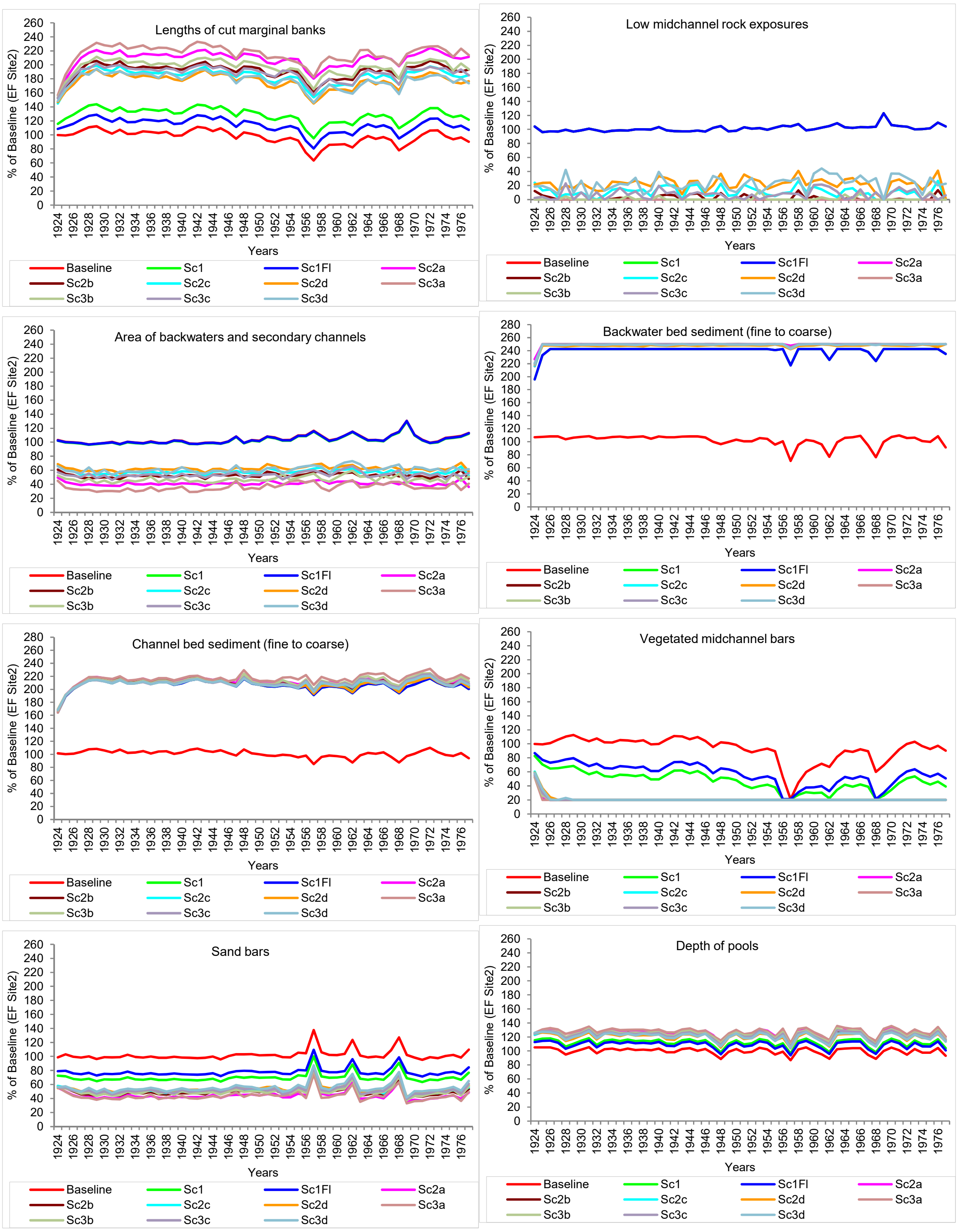

Figure 7.7 **Time-series of predicted changes in geomorphological indicators at EF Site 2. Scenario lines not visible are hidden by those showing.**

This is expected to be equal to or possibly even greater than at EF Site 1 despite the fact that EF Site 2 is situated quite some distance downstream of BGHES. The reason for this is that, unlike EF Site 1, which is bedrock dominated, EF Site 2 is characterized by much finer bed sediments and habitats that are vulnerable to flushing (particularly in the backwater areas).

EF Site 2 has a wider, flatten lateral profile and thus a different response to peaking from EF Site 1. There are also more sand bands and vegetated islands, which will be vulnerable to the rapid flow changes associated with peaking, which will be exacerbated by the reduction in sediment supply, albeit small. The changes in geomorphology at EF Site 2 (Figure 7.7) are driven by:

- the characteristics of the reach represented by EF Site 2;
- slightly reduced bedload supply;
- slightly reduced suspended sediment supply for much of the year as a result of trapping of sediments in the reservoir; and;
- peaking power releases for several hours a day.

7.2.3.2 Vegetation

The main effect of the BGHES on vegetation under Sc1 and Sc1Fl is related to the expected reduction in sediments (Figure 7.8).

For the marginal graminoids and shrubs, the peaking will provide additional water in the dry and transitional seasons. This is expected to have a slight positive effect, which will slightly offset the effects of reduced sediments. As a result these indicators increase in abundance under the peaking scenarios. Conversely, peaking is expected to flush any settled organic particulate matter, algae and diatoms leaving little available as a food source for biota.

The lower riparian trees are also expected to benefit slightly from peaking flows, as the shape of the channel at EF Site 1 means that they are slightly wetted by the peak flows. The upper zone trees are expected to be unaffected by BGHES.

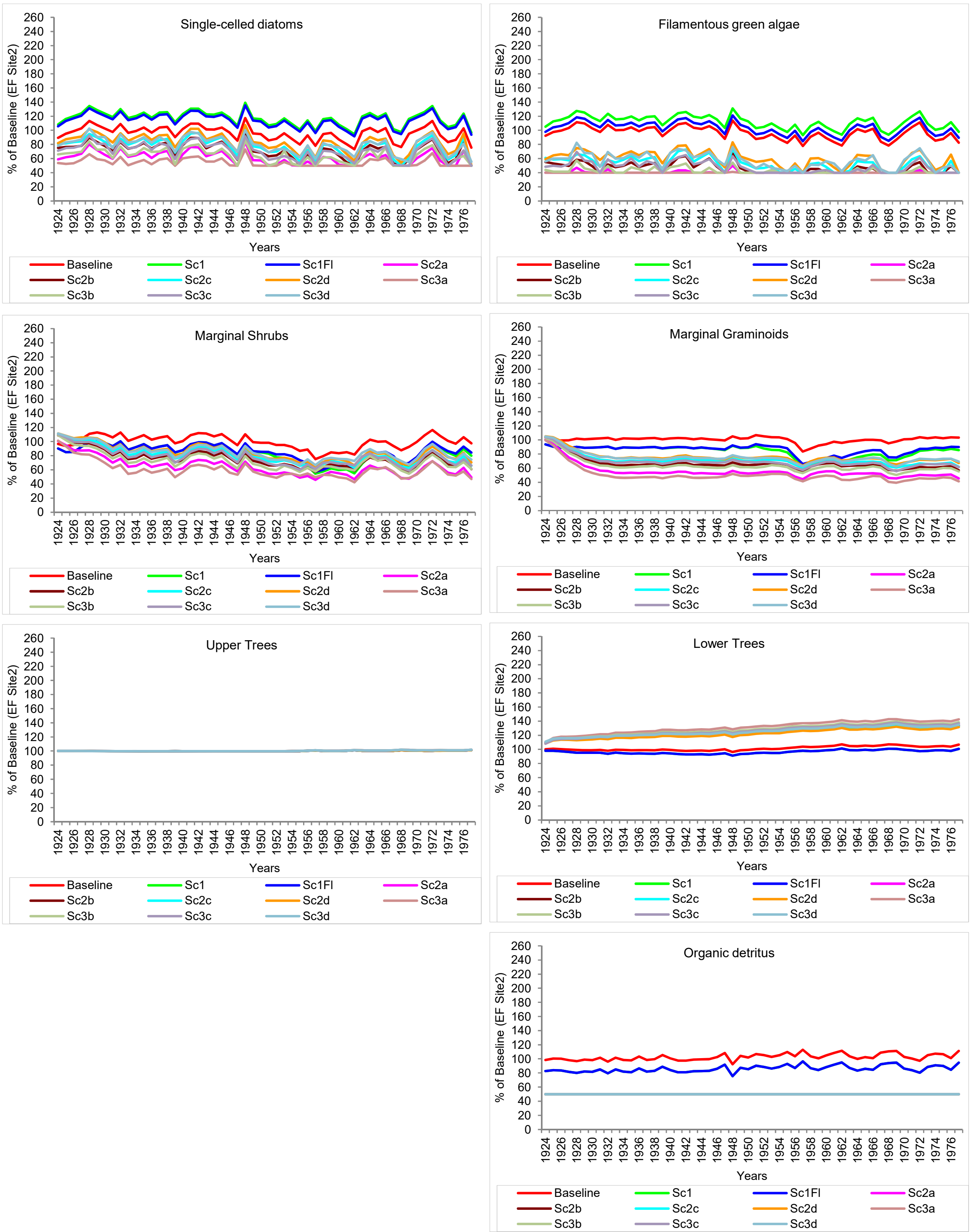

Figure 7.8 **Time-series of predicted changes in vegetation indicators at EF Site 2. Scenario lines not visible are hidden by those showing.**

7.2.3.3 Macroinvertebrates

Aquatic invertebrates would remain at approximately baseline abundances under S1 and S1Fl.

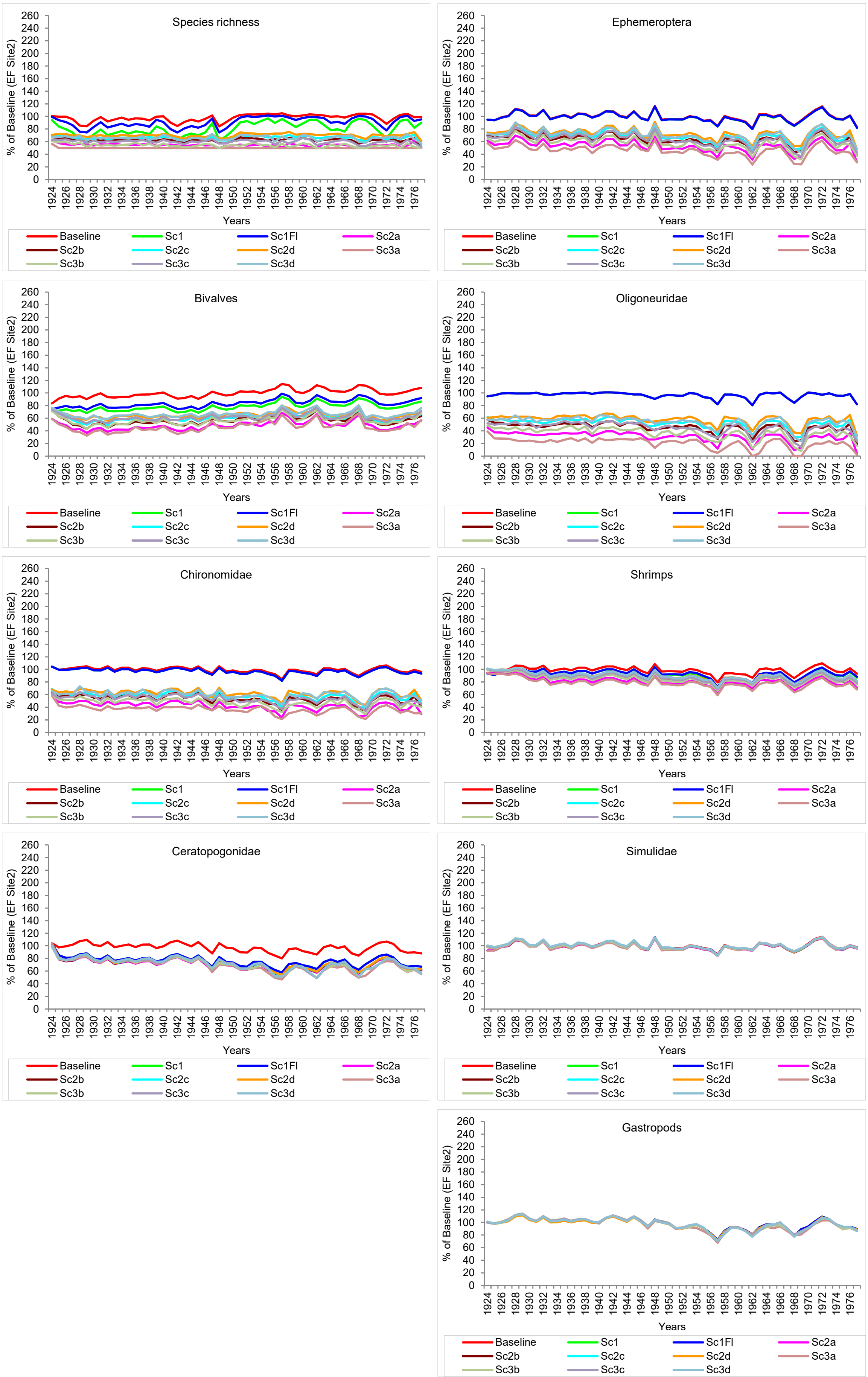

Figure 7.9 **Time-series of predicted changes in invertebrate indicators at EF Site 2. Scenario lines not visible are hidden by those showing.**

7.2.3.4 Fish

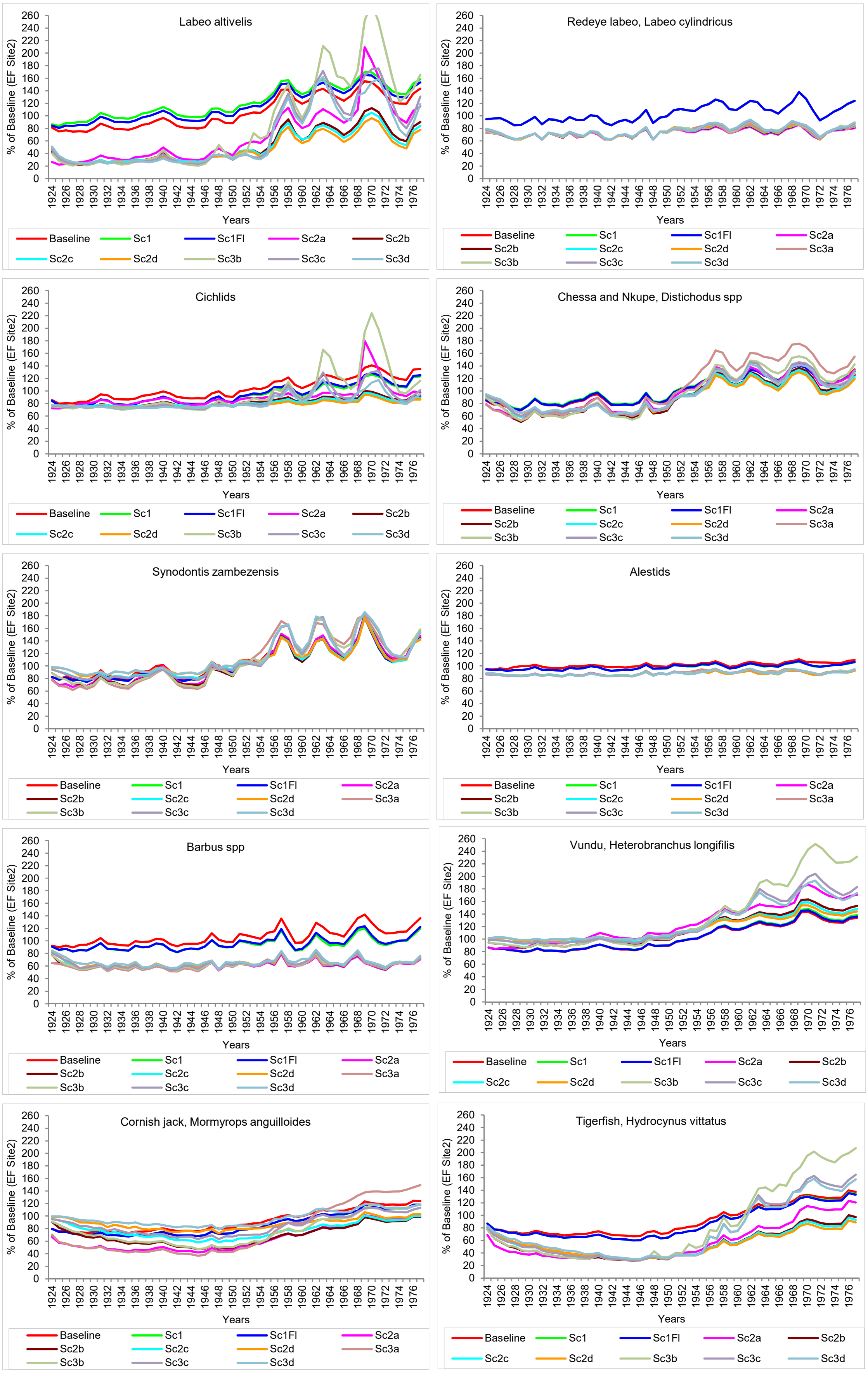

Figure 7.10 **Time-series of predicted changes in fish indicators at EF Site 2. Scenario lines not visible are hidden by those showing.**

The outcomes for fish at EF Site 2 (Figure 7.10) are similar to those reported for EF Site 1. The effect of the BGHES on fish abundance is related to:

- peaking flows that considerably disrupt spawning behavior, survival of eggs and survival of juveniles;
- reduction in algae and macroinvertebrates, which are a food source for some of the fish.

By virtue of their life histories and behaviour, these effects are greatest on the cichlids, mormyrids and tiger fish. It is worth reiterating that one of the mormyrids, a species of *Cyphomyrus*, was collected for the first time in the Middle Zambezi in this study and is currently under taxonomic/genetic investigation.

7.2.3.5 Crocodiles

In the DRIFT DSS, Crocodiles at EF Site 2 are only linked to the fluctuating flows with peaking releases. Thus, the predicted responses with Scenarios 2 and 3 are as a result of daily fluctuating flows disrupting nests (Dry Season) and washing out the young (Transition Season 1; Figure 7.11; Swanepoel et al. 2000).

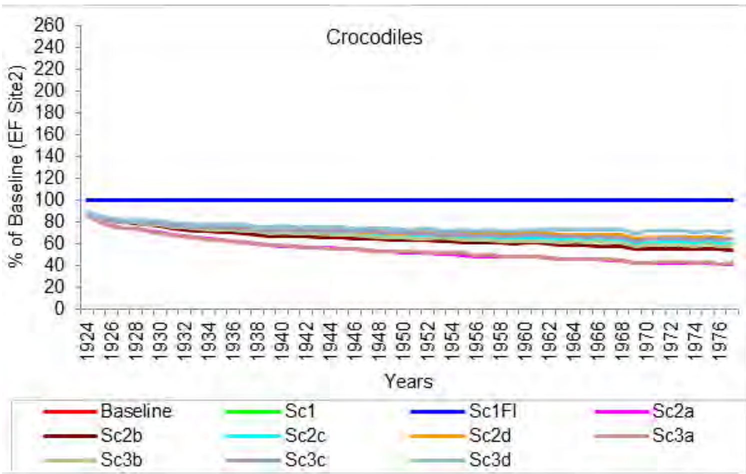

Figure 7.11 Time-series of predicted changes in crocodiles at EF Site 2. Scenario lines not visible are hidden by those showing.

7.2.4 Overall Ecosystem Integrity

The Overall Integrity for each the scenarios at BGHES EF Site 2 is illustrated in Figure 7.12. Comments are provided in Section 8.

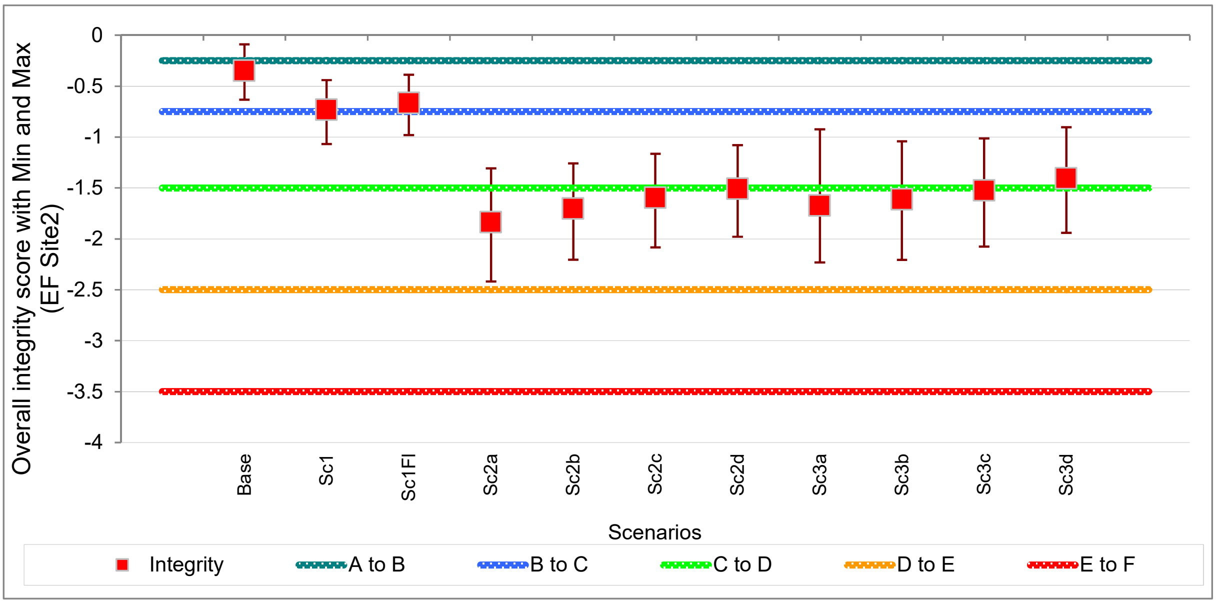

Figure 7.12 **Overall ecosystem integrity scores for the scenarios at EF Site 2 (upstream Lake Kariba).**

8 OVERALL INTEGRITY FOR ALL SITES AND ALL SCENARIOS

The overall integrity scores for all sites and all scenarios are presented in Figure 8.1, which gives an indication of the distribution of impacts on the Zambezi River in the study area.

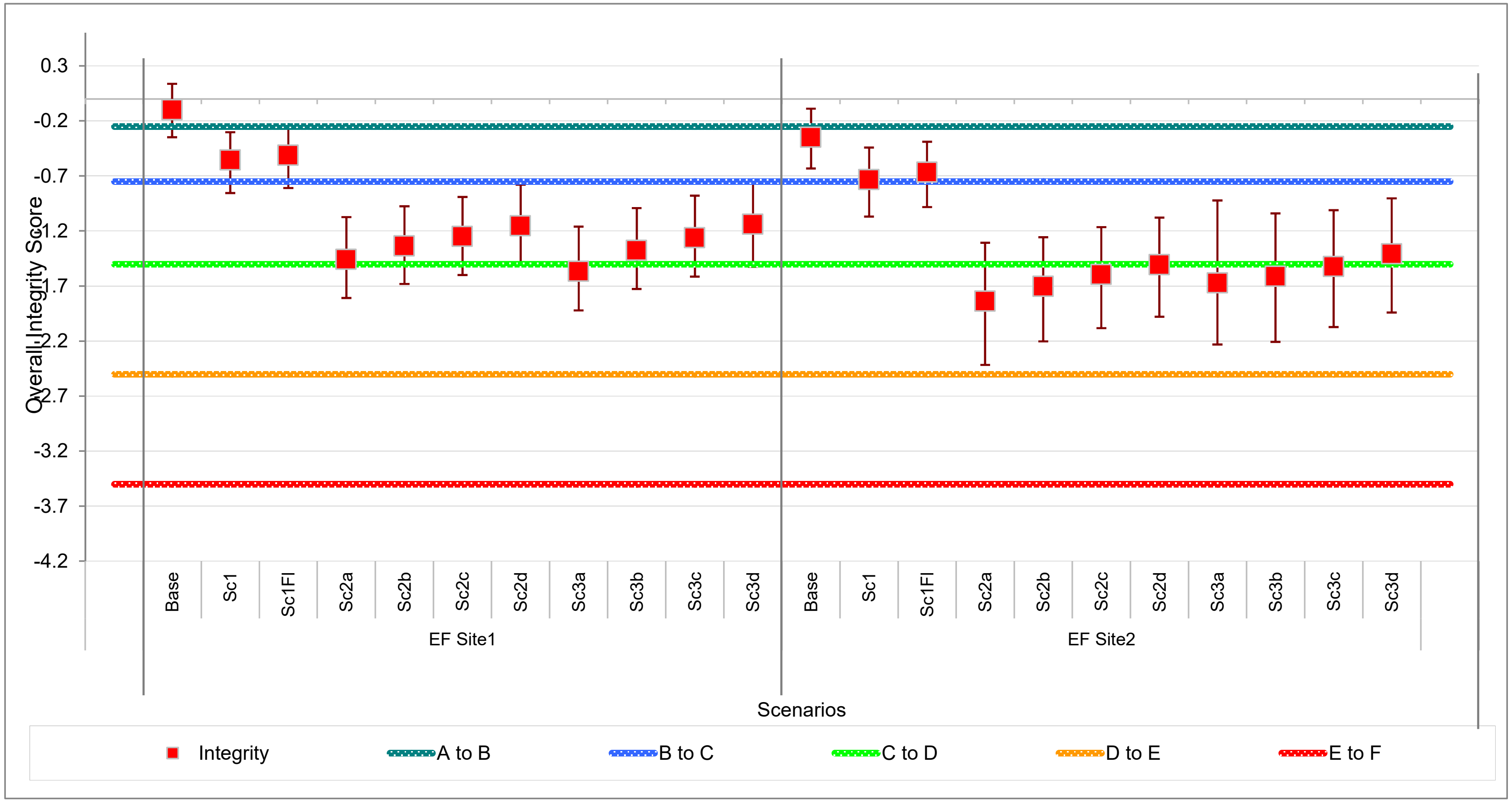

Figure 8.1 Overall integrity scores for all sites and all scenarios

The Overall Integrity plots show clearly that, if operated at a genuine run-of-river plant, the BGHES is expected to have only minor impacts on the downstream riverine ecosystem. The few impacts predicted are a result of a slight decline in suspended sediments as a result of BGHES dam wall. These impacts are expected to be slightly greater at EF Site 2 than at EF Site 1, despite its greater distance from the BGHES. This is because the character of the site, with its sandy banks and vegetated islands means that it is more vulnerable to erosion than EF Site 1.

The overall results for the scenarios can be summarized as follows:

8.1 EF SITE 1

Scenario 1: No change from an A/B Category. Essentially the change should be unnoticeable.
Scenario 1 (Flushing): No change from an A/B. Very similar to Scenario 1, some effects slightly reduced by periodic flushing of sediments.
Scenario 2a: Decline in condition from an A/B to a D Category.
Scenario 2b: Decline in condition from an A/B to a C/D Category.
Scenario 2c: Decline in condition from an A/B to a C/D Category.
Scenario 2d: Decline in condition from an A/B to a C Category.
Scenario 3a: Decline in condition from an A/B to a D Category.
Scenario 3b: Decline in condition from an A/B to a C/D Category.
Scenario 3c: Decline in condition from an A/B to a C/D Category.
Scenario 3d: Decline in condition from an A/B to a C Category.

Thus Scenarios 1 and 1Fl meet the criteria for minimum degradation (see Section 6.7). For the Scenario 2 and 3, the increased minimum flow releases A through D, are expected to have a marked impact on the overall condition, with the higher releases resulting in fewer impacts.

8.2 EF SITE 2

Very similar in pattern but slightly more severe than changes expected at EF Site 1,
Scenario 1: Very slight decline in condition from a B to B/C Category.
Scenario 1 (Flushing): Same as Sc1.
Scenario 2a: Decline in condition from a B to a D Category.
Scenario 2b: Decline in condition from a B to a D Category.
Scenario 2c: Decline in condition from a B to a D Category.
Scenario 2d: Decline in condition from a B to a D Category.
Scenario 3a: Decline in condition from a B to a D Category.
Scenario 3b: Decline in condition from a B to a D Category.
Scenario 3c: Decline in condition from a B to a D Category.
Scenario 3d: Decline in condition from a B to a C/D Category.

As is the case for EF Site 1, Scenarios 1 and 1Fl meet the criteria for minimum degradation (see Section 6.7). For the Scenario 2 and 3, the increased minimum flow releases A through D, are expected to have a marked impact on the overall condition, with the higher releases resulting in fewer impacts.

9 COMMENTS ON COMPOUNDING IMPACTS AT EF SITE 1 AND 2 RELATED TO WATER QUALITY CHANGES AS A RESULT OF THE BGHES

Water quality was not included in the DRIFT assessment, which concentrated on the effects of potential flow and sediment changes, and barrier effects, as a result of the BGHES. However, this section provides a qualitatively assessment of the additional effects on the downstream environment as a result of expected changes in water quality, based on the outcome the water quality modelling undertaken by ERM.

9.1 SUMMARY OF WATER QUALITY MODELLING RESULTS

Three different annual inflow hydrographs were selected from the Victoria Falls historical flow record to use for the water quality analysis as follows:

- 1931 was chosen to represent a median flow year
- 1957 was chosen to represent an extreme high flow year.

The downstream analysis focussed on temperature and dissolved oxygen conditions in the reservoir and downstream for the different powerhouse intake configurations presented in SP (2014). Since the results for 1931 and those for 1957 did not differ markedly, only the median flow year (1931) is referred to here.

The simulated time-series of temperature and dissolved oxygen at the reservoir outlet under median annual inflow conditions are presented in Figure 9.1 and Figure 9.2, respectively[8].

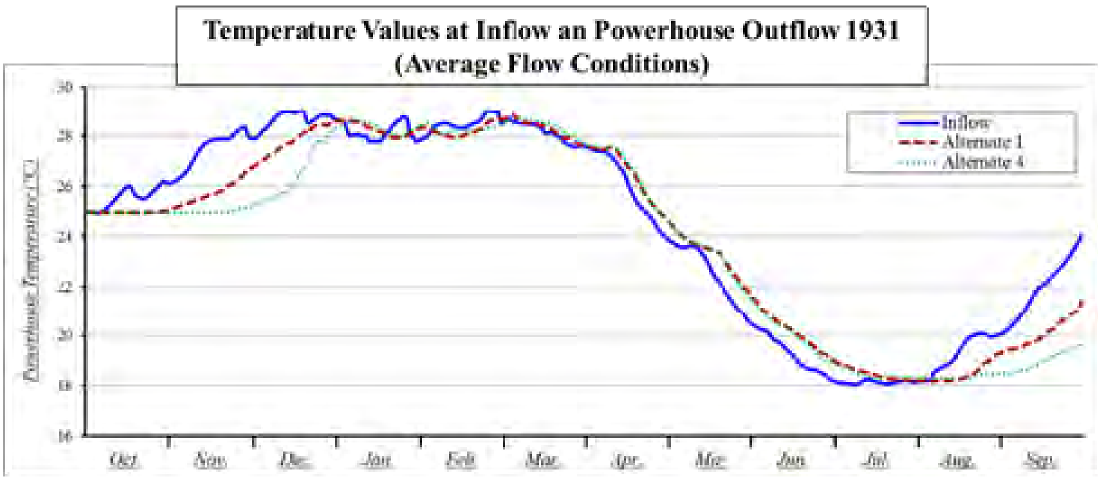

Figure 9.1 Temperature of the water at the inflow and powerhouse outflows under median hydrological conditions (ERM 2014)

[8] ERM warn that the influent water temperature and dissolved oxygen data are derived from available meteorological data for the region and so the results should be interpreted in comparative terms only.

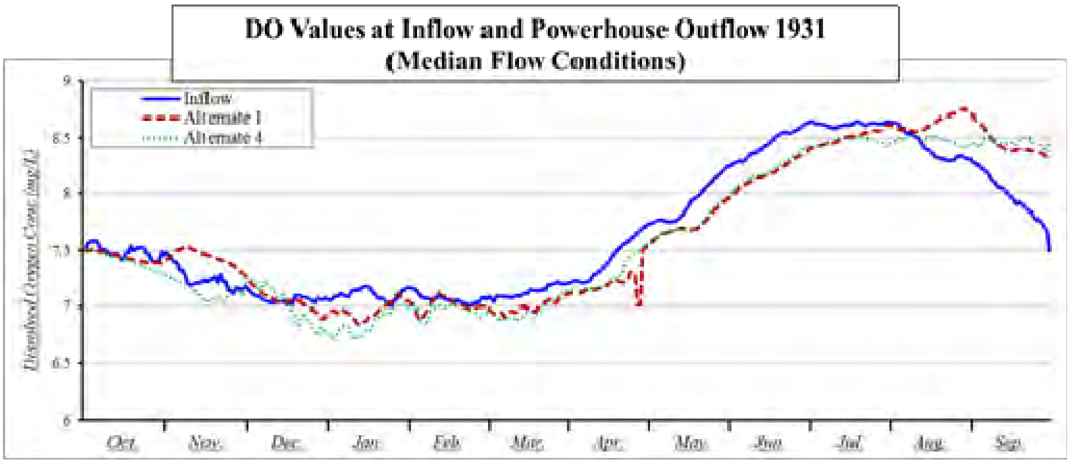

Figure 9.2 **Dissolved oxygen values at the inflow and powerhouse outflows under median hydrological conditions (ERM 2014)**

9.1.1 Temperature

In broad terms, the results show that the reservoir becomes stratified under low inflow conditions, and as a result the outflow from the lower intake (Alternative 4) is a few degrees cooler for a period of a few months at the beginning of the hydrological year. However, under average and high flow conditions (December onwards) the reservoir becomes vertically mixed as larger inflows are passed through the powerhouse. The vertically mixed condition causes outflow temperatures to be similar to natural river conditions. These effects do not significantly change for the different operational scenarios considered, i.e., with different peaking and minimum outflow requirements.

9.1.2 Dissolved oxygen

A similar effect is evident for dissolved oxygen. There is a small lag between natural and reservoir conditions because of stratification in the reservoir as inflows begin to rise. However, there is negligible difference between the two intake configurations for these impacts.

9.1.3 Downstream attenuation of effects

Preliminary calculations based upon estimated surface heat exchange conditions and re-aeration coefficients suggests that there will be only limited recovery of temperature and dissolved oxygen between the dam and EF Site 2 owing to the surface area constraints introduced by the gorge and the fast flow of the river.

9.2 *COMPOUNDING IMPACTS AT EF SITE 1 AND 2 RELATED TO WATER QUALITY CHANGES*

9.2.1 Geomorphology

Changes in temperature and dissolved oxygen of the levels described by the modelling will not affect any of the geomorphological indicators.

9.2.2 Vegetation

None of the vegetation indicators are linked to dissolved oxygen. One, filamentous green algae, is linked to temperature. However, the changes suggested by the modelling will be insufficient to markedly affect algal growth, as their response is mostly driven by flow.

9.2.3 Macroinvertebrates

Over the low flow period, which is the time when many of the insects are reliant on the river system to complete the aquatic phases of their life histories, a temperature difference of 3-5^{o}C as indicated in September (Figure 9.1) would affect the number of generations within a season for multi-voltine species, the success of hatching, the timing of emergence and growth rate. This would mean that under lower temperatures, more generalist (less sensitive) taxa would flourish at the expense of sensitive species, which could impact on species richness, and a reduction in the number of ephemeroptera.

9.2.4 Fish

The lower temperature at the end of the simulated year is of concern. Cichlid spawning is temperature controlled, starting as the river starts to warm up in September. A delay in temperature rise could thus delay the start of spawning. The tigerfish spawning trigger is the onset of rains, but gonad maturation in preparation is probably temperature linked as they mature in October. A few months delay until mixing occurs in December could have a definite adverse impact on spawning.

It is unlikely that there would be any impact on fish as a result of changes in dissolved oxygen as the modelled fluctuations are well within the normal range for the river.

10 IMPACTS DOWNSTREAM OF THE KARIBA HPP

This EF study has necessarily focused on the section of the Zambezi River between the proposed BGHES and Lake Kariba, but that there will be consequences further downstream if Kariba HPP is operated differently as a result of the presence of the BGHES. If this is the case, these knock-on effects, and their impacts on the Zambezi River downstream of Kariba Dam, have not, and should be assessed.

However, it is the assumption that the operating conditions for Kariba will remain relatively unchanged following the operation of the BGHES. As described in Chapter 2 of the ESIA document (ERM, 2019), and as elaborated in SP (2018), the proposed Batoka HPP, with its inflows, relatively small impoundment and hence relatively short residence time of inflows (~26 days), will allow only a daily or weekly (under specific conditions) regulation of the inflows. On the contrary, the reservoir of the Kariba HPP is large enough to guarantee the annual regulation of the inflows.

In terms of potential effects within Lake Kariba itself, given the relative storage volumes of the two reservoirs (approximately 185 km^3 for Kariba, and less than 2 km^3 for Batoka), and the capacity of Batoka to regulate primarily daily flows only, it is extremely unlikely that the Project would have any noticeable regulating effect on storage volumes or water levels in Lake Kariba (assuming that operating conditions for Kariba remain relatively unchanged). Therefore, there is unlikely to be any impact on direct water abstractions from the main body of the lake, on lake fisheries, and any noticeable impacts downstream of Kariba as a result of the operation of the Batoka HPP.

The design and location of the Batoka HPP means that its potential impacts on the flow and sediment regime in the downstream Zambezi River will be limited to the river reach between the HPP and Lake Kariba, where after any changes in the daily or monthly distribution of flows will be absorbed by the Kariba impoundment. Flow in the river downstream of Kariba Dam will be influenced by the operating rules of Kariba rather than those of the proposed Batoka HPP.

During dam filling, the reduction in flood volume due to the filling of the new dam will reduce the scale of the annual fluctuation of Kariba levels, and thus negatively impact on fish abundance and catch rates. Annual floods bring fresh sediments and associated nutrients to the western arm of Lake Kariba. After the short-term increase in sediment during and shortly after the construction phase, annual sediment and nutrient input to the western arm of Lake Kariba will be reduced as a result of the Batoka HPP. In the long-term, therefore, there may be a negative but slight impact on productivity in the western arm of Lake Kariba, unless flood releases from the dam can be designed to transport sediment from the reservoir bed.

In mitigation, it is recommended that during the filling phase, released flows should closely follow the natural flood cycle, with greater flow release at the beginning of the local rains, which act as spawning cues for many of the important fish species.

11 CONCLUSIONS

The expected downstream impacts of the proposed BGHES are expected to be low provided it is operated as a purely run-of-river plant, i.e., *c.* instantaneous inflow = *c.* instantaneous outflow. If operated in this manner, the impacts of the BGHES on the downstream river are expected to be largely limited to those related to a reduction in sediment supply. EF Site 2 is expected to be slightly more vulnerable to impacts from the BGHES than is EF Site 1, this is mainly because it is a broader and flatter section of river, and will be more affected by the expected reduction in sediment. However, under run-of-river operation (as defined above), the presence of the BGHES is expected to have only a minor impact (minimum degradation) on the integrity of the downstream Zambezi River.

However, any peaking operations are expected to have a significant negative impact on the integrity of the downstream river ecosystem. Given the slope of the river through Batoka Gorge, it is highly unlikely that these flows will be attenuated to any meaningful extent before they reach Lake Kariba.

Thus, the recommendation of this EF study is avoid peaking power releases at the BGHES. Failing this, peaking releases can be slightly mitigated through maximising the dry season minimum flow condition and thereby reducing the peaking differential.

Finally, this EF study has necessarily focused on the section of the Zambezi River between the proposed BGHES and Lake Kariba, but that there will be consequences further downstream if Kariba HPP is operated differently as a result of the presence of the BGHES. If this is the case, these knock-on effects, and their impacts on the Zambezi River downstream of Kariba Dam, have not been, and should be, assessed.

However, it is the assumption that the operating conditions for Kariba will remain relatively unchanged. Based on this assumption, the overall impact of the Batoka Gorge dam on the Lake Kariba fish and fisheries will be limited, with the possible exception of lower annual flood lake level rise, but this will likely be restricted largely to the western arm of the lake near the Zambezi inflow. Given the relative storage volumes of the two reservoirs (approximately 185 km^3 for Kariba, and less than 2 km^3 for Batoka), impacts downstream of the Kariba Dam wall on the Zambezi River, are expected to be insignificant

Please note, as stated in Section 0: The main body of the report was completed as part of the ESIA in December 2014. The outcome of a subsequent process to refine and agree on operating rules for the proposed BGHES is presented in Appendix A. The final agreed operating rules associated with this subsequent process to satisfy downstream EFlows requirements were:

AddPM04 DRY Season (**Sep-Jan**): Baseline flows; no sediment flushing.
WET Season (**Feb-Aug**): QMin with one 6-hour peak a day.

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Appendix A. ADDITIONAL ANALYSES FOR REFINEMENT OPERATING RULES

A.1. INTRODUCTION

The EF assessment undertaken for the original ESIA, which was based on the scenarios outlined in Section 5, was extended to include additional scenario designed to assist with the refinement of the operating rules for the proposed BGHES. The purpose of the additional assessments was to find a balance between minimising environmental impacts in the downstream river and maximising power output from the BGHES, specifically through the generation of power in periods of peak demand.

The process adopted for these additional assessments was:

1. December 2018 – emails and conference calls between ZRA, ERM, Southern Waters and the design engineers (Studio Pietrangeli) to agree on a work plan and exchange of information.
2. December 2018 – Studio Pietrangeli developed a series of possible wet- and dry-season operating regimes for the BGHES, distinguished from one another through different levels of releases in off-peak periods (Appendix Table 1).
3. January 2019 – Southern Waters combined the wet- and dry-season operating regimes provided by Studio Pietrangeli in various permutations (referred to Operating Rule SET A) and analysed the likely impact of these on the downstream river ecosystem using the DRIFT EF model developed for the BGHES EF assessment (Appendix B).
4. 22-23 January 2019 – Representatives of ZRA, ERM, Studio Pietrangeli and Southern Waters convened for a 2-day workshop at ERM offices in Rivonia, South Africa. At the workshop:
    a. Studio Pietrangeli explained the implications for power production of different operating regimes.
    b. Southern Waters provided feedback on the outcome of impact of the additional on the downstream river ecosystem additional scenarios relative to the impact predicted for the original (ESIA) scenarios.
    c. Workshop participants agreed an further three scenarios (referred to Operating Rule SET B), designed to highlight particular issues related to hydropower production and impacts on the downstream river ecosystem, which were constructed, analysed and presented on the second day of the workshop.
    d. On the basis of the results for all of the scenarios, workshop participants agreed on a set of environmental and engineering criteria (Appendix Table 2) for selecting a scenario that would become the operating rules for the BGHES.
5. 30 January 2019 - In an effort to arrive at a scenario that met both the environmental and the engineering criteria, Studio Pietrangeli designed three additional power-generation scenarios for evaluation, and Southern Waters designed one additional flow scenario

(referred to Operating Rule SET C). NB. Some of these scenarios included two peaks per day, i.e., similar to the ESIA pattern of peaking but with lower peak discharges. The downstream impacts of these four scenarios were also evaluated using DRIFT.

Appendix Table 1 Monthly percentiles used in design of the additional scenarios

	Dry	Wet	Wet	Wet	Wet	Wet	Wet/ Dry[9]	Wet/ Dry[10]	Dry	Dry	Dry	Dry
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q_avg (m^3/s)	660	1130	2112	2958	2545	1585	814	484	345	264	265	404
Q_min (m^3/s)	319	443	602	784	871	447	281	220	161	116	118	199
Q_05 (m^3/s)	441	628	861	1122	1089	637	394	294	218	169	162	261
Q_10 (m^3/s)	467	666	893	1230	1328	899	468	333	247	179	182	276
Q_20 (m^3/s)	503	747	1048	1529	1700	1158	569.2	369.8	265	204	207	308

Appendix Table 2 Agreed environmental and engineering criteria for deciding on a scenario

Type	Criteria
Environmental criteria	No more than a 1.5 class drop in Overall Ecosystem Condition in the downstream river, i.e., from A/B to no less than a mid-C category. This represents a drop in ecological category from "near natural" to "moderately modified" (Table 3.2), which is still considered a healthy functioning ecosystem.
	No more than a 25% reduction in abundance for 90% of the fish species.
Engineering criteria[11]	Minimum constraints on power generation in the wet season (when flows are lower than Q20).
	Peak discharges cannot exceed 75% of design peak flows, with Kariba to compensate for this gap.
	No constraints in the wet seasons, unless it is a low flow year in which case ramping up to reduced peak with Kariba compensating.
	Dry seasons Q20 with some minor modifications.

The predicted impacts on the downstream river ecosystem (EF Site 2) for the sets of scenarios tested as part of this process are presented in Sections A.2.1 to A.2.3. Depictions of the flow regimes associated with each scenario are presented in Appendix B. Note there is considerable, and intentional, overlap between the scenarios in each of the sets. This is to facilitate comparison between the various scenarios.

[9] Whether July was treated as dry or wet month depended on the scenario

[10] Whether August was treated as dry or wet month depended on the scenario.

[11] The engineering criteria informed the construction of operating SET C criteria – but see SET C descriptions in Section A.2.3.

A.2. RESULTS OF SCENARIO ASSESSMENTS USING DRIFT

A.2.1. OPERATING RULE SET A

The scenarios presented for Operating Rule Set A comprise the full suite of scenarios from the ESIA, plus eight additional scenarios derived from the wet and dry season data sent by SP, as follows[12] (monthly values corresponding to Qmin, Q10, etc. are given in Appendix Table 1):

QMin	Whole year: Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Qmin; no sediment flushing.
QMinB	DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Qmin; no sediment flushing. WET Season (Feb-Jun): Baseline, i.e., no peaking.
Q05	Whole year: Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q5%; no sediment flushing.
Q05B	DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q5%; no sediment flushing. WET Season: Baseline, i.e., no peaking.
Q10	Whole year: Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q10%; no sediment flushing.
Q10B	DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q10%; no sediment flushing. WET Season: Baseline, i.e., no peaking.
Q20	DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q20%; no sediment flushing. WET Season: Baseline, i.e., no peaking.
Q30	DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q30%; no sediment flushing. WET Season: Baseline, i.e., no peaking.
Int	Whole year: Daily 6-hour peak at maximum of 1371 m^3s^{-1}; median off-peak release of 297 m^3s^{-1}; no sediment flushing.

Each flow regime comprised hourly data for 90 years. The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule Set A at EF Site 1 and 2 are given in Appendix Table 3 and Appendix Table 4, respectively. Depictions of the flow regimes associated with each scenario are presented in Appendix B.

The estimated mean percentage change in abundance/area/concentration of ecosystem indicators at EF Site and 2 under the SET A scenarios are given in Appendix Table 5 and Appendix Table 6, respectively. EF Site 2 has slightly more diverse habitats, and hence a larger array of species indicators. The tables are colour-coded to facilitate identification of major impacts. The colours <u>*do not*</u> denote whether the predicted change is a move towards or away from the natural condition of the river ecosystem.

The Overall Integrity for each the SET A scenarios at EF Site 1 and 2 are illustrated in Appendix Figure 1 and Appendix Figure 2, respectively.

[12] Note: Off-peak releases were equal to inflow when inflow was less than the relevant percentile discharge.

The result clearly illustrate that the operating regimes provided by SP for testing result in fewer downstream impacts in the river reaches represented by both EF sites than those originally tested in the ESIA. At the more sensitive of the two sites, EF Site 2, the differences between the two sets of operating rules result in an improvement in Overall Integrity of between half and one ecological category, depending on which scenarios are compared with one another. While predicted impacts on bed sediment size and sand banks are only slightly lower under the SP scenarios, the predicted impacts on vegetation, invertebrates, fish, and crocodiles are considerably lower. This is mostly attributable the fact that the additional operating scenario mostly comprise only a single daily peak[13] and significantly lower peak discharges, relative to the ESIA scenarios.

[13] There are exceptions to this in operating Rule SET C.

Appendix Table 3 **The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule Set A at EF Site 1. Units are given in Table 7.1.**

EF1	Base	Sc1noFl	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q30	Int1
Mean annual runoff (Mm^3)	35738	35738	35738	35534	35534	35534	35534	35533	35533	35533	35533	35738	35738	35738	35738	35738	35738	35738	35738	35725
Dry season onset	35.0	35.0	35.0	35.0	35.0	35.0	35.0	33.0	33.5	34.0	34.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Dry season duration	110.5	110.5	110.5	110.5	110.5	110.5	110.5	115.0	117.5	117.0	117.0	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5
Dry season Min 5d Q	220.6	220.6	220.6	220.6	220.6	220.7	255.0	202.6	216.2	222.0	255.0	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6
Wet season onset	7.0	7.0	7.0	7.0	8.0	8.0	8.0	6.0	6.0	6.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Wet season duration	147.0	147.0	147.0	145.0	145.0	142.5	135.5	156.5	156.0	151.0	143.5	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Wet season Max 5d Q	3309	3309	3309	3294	3294	3294	3294	3257	3257	3257	3257	3309	3309	3309	3309	3309	3309	3309	3309.1	3309.1
Flood volume	26798	26798	26798	26502	26437	26161	25658	26834	26834	26705	26333	26798	26798	26798	26798	26798	26798	26798	26798	26798
Dry season ave daily vol	25.7	25.7	25.7	25.7	25.7	25.7	26.1	26.5	26.2	26.1	26.5	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
T1 ave daily vol	56.6	56.6	56.6	56.6	56.6	56.6	57.9	46.7	48.8	49.6	51.2	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6
Wet season ave daily vol	169.6	169.6	169.6	167.5	169.6	172.3	176.9	164.9	164.9	165.9	170.3	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6
T2 ave daily vol	48.3	48.3	48.3	48.3	48.3	48.3	48.3	53.2	52.3	52.0	51.3	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.3	48.4
Dry within day range	0.0	0.0	0.0	746.0	402.0	258.0	102.0	906.5	419.4	217.8	4.9	563.3	563.3	337.4	337.4	256.3	256.3	162.6	81.7	404.6
T1 within day range	0.0	0.0	0.0	2166.0	1894.2	1750.2	1644.2	1921.0	1663.9	1536.8	1446.6	1089.9	980.1	750.9	610.3	662.3	518.6	372.5	216.6	645.8
Wet within day range	0.0	0.0	0.0	823.1	823.1	816.9	714.9	319.2	319.2	319.2	311.9	79.8	33.1	75.8	33.1	66.8	33.1	33.1	33.1	33.1
T2 within day range	0.0	0.0	0.0	1733.7	1386.8	1242.8	1086.8	2192.3	1874.7	1639.5	1365.4	1151.3	1151.3	814.3	814.3	618.6	618.6	395.0	219.0	819.7
Dry season Min 5d Depth	7.7	7.7	7.7	7.7	7.7	7.6	7.5	7.8	7.8	7.6	7.5	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Dry season Min 5d Velocity	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dry season Min 5d WetPerim	223.7	223.7	223.7	223.7	223.7	223.7	229.9	217.2	222.8	223.9	229.9	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7
Wet season Max 5d Depth	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Wet season Max 5d Velocity	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Wet season Max 5d WetPerim	289.2	289.2	289.2	289.1	289.1	289.1	289.1	288.8	288.8	288.8	288.8	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2
Wet season Min 5d Depth	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.2	8.2	8.2	8.3	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Wet season Min 5d Velocity	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Wet season Min 5d WetPerim	262.4	262.4	262.4	262.4	262.4	262.4	262.5	259.1	259.1	259.3	260.6	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4
Wet: ave Fine suspended sediment (%)	100.0	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Wet: max Fine suspended sediment(%)	100.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Wet: ave Coarse suspended sediment(%)	100.0	29.9	41.8	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9
Wet: max Coarse suspended sediment(%)	100.0	40.0	120.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Appendix Table 4 **The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule Set A at EF Site 2. (If not provided, units are given in Table 7.1.**

EF2	Base	Sc1noFl	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q30	Int1
Mean annual runoff (Mm^3)	35738	35738	35738	35534	35534	35534	35534	35533	35533	35533	35533	35738	35738	35738	35738	35738	35738	35738	35738	35725
Dry season onset	35.0	35.0	35.0	35.0	35.0	35.0	35.0	33.0	33.5	34.0	34.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Dry season duration	110.5	110.5	110.5	110.5	110.5	110.5	110.5	115.0	117.5	117.0	117.0	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5
Dry season Min 5d Q	220.6	220.6	220.6	220.6	220.6	220.7	255.0	202.6	216.2	222.0	255.0	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6
Wet season onset	7.0	7.0	7.0	7.0	8.0	8.0	8.0	6.0	6.0	6.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Wet season duration	147.0	147.0	147.0	145.0	145.0	142.5	135.5	156.5	156.0	151.0	143.5	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Wet season Max 5d Q	3309.2	3309.2	3309.2	3294.5	3294.5	3294.5	3294.5	3256.6	3256.6	3256.6	3256.6	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1
Flood volume	26798	26798	26798	26502	26437	26161	25658	26834	26834	26705	26333	26798	26798	26798	26798	26798	26798	26798	26798	26798
Dry season ave daily vol	25.7	25.7	25.7	25.7	25.7	25.7	26.1	26.5	26.2	26.1	26.5	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
T1 ave daily vol	56.6	56.6	56.6	56.6	56.6	56.6	57.9	46.7	48.8	49.6	51.2	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6
Wet season ave daily vol	169.6	169.6	169.6	167.5	169.6	172.3	176.9	164.9	164.9	165.9	170.3	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6
T2 ave daily vol	48.3	48.3	48.3	48.3	48.3	48.3	48.3	53.2	52.3	52.0	51.3	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.3	48.4
Dry within day range	0.0	0.0	0.0	746.0	402.0	258.0	102.0	906.5	419.4	217.8	4.9	563.3	563.3	337.4	337.4	256.3	256.3	162.6	81.7	404.6
T1 within day range	0.0	0.0	0.0	2166.0	1894.2	1750.2	1644.2	1921.0	1663.9	1536.8	1446.6	1089.9	980.1	750.9	610.3	662.3	518.6	372.5	216.6	645.8
Wet within day range	0.0	0.0	0.0	823.1	823.1	816.9	714.9	319.2	319.2	319.2	311.9	79.8	33.1	75.8	33.1	66.8	33.1	33.1	33.1	33.1
T2 within day range	0.0	0.0	0.0	1733.7	1386.8	1242.8	1086.8	2192.3	1874.7	1639.5	1365.4	1151.3	1151.3	814.3	814.3	618.6	618.6	395.0	219.0	819.7
Dry season Min 5d Depth	4.5	4.5	4.5	4.5	4.5	4.5	4.6	4.4	4.4	4.5	4.6	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Dry season Min 5d Velocity	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Dry season Min 5d WetPerim	120.4	120.4	120.4	120.4	120.4	120.4	121.7	120.3	120.4	120.5	121.7	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4
Wet season Max 5d Depth	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Wet season Max 5d Velocity	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Wet season Max 5d WetPerim	455.5	455.5	455.5	455.3	455.3	455.3	455.3	453.6	453.6	453.6	453.6	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5
Wet season Min 5d Depth	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.5	3.5	3.5	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Wet season Min 5d Velocity	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Wet season Min 5d WetPerim	259.4	259.4	259.4	259.2	259.3	259.5	260.2	215.3	215.4	218.0	236.2	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3
Wet: ave Fine suspended sediment(%)	100.0	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	14.8	19.8	19.8	19.8	19.8	19.8
Wet: max Fine suspended sediment(%)	100.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	15.0	20.0	20.0	20.0	20.0	20.0
Wet: ave Coarse suspended sediment(%)	100.0	39.3	50.7	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	29.9	39.3	39.3	39.3	39.3	39.3
Wet: max Coarse suspended sediment(%)	100.0	40.0	100.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

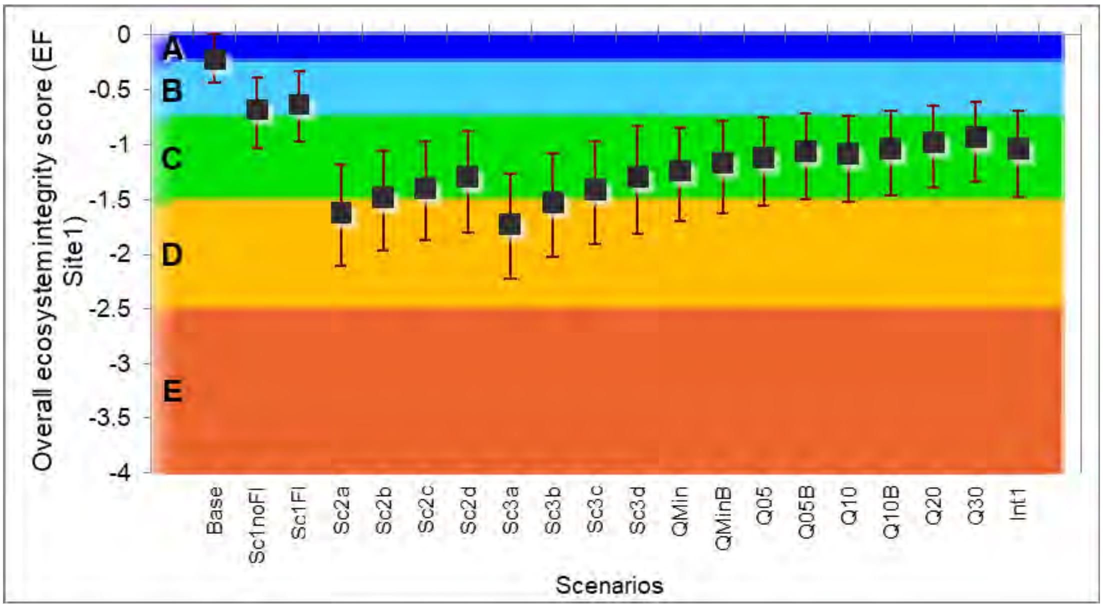
Appendix Table 5 **BGHES EF Site 1: The mean percentage changes in abundance (relative to baseline) for the indicators for the SET A scenarios. Blue and green are major changes that represent an INCREASE: green = 40-70%; blue = >70%. Orange and red are major changes that represent a DECREASE: orange = 40-70%; red = >70%. Baseline, by definition, equals 100%.**

	Base	Sc1noFl	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q30	Int1
Geomorphology																				
Low mid-channel rock exposures	0.3	0.5	0.0	-69.9	-57.9	-52.3	-48.0	-73.6	-58.8	-52.5	-46.7	-41.3	-34.9	-25.4	-22.4	-20.7	-18.6	-14.1	-10.7	-23.2
Backwater bed sediment (fine to coarse)	0.9	100.7	100.7	113.2	111.6	110.8	110.0	114.1	112.1	111.4	110.7	109.7	108.6	106.8	106.2	105.6	105.2	104.0	103.2	106.5
Area of backwaters and secondary channels	0.9	-1.3	-0.5	-38.8	-31.7	-28.4	-24.7	-39.9	-31.6	-27.1	-22.7	-24.1	-21.3	-17.5	-16.0	-15.1	-13.9	-11.4	-9.1	-16.5
Channel bed sediment size (fine to coarse)	1.5	99.0	99.0	112.3	110.7	109.8	109.0	112.9	111.0	110.2	109.4	108.8	108.2	106.6	106.0	105.5	105.0	103.9	102.7	106.2
Depth of pools	-1.1	-2.1	-1.0	5.6	3.5	2.7	2.0	6.6	4.0	2.9	2.0	1.9	1.3	0.3	0.0	-0.2	-0.4	-0.8	-1.2	0.0
Sand bars	0.9	-66.3	-49.0	-80.8	-78.3	-77.3	-76.2	-81.6	-79.6	-78.3	-76.6	-76.1	-75.4	-73.9	-73.4	-72.9	-72.5	-71.5	-70.5	-73.6
Riparian vegetation																				
Single-celled diatoms	0.3	17.0	14.8	-26.1	-15.9	-10.7	-5.4	-29.8	-17.6	-11.5	-4.8	-6.3	-3.0	2.2	3.8	5.0	6.1	8.7	10.7	3.7
Filamentous green algae	-0.1	18.5	16.9	-41.8	-30.4	-24.2	-18.0	-44.2	-31.8	-24.7	-16.5	-16.1	-11.1	-3.3	-1.0	0.8	2.4	6.2	9.2	-1.1
Bryophyta	-2.0	15.7	12.5	82.2	67.2	61.3	59.2	88.5	71.5	63.8	59.7	51.1	46.2	38.3	36.1	33.9	32.3	28.3	25.1	36.1
Marginal Graminoids	-1.8	-18.0	-13.5	-7.9	-7.6	-6.9	-6.5	-9.2	-8.4	-7.7	-7.3	-8.0	-8.5	-8.5	-9.3	-8.9	-9.6	-10.1	-10.7	-9.4
Marginal Shrubs	-1.6	-10.4	-10.4	13.4	14.1	14.9	14.5	13.3	13.9	14.7	15.6	12.9	12.3	10.7	9.6	9.6	8.6	6.8	5.0	10.2
Lower Trees	-1.5	-5.6	-5.6	1.2	0.2	-0.3	-0.9	4.0	2.4	1.6	0.7	-3.3	-3.6	-4.0	-4.3	-4.1	-4.5	-4.7	-4.8	-5.0
Upper Trees	0.1	0.0	0.0	0.0	0.0	0.0	-0.1	0.3	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Organic detritus	-0.4	-11.4	-11.4	-42.5	-39.9	-37.8	-35.5	-44.5	-39.8	-36.9	-34.1	-36.1	-33.5	-28.9	-27.1	-25.8	-24.5	-21.5	-19.1	-27.3
Macroinvertebrates																				
Species richness	-1.9	-25.8	-23.8	-43.4	-42.6	-42.5	-41.8	-43.2	-42.1	-41.9	-41.0	-42.7	-41.1	-41.0	-39.8	-40.0	-39.0	-37.6	-36.0	-40.6
Ephemeroptera	-1.3	0.0	0.0	-60.1	-50.0	-44.6	-39.1	-66.0	-53.3	-46.1	-38.8	-41.5	-36.8	-32.4	-29.6	-28.7	-26.3	-22.1	-18.4	-30.5
Oligoneuridae	-1.9	0.1	0.0	-61.3	-45.8	-39.0	-33.3	-68.9	-50.8	-42.7	-35.0	-32.8	-28.4	-20.5	-18.5	-16.5	-15.1	-11.5	-8.7	-18.6
Chironomidae	0.9	-3.0	-2.9	-55.4	-43.8	-40.2	-37.1	-61.1	-48.6	-43.5	-38.7	-30.6	-26.7	-19.8	-18.0	-16.1	-14.9	-11.4	-8.8	-18.2
Ceratopogonidae	-0.9	-24.5	-24.2	-29.5	-28.2	-28.7	-27.9	-36.1	-33.9	-33.4	-32.1	-26.8	-26.4	-25.1	-24.9	-24.4	-24.2	-23.5	-22.8	-25.1
Simulidae	0.4	0.0	0.0	-69.1	-52.4	-44.8	-38.5	-74.8	-55.1	-45.9	-37.6	-37.2	-32.1	-23.6	-21.3	-19.1	-17.5	-13.3	-10.0	-21.4
Gastropods	1.6	-0.3	0.0	-0.4	-0.4	-0.5	-0.7	-1.3	-0.7	-0.6	-0.8	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Fish																				
Redeye labeo, Labeo cylindricus	-0.5	-0.1	0.0	-37.5	-37.1	-36.6	-36.2	-36.8	-35.7	-35.2	-34.4	-35.6	-28.5	-31.9	-24.8	-29.9	-23.2	-21.0	-19.5	-26.9
Cichlids	-1.4	-5.4	-5.2	-46.2	-43.2	-40.0	-30.2	-46.6	-44.0	-38.5	-26.3	-41.5	-41.0	-38.3	-37.8	-35.9	-35.3	-29.9	-24.5	-38.0
Synodontis zambezensis	-2.0	-2.2	-2.2	-21.7	-15.9	-10.2	-2.9	-24.6	-18.2	-11.1	-1.8	-11.4	-10.6	-8.5	-8.0	-7.6	-7.2	-6.1	-5.2	-7.7
Alestids	-1.7	-1.4	-1.4	-15.5	-9.9	-5.3	-2.0	-19.7	-10.0	-4.3	0.0	-7.8	-7.0	-5.6	-5.2	-4.8	-4.5	-3.8	-3.2	-5.3
Cornish jack, Mormyrops anguilloides	-1.7	-6.5	-6.1	-47.6	-46.8	-46.0	-43.8	-47.5	-46.6	-45.6	-40.2	-46.7	-46.7	-46.3	-46.3	-46.0	-45.9	-44.7	-43.1	-46.3
Vundu, Heterobranchus longifilis	-1.5	-0.7	-0.6	-8.6	-6.5	-4.1	-0.3	-9.1	-5.3	-2.7	1.6	-6.6	-5.7	-5.9	-5.1	-5.6	-4.9	-4.5	-4.2	-5.3
Tigerfish, Hydrocynus vittatus	-1.9	-1.5	-1.5	-39.6	-33.8	-28.7	-23.2	-40.1	-32.2	-26.2	-18.9	-27.2	-22.3	-22.2	-18.2	-20.3	-16.6	-14.6	-12.9	-19.0
Crocodiles																				
Crocodiles	0.0	0.0	0.0	-34.3	-29.5	-27.5	-25.8	-42.5	-34.4	-31.1	-28.9	-12.8	-11.2	-8.9	-7.2	-7.9	-6.2	-5.0	-4.1	-4.3

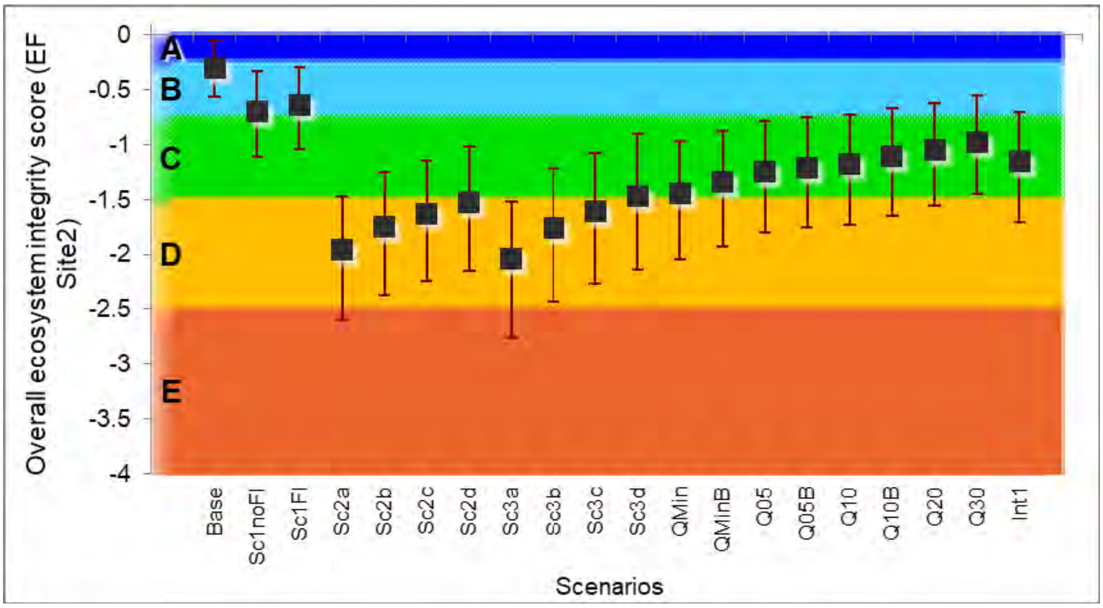
Appendix Table 6 **BGHES EF Site 2: The mean percentage changes in abundance (relative to baseline) for the indicators for the SET A scenarios. Blue and green are major changes that represent an INCREASE: green = 40-70%; blue = >70%. Orange and red are major changes that represent a DECREASE: orange = 40-70%; red = >70%. Baseline, by definition, equals 100%.**

	Base	Sc1noFl	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q30	Int1
Geomorphology																				
Low midchannel rock exposures	1.0	0.0	0.0	-71.4	-58.8	-51.5	-44.9	-70.8	-55.6	-48.5	-40.5	-42.3	-35.9	-26.2	-23.2	-21.5	-19.4	-14.9	-11.4	-23.7
Lengths of cut marginal banks	-1.3	23.3	13.3	90.6	75.3	69.0	63.9	94.8	77.6	70.1	62.9	59.2	54.2	46.1	51.3	41.7	40.2	36.1	32.9	43.9
Backwater bed sediment size (fine to coarse)	1.8	103.4	103.4	115.0	115.1	114.4	112.4	114.2	114.5	113.5	111.5	112.4	111.9	111.1	111.1	110.2	110.1	108.9	107.6	111.1
Area of backwaters and secondary channels	1.9	-0.6	-0.2	-47.2	-37.8	-33.7	-29.9	-48.5	-37.8	-32.9	-28.0	-28.0	-24.3	-19.6	-17.9	-16.7	-15.3	-12.4	-10.0	-18.1
Vegetated midchannel bars	-1.9	-40.1	-30.7	-71.0	-69.0	-68.2	-67.6	-71.4	-68.9	-67.9	-67.1	-66.0	-62.8	-58.6	-58.3	-55.4	-53.9	-50.9	-48.3	-58.3
Channel bed sediment (fine to coarse)	1.5	78.2	78.2	84.3	81.3	80.2	79.4	87.3	82.7	81.0	80.1	82.5	82.5	80.7	101.2	80.2	80.2	79.6	79.2	81.1
Depth of pools	-1.1	6.4	5.3	15.3	13.1	12.2	11.4	16.3	13.5	12.4	11.4	11.2	10.6	9.4	9.4	8.9	8.6	8.1	7.7	9.2
Sand bars	0.3	-21.0	-15.9	-46.3	-41.1	-38.9	-36.7	-47.4	-40.5	-37.8	-35.3	-35.8	-33.2	-30.9	-33.3	-29.5	-28.4	-26.9	-25.8	-30.0
Riparian vegetation																				
Single-celled diatoms	-0.3	14.4	12.4	-28.4	-18.4	-13.3	-8.1	-31.6	-19.8	-13.9	-7.3	-8.8	-5.5	-0.3	3.8	2.5	3.5	6.1	8.1	1.2
Filamentous green algae	-1.2	15.9	14.4	-42.7	-32.6	-26.6	-21.2	-44.8	-33.8	-27.2	-20.0	-18.7	-13.7	-5.9	-1.0	-1.8	-0.2	3.6	6.6	-3.8
Marginal Graminoids	-0.7	-11.8	-10.7	-37.1	-27.3	-22.9	-19.9	-40.9	-29.0	-23.6	-19.7	-18.0	-14.4	-9.5	-12.1	-7.5	-7.5	-6.3	-5.5	-9.2
Marginal Shrubs	-1.5	-12.2	-10.9	-27.3	-17.1	-12.7	-10.4	-30.0	-18.3	-12.8	-8.4	-8.7	-5.2	-1.8	-4.5	-0.5	-0.7	-0.6	-1.0	-1.5
Lower Trees	-1.1	-4.8	-4.8	9.9	8.7	8.1	7.3	13.2	11.1	10.1	9.2	0.8	0.4	-0.2	-1.5	-0.6	-1.0	-1.5	-2.1	-2.5
Upper Trees	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Organic detritus	1.2	-10.8	-10.8	-44.3	-41.7	-39.6	-37.3	-46.3	-41.6	-38.5	-35.5	-37.4	-33.9	-28.7	-27.4	-25.5	-24.2	-21.0	-18.5	-27.1
Macroinvertebrates																				
Species richness	-1.9	-18.8	-16.7	-38.0	-29.7	-26.3	-23.2	-41.2	-33.3	-28.9	-24.8	-23.0	-22.1	-19.2	-21.9	-18.3	-18.6	-18.1	-17.7	-18.3
Ephemeroptera	-1.7	-1.2	-1.2	-41.6	-30.6	-25.3	-21.6	-46.3	-32.5	-26.1	-21.1	-22.5	-19.5	-13.9	-13.1	-11.2	-10.4	-7.9	-6.0	-12.9
Bivalves	-1.7	-16.5	-12.4	-41.6	-33.9	-29.5	-24.7	-43.8	-33.1	-28.2	-23.0	-29.4	-27.1	-24.8	-27.4	-23.7	-22.7	-21.4	-20.5	-24.0
Oligoneuridae	-1.9	0.0	0.0	-55.5	-41.2	-35.1	-30.0	-62.9	-45.4	-37.7	-30.8	-30.4	-26.6	-19.2	-17.5	-15.5	-14.3	-10.8	-8.1	-17.8
Chironomidae	1.3	-3.7	-3.6	-48.3	-39.3	-36.4	-33.0	-50.9	-41.3	-37.3	-32.5	-28.6	-25.5	-20.2	-18.8	-17.3	-16.3	-13.5	-11.1	-18.9
Shrimps	-0.9	-4.8	-4.3	-15.2	-10.5	-8.3	-6.5	-17.0	-10.8	-8.2	-6.0	-7.2	-5.8	-3.8	-4.8	-3.0	-3.0	-2.5	-2.2	-3.7
Ceratopogonidae	0.7	-25.2	-24.9	-28.8	-28.8	-28.9	-28.5	-31.0	-30.9	-30.4	-29.9	-28.0	-28.0	-27.5	-27.4	-27.2	-27.1	-26.8	-26.4	-27.5
Simulidae	0.1	-0.9	-0.8	-70.1	-53.3	-45.6	-39.3	-75.4	-55.7	-46.5	-38.1	-36.8	-31.5	-23.0	-20.9	-18.4	-16.8	-12.7	-9.6	-20.6
Gastropods	0.5	-0.3	0.0	-0.6	-0.3	-0.4	-0.5	-1.9	-1.3	-1.0	-0.9	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6

	Base	Sc1noFl	Sc1Fl	Sc2a	Sc2b	Sc2c	Sc2d	Sc3a	Sc3b	Sc3c	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q30	Int1
Fish																				
Labeo altivelis	-0.6	17.0	14.8	-76.7	-74.5	-72.9	-71.0	-73.8	-68.7	-66.6	-62.7	-70.0	-58.0	-58.3	-40.0	-51.3	-36.7	-29.2	-23.6	-46.8
Redeye labeo, Labeo cylindricus	1.1	0.0	0.0	-34.6	-33.6	-32.7	-31.7	-33.3	-31.9	-30.9	-29.4	-31.4	-25.2	-27.8	-22.1	-26.1	-20.7	-19.0	-17.7	-23.7
Cichlids	-0.1	-8.3	-7.6	-29.7	-29.4	-29.0	-28.6	-29.8	-29.4	-28.9	-27.9	-28.7	-28.2	-27.9	-27.9	-27.7	-27.4	-27.1	-26.4	-27.7
Chessa and Nkupe, Distichodus spp	-1.7	-1.3	-1.3	-25.0	-19.0	-15.3	-12.2	-24.8	-16.9	-13.0	-9.2	-15.8	-14.2	-13.1	-12.0	-12.1	-10.8	-9.7	-8.8	-12.2
Synodontis zambezensis	0.8	-3.0	-2.7	-24.9	-16.2	-8.5	-1.2	-28.7	-14.1	-4.9	3.8	-12.7	-11.0	-8.3	-8.1	-7.1	-6.7	-5.5	-4.7	-7.7
Alestids	-1.3	-2.0	-1.9	-14.5	-13.7	-13.2	-12.8	-14.9	-13.8	-13.1	-12.6	-13.4	-12.3	-12.6	-11.6	-12.2	-10.9	-10.3	-9.7	-11.8
Barbus spp	0.0	-9.3	-8.3	-53.8	-52.4	-51.1	-47.9	-53.9	-52.2	-50.0	-44.9	-51.3	-48.9	-48.3	-46.1	-45.9	-42.3	-37.4	-33.0	-47.1
Cornish jack, Mormyrops anguilloides	**-2.4**	-12.9	-11.9	-80.1	-69.1	-59.3	-43.2	-83.3	-66.6	-51.9	-32.9	-69.3	-67.8	-62.2	-62.4	-58.8	-58.4	-53.2	-48.1	-63.5
Vundu, Heterobranchus longifilis	-0.7	0.7	0.5	-0.5	1.3	5.1	10.5	0.1	4.7	8.5	14.2	-0.3	0.2	0.0	0.4	0.1	0.3	0.3	0.3	0.3
Tigerfish, Hydrocynus vittatus	0.7	-5.5	-5.2	-65.9	-61.7	-59.0	-55.6	-38.9	-38.2	-38.6	-34.3	-51.5	-43.8	-40.9	-35.7	-37.8	-33.0	-30.1	-27.2	-36.1
Crocodiles																				
Crocodiles	0.0	0.0	0.0	-34.3	-29.5	-27.5	-25.8	-42.5	-34.4	-31.1	-28.9	-12.8	-11.2	-8.9	-7.2	-7.9	-6.2	-5.0	-4.1	-4.3



Appendix Figure 1 **Overall ecosystem integrity scores for the scenarios at EF Site 1 under the SET A scenarios.**



Appendix Figure 2 **Overall ecosystem integrity scores for the scenarios at EF Site 2 under the SET A scenarios.**

A.2.2. OPERATING RULE SET B

Discussion of the SET A results at the two-day workshop (See Section A.1) led to the formulation of three additional scenarios, with slightly different combinations of wet and dry operating rules in an attempt to reduce impact power-production, while limiting downstream impacts. These were tested and presented on the second day of the workshop (SET B; Section A3).

The scenarios presented for Operating Rule Set B comprise one of the ESIA scenarios (Sc3d), which was retained for the purposes of comparison, the eight additional scenarios derived from the wet and dry season data sent by SP (see Section A.2.1), plus three scenarios that were designed at the 2-day workshop. The three scenarios were:

Q20Q10 DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q20; no sediment flushing. WET Season: Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q10; no sediment flushing.

Q20QMin DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q20; no sediment flushing. WET Season: Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at QMin; no sediment flushing.

Q20Q10Q10: DRY Season (Jul-Jan): Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at Q20; except for July and August, which were set at Q10; no sediment flushing. WET Season: Daily 6-hour peak at maximum of 1645 m^3s^{-1}, with off-peak releases set at QMin; no sediment flushing

The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule Set B at EF Site 1 and 2 are given in Appendix Table 7 and Appendix Table 8, respectively. Depictions of the flow regimes (over three hydrological years) associated with each scenario are presented in Appendix B. The estimated mean percentage change in abundance/area/concentration of ecosystem indicators at EF Site and 2 under the SET B scenarios are given in Appendix Table 9 and Appendix Table 10, respectively. EF Site 2 has slightly more diverse habitats, and hence a larger array of species indicators. The tables are colour-coded to facilitate identification of major impacts. The colours ***do not*** denote whether the predicted change is a move towards or away from the natural condition of the river ecosystem.

The Overall Integrity for each the SET B scenarios at EF Site 1 and 2 are illustrated in Appendix Figure 3 and Appendix Figure 4, respectively.

The results of the workshop scenarios were not markedly different from those for SET A, but they did provide some insight into the relative effect of small adjustments, and the direction needed to arrive at a fair trade-off between power production and downstream impacts. The agreed maximum drop in ecosystem condition (Appendix Table 2) is marked on Appendix Figure 3 and Appendix Figure 4, which shows that at EF Site 2, Q10B, Q20, Q20Q10 and Q30 meet the ecosystem condition criterion set at the workshop. However, none of these four scenarios meet the criterion that at least 90% of fish species are not impacted by more than 25%.

Appendix Table 7 The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule Set B at EF Site 1. Where not provided, units are given in Table 7.1.

EF1	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	Q30	Int1
Mean annual runoff (Mm^3)	35738	35533	35738	35738	35738	35738	35738	35738	35738	35738	35738	35738	35738	35725
Dry season onset	35.0	34.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Dry season duration	110.5	117.0	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5
Dry season Min 5d Q	220.6	255.0	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6
Wet season onset	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Wet season duration	147.0	143.5	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Wet season Max 5d Q	3309	3257	3309	3309	3309	3309	3309	3309	3309	3309	3309	3309.1	3309.1	3309.1
Flood volume	26798	26333	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798.0	26798	26798
Dry season ave daily vol	25.7	26.5	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
T1 ave daily vol	56.6	51.2	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6
Wet season ave daily vol	169.6	170.3	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6
T2 ave daily vol	48.3	51.3	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.3	48.4
Dry within day range	0.0	4.9	563.3	563.3	337.4	337.4	256.3	256.3	162.6	162.6	162.6	178.6	81.7	404.6
T1 within day range	0.0	1446.6	1089.9	980.1	750.9	610.3	662.3	518.6	372.5	539.7	760.4	539.7	216.6	645.8
Wet within day range	0.0	311.9	79.8	33.1	75.8	33.1	66.8	33.1	33.1	66.8	79.8	66.8	33.1	33.1
T2 within day range	0.0	1365.4	1151.3	1151.3	814.3	814.3	618.6	618.6	395.0	395.0	395.0	610.7	219.0	819.7
Dry season Min 5d Depth	7.7	7.5	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Dry season Min 5d Velocity	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dry season Min 5d WetPerim	223.7	229.9	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7
Wet season Max 5d Depth	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Wet season Max 5d Velocity	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Wet season Max 5d WetPerim	289.2	288.8	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2
Wet season Min 5d Depth	8.4	8.3	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Wet season Min 5d Velocity	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Wet season Min 5d WetPerim	262.4	260.6	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4
Wet: ave Fine suspended sediment (%)	100.0	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Wet: max Fine suspended sediment (%)	100.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Wet: ave Coarse suspended sediment (%)	100.0	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9
Wet: max Coarse suspended sediment (%)	100.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Appendix Table 8 The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule Set B at EF Site 2. Where not provided, units are given in Table 7.1.

EF2	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	Q30	Int1
Mean annual runoff (Mm^3)	35738	35533	35738	35738	35738	35738	35738	35738	35738	1101.7	1101.7	1101.7	35738	35725
Dry season onset	35.0	34.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Dry season duration	110.5	117.0	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5
Dry season Min 5d Q	220.6	255.0	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6
Wet season onset	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Wet season duration	147.0	143.5	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Wet season Max 5d Q	3309.2	3256.6	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1
Flood volume	26798	26333	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798
Dry season ave daily vol	25.7	26.5	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
T1 ave daily vol	56.6	51.2	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6
Wet season ave daily vol	169.6	170.3	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6
T2 ave daily vol	48.3	51.3	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.3	48.4
Dry within day range	0.0	4.9	563.3	563.3	337.4	337.4	256.3	256.3	162.6	162.6	162.6	178.6	81.7	404.6
T1 within day range	0.0	1446.6	1089.9	980.1	750.9	610.3	662.3	518.6	372.5	539.7	760.4	539.7	216.6	645.8
Wet within day range	0.0	311.9	79.8	33.1	75.8	33.1	66.8	33.1	33.1	66.8	79.8	66.8	33.1	33.1
T2 within day range	0.0	1365.4	1151.3	1151.3	814.3	814.3	618.6	618.6	395.0	395.0	395.0	610.7	219.0	819.7
Dry season Min 5d Depth	4.5	4.6	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Dry season Min 5d Velocity	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Dry season Min 5d WetPerim	120.4	121.7	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4
Wet season Max 5d Depth	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Wet season Max 5d Velocity	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Wet season Max 5d WetPerim	455.5	453.6	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5
Wet season Min 5d Depth	3.2	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Wet season Min 5d Velocity	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Wet season Min 5d WetPerim	259.4	236.2	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3
Wet: ave Fine suspended sediment (%)	100.0	19.8	19.8	19.8	19.8	14.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8
Wet: max Fine suspended sediment (%)	100.0	20.0	20.0	20.0	20.0	15.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Wet: ave Coarse suspended sediment (%)	100.0	39.3	39.3	39.3	39.3	29.9	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3
Wet: max Coarse suspended sediment (%)	100.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

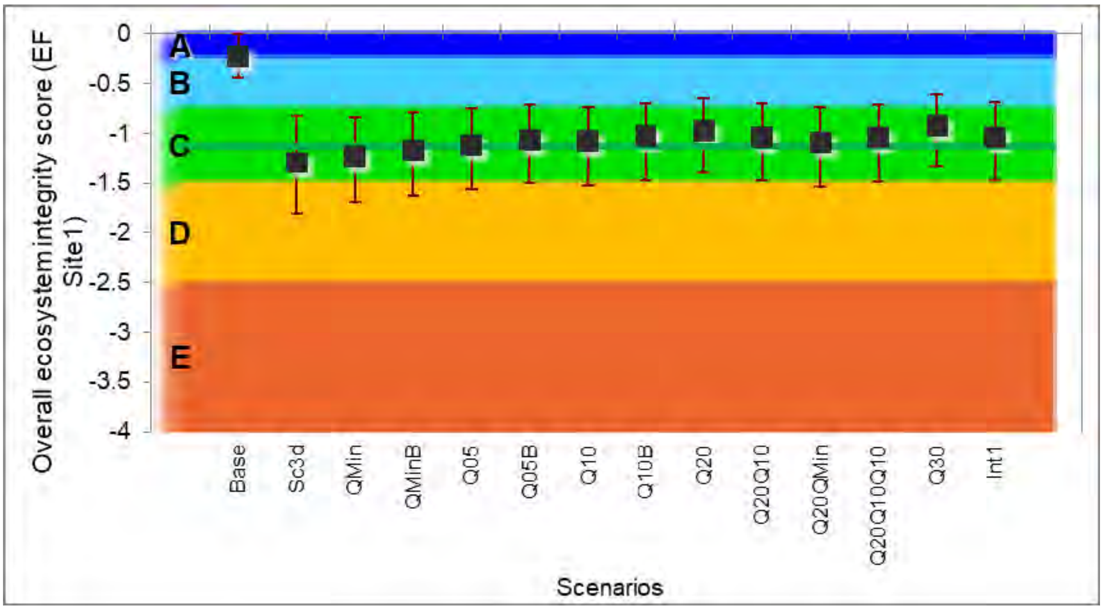
Appendix Table 9 **BGHES EF Site 1: The mean percentage changes in abundance (relative to baseline) for the indicators for the SET B scenarios. Blue and green are major changes that represent an INCREASE: green = 40-70%; blue = >70%. Orange and red are major changes that represent a DECREASE: orange = 40-70%; red = >70%. Baseline, by definition, equals 100%.**

	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	Q30	Int1
Geomorphology														
Low midchannel rock exposures	0.3	-46.7	-41.3	-34.9	-25.4	-22.4	-20.7	-18.6	-14.1	-15.9	-20.4	-17.0	-10.7	-23.2
Backwater bed sediment (fine to coarse)	0.9	110.7	109.7	108.6	106.8	106.2	105.6	105.2	104.0	104.5	105.7	105.1	103.2	106.5
Area of backwaters and secondary channels	0.9	-22.7	-24.1	-21.3	-17.5	-16.0	-15.1	-13.9	-11.4	-12.4	-14.4	-13.2	-9.1	-16.5
Channel bed sediment size (fine to coarse)	1.5	109.4	108.8	108.2	106.6	106.0	105.5	105.0	103.9	104.3	104.9	104.8	102.7	106.2
Depth of pools	-1.1	2.0	1.9	1.3	0.3	0.0	-0.2	-0.4	-0.8	-0.7	-0.3	-0.6	-1.2	0.0
Sand bars	0.9	-76.6	-76.1	-75.4	-73.9	-73.4	-72.9	-72.5	-71.5	-71.9	-72.5	-72.4	-70.5	-73.6
Riparian vegetation														
Single-celled diatoms	0.3	-4.8	-6.3	-3.0	2.2	3.8	5.0	6.1	8.7	7.7	5.5	6.8	10.7	3.7
Filamentous green algae	-0.1	-16.5	-16.1	-11.1	-3.3	-1.0	0.8	2.4	6.2	4.9	1.5	3.5	9.2	-1.1
Bryophyta	-2.0	59.7	51.1	46.2	38.3	36.1	33.9	32.3	28.3	29.6	32.8	31.4	25.1	36.1
Marginal Graminoids	-1.8	-7.3	-8.0	-8.5	-8.5	-9.3	-8.9	-9.6	-10.1	-9.1	-8.0	-8.9	-10.7	-9.4
Marginal Shrubs	-1.6	15.6	12.9	12.3	10.7	9.6	9.6	8.6	6.8	8.2	9.4	8.4	5.0	10.2
Lower Trees	-1.5	0.7	-3.3	-3.6	-4.0	-4.3	-4.1	-4.5	-4.7	-4.2	-4.0	-4.2	-4.8	-5.0
Upper Trees	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Organic detritus	-0.4	-34.1	-36.1	-33.5	-28.9	-27.1	-25.8	-24.5	-21.5	-22.6	-25.0	-23.7	-19.1	-27.3
Macroinvertebrates														
Species richness	-1.9	-41.0	-42.7	-41.1	-41.0	-39.8	-40.0	-39.0	-37.6	-38.8	-39.3	-39.0	-36.0	-40.6
Ephemeroptera	-1.3	-38.8	-41.5	-36.8	-32.4	-29.6	-28.7	-26.3	-22.1	-24.7	-28.0	-26.0	-18.4	-30.5
Oligoneuridae	-1.9	-35.0	-32.8	-28.4	-20.5	-18.5	-16.5	-15.1	-11.5	-12.6	-15.4	-14.0	-8.7	-18.6
Chironomidae	0.9	-38.7	-30.6	-26.7	-19.8	-18.0	-16.1	-14.9	-11.4	-12.5	-15.2	-13.9	-8.8	-18.2
Ceratopogonidae	-0.9	-32.1	-26.8	-26.4	-25.1	-24.9	-24.4	-24.2	-23.5	-23.6	-23.9	-23.9	-22.8	-25.1
Simulidae	0.4	-37.6	-37.2	-32.1	-23.6	-21.3	-19.1	-17.5	-13.3	-14.6	-18.0	-16.4	-10.0	-21.4
Gastropods	1.6	-0.8	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Fish														
Redeye labeo, Labeo cylindricus	-0.5	-34.4	-35.6	-28.5	-31.9	-24.8	-29.9	-23.2	-21.0	-28.8	-33.9	-28.8	-19.5	-26.9
Cichlids	-1.4	-26.3	-41.5	-41.0	-38.3	-37.8	-35.9	-35.3	-29.9	-30.6	-31.7	-31.6	-24.5	-38.0
Synodontis zambezensis	-2.0	-1.8	-11.4	-10.6	-8.5	-8.0	-7.6	-7.2	-6.1	-6.5	-7.0	-6.8	-5.2	-7.7
Alestids	-1.7	0.0	-7.8	-7.0	-5.6	-5.2	-4.8	-4.5	-3.8	-4.1	-4.7	-4.4	-3.2	-5.3
Cornish jack, Mormyrops anguilloides	-1.7	-40.2	-46.7	-46.7	-46.3	-46.3	-46.0	-45.9	-44.7	-44.9	-45.2	-45.1	-43.1	-46.3
Vundu, Heterobranchus longifilis	-1.5	1.6	-6.6	-5.7	-5.9	-5.1	-5.6	-4.9	-4.5	-5.3	-5.9	-5.3	-4.2	-5.3
Tigerfish, Hydrocynus vittatus	-1.9	-18.9	-27.2	-22.3	-22.2	-18.2	-20.3	-16.6	-14.6	-18.5	-21.9	-18.8	-12.9	-19.0
Crocodiles														
Crocodiles	0.0	-28.9	-12.8	-11.2	-8.9	-7.2	-7.9	-6.2	-5.0	-7.2	-8.9	-7.2	-4.1	-4.3

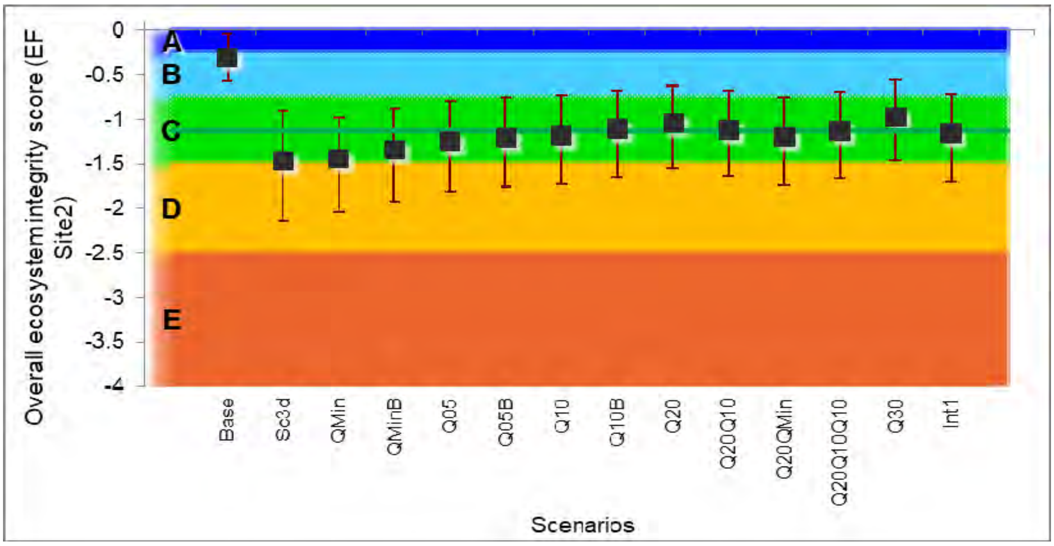
Appendix Table 10 **BGHES EF Site 2: The mean percentage changes in abundance (relative to baseline) for the indicators for the SET B scenarios. Blue and green are major changes that represent an INCREASE: green = 40-70%; blue = >70%. Orange and red are major changes that represent a DECREASE: orange = 40-70%; red = >70%. Baseline, by definition, equals 100%.**

	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	Q30	Int1
Geomorphology														
Low midchannel rock exposures	1.0	-40.5	-42.3	-35.9	-26.2	-23.2	-21.5	-19.4	-14.9	-16.7	-21.1	-17.8	-11.4	-23.7
Lengths of cut marginal banks	-1.3	62.9	59.2	54.2	46.1	51.3	41.7	40.2	36.1	37.4	40.8	39.2	32.9	43.9
Backwater bed sediment size (fine to coarse)	1.8	111.5	112.4	111.9	111.1	111.1	110.2	110.1	108.9	109.0	109.3	109.5	107.6	111.1
Area of backwaters and secondary channels	1.9	-28.0	-28.0	-24.3	-19.6	-17.9	-16.7	-15.3	-12.4	-13.8	-16.3	-14.8	-10.0	-18.1
Vegetated midchannel bars	-1.9	-67.1	-66.0	-62.8	-58.6	-58.3	-55.4	-53.9	-50.9	-52.2	-55.8	-53.8	-48.3	-58.3
Channel bed sediment (fine to coarse)	1.5	80.1	82.5	82.5	80.7	101.2	80.2	80.2	79.6	79.6	79.6	79.7	79.2	81.1
Depth of pools	-1.1	11.4	11.2	10.6	9.4	9.4	8.9	8.6	8.1	8.3	8.7	8.5	7.7	9.2
Sand bars	0.3	-35.3	-35.8	-33.2	-30.9	-33.3	-29.5	-28.4	-26.9	-28.1	-29.9	-28.2	-25.8	-30.0
Riparian vegetation														
Single-celled diatoms	-0.3	-7.3	-8.8	-5.5	-0.3	3.8	2.5	3.5	6.1	5.2	2.9	4.2	8.1	1.2
Filamentous green algae	-1.2	-20.0	-18.7	-13.7	-5.9	-1.0	-1.8	-0.2	3.6	2.3	-1.1	0.9	6.6	-3.8
Bryophyta	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marginal Graminoids	-0.7	-19.7	-18.0	-14.4	-9.5	-12.1	-7.5	-7.5	-6.3	-5.7	-6.3	-6.3	-5.5	-9.2
Marginal Shrubs	-1.5	-8.4	-8.7	-5.2	-1.8	-4.5	-0.5	-0.7	-0.6	0.1	-0.4	-0.4	-1.0	-1.5
Lower Trees	-1.1	9.2	0.8	0.4	-0.2	-1.5	-0.6	-1.0	-1.5	-0.8	0.0	-0.7	-2.1	-2.5
Upper Trees	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Organic detritus	1.2	-35.5	-37.4	-33.9	-28.7	-27.4	-25.5	-24.2	-21.0	-22.2	-25.1	-23.3	-18.5	-27.1
Macroinvertebrates														
Species richness	-1.9	-24.8	-23.0	-22.1	-19.2	-21.9	-18.3	-18.6	-18.1	-17.7	-16.8	-17.9	-17.7	-18.3
Ephemeroptera	-1.7	-21.1	-22.5	-19.5	-13.9	-13.1	-11.2	-10.4	-7.9	-8.5	-10.3	-9.5	-6.0	-12.9
Bivalves	-1.7	-23.0	-29.4	-27.1	-24.8	-27.4	-23.7	-22.7	-21.4	-22.4	-23.9	-22.4	-20.5	-24.0
Oligoneuridae	-1.9	-30.8	-30.4	-26.6	-19.2	-17.5	-15.5	-14.3	-10.8	-11.8	-14.4	-13.1	-8.1	-17.8
Chironomidae	1.3	-32.5	-28.6	-25.5	-20.2	-18.8	-17.3	-16.3	-13.5	-14.3	-16.4	-15.4	-11.1	-18.9
Shrimps	-0.9	-6.0	-7.2	-5.8	-3.8	-4.8	-3.0	-3.0	-2.5	-2.3	-2.5	-2.5	-2.2	-3.7
Ceratopogonidae	0.7	-29.9	-28.0	-28.0	-27.5	-27.4	-27.2	-27.1	-26.8	-26.8	-26.9	-26.9	-26.4	-27.5
Simulidae	0.1	-38.1	-36.8	-31.5	-23.0	-20.9	-18.4	-16.8	-12.7	-14.0	-17.4	-15.7	-9.6	-20.6
Gastropods	0.5	-0.9	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6

	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	Q30	Int1
Fish														
Labeo altivelis	-0.6	-62.7	-70.0	-58.0	-58.3	-40.0	-51.3	-36.7	-29.2	-45.3	-58.9	-46.5	-23.6	-46.8
Redeye labeo, Labeo cylindricus	1.1	-29.4	-31.4	-25.2	-27.8	-22.1	-26.1	-20.7	-19.0	-25.2	-29.4	-25.2	-17.7	-23.7
Cichlids	-0.1	-27.9	-28.7	-28.2	-27.9	-27.9	-27.7	-27.4	-27.1	-27.5	-27.7	-27.6	-26.4	-27.7
Chessa and Nkupe, Distichodus spp	-1.7	-9.2	-15.8	-14.2	-13.1	-12.0	-12.1	-10.8	-9.7	-11.1	-12.3	-11.5	-8.8	-12.2
Synodontis zambezensis	0.8	3.8	-12.7	-11.0	-8.3	-8.1	-7.1	-6.7	-5.5	-5.8	-6.6	-6.2	-4.7	-7.7
Alestids	-1.3	-12.6	-13.4	-12.3	-12.6	-11.6	-12.2	-10.9	-10.3	-11.9	-12.7	-11.9	-9.7	-11.8
Barbus spp	0.0	-44.9	-51.3	-48.9	-48.3	-46.1	-45.9	-42.3	-37.4	-42.2	-46.0	-42.9	-33.0	-47.1
Cornish jack, Mormyrops anguilloides	-2.4	-32.9	-69.3	-67.8	-62.2	-62.4	-58.8	-58.4	-53.2	-53.6	-54.5	-54.5	-48.1	-63.5
Vundu, Heterobranchus longifilis	-0.7	14.2	-0.3	0.2	0.0	0.4	0.1	0.3	0.3	0.2	-0.3	0.2	0.3	0.3
Tigerfish, Hydrocynus vittatus	0.7	-34.3	-51.5	-43.8	-40.9	-35.7	-37.8	-33.0	-30.1	-34.7	-41.7	-35.0	-27.2	-36.1
Crocodiles														
Crocodiles	0.0	-28.9	-12.8	-11.2	-8.9	-7.2	-7.9	-6.2	-5.0	-7.2	-8.9	-7.2	-4.1	-4.3



Appendix Figure 3 **Overall ecosystem integrity scores for the scenarios at EF Site 1 under the SET B scenarios. The line in category C shows the agreed maximum drop in ecosystem condition in the ecological criteria.**



Appendix Figure 4 **Overall ecosystem integrity scores for the scenarios at EF Site 2 under the SET B scenarios. The line in category C shows the agreed maximum drop in ecosystem condition in the ecological criteria.**

A.2.3. OPERATING RULE SET C

The scenarios presented for Operating Rule Set C comprise one of the ESIA scenarios (Sc3d), which was retained for the purposes of comparison, the nine Set A scenarios, 3 Set B scenarios and an additional four scenarios that were designed and evaluated after the workshop. Three of these: AddPM01-ADDPM03 were contributed by SP (see Memo in Appendix Table 11), and AddPM04 was contributed by Southern Waters, as follows:

AddPM01[14]	DRY Season (**Sep-Jan**): Two 3 hour peaks a day, at maximum of 1.5 x the off-peak flows when Q is between Q10 and Q30; run of river when Q<Q10; peaking ramped up to the maximum; off-peak minimum set at Q10%; no sediment flushing. WET Season (**Feb-Aug**): Two 3 hour peaks a day, at maximum of 1.75 x the off-peak flows when Q is < Q10; peaking ramped up to the maximum; off-peak releases set at Q10%; no sediment flushing.
AddPM02	DRY Season (**Sep-Jan**): Two 3 hour peaks a day with no constraints when Q > Q30; run of river when Q<Q30; peaking ramped up to the maximum; no sediment flushing. WET Season(**Feb-Aug**): As for AddPM01.
AddPM03	DRY Season (**Sep-Jan**): Two 3 hour peaks a day, at maximum of 1.5 x the off-peak flows when Q is between Q10 and Q30; run of river when Q<Q10; peaking ramped up to the maximum; off-peak minimum set at Q20%; no sediment flushing. WET Season(**Feb-Aug**): As for AddPM01.
AddPM04	DRY Season (**Sep-Jan**): Baseline flows; no sediment flushing. WET Season(**Feb-Aug**): QMin with one 6-hour peak a day.

Appendix Table 11 SP Memo from SP for AddPM01-ADDPM03

SCENARIO PM01
WET SEASON (February-August) If Q_{in} >= Q_10% no constraint for the plant and peaking time of 6 h If Q_{in} < Q_10% following criteria are applied: Q_{off_peak} for 18 h a day $Q_{rump\ up/down} = 1.375*Q_{off\_peak}$ for 4 h a day[15] $Q_{peak} = 1.75*Q_{off\_peak}$ for 2 h a day TWO peaking timeframes are considered within the day, between 6-9 am and 6-9 pm, as follows: 6-7 am/pm RAMP UP; 7-8 am/pm PEAK; 8-9 am/pm RAMP DOWN spilled , if any, is always released **DRY SEASON (September-January)** If Q_{in} >= Q_30% no constraint for the plant and peaking time of 6 h If Q_{in} <= Q_10% the plant is run of the river If Q_10%< Q_{in} < Q_30% following criteria are applied: Q_{off_peak} for 18 h a day (with Q_{off_peak} MIN = Q_10%) $Q_{rump\ up/down} = 1.25*Q_{off\_peak}$ for 4 h a day $Q_{peak} = 1.5*Q_{off\_peak}$ for 2 h a day TWO peaking timeframes are considered within the day, between 6-9 am and 6-9 pm, as follows: 6-7 am/pm RAMP UP; 7-8 am/pm PEAK; 8-9 am/pm RAMP DOWN

[14] AddPM for: Additional Scenarios, Post Meeting.
[15] Hourly flows received did not show ramping.

SCENARIO 02 190123
WET SEASON (February-August) same as scenario AddPM01 **DRY SEASON (September-January)** If Q_{in} >= Q_30% no constraint for the plant and peaking time of 6 h If Q_{in} <= Q_30% the plant is run of the river
SCENARIO 03 190123
WET SEASON (February-August) same as scenario 01 190123 **DRY SEASON (September-January)** If Q_{in} >= Q_30% no constraint for the plant and peaking time of 6 h If Q_{in} <= Q_20% the plant is run of the river If Q_20%< Q_{in} < Q_30% following criteria are applied: Q_{off_peak} for 18 h a day (with Q_{off_peak} MIN = Q_20%) $Q_{rump\ up/down}$ = 1.25*Q_{off_peak} for 4 h a day Q_{peak} = 1.5*Q_{off_peak} for 2 h a day TWO peaking timeframes are cosidered within the day: between 6-9 am and 6-9 pm, as follows: 6-7 am/pm RAMP UP; 7-8 am/pm PEAK; 8-9 am/pm RAMP DOWN

The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule Set C at EF Site 1 and 2 are given in Appendix Table 12 and Appendix Table 13, respectively. Depictions of the flow regimes associated with each scenario are presented in Appendix B. The estimated mean percentage change in abundance/area/concentration of ecosystem indicators at EF Site and 2 under the SET C scenarios are given in Appendix Table 9 and Appendix Table 10, respectively. Please note that the colour code used in these tables differs from that of the previous tables in this Appendix. In Appendix Table 14 and Appendix Table 15, only predicted changes greater than 25% in FISH species are highlighted, as these are of interest for the environmental criterion in Appendix Table 2.

The Overall Integrity for each of the SET C scenarios at EF Site 1 and 2 are illustrated in Appendix Figure 3 and Appendix Figure 4, respectively.

The results indicate that with respect to the environmental criteria in Appendix Table 2:

- All of the AddPM scenarios (AddPM01, AddPM02, AddPM03 and AddPM04) meet the criterion of no more than a 1.5 class drop in Overall Ecosystem Condition in the downstream river, i.e., from A/B to no less than a mid-C category, at both EF sites.
- Only AddPM04 meets the criterion that at least 90% of fish species should be impacted by <25%, at both EF sites.

We did not assess AddPM04 WET with two 3-hour peak a day, but our expectation is that it would also meet the criterion that at least 90% of fish species should be impacted by <25%, at both EF sites.

Appendix Table 12 **The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule SET C at EF Site 1. Where not provided, units are given in Table 7.1.**

	Baseline	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	AddPM01	AddPM02	AddPM03	AddPM04	Q30	Int1
Mean annual runoff (Mm^3)	35738	35533	35738	35738	35738	35738	35738	35738	35738	35738	35738	35738	35737	35738	35738	35738	35738	35725
Dry season onset	35.0	34.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Dry season duration	110.5	117.0	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5
Dry season Min 5d Q	220.6	255.0	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.7	220.6	220.7	220.6	220.6	220.6
Wet season onset	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Wet season duration	147.0	143.5	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Wet season Max 5d Q	3309	3257	3309	3309	3309	3309	3309	3309	3309	3309	3309	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1
Flood volume	26798	26333	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798
Dry season ave daily vol	25.7	26.5	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.8	25.7	25.7
T1 ave daily vol	56.6	51.2	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6
Wet season ave daily vol	169.6	170.3	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6
T2 ave daily vol	48.3	51.3	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.3	48.3	48.3	48.3	48.3	48.4
Dry within day range	0.0	4.9	563.3	563.3	337.4	337.4	256.3	256.3	162.6	162.6	162.6	178.6	122.5	119.8	124.2	3.5	81.7	404.6
T1 within day range	0.0	1446.6	1089.9	980.1	750.9	610.3	662.3	518.6	372.5	539.7	760.4	539.7	423.6	423.6	423.6	15.0	216.6	645.8
Wet within day range	0.0	311.9	79.8	33.1	75.8	33.1	66.8	33.1	33.1	66.8	79.8	66.8	78.6	78.6	78.6	56.6	33.1	33.1
T2 within day range	0.0	1365.4	1151.3	1151.3	814.3	814.3	618.6	618.6	395.0	395.0	395.0	610.7	413.0	413.0	413.0	6.0	219.0	819.7
Dry season Min 5d Depth	7.7	7.5	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Dry season Min 5d Velocity	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dry season Min 5d WetPerim	223.7	229.9	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7
Wet season Max 5d Depth	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Wet season Max 5d Velocity	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Wet season Max 5d WetPerim	289.2	288.8	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2	289.2
Wet season Min 5d Depth	8.4	8.3	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Wet season Min 5d Velocity	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Wet season Min 5d WetPerim	262.4	260.6	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4	262.4
Wet: ave Fine suspended sediment (%)	100.0	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Wet: max Fine suspended sediment (%)	100.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Wet: ave Coarse suspended sediment (%)	100.0	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9
Wet: max Coarse suspended sediment (%)	100.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Appendix Table 13 **The suite of flow, hydraulic and sediment indicators calculated from the hourly data for Operating Rule SET C at EF Site 2. Where not provided, units are given in Table 7.1.**

EF2	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	AddPM01	AddPM02	AddPM03	AddPM03	Q30	Int1
Mean annual runoff (Mm³)	35738	35533	35738	35738	35738	35738	35738	35738	35738	35738	35738	35738	35737	35738	35738	35738	35738	35725
Dry season onset	35.0	34.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Dry season duration	110.5	117.0	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5	110.5
Dry season Min 5d Q	220.6	255.0	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.6	220.7	220.6	220.7	220.6	220.6	220.6
Wet season onset	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Wet season duration	147.0	143.5	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Wet season Max 5d Q	3309.2	3256.6	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1	3309.1
Flood volume	26798	26333	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798	26798
Dry season ave daily vol	25.7	26.5	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.8	25.7	25.7
T1 ave daily vol	56.6	51.2	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6	56.6
Wet season ave daily vol	169.6	170.3	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6	169.6
T2 ave daily vol	48.3	51.3	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.3	48.3	48.3	48.3	48.3	48.4
Dry within day range	0.0	4.9	563.3	563.3	337.4	337.4	256.3	256.3	162.6	162.6	162.6	178.6	122.5	119.8	124.2	3.5	81.7	404.6
T1 within day range	0.0	1446.6	1089.9	980.1	750.9	610.3	662.3	518.6	372.5	539.7	760.4	539.7	423.6	423.6	423.6	15.0	216.6	645.8
Wet within day range	0.0	311.9	79.8	33.1	75.8	33.1	66.8	33.1	33.1	66.8	79.8	66.8	78.6	78.6	78.6	56.6	33.1	33.1
T2 within day range	0.0	1365.4	1151.3	1151.3	814.3	814.3	618.6	618.6	395.0	395.0	395.0	610.7	413.0	413.0	413.0	6.0	219.0	819.7
Dry season Min 5d Depth	4.5	4.6	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Dry season Min 5d Velocity	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Dry season Min 5d WetPerim	120.4	121.7	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4
Wet season Max 5d Depth	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Wet season Max 5d Velocity	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Wet season Max 5d WetPerim	455.5	453.6	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5	455.5
Wet season Min 5d Depth	3.2	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Wet season Min 5d Velocity	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Wet season Min 5d WetPerim	259.4	236.2	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3	259.3
Wet: ave Fine suspended sediment (%)	100.0	19.8	19.8	19.8	19.8	14.8	19.8	19.8	19.8	19.8	19.8	19.8	14.8	14.8	14.8	14.8	19.8	19.8
Wet: max Fine suspended sediment (%)	100.0	20.0	20.0	20.0	20.0	15.0	20.0	20.0	20.0	20.0	20.0	20.0	15.0	15.0	15.0	15.0	20.0	20.0
Wet: ave Coarse suspended sediment (%)	100.0	39.3	39.3	39.3	39.3	29.9	39.3	39.3	39.3	39.3	39.3	39.3	29.9	29.9	29.9	29.9	39.3	39.3
Wet: max Coarse suspended sediment (%)	100.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

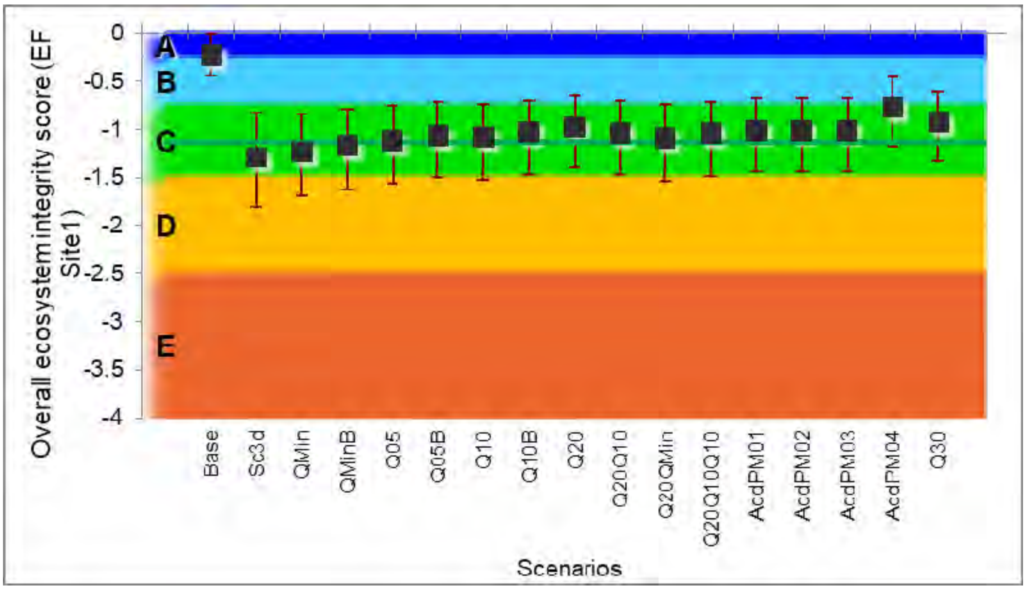
Appendix Table 14 **BGHES EF Site 1: The mean percentage changes in abundance (relative to baseline) for the indicators for the SET C scenarios. Predicted changes in FISH species greater than 25% are highlighted. Baseline, by definition, equals 100%.**

	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	AddPM01	AddPM02	AddPM03	AddPM04	Q30	Int1
Geomorphology																		
Low midchannel rock exposures	0.3	**-46.7**	**-41.3**	**-34.9**	**-25.4**	-22.4	-20.7	-18.6	-14.1	-15.9	-20.4	-17.0	-13.7	-13.7	-13.7	-2.7	-10.7	-23.2
Backwater bed sediment (fine to coarse)	0.9	**110.7**	**109.7**	**108.6**	**106.8**	**106.2**	**105.6**	**105.2**	**104.0**	**104.5**	**105.7**	**105.1**	**104.4**	**104.4**	**104.4**	**101.8**	**103.2**	**106.5**
Area of backwaters and secondary channels	0.9	-22.7	-24.1	-21.3	-17.5	-16.0	-15.1	-13.9	-11.4	-12.4	-14.4	-13.2	-11.9	-11.4	-11.9	-2.8	-9.1	-16.5
Channel bed sediment size (fine to coarse)	1.5	**109.4**	**108.8**	**108.2**	**106.6**	**106.0**	**105.5**	**105.0**	**103.9**	**104.3**	**104.9**	**104.8**	**103.8**	**103.8**	**103.8**	**99.5**	**102.7**	**106.2**
Depth of pools	-1.1	2.0	1.9	1.3	0.3	0.0	-0.2	-0.4	-0.8	-0.7	-0.3	-0.6	-0.9	-0.9	-0.9	-1.9	-1.2	0.0
Sand bars	0.9	**-76.6**	**-76.1**	**-75.4**	**-73.9**	**-73.4**	**-72.9**	**-72.5**	**-71.5**	**-71.9**	**-72.5**	**-72.4**	**-72.2**	**-72.1**	**-72.2**	**-67.1**	**-70.5**	**-73.6**
Riparian vegetation																		
Single-celled diatoms	0.3	-4.8	-6.3	-3.0	2.2	3.8	5.0	6.1	8.7	7.7	5.5	6.8	8.6	8.6	8.6	15.4	10.7	3.7
Filamentous green algae	-0.1	-16.5	-16.1	-11.1	-3.3	-1.0	0.8	2.4	6.2	4.9	1.5	3.5	6.2	6.2	6.2	16.2	9.2	-1.1
Bryophyta	-2.0	**59.7**	**51.1**	**46.2**	**38.3**	**36.1**	**33.9**	**32.3**	**28.3**	**29.6**	**32.8**	**31.4**	**28.7**	**28.6**	**28.7**	17.9	**25.1**	**36.1**
Marginal Graminoids	-1.8	-7.3	-8.0	-8.5	-8.5	-9.3	-8.9	-9.6	-10.1	-9.1	-8.0	-8.9	-8.0	-8.0	-8.0	-12.3	-10.7	-9.4
Marginal Shrubs	-1.6	15.6	12.9	12.3	10.7	9.6	9.6	8.6	6.8	8.2	9.4	8.4	8.7	8.7	8.7	-2.0	5.0	10.2
Lower Trees	-1.5	0.7	-3.3	-3.6	-4.0	-4.3	-4.1	-4.5	-4.7	-4.2	-4.0	-4.2	-4.4	-4.4	-4.4	-4.5	-4.8	-5.0
Upper Trees	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Organic detritus	-0.4	**-34.1**	**-36.1**	**-33.5**	**-28.9**	**-27.1**	**-25.8**	-24.5	-21.5	-22.6	**-25.0**	-23.7	-21.5	-21.4	-21.5	-13.1	-19.1	**-27.3**
Macroinvertebrates																		
Species richness	-1.9	**-41.0**	**-42.7**	**-41.1**	**-41.0**	**-39.8**	**-40.0**	**-39.0**	**-37.6**	**-38.8**	**-39.3**	**-39.0**	**-39.3**	**-38.7**	**-39.2**	**-28.0**	**-36.0**	**-40.6**
Ephemeroptera	-1.3	**-38.8**	**-41.5**	**-36.8**	**-32.4**	**-29.6**	**-28.7**	**-26.3**	-22.1	-24.7	**-28.0**	**-26.0**	**-25.8**	**-25.0**	**-25.7**	-4.9	-18.4	**-30.5**
Oligoneuridae	-1.9	**-35.0**	**-32.8**	**-28.4**	-20.5	-18.5	-16.5	-15.1	-11.5	-12.6	-15.4	-14.0	-11.2	-11.2	-11.3	-1.8	-8.7	-18.6
Chironomidae	0.9	**-38.7**	**-30.6**	**-26.7**	-19.8	-18.0	-16.1	-14.9	-11.4	-12.5	-15.2	-13.9	-11.5	-11.5	-11.5	-4.7	-8.8	-18.2
Ceratopogonidae	-0.9	**-32.1**	**-26.8**	**-26.4**	**-25.1**	-24.9	-24.4	-24.2	-23.5	-23.6	-23.9	-23.9	-23.5	-23.4	-23.5	-24.3	-22.8	**-25.1**
Simulidae	0.4	**-37.6**	**-37.2**	**-32.1**	-23.6	-21.3	-19.1	-17.5	-13.3	-14.6	-18.0	-16.4	-13.4	-13.4	-13.4	-2.4	-10.0	-21.4
Gastropods	1.6	-0.8	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.3	-0.4	-0.4
Fish																		
Redeye labeo, Labeo cylindricus	-0.5	**-34.4**	**-35.6**	**-28.5**	**-31.9**	-24.8	**-29.9**	-23.2	-21.0	**-28.8**	**-33.9**	**-28.8**	**-32.6**	**-32.4**	**-32.6**	-10.9	-19.5	**-26.9**
Cichlids	-1.4	**-26.3**	**-41.5**	**-41.0**	**-38.3**	**-37.8**	**-35.9**	**-35.3**	**-29.9**	**-30.6**	**-31.7**	**-31.6**	**-29.6**	**-27.2**	**-29.3**	-7.2	-24.5	**-38.0**
Synodontis zambezensis	-2.0	-1.8	-11.4	-10.6	-8.5	-8.0	-7.6	-7.2	-6.1	-6.5	-7.0	-6.8	-6.1	-6.0	-6.1	-2.8	-5.2	-7.7
Alestids	-1.7	0.0	-7.8	-7.0	-5.6	-5.2	-4.8	-4.5	-3.8	-4.1	-4.7	-4.4	-4.0	-3.9	-4.0	-1.9	-3.2	-5.3
Cornish jack, Mormyrops anguilloides	-1.7	**-40.2**	**-46.7**	**-46.7**	**-46.3**	**-46.3**	**-46.0**	**-45.9**	**-44.7**	**-44.9**	**-45.2**	**-45.1**	**-44.7**	**-44.1**	**-44.6**	-10.2	**-43.1**	**-46.3**
Vundu, Heterobranchus longifilis	-1.5	1.6	-6.6	-5.7	-5.9	-5.1	-5.6	-4.9	-4.5	-5.3	-5.9	-5.3	-5.6	-5.6	-5.6	-2.0	-4.2	-5.3
Tigerfish, Hydrocynus vittatus	-1.9	-18.9	**-27.2**	-22.3	-22.2	-18.2	-20.3	-16.6	-14.6	-18.5	-21.9	-18.8	-19.9	-19.7	-19.9	-6.8	-12.9	-19.0
Crocodiles																		
Crocodiles	0.0	**-28.9**	-12.8	-11.2	-8.9	-7.2	-7.9	-6.2	-5.0	-7.2	-8.9	-7.2	-6.2	-6.2	-6.3	-5.4	-4.1	-4.3

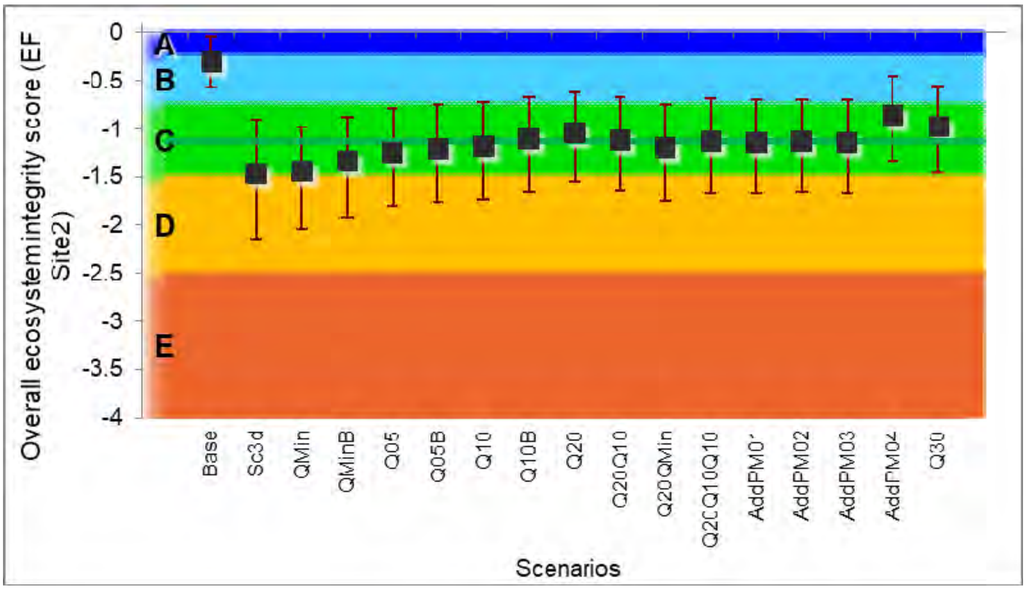
Appendix Table 15 BGHES EF Site 2: The mean percentage changes in abundance (relative to baseline) for the indicators for the SET C scenarios. Predicted changes in FISH species greater than 25% are highlighted. Baseline, by definition, equals 100%.

	Base	Sc3d	QMin	QMinB	Q05	Q05B	Q10	Q10B	Q20	Q20Q10	Q20QMin	Q20Q10Q10	AddPM01	AddPM02	AddPM03	AddPM04	Q30	Int1
Geomorphology																		
Low midchannel rock exposures	1.0	**-40.5**	**-42.3**	**-35.9**	**-26.2**	-23.2	-21.5	-19.4	-14.9	-16.7	-21.1	-17.8	-14.4	-14.4	-14.4	-3.2	-11.4	-23.7
Lengths of cut marginal banks	-1.3	**62.9**	**59.2**	**54.2**	**46.1**	**51.3**	**41.7**	**40.2**	**36.1**	**37.4**	**40.8**	**39.2**	**43.8**	**43.8**	**43.8**	**33.1**	**32.9**	**43.9**
Backwater bed sediment (fine to coarse)	1.8	**111.5**	**112.4**	**111.9**	**111.1**	**111.1**	**110.2**	**110.1**	**108.9**	**109.0**	**109.3**	**109.5**	**109.2**	**108.6**	**109.2**	**104.1**	**107.6**	**111.1**
Area of backwaters and secondary channels	1.9	**-28.0**	**-28.0**	-24.3	-19.6	-17.9	-16.7	-15.3	-12.4	-13.8	-16.3	-14.8	-13.6	-13.4	-13.6	-2.9	-10.0	-18.1
Vegetated midchannel bars	-1.9	**-67.1**	**-66.0**	**-62.8**	**-58.6**	**-58.3**	**-55.4**	**-53.9**	**-50.9**	**-52.2**	**-55.8**	**-53.8**	**-54.3**	**-54.3**	**-54.3**	**-45.6**	**-48.3**	**-58.3**
Channel bed sediment size (fine to coarse)	1.5	**80.1**	**82.5**	**82.5**	**80.7**	**101.2**	**80.2**	**80.2**	**79.6**	**79.6**	**79.6**	**79.7**	**100.0**	**100.0**	**100.0**	**99.0**	**79.2**	**81.1**
Depth of pools	-1.1	11.4	11.2	10.6	9.4	9.4	8.9	8.6	8.1	8.3	8.7	8.5	8.3	8.3	8.3	7.0	7.7	9.2
Sand bars	0.3	**-35.3**	**-35.8**	**-33.2**	**-30.9**	**-33.3**	**-29.5**	**-28.4**	**-26.9**	**-28.1**	**-29.9**	**-28.2**	**-31.4**	**-31.2**	**-31.4**	**-26.5**	**-25.8**	**-30.0**
Riparian vegetation																		
Single-celled diatoms	-0.3	-7.3	-8.8	-5.5	-0.3	3.8	2.5	3.5	6.1	5.2	2.9	4.2	8.7	8.7	8.7	15.4	8.1	1.2
Filamentous green algae	-1.2	-20.0	-18.7	-13.7	-5.9	-1.0	-1.8	-0.2	3.6	2.3	-1.1	0.9	6.2	6.2	6.2	16.2	6.6	-3.8
Marginal Graminoids	-0.7	-19.7	-18.0	-14.4	-9.5	-12.1	-7.5	-7.5	-6.3	-5.7	-6.3	-6.3	-6.3	-6.3	-6.3	-5.6	-5.5	-9.2
Marginal Shrubs	-1.5	-8.4	-8.7	-5.2	-1.8	-4.5	-0.5	-0.7	-0.6	0.1	-0.4	-0.4	-1.2	-1.2	-1.2	-5.8	-1.0	-1.5
Lower Trees	-1.1	9.2	0.8	0.4	-0.2	-1.5	-0.6	-1.0	-1.5	-0.8	0.0	-0.7	-1.6	-1.6	-1.6	-3.3	-2.1	-2.5
Upper Trees	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Organic detritus	1.2	**-35.5**	**-37.4**	**-33.9**	**-28.7**	**-27.4**	**-25.5**	-24.2	-21.0	-22.2	**-25.1**	-23.3	-21.7	-21.7	-21.7	-13.5	-18.5	**-27.1**
Macroinvertebrates																		
Species richness	-1.9	-24.8	-23.0	-22.1	-19.2	-21.9	-18.3	-18.6	-18.1	-17.7	-16.8	-17.9	-19.8	-19.8	-19.8	-20.2	-17.7	-18.3
Ephemeroptera	-1.7	-21.1	-22.5	-19.5	-13.9	-13.1	-11.2	-10.4	-7.9	-8.5	-10.3	-9.5	-7.8	-7.8	-7.8	-1.8	-6.0	-12.9
Bivalves	-1.7	-23.0	**-29.4**	**-27.1**	-24.8	**-27.4**	-23.7	-22.7	-21.4	-22.4	-23.9	-22.4	**-25.4**	**-25.2**	**-25.4**	-20.9	-20.5	-24.0
Oligoneuridae	-1.9	**-30.8**	**-30.4**	**-26.6**	-19.2	-17.5	-15.5	-14.3	-10.8	-11.8	-14.4	-13.1	-10.7	-10.6	-10.7	-1.7	-8.1	-17.8
Chironomidae	1.3	**-32.5**	**-28.6**	**-25.5**	-20.2	-18.8	-17.3	-16.3	-13.5	-14.3	-16.4	-15.4	-13.6	-13.4	-13.6	-5.3	-11.1	-18.9
Shrimps	-0.9	-6.0	-7.2	-5.8	-3.8	-4.8	-3.0	-3.0	-2.5	-2.3	-2.5	-2.5	-2.5	-2.5	-2.5	-2.2	-2.2	-3.7
Ceratopogonidae	0.7	**-29.9**	**-28.0**	**-28.0**	**-27.5**	**-27.4**	**-27.2**	**-27.1**	**-26.8**	**-26.8**	**-26.9**	**-26.9**	**-26.8**	**-26.7**	**-26.8**	**-25.3**	**-26.4**	**-27.5**
Simulidae	0.1	**-38.1**	**-36.8**	**-31.5**	-23.0	-20.9	-18.4	-16.8	-12.7	-14.0	-17.4	-15.7	-12.6	-12.6	-12.6	-2.8	-9.6	-20.6
Gastropods	0.5	-0.9	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.7	-0.7	-0.7	-0.3	-0.6	-0.6

Fish																		
Labeo altivelis	-0.6	**-62.7**	**-70.0**	**-58.0**	**-58.3**	**-40.0**	**-51.3**	**-36.7**	**-29.2**	**-45.3**	**-58.9**	**-46.5**	**-47.6**	**-47.3**	**-47.7**	-1.5	-23.6	**-46.8**
Redeye labeo, Labeo cylindricus	1.1	**-29.4**	**-31.4**	**-25.2**	**-27.8**	-22.1	**-26.1**	-20.7	-19.0	**-25.2**	**-29.4**	**-25.2**	**-28.1**	**-27.9**	**-28.1**	-8.8	-17.7	-23.7
Cichlids	-0.1	**-27.9**	**-28.7**	**-28.2**	**-27.9**	**-27.9**	**-27.7**	**-27.4**	**-27.1**	**-27.5**	**-27.7**	**-27.6**	**-27.7**	**-27.6**	**-27.7**	-13.7	**-26.4**	**-27.7**
Chessa and Nkupe, Distichodus spp	-1.7	-9.2	-15.8	-14.2	-13.1	-12.0	-12.1	-10.8	-9.7	-11.1	-12.3	-11.5	-11.5	-11.5	-11.5	-2.6	-8.8	-12.2
Synodontis zambezensis	0.8	3.8	-12.7	-11.0	-8.3	-8.1	-7.1	-6.7	-5.5	-5.8	-6.6	-6.2	-5.6	-5.5	-5.6	-3.0	-4.7	-7.7
Alestids	-1.3	-12.6	-13.4	-12.3	-12.6	-11.6	-12.2	-10.9	-10.3	-11.9	-12.7	-11.9	-12.6	-12.6	-12.6	-6.2	-9.7	-11.8
Barbus spp	0.0	**-44.9**	**-51.3**	**-48.9**	**-48.3**	**-46.1**	**-45.9**	**-42.3**	**-37.4**	**-42.2**	**-46.0**	**-42.9**	**-45.4**	**-43.6**	**-45.2**	-14.9	**-33.0**	**-47.1**
Cornish jack, Mormyrops anguilloides	-2.4	**-32.9**	**-69.3**	**-67.8**	**-62.2**	**-62.4**	**-58.8**	**-58.4**	**-53.2**	**-53.6**	**-54.5**	**-54.5**	**-53.4**	**-51.1**	**-53.0**	-18.5	**-48.1**	**-63.5**
Vundu, Heterobranchus longifilis	-0.7	14.2	-0.3	0.2	0.0	0.4	0.1	0.3	0.3	0.2	-0.3	0.2	0.0	0.0	0.0	0.5	0.3	0.3
Tigerfish, Hydrocynus vittatus	0.7	**-34.3**	**-51.5**	**-43.8**	**-40.9**	**-35.7**	**-37.8**	**-33.0**	**-30.1**	**-34.7**	**-41.9**	**-35.0**	**-36.6**	**-36.5**	**-36.6**	-15.3	**-27.2**	**-36.1**
Crocodiles																		
Crocodiles	0.0	**-28.9**	-12.8	-11.2	-8.9	-7.2	-7.9	-6.2	-5.0	-7.2	-8.9	-7.2	-6.2	-6.2	-6.3	-5.4	-4.1	-4.3

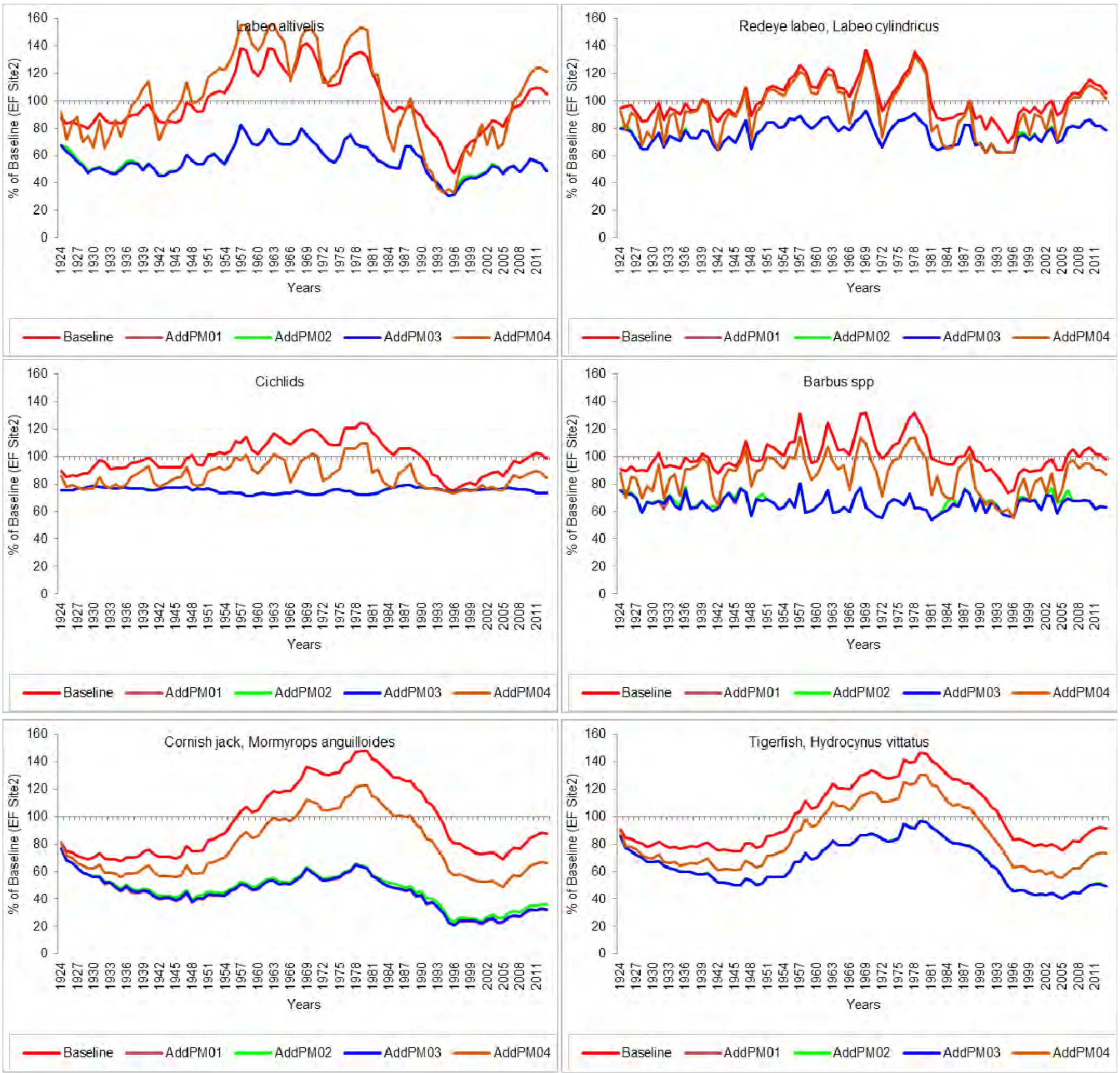


Appendix Figure 5 **Overall ecosystem integrity scores for the scenarios at EF Site 1 under the SET C scenarios. The line in category C shows the agreed maximum drop in ecosystem condition in the ecological criteria.**



Appendix Figure 6 **Overall ecosystem integrity scores for the scenarios at EF Site 2 under the SET C scenarios. The line in category C shows the agreed maximum drop in ecosystem condition in the ecological criteria.**

Finally, as mentioned, the projected impacts associated with the scenarios in Appendix Table 14 and Appendix Table 15 are based on median changes in abundance/concentration/area of the indicators over a 90-year flow sequence. However, these abundances are expected to vary year-on-year, based on climatic and other conditions, e.g., wet years versus dry years. The modelled time-series of fish abundances under the SET C scenarios, should similar climatic and development conditions prevail over the next 90 years, are illustrated in Appendix Figure 7. It is important to take these expected annual variations into consideration in the design and implementation of the monitoring and evaluation of the downstream impact of BGHES, as exclusive use of the median values could result in misinterpretation of the monitoring results.



Appendix Figure 7 **Modelled time-series of abundances for a selection of fish indicators at EF Site 2 under the AddPM scenarios.**

A.3. DECISION ON OPERATING RULES TO MEET EFLOWS FOR THE DOWNSTREAM RIVER

The final agreed operating rules to satisfy downstream EFlows requirements were:

AddPM04 DRY Season (**Sep-Jan**): Baseline flows; no sediment flushing.
WET Season (**Feb-Aug**): QMin with one 6-hour peak a day.

A.4. EFLOWS FOR THE DEWATERED REACHES BETWEEN THE WEIR AND THE TAILRACE

EFlows releases to cater for the 600 m of river between the weir and the tailrace were not explicitly considered in the ESIA or the subsequent assessments. However, there was general agreement that the EFlows operating rules would focus on the Zambezi River downstream of the tailrace, and that forgoing peaking in the dry months would result in a significantly greater reduction of the impacts of the HPP on the river than would forcing high EFlows releases at the weir.

Thus, for the 600-m dewatered section, the following provisions have been agreed to:

- Minimum release of 10% of the mean annual dry season discharge in the hydrological record used for the EFlows assessment. This equates to a daily volume of 2.57 m^3.
- Provision to ensure that there are permanent pools covering at least 50% of the previously wetted area in the 600 m section to provide habitat during the dry months, and to reduce the impression of dewatering. There is a likelihood that this will require some construction to create artificial pools, but this will be decided once Batoka Weir is in place.

A.5. EFLOWS DURING HYDROPOWER MAINTENANCE OPERATIONS

Details of the maintenance schedules for the BGHES are not available at this stage. However, as a general rule, EFlows releases as agreed should be maintained during maintenance operations. In instances where short deviations are unavoidable, these should not exceed four hours and at no point shall there be a complete suspension of downstream releases.

A.6. RESERVOIR FILLING RULES

Reservoir filling rules were not explicitly considered in the ESIA or the subsequent assessments. However, the environmental criteria in Appendix Table 2 offer some guidance for setting these. Thus, the impacts on the downstream river ecosystem of the following reservoir filling rules were tested:

Q10NP – All seasons: if flows are above the monthly 10^{th} percentile values (Appendix Table 1), the surplus is stored, the rest released; no peaking; no sediment flushing.

Q20NP – All seasons: if flows are above the monthly 20^{th} percentile values (Appendix Table 1), the surplus is stored, the rest released; no peaking; no sediment flushing.

Q30NP – All seasons: if flows are above the monthly 30^{th} percentile values (Appendix Table 1), the surplus is stored, the rest released; no peaking; no sediment flushing.

The estimated mean percentage change in abundance/area/concentration of ecosystem indicators at EF Site and 2 under the SET C scenarios are given in Appendix Table 16 and Appendix Table 17, respectively.

The Overall Integrity for each of the SET C scenarios at EF Site 1 and 2 are illustrated in Appendix Figure 3 and Appendix Figure 4, respectively.

The results indicate that with respect to the environmental criteria in Appendix Table 2, and at the more-sensitive EF Site 2:

- Q20NP and Q30NP meet the criterion of no more than a 1.5 class drop in Overall Ecosystem Condition in the downstream river, i.e., from A/B to no less than a mid-C category, at both EF sites.
- None of the scenarios meets the criterion that at least 90% of fish species should be impacted by <25%, at both EF sites.

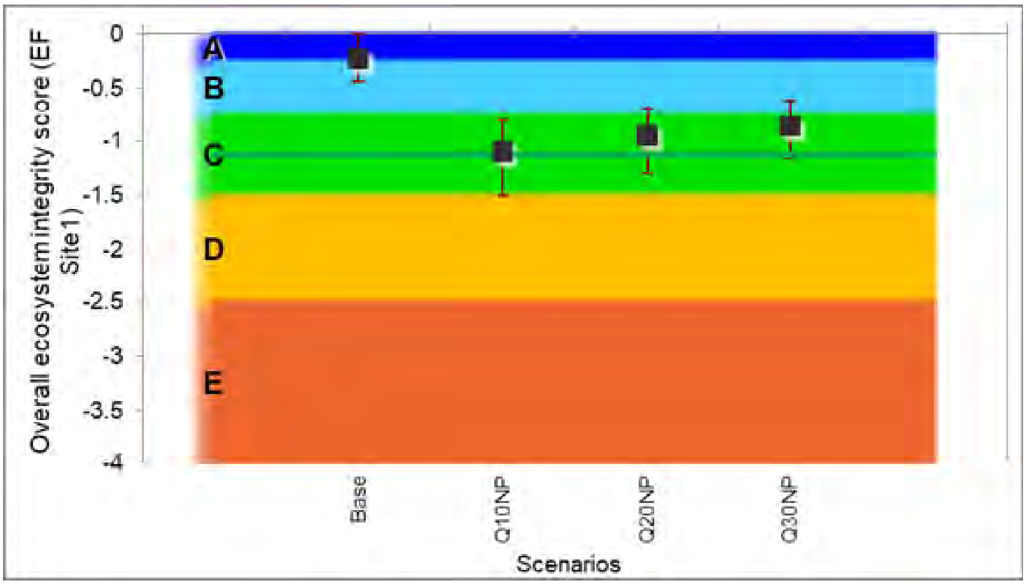
However, the scenarios evaluated assume that the filling rules will be applied consistently for 90 years. In our opinion, given the outcome of the scenarios assessed, i.e., that even if applied for 90 years, both Q20NP and Q30NP meet the first of the two ecological criteria, the releases during reservoir filling should be in line with Q20NP, provided this is not applied for longer than two years.

Appendix Table 16 **BGHES EF Site 1: The mean percentage changes in abundance (relative to baseline) for the indicators for the Reservoir Filling scenarios. Predicted changes in FISH species greater than 25% are highlighted. Baseline, by definition, equals 100%.**

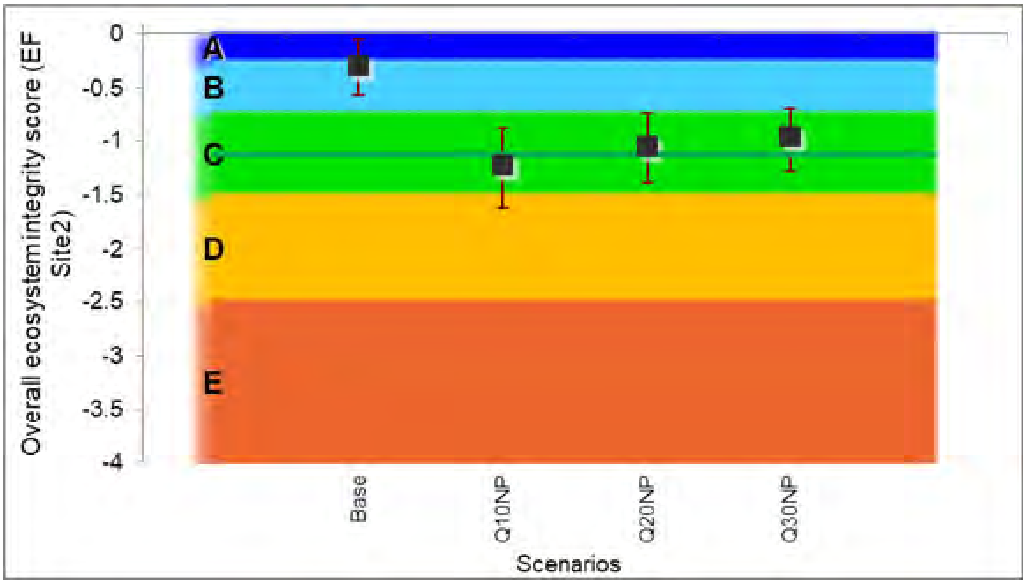
EF1	Base	Q10NP	Q20NP	Q30NP
Geomorphology				
Low midchannel rock exposures	0.3	1.6	1.7	-0.1
Backwater bed sediment (fine to coarse)	0.9	**95.6**	**96.9**	**98.6**
Area of backwaters and secondary channels	0.9	-6.9	-5.5	-4.8
Channel bed sediment (fine to coarse)	1.5	**103.7**	**103.5**	**103.0**
Depth of pools	-1.1	-4.5	-2.3	-1.8
Sand bars	0.9	**-67.0**	**-68.3**	**-68.3**
Riparian vegetation				
Single-celled diatoms	0.3	**30.3**	**25.5**	**25.2**
Filamentous green algae	-0.1	**29.0**	**26.5**	**25.7**
Bryophyta	-2.0	**38.6**	**32.1**	**28.6**
Marginal Graminoids	-1.8	-14.0	-14.7	-14.6
Marginal Shrubs	-1.6	3.5	3.2	3.8
Lower Trees	-1.5	-14.6	-11.4	-10.0
Upper Trees	0.1	-3.7	-1.7	-0.6
Organic detritus	-0.4	-19.2	-16.9	-14.0
Macroinvertebrates				
Species richness	-1.9	**-30.1**	**-27.9**	**-28.5**
Ephemeroptera	-1.3	3.2	4.0	2.7
Oligoneuridae	-1.9	1.2	1.4	1.3
Chironomidae	0.9	14.1	7.3	4.2
Ceratopogonidae	-0.9	-3.8	-12.1	-15.7
Simulidae	0.4	0.3	1.0	0.1
Gastropods	1.6	23.7	14.2	9.0
Fish				
Redeye labeo, Labeo cylindricus	-0.5	-14.6	-10.2	-7.8
Cichlids	-1.4	**-28.2**	-17.4	-14.7
Synodontis zambezensis	-2.0	**-25.9**	-23.5	-16.6
Alestids	-1.7	-22.9	-15.2	-11.5
Cornish jack, Mormyrops anguilloides	-1.7	**-46.1**	**-35.9**	**-29.6**
Vundu, Heterobranchus longifilis	-1.5	**-27.2**	-18.8	-14.5
Tigerfish, Hydrocynus vittatus	-1.9	**-42.8**	**-30.5**	-23.7
Crocodiles				
Crocodiles	0.0	0.0	0.0	0.0

Appendix Table 17 BGHES EF Site 2: The mean percentage changes in abundance (relative to baseline) for the indicators for the Reservoir Filling scenarios. Predicted changes in FISH species greater than 25% are highlighted. Baseline, by definition, equals 100%.

	Base	Q10NP	Q20NP	Q30NP
Geomorphology				
Low midchannel rock exposures	1.0	-0.9	-1.1	0.3
Lengths of cut marginal banks	-1.3	**42.9**	**39.8**	**37.9**
Backwater bed sediment (fine to coarse)	1.8	**103.9**	**103.8**	**104.1**
Area of backwaters and secondary channels	1.9	-5.2	-4.1	-3.0
Vegetated midchannel bars	-1.9	**-26.4**	**-28.4**	**-31.0**
Channel bed sediment (fine to coarse)	1.5	**103.7**	**103.5**	**103.0**
Depth of pools	-1.1	3.3	6.4	7.1
Sand bars	0.3	**-25.3**	**-26.7**	**-26.2**
Riparian vegetation				
Single-celled diatoms	-0.3	**28.4**	**25.6**	**25.3**
Filamentous green algae	-1.2	**30.1**	**27.6**	**26.8**
Marginal Graminoids	-0.7	-8.4	-8.2	-7.2
Marginal Shrubs	-1.5	2.6	2.9	3.5
Lower Trees	-1.1	-15.0	-11.8	-10.4
Upper Trees	0.1	-3.3	-1.5	-0.5
Organic detritus	1.2	-13.4	-11.9	-11.6
Macroinvertebrates				
Species richness	-1.9	**-37.4**	**-34.5**	**-33.1**
Ephemeroptera	-1.7	0.5	4.3	2.4
Bivalves	-1.7	**-29.1**	**-26.1**	-23.7
Oligoneuridae	-1.9	0.8	3.4	3.8
Chironomidae	1.3	3.5	-1.7	-3.9
Shrimps	-0.9	0.9	0.7	-0.5
Ceratopogonidae	0.7	-8.4	-16.2	-18.8
Simulidae	0.1	3.4	3.4	1.5
Gastropods	0.5	17.9	9.7	6.8
Fish				
Labeo altivelis	-0.6	-20.0	-7.9	-3.2
Redeye labeo, Labeo cylindricus	1.1	-20.0	-14.6	-11.7
Cichlids	-0.1	**-26.4**	-21.0	-17.5
Chessa and Nkupe, Distichodus spp	-1.7	**-49.9**	**-35.2**	**-28.9**
Synodontis zambezensis	0.8	**-39.8**	**-28.4**	-22.5
Alestids	-1.3	-9.4	-6.3	-4.7
Barbus spp	0.0	-21.2	-15.9	-12.1
Cornish jack, Mormyrops anguilloides	-2.4	**-82.8**	**-58.2**	**-47.6**
Vundu, Heterobranchus longifilis	-0.7	**-39.0**	**-25.5**	-19.5
Tigerfish, Hydrocynus vittatus	0.7	**-71.0**	**-64.6**	**-56.5**
Crocodiles				
Crocodiles	0.0	0.0	0.0	0.0



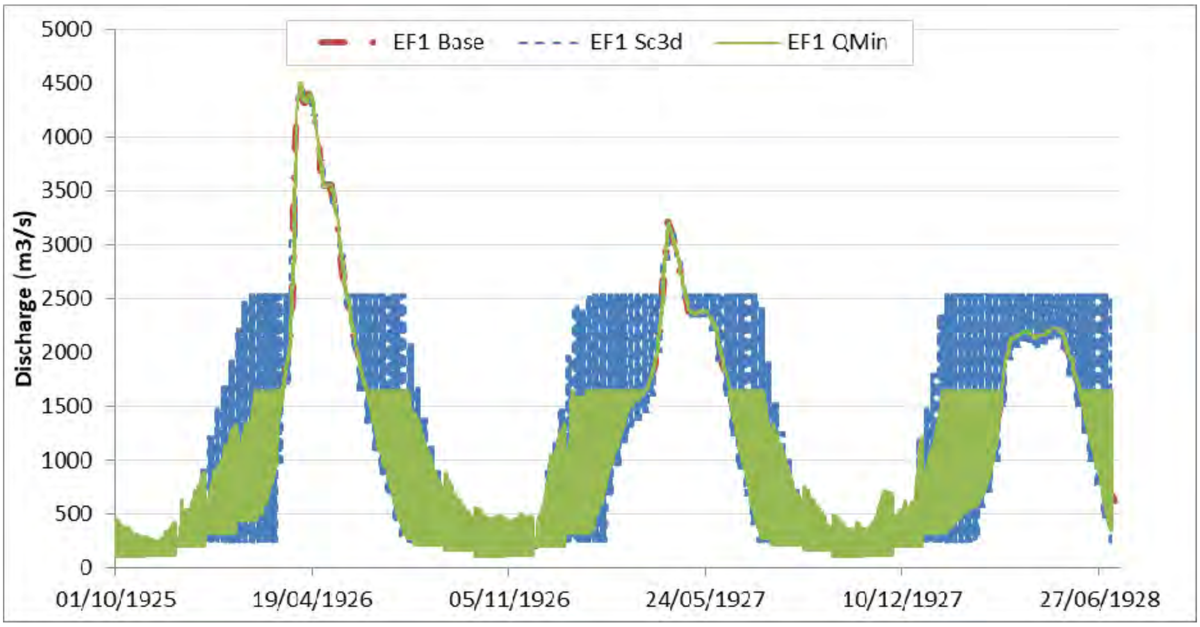
Appendix Figure 8 **Overall ecosystem integrity scores for the scenarios at EF Site 1 under the Reservoir Filling scenarios. The line in category C shows the agreed maximum drop in ecosystem condition in the ecological criteria.**

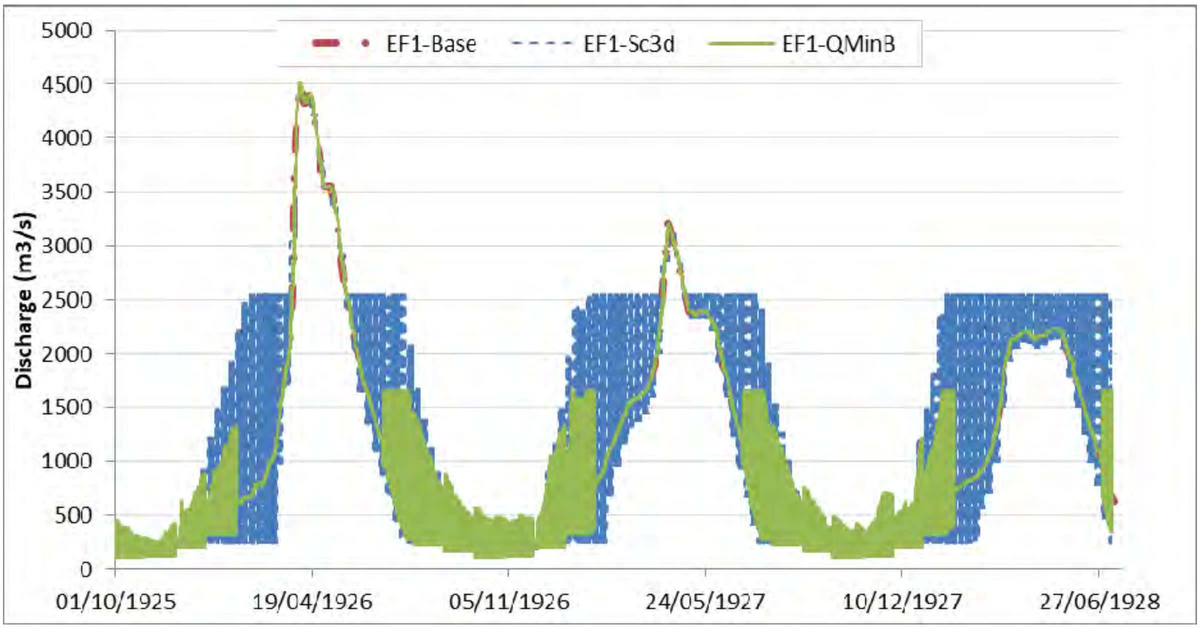


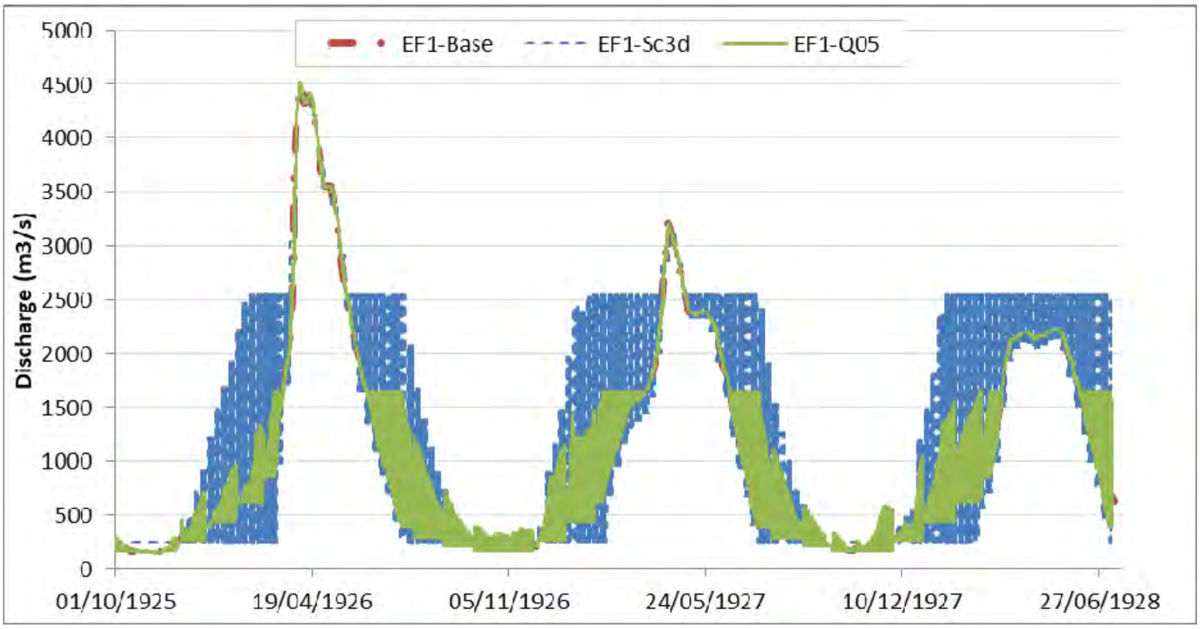
Appendix Figure 9 **Overall ecosystem integrity scores for the scenarios at EF Site 2 under the Reservoir Filling scenarios. The line in category C shows the agreed maximum drop in ecosystem condition in the ecological criteria.**

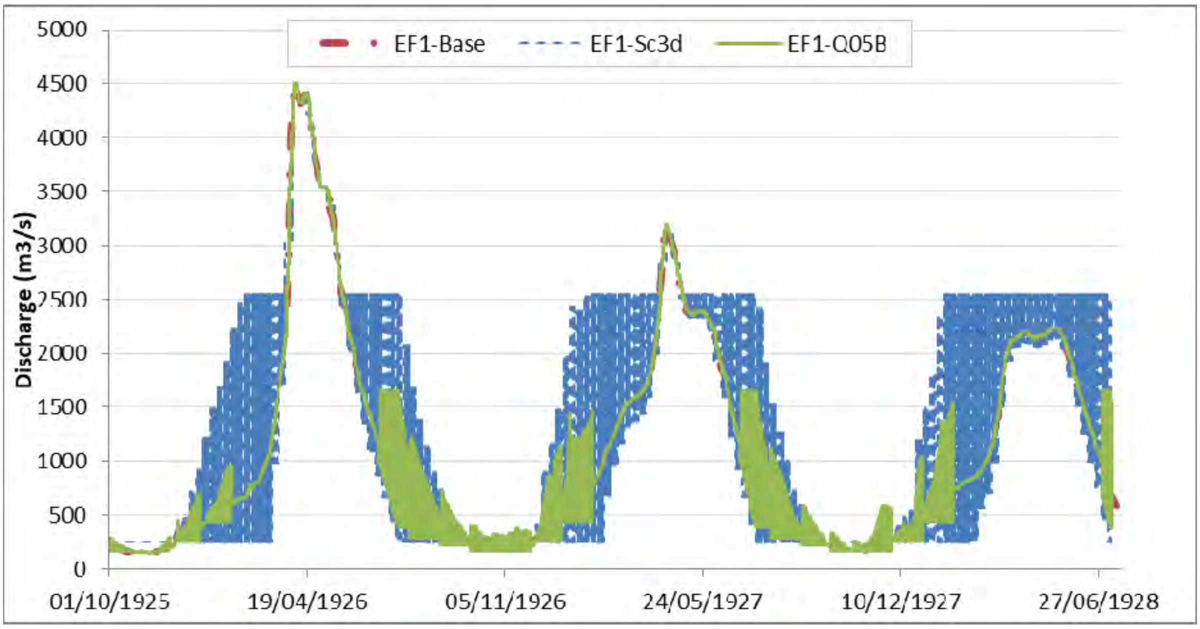
Appendix B. DEPICTIONS OF THE FLOW REGIMES ASSOCIATED WITH EACH OPERATIONAL SCENARIO

Each of the additional operating scenarios are shown with the Baseline (EF1-Base) and one of the ESIA scenarios (EF-Sc3d) as reference.






EF1-Base
EF1-Sc3d
EF1-Q05
Discharge (m3/s)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/10/1925
19/04/1926
05/11/1926
24/05/1927
10/12/1927
27/06/1928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EF1-Sc3d
EF1-Q05B
Discharge (m3/s)
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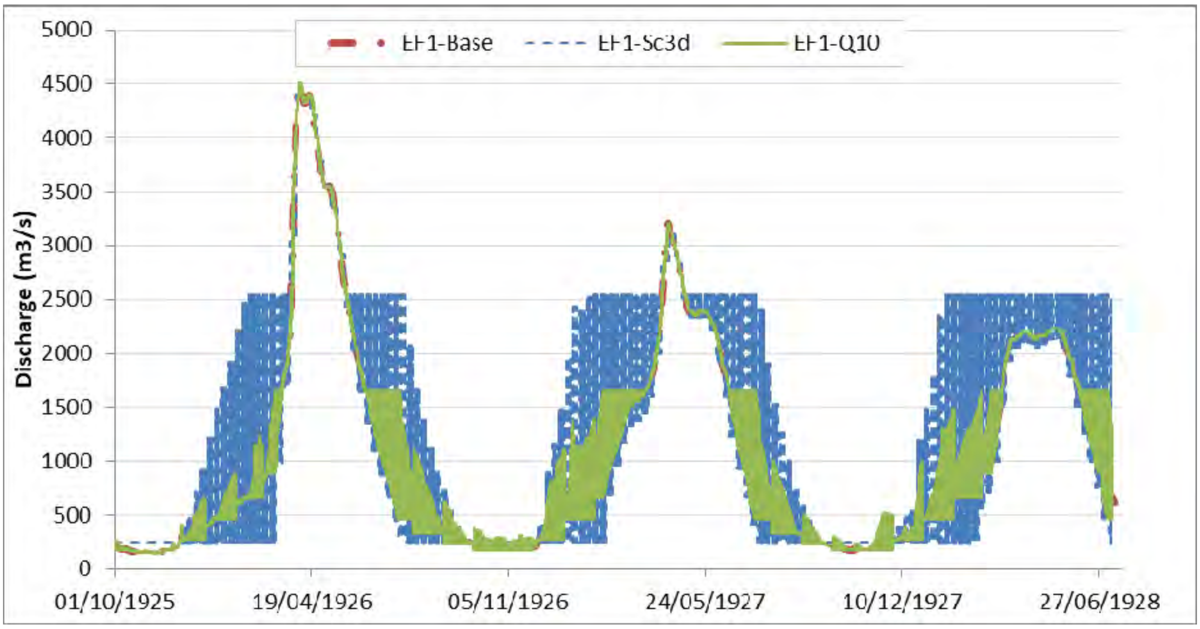
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/10/1925
19/04/1926
05/11/1926
24/05/1927
10/12/1927
27/06/1928


EF1-Base
EF1-Sc3d
EF1-Q10
Discharge (m3/s)
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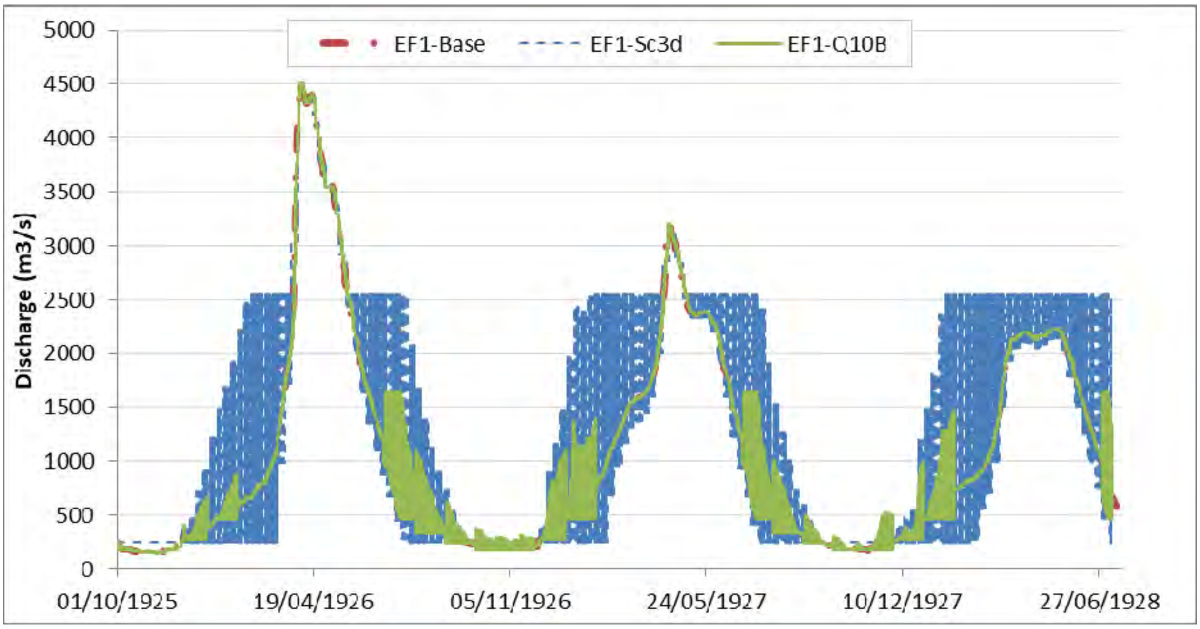
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/10/1925
19/04/1926
05/11/1926
24/05/1927
10/12/1927
27/06/1928


EF1-Base
EF1-Sc3d
EF1-Q10B
Discharge (m3/s)
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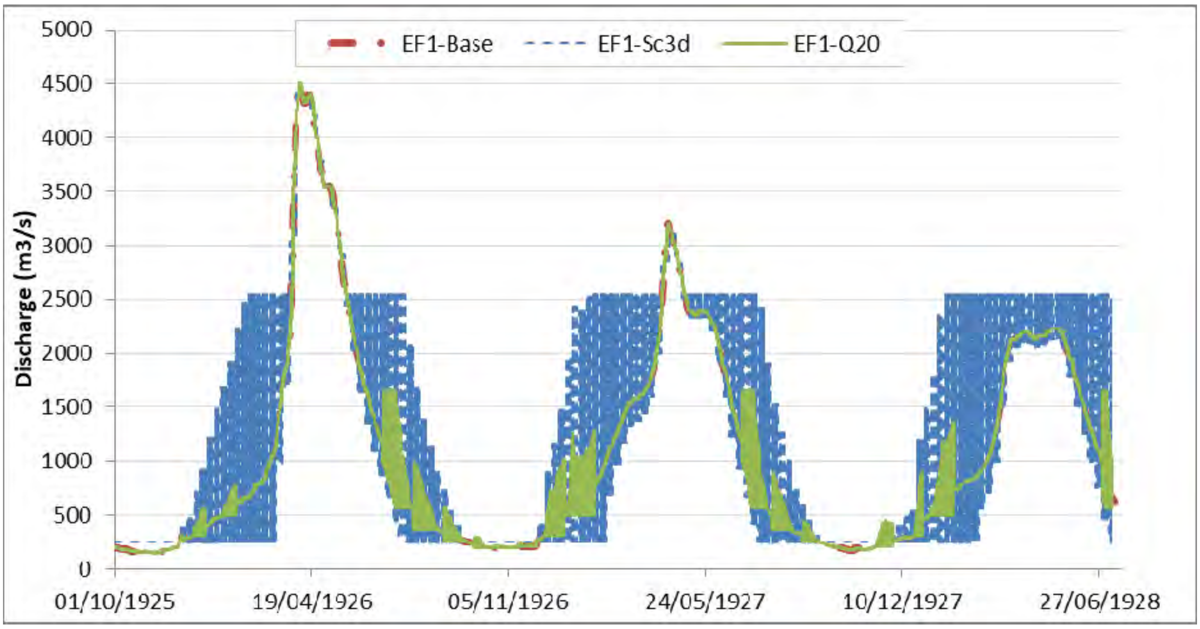
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/10/1925
19/04/1926
05/11/1926
24/05/1927
10/12/1927
27/06/1928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EF1-Sc3d
EF1-Q20
Discharge (m3/s)
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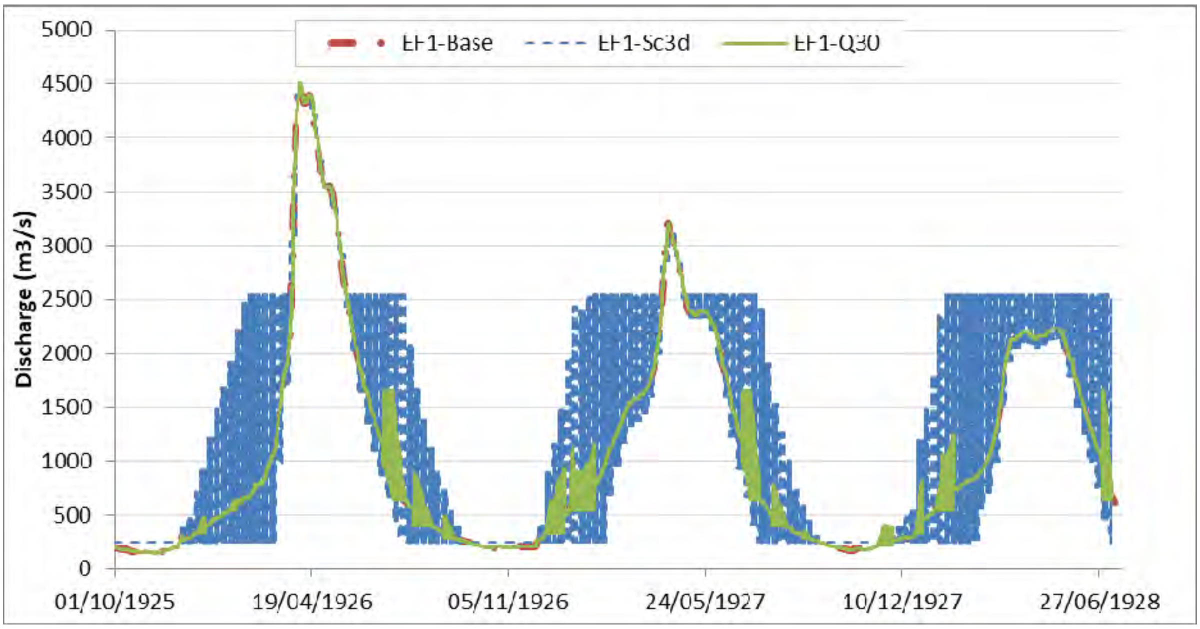
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/10/1925
19/04/1926
05/11/1926
24/05/1927
10/12/1927
27/06/1928


EF1-Base
EF1-Sc3d
EF1-Q30
Discharge (m3/s)
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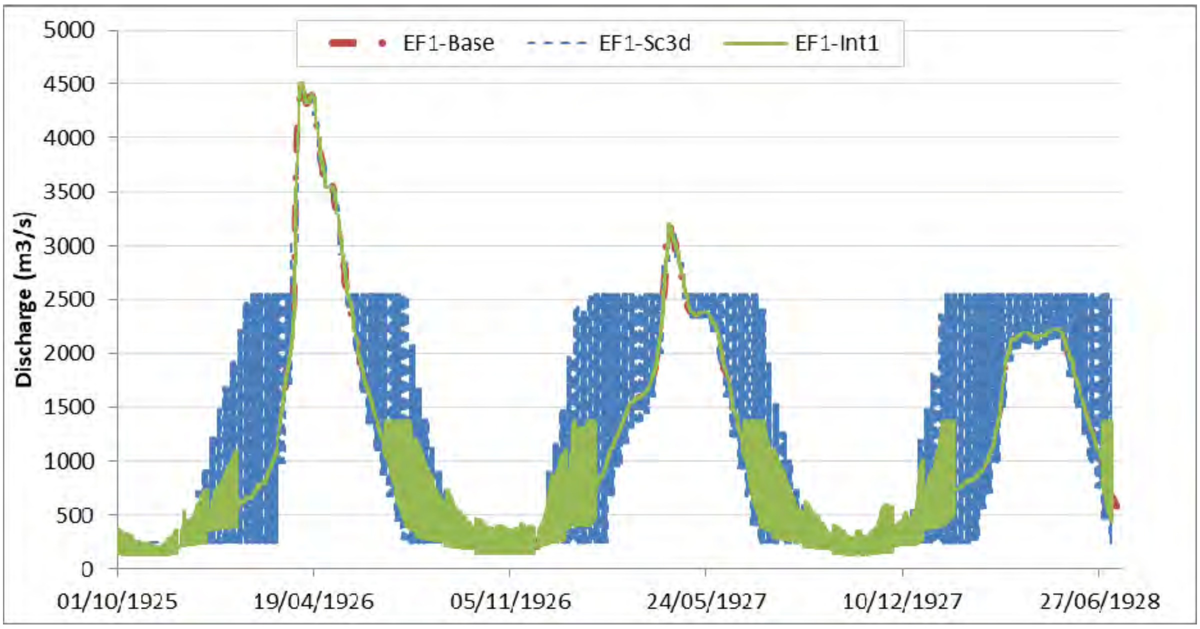
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/10/1925
19/04/1926
05/11/1926
24/05/1927
10/12/1927
27/06/1928


EF1-Base
EF1-Sc3d
EF1-Int1
Discharge (m3/s)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/10/1925
19/04/1926
05/11/1926
24/05/1927
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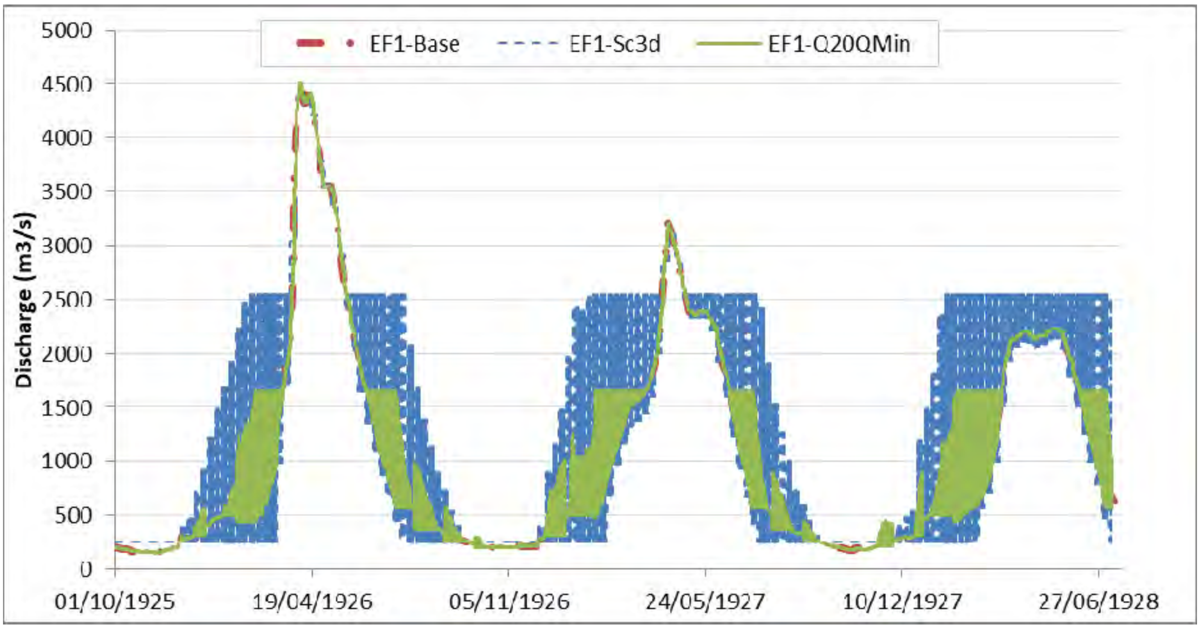
27/06/1928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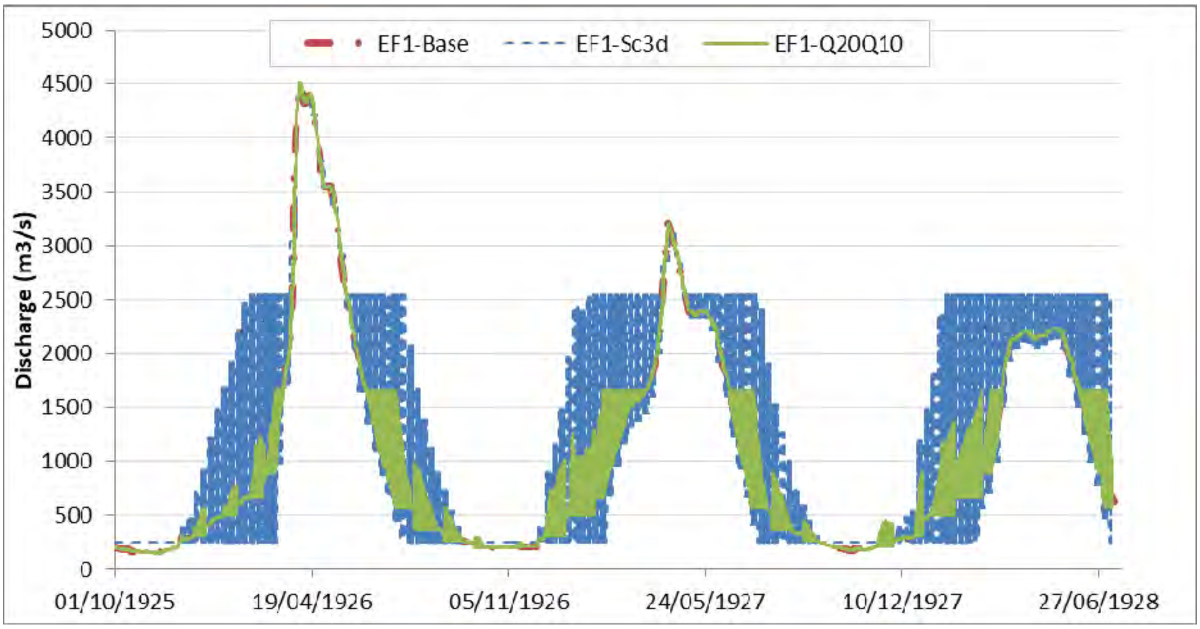
01/10/1925
19/04/1926
05/11/1926
24/05/1927
10/12/1927
27/06/1928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24/05/1927
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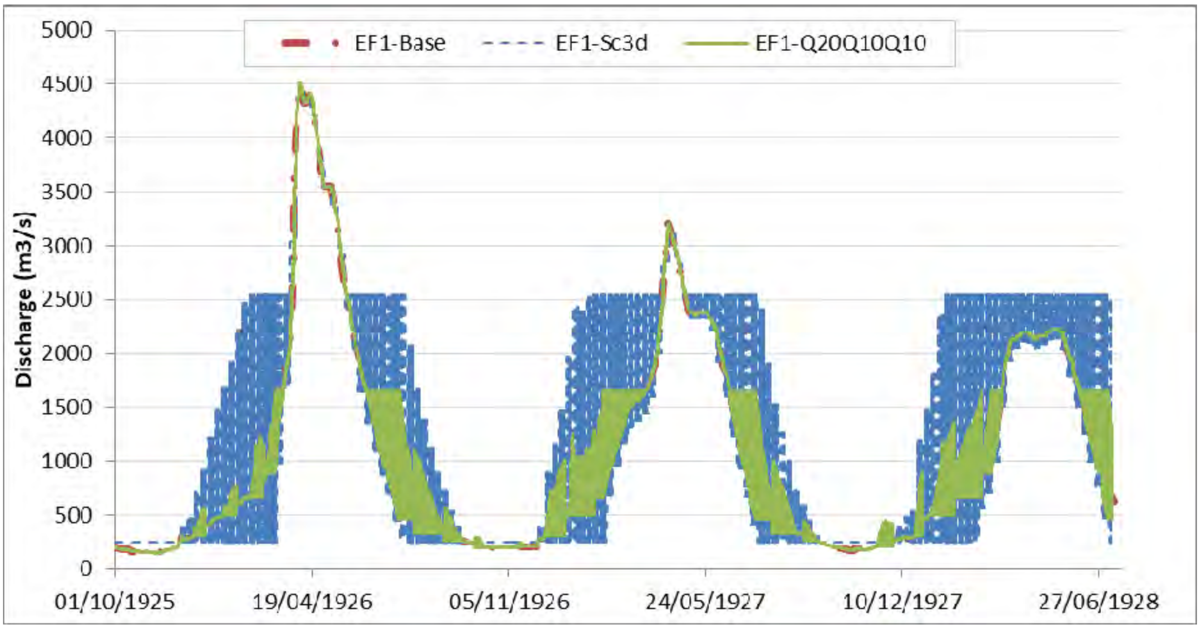
27/06/1928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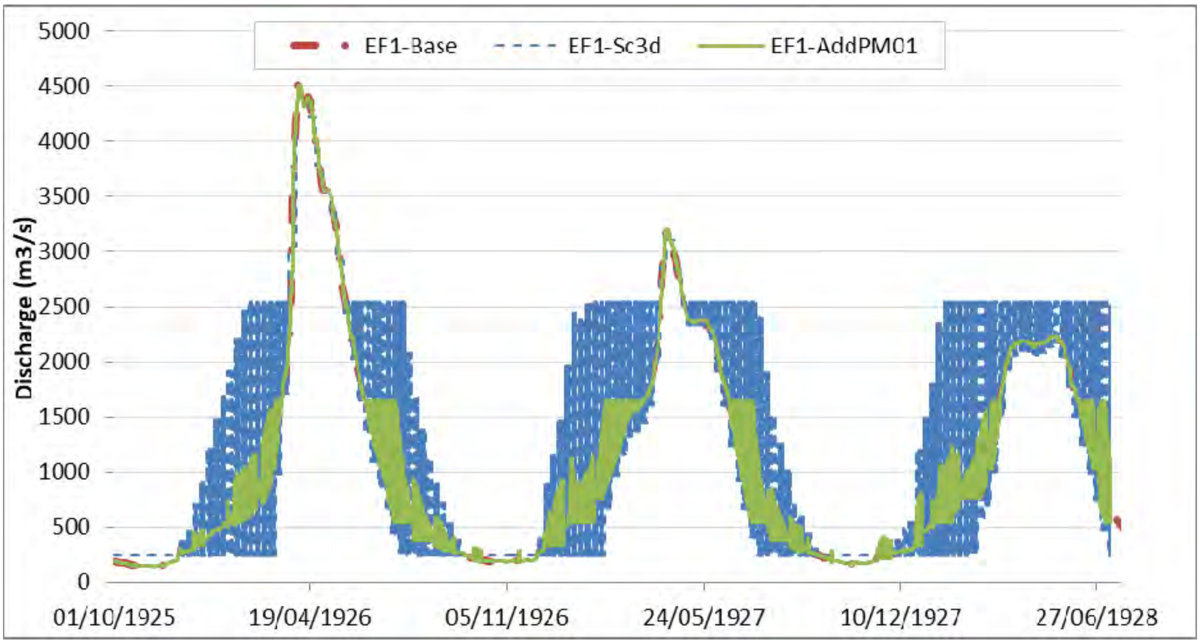
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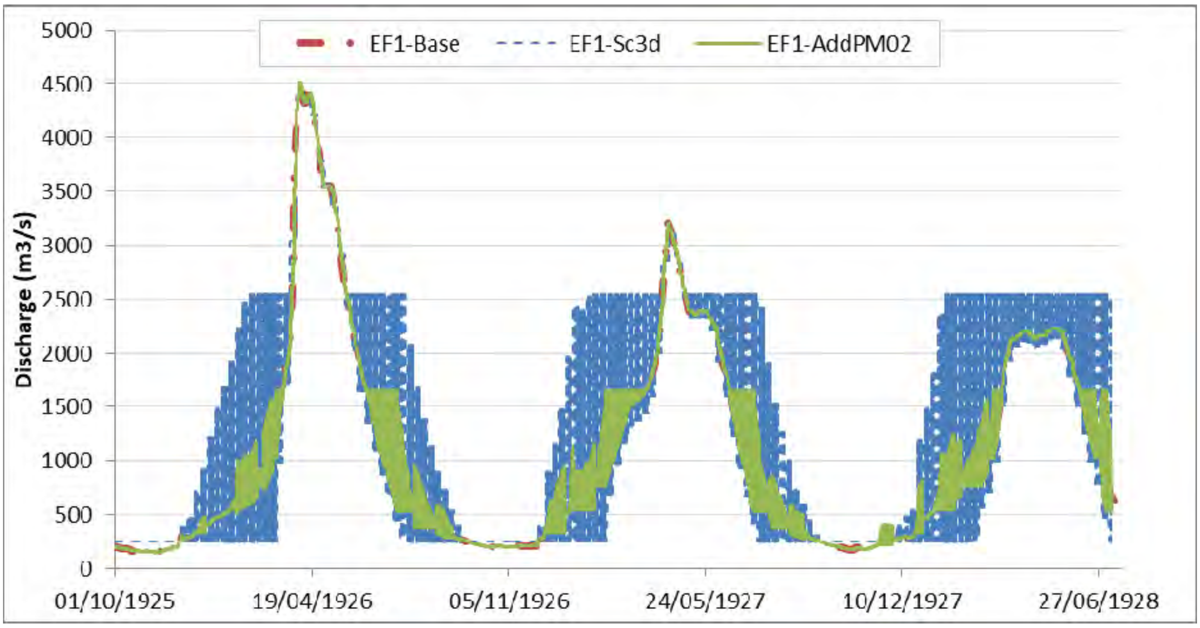
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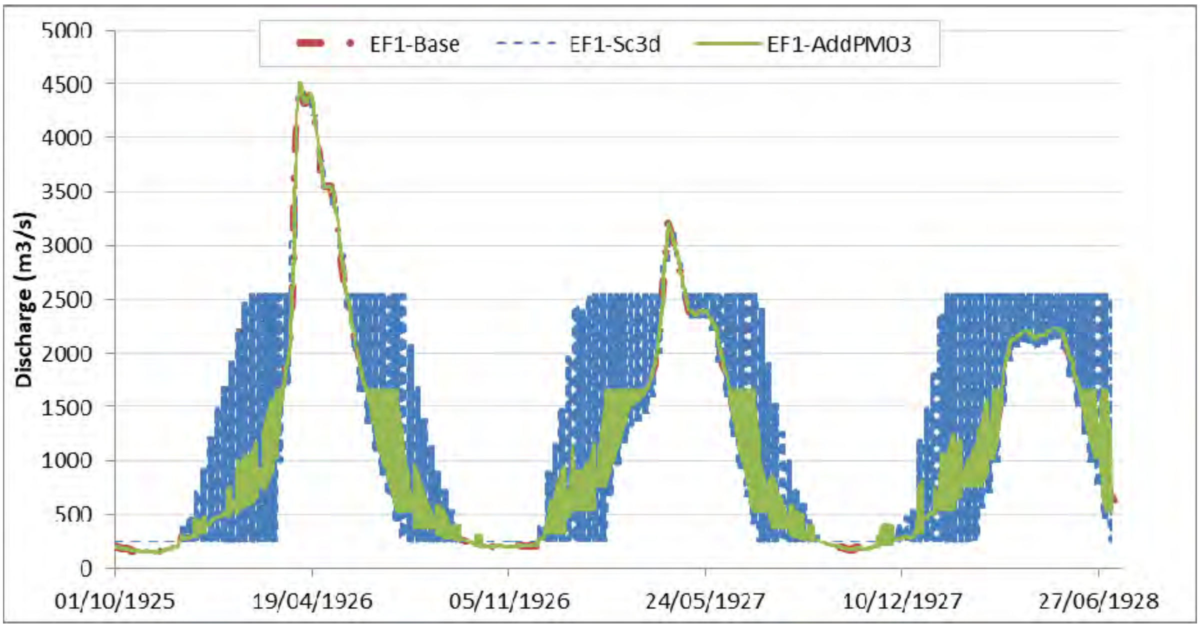
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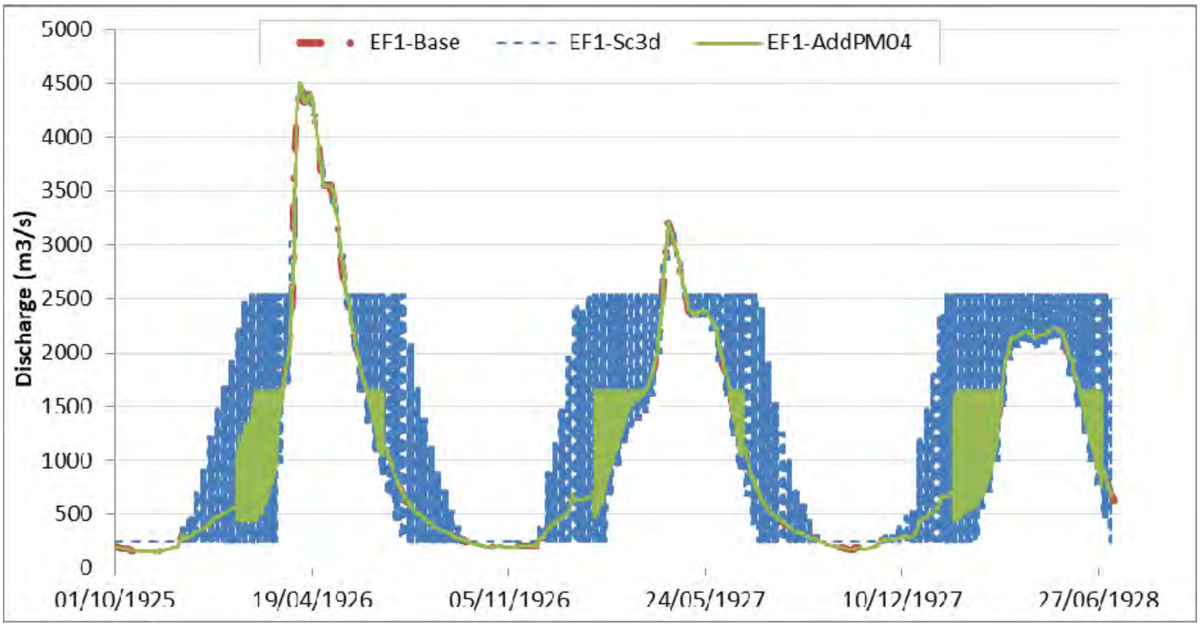
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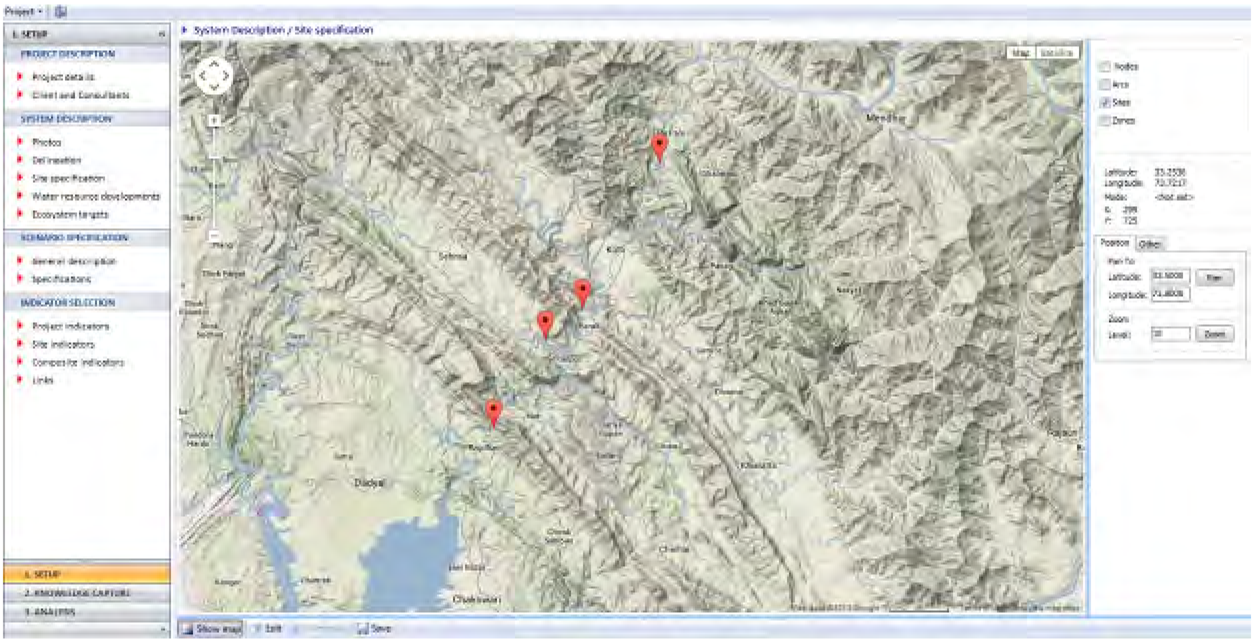
05/11/1926
24/05/1927
10/12/1927
27/06/1928

Appendix C. OVERVIEW OF DRIFT

C.1. DRIFT-DSS

The DRIFT-DSS is programmed using Delphi XE and uses a NexusDB v3 database. The software is designed for use in all computers running Windows XP and upwards.

The DSS makes use of Google Earth (standard version) and Google Kml files (Appendix Figure 10). No licence is required unless Google Earth images are used in any reports.

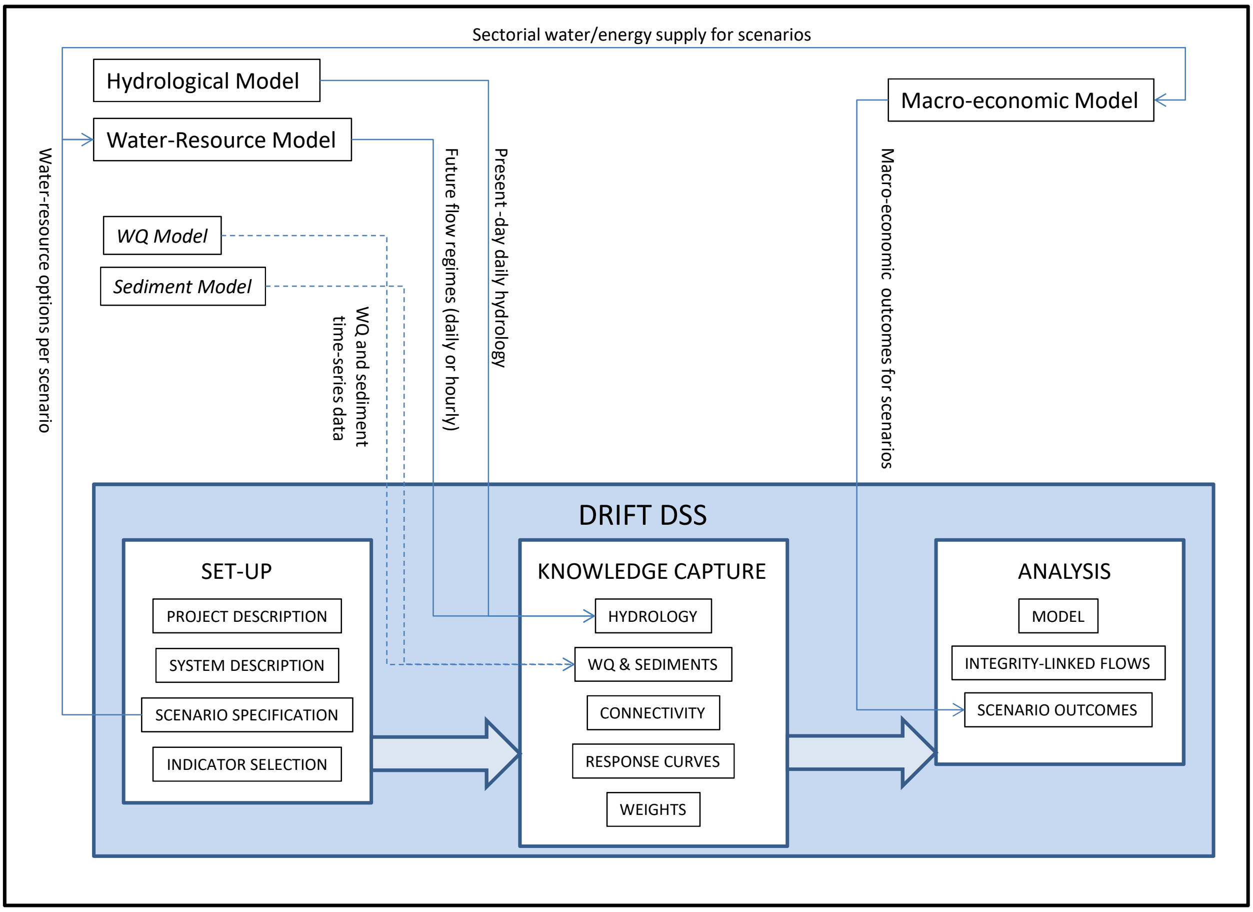


Appendix Figure 10 Screen shot of DRIFT map page showing the Zambezi River, and the EF sites.

The DRIFT DSS is divided into three sections, each dealing with a different stage in the EF determination process. These are (Brown *et al*. 2013; Appendix Figure 11):

6. Set-up
7. Knowledge Capture
8. Analysis.

The first two sections deal with the population of the DSS and the calibration of the relationships that will be used to predict the ecosystem response to changes in flows. The third section is used to generate results once the first two sections have been populated, and to produce the reports and graphics detailing the predictions for the scenarios under consideration.



Appendix Figure 11 Arrangement of modules in the DRIFT-DSS and inputs required from external models.

All hydrological modelling is done outside of the DSS. The DSS is dependent on the outputs of two external models, namely:

- an Hydrological Model used to provide baseline basin hydrology; and
- a Water Resource Model used to predict the changes in the flow regime associated with the existing and proposed water-resource developments under the various scenarios.

The module groups in the DRIFT DSS and external models are shown in Appendix Figure 11, and an example of the DRIFT-DSS Response Curves entry datasheet for fish, showing BGHES data I shown in Appendix Figure 12. Additional detail on the DSS, including a User Manual, is available in Brown *et al.* (2013).

Appendix Figure 12 Example of the DRIFT-DSS Response Curves entry datasheet for fish, showing BGHES data.

C.2. SUMMARY OF DRIFT PROCESS

DRIFT (Downstream Response to Imposed Flow Transformations; King *et al.* 2003) was used to evaluate different water management scenarios for the Zambezi River upstream and downstream of BGHES for, *inter alia*, the following reasons:

1. It is a holistic interactive method, which provides the biophysical consequences for the downstream river for various scenarios of flow change. These scenarios can then be used to determine the impact of proposed operating rules for the dam, and possible mitigation thereof.
2. It is a published method (King *et al*. 2003), with a detailed User Manual (Brown *et al.,* 2008), and as such is has been peer reviewed.
3. It has been widely applied in the Southern African Development Community, such as Lesotho (King *et al*. 2003), Mozambique (Beilfuss and Brown, 2010; Southern Waters 2011), Namibia (Southern Waters 2010), Peru (Norconsult and Southern Waters 2011), South Africa (e.g. Brown *et al*., 2006), Tanzania (PBWO/IUCN 2008), Zimbabwe (Brown 2007) and Sudan (Southern Waters 2009). It was used as the basis of a basin-wide EF assessment in the Okavango River Basin (Angola, Namibia and Botswana; King and Brown 2009), and has been used in Pakistan on the Neelum-Jhellum River (Southern Waters and Hagler-Bailly Pakistan 2013).
4. It is based on Response Curves constructed from any relevant knowledge including expert opinion and local wisdom and as such is suitable for use in regions where there are few biophysical data available for the flow-related aspects of the rivers, as was the case for the Zambezi River

5. It aims to provide an objective and transparent assessment of the effects of changes in flow on the downstream environment based solely on structured consideration of the biophysical aspects thereof.

DRIFT is a data-management tool, allowing data and knowledge to be used to their best advantage in a structured way. Within DRIFT, each specialist, to derive the links between river flow and river condition, uses discipline-specific methods. The central rationale of DRIFT is that different aspects of the flow regime of a river elicit different responses from the riverine ecosystem. Thus, removal of part or all of a particular element of the flow regime will affect the riverine ecosystem differently than will removal of some other element.

In DRIFT, the long-term daily-flow time-series is partitioned into parts of the flow regime that are thought to play different roles in sculpting and maintaining the river ecosystem, such as the onset of important flow seasons, which may affect breeding cycles, or the magnitude of the annual flood, which may inundate a floodplain. This makes it easier for ecologists to predict how changes in the flow regime could affect the ecosystem. The 'parts' of the flow regime used in DRIFT are called flow indicators. In flow indicators used in this project are listed in Table 4.1.

The variability of the flow regime in timing and magnitude, both in its natural state and in any future scenario, was captured automatically through instructions within the hydrological module of the DSS that identify the flow indicators year-by-year. Thus, for the Zambezi River, the time-series are made up of annual time-series of each flow indicator for the 50 years of flow record. This means the specialists can consider a response to a condition for a particular time-step rather than thinking of an averaged response over several years. They can also use data from a particular year or season to calibrate time-series responses.

The study process was structured as follows:

1. The study focused on four EF sites on the Zambezi Rivers (Table 3.1).
2. The flow changes that were evaluated encompass a mixture of:
    i. Changes in magnitude.
    ii. Changes in duration.
    iii. Changes in timing (e.g., delayed onset of wet season or range of hourly discharge fluctuations).
3. Specialists provided opinion on the consequences of these changes in the form of Response Curves. The disciplines represented were:
    i. Water quality
    ii. Hydraulics
    iii. Geomorphology
    iv. Algae
    v. Riparian vegetation
    vi. Invertebrates
    vii. Fish
    viii. Socioeconomics.
4. The database was used to evaluate

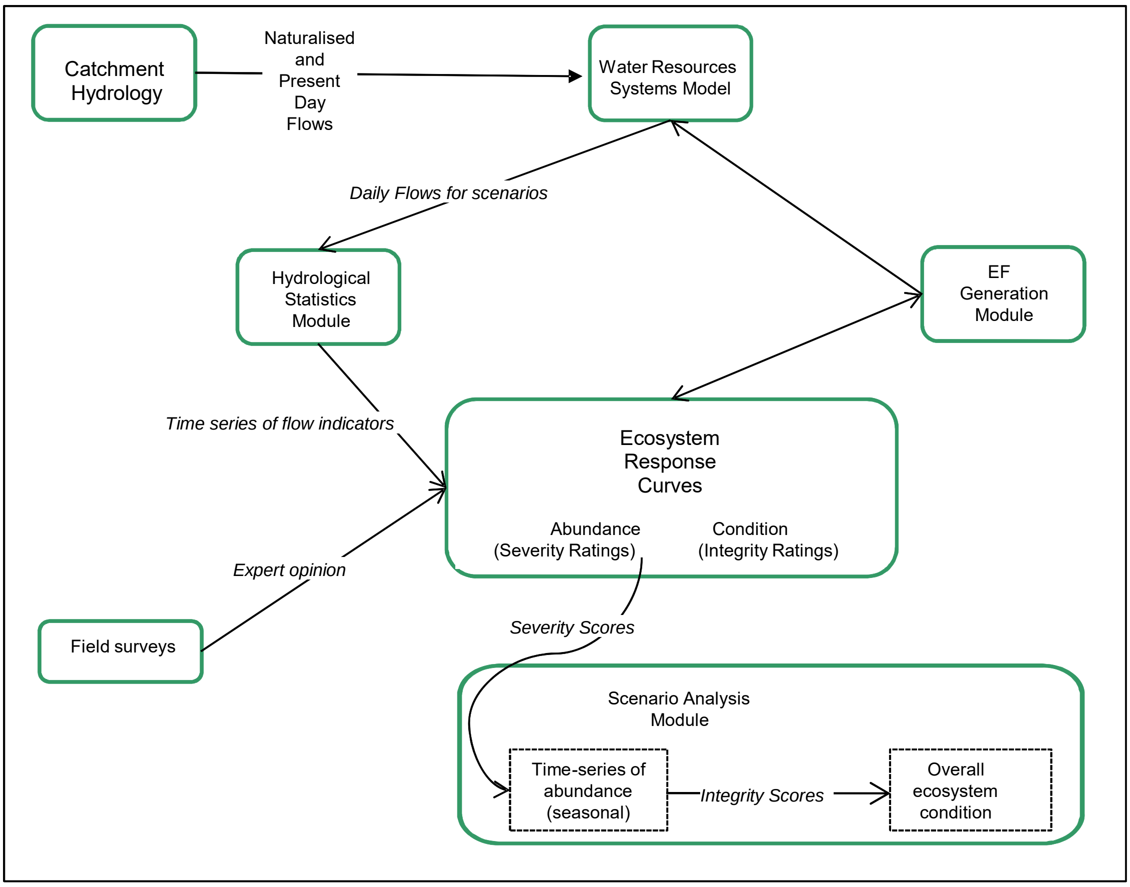
i. changes in individual aspects of the ecosystem (e.g. fish, vegetation), for each site and scenario;

ii. changes in the overall condition of the river, for each site and scenario.

5. The outputs of the DRIFT database are written up in Sections 7 and 0.

The basic sequence of activities in the DRIFT DSS can be summarised as follows (Appendix Figure 13):

1. Collect data for the study at the river.
2. Augment with expert knowledge for similar river systems and a global understanding of river functioning.
3. Construct relationships for the expected response of individual ecosystem indicators to changes in aspects of the flow regime (Response Curves).
4. Use Response Curves to predict time-series of abundance changes.
5. Adjust the severity ratings to integrity ratings by assigning a negative sign for a move away from the natural ecosystem condition and a positive for a move towards natural.
6. Model future changes in catchment hydrology.
7. Calculate annual flow indicator time-series.
8. Use Response curves to calculate severity scores and develop time-series of change in abundance for ecosystem indicators.
9. Calculate average severity score for each indicator for entire hydrological time-series.
10. Convert severity scores to Integrity Scores to predict overall ecological condition.



Appendix Figure 13 Flow chart of DRIFT process

C.3. *RESPONSE CURVES*[16]

Response Curves depict the relationship between a biophysical or socio-economic indicator and a driving variable (e.g., flow). In this EF assessment, Response Curves linked an indicator to any other indicator deemed to be driving change. The aim is not to ensure that every conceivable link is captured but rather to restrict the linkages to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the flow or sediment regimes of the river.

Response curves are constructed using severity ratings (Section C.4).

The full set of Response Curves for this study are presented in Volume 2: Specialists' Report.

The number of Response Curves constructed for an EF assessment depends on the level of detail at which a flow assessment is done. In this assessment, the specialists collectively completed c. 200 Response Curves for EFs Site 2. These were used to evaluate scenarios by taking the value of the flow indicator for any one scenario and reading off the resultant value for the biophysical indicators from their respective Response Curves. Once this had been done the database combined these values to predict the overall change in each biophysical indicator and in the overall ecosystem under each scenario.

C.3.1. *CONSTRUCTION OF THE RESPONSE CURVES*

The Response Curves used in this project were constructed as follows:

- Draft curves constructed at a workshop in Cape Town attended by all the EF team members.
- Draft curves were re-evaluated by Southern Waters once the scenarios has been run, and referred back to the specialists for adjustment where deemed necessary.
- Draft curves re-evaluated by relevant specialists using the scenarios as reference, and adjusted where deemed necessary.

Note: The final curves and explanations for their shape are contained in the DRIFT DSS, and addressed in Volume 2: Specialists' Report.

C.3.2. *RESPONSE CURVES AND CUMULATIVE CHANGE*

The time-series approach means that the Response Curves are used to predict the likely seasonal change in an ecosystem indicator in response to the flow/sediment conditions experienced in that, or possibly preceding, seasons. For instance, the kind of question typically asked to facilitate setting the dry season discharge Response Curve for Kashmir catfish are:

- "If the dry season discharge declines from baseline values, what will be the consequences for the abundance of Kashmir catfish?":

[16] The bulk of this section is taken from Joubert *et al*., 2009.

- Do Kashmir catfish use the main river in the dry season?
- Do Kashmir catfish abundances change noticeably over the climatic range covered in the baseline, i.e., are they noticeably more abundant in wet years than in dry years, or vice versa?
- What kinds of habitat do adult Kashmir catfish use in the main river?
- Do Kashmir catfish breed in the dry season?
- Do they breed in the main river or in the tributaries?
- Where do Kashmir catfish lay their eggs?
- What sorts of habitat do fry, fingerlings and juvenile trout use in the main river?
- At what discharge(s) does the favoured habitat(s) disappear?
- What is the consequence of these habitats not being available for one season?
- If discharge reaches zero for one season, are there pools that the trout will be able to survive in?
- Can the Kashmir catfish survive for a dry season in pools?
- Is water temperature a concern, i.e., would winter temperature be an issue for Kashmir catfish if discharge dropped?
- What do Kashmir catfish adults/juveniles/fingerlings/fry eat?
- How will the food base be affected by changes in dry season lowflows?
- Etc.

Often, a species (such as Kashmir catfish will be expected to survive even an extremely-dry dry season, with possibly only minor changes (5-10%) in overall abundance if dry season flows drop to zero. If, however, the flows drop to this level in the dry season year after year, then the cumulative effect on trout populations is likely to be far greater. The time-series enable the DSS to capture this cumulative effect.

C.4. SCORING SYSTEM USED

Into the foreseeable future, predictions of river change will be based on limited knowledge. Most river scientists, particularly when using sparse data, are thus reluctant to quantify predictions: it is relatively easy to predict the nature and direction of ecosystem change, but more difficult to predict its timing and intensity. To calculate the implications of loss of resources to subsistence and other users in order to facilitate discussion and tradeoffs, it is nevertheless necessary to quantify these predictions as accurately as possible.

Two types of information are generated for each biophysical indicator, *viz*.:

- Severity ratings, which describe increase/decreases for an indicator in response to changes in the flow indicators, and;
- Integrity ratings, which indicate whether the predicted change is a move towards or away from natural, i.e., how the change influences overall ecosystem condition.

The severity ratings are used to construct the Response Curves. The Integrity ratings are used to describe overall ecosystem condition/health.

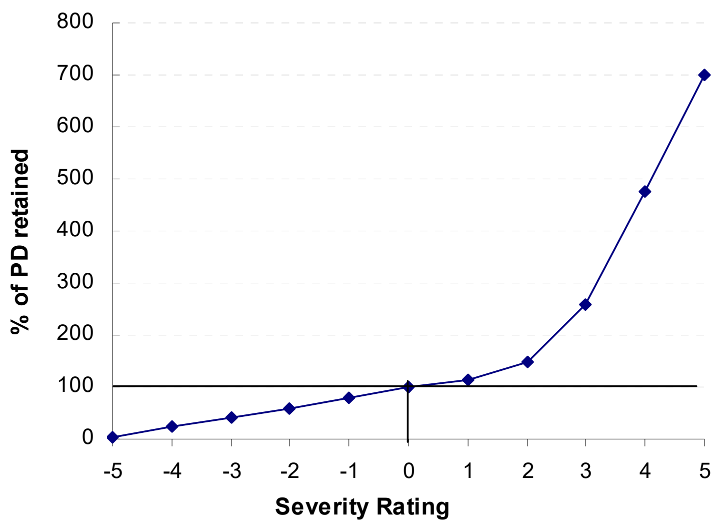
C.4.1. SEVERITY RATINGS

The severity ratings comprise 11-point scale of -5 (large reduction) to +5 (very large change; Brown *et al*., 2008; Appendix Table 18), where the + or – denotes a increase or decrease in abundance or extent. These ratings are converted to percentages using the relationships provided in Appendix Table 18. The scale accommodates uncertainty, as each rating encompasses a range of percentages; however, greater uncertainty can also be expressed through providing a range of severity ratings (i.e. a range of ranges) for any one predicted change (after King *et al*., 2003).

Appendix Table 18 DRIFT severity ratings and their associated abundances and losses – a negative score means a loss in abundance relative to baseline, a positive means a gain.

Severity rating	Severity	% abundance change
5	Critically severe	501% gain to ∞ up to pest proportions
4	Severe	251-500% gain
3	Moderate	68-250% gain
2	Low	26-67% gain
1	Negligible	1-25% gain
0	**None**	**no change**
-1	Negligible	80-100% retained
-2	Low	60-79% retained
-3	Moderate	40-59% retained
-4	Severe	20-39% retained
-5	Critically severe	0-19% retained includes local extinction

Note that the percentages applied to severity ratings associated with gains in abundance are strongly non-linear[17] and that negative and positive percentage changes are not symmetrical (Appendix Figure 14; King *et al*. 2003).



17 The non-linearity is necessary because the scores have to be able to show that a critically-severe loss equates to local extinction whilst a critically severe gain equates to proliferation to pest proportions.

Appendix Figure 14 **The relationship between severity ratings (and severity scores) and percentage abundance lost or retained as used in DRIFT and adopted for the DSS. (PD=present day AND = 100%).**

For each year of hydrological record, and for each ecosystem indicator, the severity rating corresponding to the value of a flow indicator is read off its Response Curve. The severity ratings for each flow indicator are then combined to produce a severity score, which provides an indication of how abundance, area or concentration of an indicator is expected to change under the given flow conditions in each year, relative to the changes that would have been expected under baseline conditions in the catchment.

C.4.2. INTEGRITY RATINGS

Integrity ratings use the absolute value of between 0 and 5 provided for the severity scores but include a negative or positive sign, depending on whether the change in abundance predicted by the severity score represents a shift to/away from naturalness, *viz*. (Brown and Joubert 2003):

- *toward natural* ecosystem condition is represented by a positive integrity rating; and
- *away from natural* ecosystem condition is represented by a negative integrity rating.

The integrity ratings are calculated using the average severity score for each ecosystem indicator over the entire hydrological time-series. The integrity ratings for each indicator are then combined to provide an Overall Integrity Score, which is used to place a flow scenario within a classification of overall river condition, using the South African eco-classification categories A to F (Appendix Table 19; Kleynhans 1996; Kleynhans 1999; Brown and Joubert 2003). The ecological condition of a river is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural

Appendix Table 19 **Definitions of the Present Ecological State (PES) categories (after Kleynhans 1996).**

Ecological category	Description of the habitat
A	Unmodified. Still in a natural condition.
B	Slightly modified. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.

Ecological category	Description of the habitat
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Critically / Extremely modified. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.

characteristics of ecosystems of the region. For instance, if the present ecological status (PES) of a river is a B-category, a scenario that yields a negative Integrity Score would represent movement in the direction of a category C-F, whilst one with a positive score would indicate movement toward a category A, as follows:

If the Overall Integrity Score is positive, this denotes a move toward natural, i.e. restoration initiatives:

- ≤1 or ≥-1, the ecological condition will remain within the same category as present day/baseline;
- >1 and ≤2, the ecological condition will move one category closer to natural;
- >2 and ≤3, the ecological condition will move two categories closer to natural;
- Etc.

If the Overall Integrity Score is negative, this denotes a move away from natural:

- ≥-1, the ecological condition will remain within the same category as present day;
- <1 and ≥ 2, the ecological condition will move one category further away from natural;
- <2 and ≥ 3, the ecological condition will move two categories further away from natural;
- Etc.

Note : In South Africa, the D-category is considered to represent the lower limit of degradation allowable under sustainable development (e.g., Dollar et al. 2006; Dollar *et al*. 2010).

Overall Integrity Scores are calculated for the ecosystem as a whole, i.e., the combined effect of changes in the indicators. The results can be plotted as Overall Integrity Score (y-axis) vs. percentage or volume of MAR (x-axis) or, where there are relatively few points as in this project, simply as a plot of Overall Integrity Scores per site, which allows for easy comparison between sites. The categories actually represent points along a continuum, thus the 'divisions' between the categories are only guides as to the general position at which the ecological condition might be expected to shift from one category to the next. Furthermore, the rules for the integrity categories were developed on rivers outside of Kashmir, and have not been tested on Kashmir rivers. They provide an indication of the relative categories associated with each scenario and should not be misconstrued as an absolute prediction of future condition.

C.5. IDENTIFICATION OF ECOLOGICALLY-RELEVANT ELEMENTS OF THE FLOW REGIME

One of the main assumptions underlying the DRIFT EFs process is that it is possible to identify ecologically-relevant elements of the flow regime and isolate them within the historical hydrological record. Thus, one of the first steps in the DRIFT process is to identify the ecologically-important flow indicators, which are calculated per season for each year. The rules and thresholds for defining the seasons on the Zambezi River are given in Section 6.1, and the list of flow indicators calculated for BGHES are provided in Table 4.1.

C.6. MAJOR ASSUMPTIONS AND LIMITATIONS OF DRIFT

Predicting the effect of flow changes on rivers is difficult because the actual trajectory and magnitude of the change is additionally dependent on so many other variables, such as climate, sediment supply and human use of the system. Thus, several assumptions underlie the predictions. Should any of these assumptions prove to be invalid, the actual changes may not match the predicted changes. This does not necessarily make the predictions themselves incorrect or invalid, but simply means that the surrounding set of circumstances that support the predictions has changed.

The following important major assumptions apply:

- The baseline hydrology closely approximates the actual flow conditions in the river over the period of record.
- Different parts of the flow regime sustain the river ecosystem in different ways. Changing one part of the flow regime will change the river in a different way than will changing another part.
- It is possible to identify ecologically-relevant elements of the flow regime and isolate them within the historical hydrological record (see Section C.5)
- Measured flows (1924 - 2014) in the Zambezi River were used as the baseline flow for predicting change, and change was expressed as a percentage move towards or away from the 2014.
- Changes include flow and non-flow related changes.
- The expected operational scenario for the BGHES (Sc1) does not include any flow changes associated with BGHES, and only include predictions of ecosystem condition expected with a slight reduction in suspended sediment load.
- Predicted changes in ecological status are relative to the baseline ecological state (2014).
- Predictions are based on a 90-year horizon.

The main limitation is the paucity of data. This is a universal problem, as ecosystems are complex and we will probably never have complete certainty of their present and possible future characteristics. Instead it is essential to push ahead cautiously and aid decision-making, using best available information. The alternative is that water resource development decisions are made without consideration of the consequences for the supporting ecosystems, eventually probably making management of sustainability impossible. Data paucity is addressed in the DRIFT process by accessing every kind of knowledge available - general scientific understanding, international scientific literature, local wisdom and specific data from the river under consideration or from similar ones – and capturing these in a structured process that is transparent, with the DSS inputs and outputs checked and approved at every step. The Response Curves used (and the reasoning used to construct them) are available for scrutiny within the DSS and they, as well as the DRIFT DSS, can be updated as new information becomes available.

A second aspect of the paucity of data is that it is neither known what the river was like in its pristine condition nor exactly how abundant each ecosystem aspect (sand bars, fish, etc.) was then or is now. To address this, all DRIFT predictions are made relative to the baseline situation (there will be a little more, or a lot less, than today, and so on), as explained further below.

These inherent uncertainties also mean that the trends and relative position of the scenarios are more reliable predictors of the impacts of the scenarios than are their absolute values. Also, DRIFT is designed to predict overall condition, and focusing on one indicator to the exclusion of others is not recommended.

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BATOKA HYDROPOWER PLANT

ENVIRONMENTAL FLOW ASSESSMENT

VOLUME 2 (of 2): SPECIALIST SUPPORTING REPORT

For

ERM Southern Africa

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This report comprises input from:

Brown, Cate (Southern Waters)
Birkhead, Andrew (Streamflow Solutions)
Brown, Cate (Southern Waters)
Ewart-Smith, Justine (Freshwater Consulting Group)
Joubert, Alison (Southern Waters)
Reinecke, Karl (Southern Waters)
Rountree, Mark (Fluvius Environmental Consultants)
Tweddle, Denis (SAIAB)

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Abbreviations and acronyms

ASPT	Average Score Per Taxon
RSF	Rippled Surface Flow
SBT	Smooth Boundary Turbulent
SIC	Stones-in-current
SOOC	Stones-out-of-current
VIC	Vegetation-in-current
VOOC	Vegetation-out-of-current
ZISS	Zambian Scoring System
ZISS	Zambian Scoring System

Habitat: biotic and abiotic environment of a species which is described by substratum type, hydraulic characteristics and refuge value.

Hydraulic biotope: Spatially distinct instream flow environments characterised by specific hydraulic attributes that provide the abiotic environment in which species assemblages or communities live.

1 INTRODUCTION

1.1 BACKGROUND

The Inception Report for the ESIA (ERM et al. 2014) provides a comprehensive summary of the historical background to the Batoka HPP.

Zambezi River Authority (ZRA) has commissioned Environmental Resources Management (ERM), in association with Kaizen Consulting (Zambia) and Black Crystal Consulting (Zimbabwe) to produce an updated Environmental and Social Impact Assessment (ESIA) to inform the Governments of Zambia and Zimbabwe, the ZRA, national power utilities, interested and affected parties and other stakeholders about potential environmental and social impacts associated with development of the Batoka Gorge HydroPower Project (HPP). These will include evaluation of potential impacts at the dam site and surrounding areas, the reservoir inundation area, any upstream and or downstream impacts, as well as those from associated infrastructure, such as transmission lines, and operations infrastructure.

As part of the ESIA, Southern Waters was commissioned by ERM to undertake an environmental flow assessment for the downstream riverine ecosystem between the Batoka HPP and Kariba Dam.

This report summarises the outcome of the Environmental Flow (EF) assessment. Additional detail is available in the specialist reports and in the DRIFT DSS populated for this project (see Section 1.5).

1.2 THE PROPOSED BATOKA HYDROPOWER PROJECT

The location of the proposed Batoka HPP is on the middle Zambezi River (Figure 1-1), located at 18º1'S ; 26º 34' E, in the central portion of the Zambezi River Basin, c. 50 km downstream of Victoria Falls. It will be located in a steep-sided gorge, and the inundated area of the reservoir will be contained within the gorge, stopping just short of the falls themselves. The development will extend across the international boundary between Zambia and Zimbabwe, with a power house and tailrace on each bank. The proposed high arch gravity dam wall will be 180 m high (SP 2014). The full supply level (FSL) of the reservoir is tentatively set at 762 masl. After impoundment to the FSL, the reservoir surface area will cover approximately 23 km^2. The most recent principal data for the scheme are provided in Table 1-1.

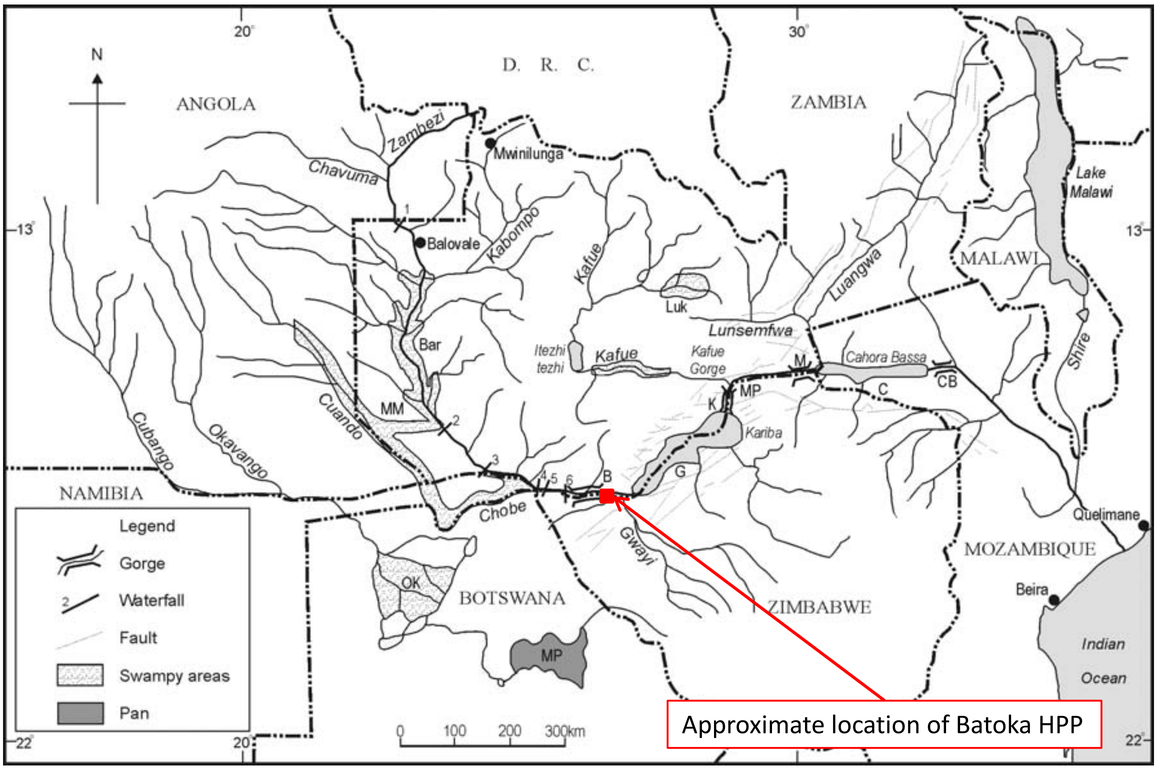


Figure 1.1 Zambezi River basin (Source: Moore *et al.* 2007).

Table 1.1 Principal data for the recommended design proposed for Batoka HPP on the Zambezi River (SP 2014)

Reservoir	Catchment area	508 000 km^2
	Full supply level	762 masl
	Minimum operation level	746 masl
	Total storage	1392 Mm^3
	Surface area at FSL	23 km^2
	Volume at FSL	1600 x 106 m^3
Spillway	Located at about two kilometres from the dam site, at the end of a canal about 2.5 km long, which will link the reservoir with a gorge parallel to the Zambezi river on the south side.	
Dam	Type	Roller Compacted Concrete Gravity Arch
	Height	180 m
	Crest level	720 m
	Crest length	766.5 m
Power Station	Type	Two above ground power stations, located at the dam toe, one on north and one on south bank.
	Installed capacity	3000 MW
	Turbines	4 Francis turbines each with 375 MW of installed capacity

The design of Batoka HPP is still being finalized. The summary characteristics provided in Table 1-1 are the latest proposals for design (SP 2014). They include an adjustment to the spillway design that may affect downstream, *viz*: *the spillway will be located at about two kilometres from the dam site, at the end of a canal about 2.5 km long, which will link the reservoir with a gorge parallel to the Zambezi River on the south side*. This new spillway design was not evaluated as part of this EF study. However, it will be evaluated the overall assessment should it remain a preferred engineering option.

1.3 THE ENVIRONMENTAL FLOW ASSESSMENT

1.3.1 Objectives

The objectives of the EF assessment were:

- to evaluate the present day condition (i.e. the present structure and functioning) of the Zambezi River from upstream of Batoka HPP to Lake Kariba;
- to evaluate how the condition of the river could change under different operational scenarios for the proposed Batoka HPP.

1.3.2 Scope of Work

Southern Waters' Scope of Work was to:

- Delineate the river within the study area and select representative sites for the EF assessment.
- Provide input to the selection of scenarios for the EF assessment.
- Collect/collate primary and secondary data for the configuration of the DRIFT EF assessment model.
- Incorporate the hydrological data provided by ERM into the DRIFT model and select ecologically-relevant flow indicators.
- Model and incorporate the ecohydraulic relationships based on survey data from EF Sites 1 and 2 into the DRIFT model.
- Select discipline indicators for the DRIFT model.
- Set up, populate and calibrate the DRIFT Decision Support System.
- Simulate scenarios.
- Present results in a report.

The Scope of Work was restricted to an assessment of the riverine biophysical aspects of the Batoka HPP, and did not include an assessment of the consequent social and economic impacts of the project.

All of the local and international EF team members visited the Zambezi River upstream and downstream of the proposed Batoka HPP between the 1st and 5th of September 2014. Thereafter (27th -31st October 2014), the population and calibration of the DRIFT Decision Support System was completed in a workshop situation in Cape Town.

The results of the assessment and the main summary report (this report) were sent to the specialists for review and correction where necessary on 7th November 2014. Their comments have been incorporated into this version of the report – submitted on 21st November 2014.

1.3.3 The EF assessment process

DRIFT (Downstream Response to Imposed Flow Transformations) is a holistic EF assessment approach (Brown *et al.* 2013) that, in this project, was applied at the level of the direct influence of the proposed Batoka HPP. This is essentially the Zambezi River from the location of the proposed Batoka HPP weir to Kariba Dam. The objective was to describe the present condition of the river ecosystem and then, through scenarios, to predict how this could change with different design and operation of the Batoka HPP.

Changes in the hydrological regime drive the assessment process. Each scenario would change flow conditions along the river in a different way, with possible different repercussions for the river system. Once these hydrological changes have been simulated, then the DRIFT software provides predictions of the consequent changes in the biotic and abiotic aspects of the river.

1.3.4 Team

The EF team members are listed in Table 1-2.

Table 1.2 EF team members

Name	Organisation	Position on team
Mr Tim Smith	ERM	ERM Task Leader
Dr Cate Brown	Southern Waters	EF Task Leader
Dr Alison Joubert	Southern Waters	DRIFT DSS
Dr Ed Buchak	ERM	Hydrology/Scenarios
Dr George Krallis	ERM	Water Quality
Dr Andrew Birkhead	Streamflow Solutions	Ecohydraulic modeling
Mr Denis Tweddle	SAIAB	Fish ecology
Mr Mark Rountree	Fluvius Consultants	Geomorphology
Dr Justine Ewart-Smith	Freshwater Consulting Group	Macroinvertebrates
Dr Karl Reinecke	Southern Waters	Riparian vegetation

1.4 LOCATION OF THE STUDY SITES

The Batoka HPP EF assessment concentrated on two sites on the Zambezi River between the proposed HPP and Kariba Dam (Table 1-3; Figure 1-2; Figure 1-3; Figure 1-4). The sites were selected considering:

- geomorphologically different river reaches (see Volume 1);
- biological variations along the length of the river;
- different types and levels of impacts likely to be incurred as a result of Batoka HPP location and operation;
- access and safety.

Table 1.3 EF sites for the Batoka EF assessment.

Site No.	Site	Description	Coordinates
1	EF Site 1	Represents the Zambezi River in Batoka Gorge from downstream of the tailrace of the proposed Batoka HPP to the end of the gorge	17°56'17.45"S 26°18'34.37"E
2	EF Site 2	Represents the Zambezi River from the end of Batoka Gorge to Lake Kariba.	18° 3'21.62"S 26°38'33.05"E

- EF Site 1 (Figure 1-3) represents the Zambezi River within Batoka Gorge. It will be affected by releases from the Batoka tailrace. It will also be affected by the barrier effect of Batoka weir, which will have consequences as mentioned above and will also alter the thermal, sediment and physicochemical regimes along the river downstream of the dam.
- EF Site 2 (Figure 1-4) represents the Zambezi River between Batoka Gorge and Lake Kariba. It will be affected by releases from the Batoka tailrace and by the barrier effect of Batoka weir and will be used to predict any anticipated recovery of the river ecosystem with distance downstream of the HPP.

The data collected for EF Site 1 were in fact collected at the location of the proposed Batoka Weir. However, the EF Site represents the Batoka Gorge from downstream of Batoka HPP to the end of the gorge and, as such, is shown some distance downstream of the tailrace in (Figure 1-3).

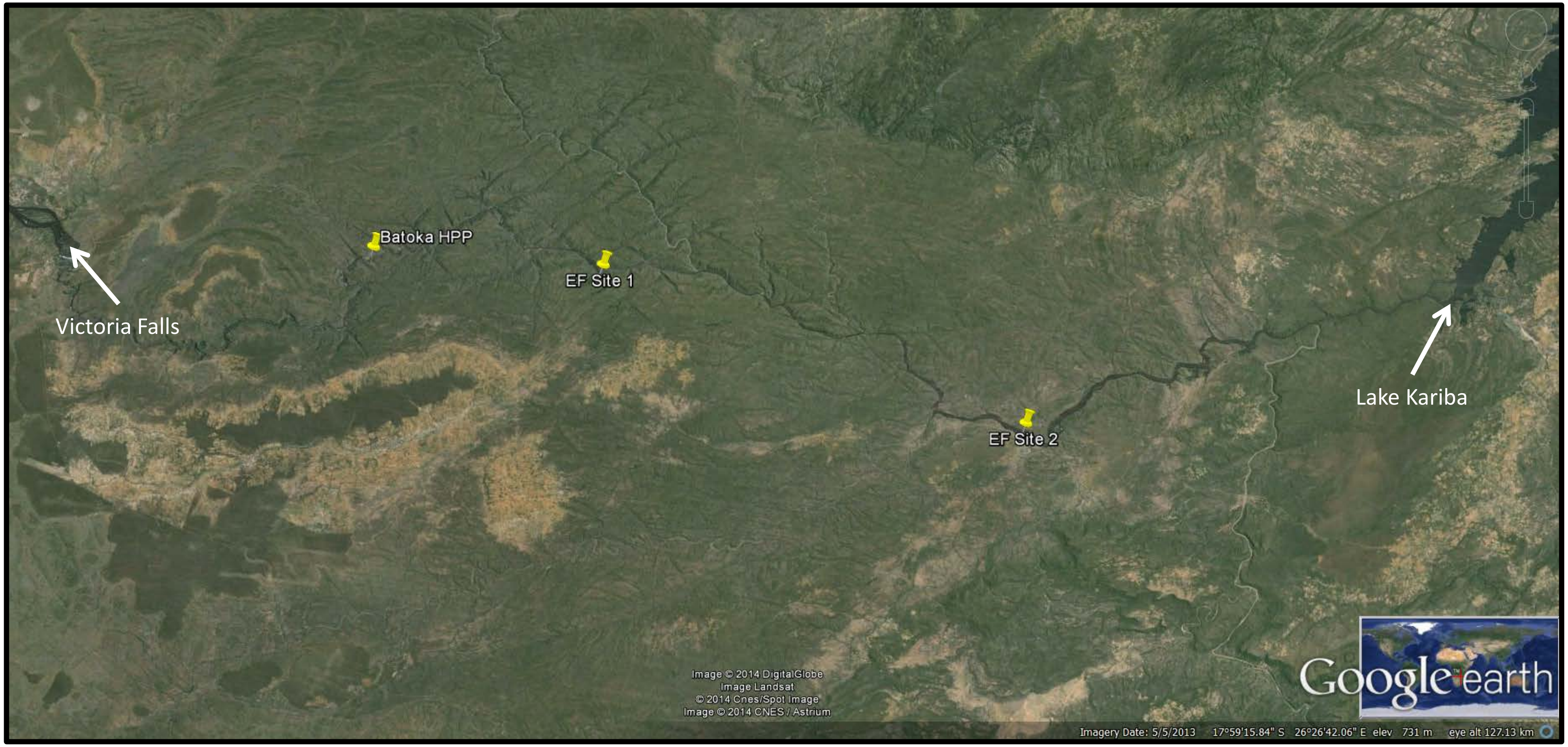


Figure 1.2 The Zambezi River between Victoria Falls and Lake Kariba, showing the approximate position of the Batoka HPP, and EF Sites 1 and 2.

Figure 1.3 EF Site 1 in the Batoka Gorge at the site of the Batoka HPP weir

Figure 1.4 EF Site 2, c. 46 km downstream of Batoka HPP and 3 km upstream of the full supply level of Kariba Dam.

In addition, although not evident in Figure 1-2, on occasion, the backup of water from Kariba Dam extends to the Hwange Fishing and Boating Club, which is located c. 3 km downstream of EF Site 2.

1.5 THIS REPORT

This report is Volume 2 of two volumes:
Volume 1: Environmental Flow Assessment: Main Report
Volume 2: Specialists' Report (*this report*).

The specialist reports presented in this report are as follows:
Section 2: Ecohydraulics – Dr Andrew Birkhead.
Section 3: Geomorphology – Mark Rountree.
Section 4: Riparian vegetation – Dr Karl Reinecke.
Section 5: Macroinvertebrates – Dr Justine Ewart-Smith.
Section 6: Fish – Denis Tweddle.

2 ECOHYDRAULICS: SPECIALIST REPORT

2.1 OBJECTIVES OF THE ECOHYDRAULICS STUDY

3 GEOMORPHOLOGY: SPECIALIST REPORT

3.1 OBJECTIVES OF THE GEOMORPHOLOGY STUDY

The main objective of the geomorphology study was to identify the relationship between geomorphological features and flow level changes, and to predict what impacts, if any, will occur with changes to the present day flow regime.

For the geomorphological component of the EF assessment, 17 days were allocated to undertaking a literature review of previous information (2 days), a site visit (6 days), data analysis of the site information collected in the field (2 days), attending a workshop to determine the prediction of impacts and generation of response curves (5 days) and report writing (2 days).

This report follows the ToR provided by Southern Waters *viz.*:

- Familiarise yourself to the extent possible with the study area, including:
  - The character of the Zambezi River in the study area.
  - Delineation of homogenous areas based on geology reach slope, and river type.
  - The character of the reaches encompassing the proposed sites.
- Prepare a coarse-level reach analysis for the study river, focussing on the study area.
- Provide detailed information for two EF sites.
- Attend the field visit with the rest of the team to:
  - Ensure that the hydraulic cross-section surveys record whatever information you require for your analyses.
  - Record at each site, where relevant, (i) the dominant and sub-dominant substrata, (ii) the degree of embeddedness of large particles, (iii) the nature and extent of instream or overhead cover (for fish).
- Take responsibility for the adequacy of the data collected and provided for the geomorphology component of the EFA.
- Select key aspects as indicators for the DRIFT assessment, in liaison with the other specialists, and provide/develop information on:
  - altered flow regime-sediment transport potential;
  - changes in habitat types with changes in the flow regime;
  - any other relevant data as your experience suggests;
  - any other available information relevant to flow assessments;
  - relevant scientific references.
- Select linked indicators that can be used to explain flow-related changes for each of your indicators.
- Attend the DRIFT Workshop(s), prepared to populate the DRIFT response curves for your selected indicators and linked indicators.

- Compile a geomorphological chapter for inclusion in the EFA Report, with particular reference to response curve motivation tables.
- Adhere to standard formatting, font and layout specifications provided by the Southern Waters for written submissions.

3.2 LAYOUT OF THIS SECTION

This Section comprises the summary report for geomorphology, and provides:

- Overview of the study area, with focus on delineation of homogenous areas;
- For the EF sites:
  - o Ecostatus assessments for your discipline, with supporting evidence;
    - the DRIFT indicators chosen, and reasons therefor;
    - the relationships between the chosen indicators and flow or other, with referenced, supporting motivations.
  - o Supporting references from the international literature.
  - o Data and the details of any analyses performed.

3.3 DESCRIPTION OF THE STUDY AREA WITH THE FOCUS ON GEOMORPHOLOGY

3.3.1 Geomorphological zonation of rivers

The physical structure of a river ecosystem is determined by the geomorphological processes that shape the channel. These processes determine the material from which the channel is formed, the shape of the channel and the stability of its bed and banks. The channel geomorphology in turn determines the substrate conditions for the riverine fauna and flora and the hydraulic conditions for any given flow discharge. Structural changes to the river channel (damage to the riparian zone, sediment inputs from catchment erosion or reservoir induced changes in the flow regime) can cause long term irreversible effects for biota (O'Keeffe 2000; Kochel 1988). Geomorphology thus provides a relevant basis of classification for describing the physical habitat of riparian and aquatic ecosystems.

The aim of the longitudinal zone classification is to subdivide the longitudinal profile of the river into morphologically uniform units, with sites selected within key units to provide predictions of expected changes within the different unit types. Channel slope is well correlated with many physical habitat descriptors including channel planform, bed material and assemblage of morphological units (Rowntree and Wadeson 1999). Changes in slope down the longitudinal profile are usualy correlated with morphological changes and thus provide the basis for the delineation of zones. These breaks are usually due to changes in lithology, but can also be as a result of tectonic activity or the upstream migration of knick points (Dollar, 1998). Rowntree and Wadeson (1999) developed a hierarchical classification system for Southern African rivers based partly slope characteristics. This scale-based framework links various components of the river system, ranging from the catchment to the instream habitat (Table 1.1).

The classification system consists of six hierarchical levels:

- the catchment,
- the segment,
- the zone,
- the reach,
- the morphological unit and
- the hydraulic biotope.

Table 3.1 Definition of geomorphological classification levels (after Rowntree and Wadeson 1999)

Hierarchical unit	Description	Scale
Catchment	The catchment is the land surface which contributes water and sediment to any given stream network.	Can be applied to the whole river system from source to mouth, or to a lower order catchment above a specified point of interest.
Segment	A segment is a length of channel along which there is no significant change in the flow discharge or sediment load.	Segment boundaries will tend to be co-incident with major tributary junctions.
Longitudinal zone	A zone is a sector of the river long profile which has a distinct valley form and valley slope.	Sectors of the river long profile.
Reach	The reach is a length of channel characterised by a particular channel pattern and channel morphology, resulting from a uniform set of local constraints on channel form.	>00s of meters.
Morphological Unit	The morphological units are the basic structures recognised by fluvial geomorphologists as comprising the channel morphology and may be either erosional or depositional features.	Morphological units occur at a scale of an order similar to that of the channel width.
Hydraulic biotope	Hydraulic biotopes are spatially distinct instream flow environments with characteristic hydraulic attributes.	Hydraulic biotopes occur at a spatial scale of the order of 1 m^2 to 100 m^2 and are discharge dependent.

The longitudinal zonation of southern African rivers reflects regional geology, tectonic events and long term fluvial action, which together have affected the shape of their long profiles. The classic concave long profile may be disrupted by a number of features including outcrops of more resistant rock and rejuvenation due to tectonic uplift or a fall in sea-level, river capture or the presence of a highly resistant lithology. Segment and zone delineation has been used to describe the macro- and regional scale characteristics of the Zambezi River. Reach, morphological unit and hydraulic biotope classifications may be applied to specific EF sites, based largely on field assessment backed up by reference to available satellite imagery such as Google Earth.

The geomorphological segments and zones are used to guide the spatial framework for the delineation of Resource Units (which would also include operation rules and zones of altered hydrology), the assessment of habitat integrity, and selection of field sites for detailed study. Information derived from the field sites can then be scaled up to the zone scale to obtain a broad overview of likely condition and impacts for the entire study area.

3.3.2 The Zambezi River

The Zambezi River is the fourth largest river basin in Africa with a catchment area of nearly 1 500 000 km^2 (Davies 1986) with several major tributaries contributing to the estimates 108 km^3 annual discharge (Table 3.2). It flows over a distance of almost 3 000 kilometres, dropping from 1585 masl at its source in the north- west of Zambia down to the Indian Ocean at its delta 200 kilometres north of the Mozambican port of Beira (Figure 1.1). Headwater tributaries drain portions of eastern and southeastern Angola and northern Zambia and flow in to the very low-gradient Barotse floodplain. Further downstream at Ngonye Falls, the river steepens as it collects more flow from large tributaries such as the Cuando-Chobe River that drains southern Angola and Namibia's Caprivi Strip. Three hundred kilometres further downstream, the river flows over a nearly 100 metre drop, forming the dramatic Victoria Falls (Moore *et al.* 2007) and entering the steep, 100km long Batoka Gorge. Downstream of this the river flow in to the Kariba Reservoir, and then further downstream in to Cahorra Bassa Dam before existing and flowing across a wide, flat coastal belt in Mozambique before entering the Indian Ocean at Chinde.

Table 3.2 Mean estimated annual runoff for Zambezi sub-basins (after Beilfuss and dos Santos 2001).

Sub-Basin	Catchment Area (km^2)	Mean Annual Discharge ± 95% C.I. (m^3/s)	Mean Annual Runoff ± 95% C.I. (km^3)
Upper Zambezi	507,200	1046 ± 815	32.9 ± 25.7
Gwembe Valley	156,600	222 ± 196	7.2 ± 6.2
Total to Kariba Gorge	***663,800***	***1268 ± 997***	***40 ± 31***
		Volume of Kariba Reservoir	*180 km^3*
Kafue River	154,200	285 ± 279	9.0 ± 8.8
Luangwa River and others	232,000	888 ± 818	28.0 ± 25.8
Total to Cahora Bassa Gorge	***1,050,000***	***2442 ± 1917***	***77 ± 60***
		Volume of Cahora Bassa	*52 km^3*
Plateau Tributaries	177,500	412 ± 365	13.0 ± 11.5
Shire Basin	154,000	539 ± 422	17.0 ± 13.3
Zangue Basin	8,500	16 ± 14	0.5 ± 0.4
Total to Zambezi Delta	**1,390,000**	**3424 ± 2675**	**108 ± 84**

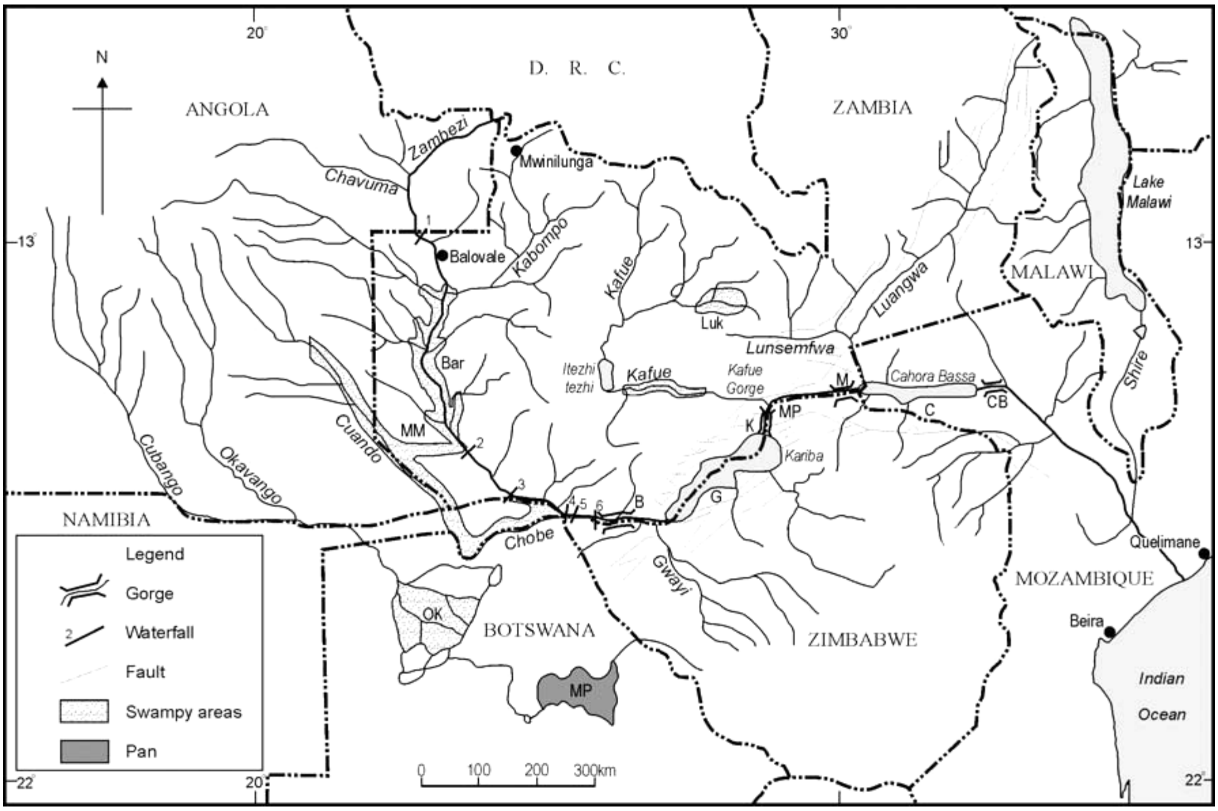


Figure 3.1 Zambezi River basin (Source: Moore et al. 2007).

At the largest scale, the Zambezi River has been divided in to three major segments, (Wellington 1955, Moore *et al.* 2007), namely:

- The Upper Zambezi, extending from the headwaters to Victoria Falls;
- The Middle Zambezi, extending from Victoria to the Mozambique coastal plain; and
- The Lower Zambezi, extending from the Cahora Bassa Gorge across the coastal plain of Mozambique (Figure 3.1).

The upper segment, above Victoria Falls, is characterised by generally low slopes and river channels with large floodplains and wetlands. The middle segment is characterised by extensive gorges, such as Batoka, Kariba and Cahora Bassa, with the confined floodplain of Mana Pools located between Kariba and Cahora Bassa (Figure 3.2). Downstream of Cahora Bassa the river flows in to the lower segment - a more than 400km long stretch of floodplains and delta across the Mozambiquan coastal belt.

In the middle segment of the Zambezi, from Victoria Falls to Cahora Bassa, the river is relatively steep and often confined to an incised, narrow channel. This segment has tremendous hydropower energy generation potential and the Kariba and Cahorra Bassa Dams are already located here. The focal study area is between Victoria Falls and Lake Kariba. This section of river has been subdivided in to three zones (Table 1.3) based on slope, valley width, the presence and diversity of morphological units, and tributary confluences.

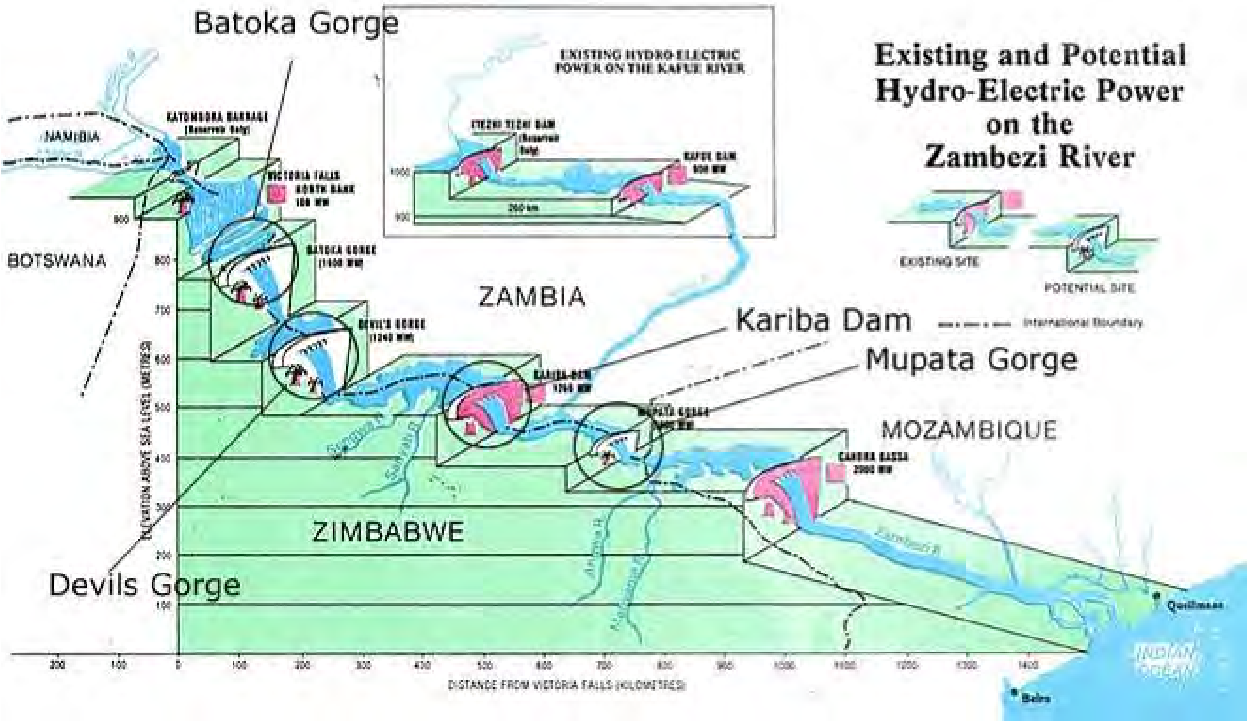


Figure 3.2 **Existing and proposed hydropower developments of the middle segment of the Zambezi River (source: Zambezi River Authority).**

Table 3.3 **Zones within the Middle Segment of the Zambezi River**

No	Zone name and description	EF site	Average slope	Length (km)
1	*Upper Gorge - no tributary inputs* Moderate to steep gradient, confined channel (gorge) with limited lateral development of alluvial features. Morphological units include bedrock fall, cascades and pool-rapid.	EF 1	0.0021	100
2	*Lower Gorge - some tributary inputs* Moderate to steep gradient, confined channel (gorge) with limited lateral development of alluvial features. Morphological units include bedrock fall, cascades and pool-rapid.	-	0.0016	24
3	*Rejuventated cascades: widened river valley* Moderate gradient, still within a confined channel, but wider and less steeply sloping banks. Limited lateral development of alluvial features. Morphological units would be cascades and pool-rapid, but also gravel bars, sand bars and vegetated islands.	EF2	0.0010	24

Zone 1 is the section of the Upper gorge, from Victoria Falls to approximately 100 km downstream. In this zone the river channel is steep and very narrow, with few morphological or sedimentary deposits within the confined valley. EF Site 1 and the proposed Batoka Dam are located within this zone. Zone 2 is associated with a less steep slope and some tributary inputs. Tributaries contribute both flow events and sediment loads to the gorge area, and their role would be increasingly important for river ecology downstream of any proposed dams. The slightly wider valley floor, together with sediment inputs from tributaries, result in some small isolated sedimentary deposits which increase habitat diversity. Zone 3 is a length of rejuventated cascades associated with a further widened river valley and shallower slope. The more moderate gradient and wider, less steeply sloping banks result in some development of lateral alluvial features, and occasional cobble and gravel bars, some sandy bank sections and infrequent vegetated islands. EF Site 2 is located within Zone 3.

3.4 LITERATURE REVIEW

The ability of the river to move sediment is referred to as its sediment transport capacity and this is largely a function of river flow. Sediment supply is controlled by catchment and riverine erosion and deposition processes and it is the interaction between the supply of sediment and the ability of a river to transport that sediment which determines the form (morphology) of a river channel. Sediment supply and sediment transport capacity interact such that:

- where sediment supply is less than the sediment transport capacity, there is an excess of erosive energy, resulting in net erosion, causing the river channel to erode its bed/banks and incise, and;
- where sediment supply is greater than sediment transport capacity, there is an excess of sediment, resulting in net deposition and the development of an aggrading river/floodplain environment.

The ability of a river to move water and sediment downstream is a function of its longitudinal connectivity. Large dams disrupt the longitudinal connectivity of rivers, causing changes in the sediment supply and transport characteristics in the downstream river, but extensive floodplains or wetlands can have a similar, albeit less extreme, impact on reducing sediment supply to downstream reaches. In the Zambezi River, the floodplains and wetlands in the upper segment (above Victoria Falls) already act as natural sediment traps, such that flows downstream of the Victoria Falls are naturally relatively sediment poor. However, some sediment still passes through to downstream reaches whereas the large Kariba reservoir traps all sediment flowing within it, such that the releases from this dam, and similarly at Cahorra Bassa further downstream, are free of bedoad and have very reduced suspended sediment loads. This has morphological and ecological consequences downstream.

3.4.1 Effects of dams and hydropower operations on river morphology

As described above, dams act as sediment traps, causing a loss of sediment supply downstream (Ibanez et al. 1996; Vorosmarty et al. 2003; Wohl 2004; Anselmetti et al. 2007; Wang et al. 2007). Large dams also have important direct biological consequences such as the fragmentation of communities and reduced migration/dispersal (Anderson *et al*. 2006; Coutant and Whitney 2000; Jansson *et al.* 2000; Lundqvist *et al*. 2008) and increased retention of nutrients and organic matter in within the reservoirs resulting in eutrophication and nutrient loss downstream (Humborg *et al*. 2006).

Downstream of large dams, water releases are largely sediment free due to the deposition of bedload and suspended load within the reservoir. This results in the erosion of the beds, banks, bars and islands in the reaches downstream of dams. Changes downstream of dams typically include:

- decreased sediment loads (Grant et al. 2003);
- coarsening of the bed material and consequent changes to the instream physical habitat conditions;
- incision of the active channel/s;
- net erosion of the beds and banks of rivers due to clean water releases from dams; and,
- abandonment of secondary channels and associated loss of islands (islands frequently become joined to the main banks due to active channel incision).

These morphological impacts below large dams arise primarily due to the reduced sediment loads downstream of dams, but the changes in hydrology (specifically the magnitude, frequency and rate of change of floods downstream of dams) can play an equally or more significant role. Many of the typical morphological impacts have been described in the lower Zambezi River (Davies et al. 2010; Ronco et al. 2010; Beilfuss et al. 2000; Timberlake 2000; Davies 1986) below the Cahorra Bassa dam.

In addition to the impacts noted above, some dams used for hydropower generation include peak power generation. Peak power generation relies on the release of daily floods to allow for enhanced power generation during peak demand periods (usually early morning and early evening). In order to maximize power generation, it is possible that peak power generation may be considered for portions of at least the low flow season in this system. Peak hydropower generation typically involves even more extreme changes to the natural hydrology, including rapid changes in discharge and often highly elevated flood frequencies. The changes to the natural hydrology can be extreme, including rapid changes in discharge and often highly elevated flood frequencies, which can have severe implications for the morphology in the downstream river, such as vegetation loss, extensive bank slumping (Rountree 2009), increased channel width and decreased depth.

Not all reaches of a river are equally sensitive to the changes in hydrology and sediment alterations. Different river reaches have been shown to respond at different rates, and occasionally with different trends, to the same alterations of hydrology and sediment (Rountree et al. 2001; 2004). Thus, the rate and nature of the morphological changes downstream of an HPP is a combination of dam size, dam operation and the sensitivity of the downstream river reaches to flow-induced change.

An assessment of the study area was thus undertaken to describe the morphological character of the river and also assess the potential sensitivity to upstream hydropower dams and the associated changes caused to sediment loads and hydrology.

3.4.2 Impacts of dams on the Zambezi

The last unobstructed major Zambezi flood on the lower Zambezi occurred in 1958 (Tinley 1994) and was estimated to have a peak of approximately 16,000 m^3/s (Kovacs 1984). The closure of Kariba and Cahora Bassa dams resulted in the river flows downstream becoming increasingly regulated (Figure 3.3). The subsequent impacts on the lower Zambezi ecology are well documented (White 1993; Tinley 1994; Beilfuss and Davies 1999; Beilfuss et al. 2000; Davies et al. 2000; Timberlake 2000; Beilfuss and Santos 2001a; Beilfuss and Santos 2001b; Moore et al. 2007; Ronco et al. 2010) and these impacts mirror the geomorphological impacts on other large dams (e.g. Shalash 1982). Prawn catch rates off the Sofala banks also declined by 60% between 1978 and 1995 (Hoguane 1997), and this is assumed to indicate the reduced freshwater and sediment flows arriving from the delta.

However, the Batoka Gorge being investigated in this study is located upstream of Kariba. Here the Zambezi still experiences relatively natural flow conditions as there are no major dams upstream of the study area. Sediment loads are also largely natural, and are assumed to be low due to the trapping effect ofthe extensive floodplains and wetlands in the upper Zambezi above Victoria Falls. Suspended and bed load sediment measurements examining the sediment loads on the lower Zambezi prior to the closure of Cahora Bassa (BEH-MFPZ 1964, in Ronco *et al.* 2010) revealed that bedload was less than 1% of the suspended load, implying that bedload sediment inputs from tributaries and through lateral erosion of the banks and bars of the channel could provide significant contributions to downstream reaches as the overall bedload was small.

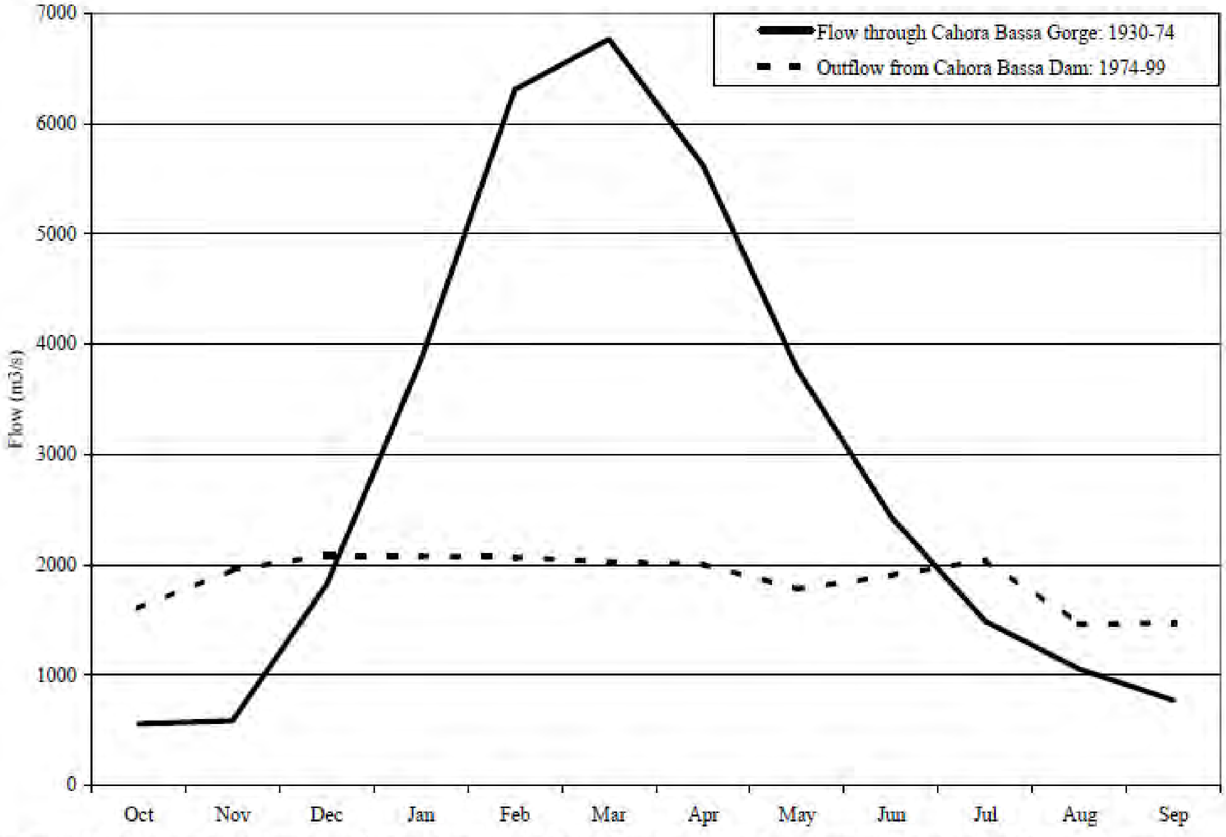


Figure 2-28. Hydrographs of mean monthly runoff at Cahora Bassa Gorge, before and after completion of Cahora Bassa Reservoir.

Figure 3.3 **Time series of mean monthly flows at Cahora Bassa Reservoir before dam closure (1930-1974) and after the dam was closed (1974-1999). The reduction in intra-annual flow variability through reduced flood flows and increased dry season flows was extreme (source: Beilfuss and dos Santos 2001).**

3.5 *DESCRIPTION OF THE EF SITES*

See Section 1.4 for a map showing the location of the EF sites.

3.5.1 EF Site 1

This site is located within the upper gorge. Morphological units include bedrock fall, cascades and pool-rapid sequences, but there are few sedimentary bars present as the trapping of sediment in the wetlands and floodplains upstream of Victoria Falls, combined with the high flow velocities in the steep, deep river channel of this gorge section, precludes the development of extensive lateral alluvial features. Bedrock and angular boulders dominate the bed and banks, with fine kalahari sands limited to small lee deposits. At the site these sand deposits are very small, but larger lee deposits of sediment are infrequently present upstream between the EF site and Victoria Falls. The zone between the low flow and high wet season water levels is almost devoid of all vegetation. Above the high water mark there is a narrow zone of riparian trees, dominated by *Combretum imberbe*.

There are small bedrock bars exposed at low flow, with some lower velocity marginal and backwaters created by the exposed bedrock of the lower banks and shallower channel areas. Very small areas of gravels can be found between the large boulders in slow flowing areas, but most of the channel is dominated by deep fast-flowing sections where bedrock and large boulders dominate.

Figure 3.4 EF Site 1 is dominated by bedrock controlled bars and banks.

3.5.2 EF Site 2

The lower EF Site is situated in the rejuventated cascades reach. This reach is characterised by a wider river valley with a more moderate slope. Although the river channel still flows within a confined channel, this channel is wider and has less steeply sloping banks and there is some development of sandy alluvial deposits in places. Typical morphological units would be cascades and pool-rapid sequences, but small gravel bars, sand bars and vegetated islands are present.

The upstream Matetsi tributary, and backup effects of the nearby large Deka tributary, would promote sediment deposition on the banks during floods. Within the main channel at low flow, low lying bedrock features are exposed during the lower flow season. These low lying rock habitats are important for the Rock Pranticole (Hockey et al. 2005). Rock pranticoles, an intra-African migrant bird species, nest on low lying rock exposures in the river channel during the low flow season between August and November.

Figure 3.5 **EF Site 2 has some sandy lateral deposits on the northern (Zambian) bank, with cobbles and bedrock dominant within he active channel.**

3.6 *ECOSTATUS OF RIVER REACHES REPRESENTED BY THE EF SITES*

An assessment of the present ecological (geomorphological) status of EF sites was undertaken based on observations and data collected during the site visit undertaken in 2014, available maps, high resolution historical and current satellite imagery, literature sources, data from previous studies and discussions with regional experts. The Geomorphological Assessment Index (GAI) prescribed by the South African Department of Water Affairs and Forestry (Rowntree and du Preez, *in press*) was used for this assessment.

The GAI generates a percentage score that enumerates the deviation of the condition of the site from the expected natural (or Reference) condition. The output percentage scores are grouped into 6 Categories ranging from A (essentially in the Reference or historic natural Condition) to F (representing the most extremely degraded condition possible). For the purposes of this study, the Reference Condition was set as that condition of the river approximately 100 years ago, prior to any major catchment developments.

3.6.1 Ecostatus of EF Site 1

The PES category of geomorphology at EF Site 1 is an A (99%) and is regarded as essentially in the Reference condition. This very high score is due to the fact that:

- there are no large dams and thus relatively minor changes to flow upstream of Victoria Falls (i.e. upstream of the site);
- any changes in sediment loads are also similarly relatively small, and are moreover attenuated in the large wetlands and slow flowing depositional areas of the upper Zambezi; and,
- the gorge in which EF Site 1 is located is insensitive to small-scale changes in sediment and flow due to its resistant, bedrock dominated morphology.

3.6.2 Ecostatus of EF Site 2

The PES category of geomorphology at EF Site 2 is an A (97%) and is similarly considered to be close to the natural or Reference condition. This high score is due to the fact that

- there are relatively minor changes to flow upstream of the site through the gorge or above Victoria Falls;
- any changes in sediment loads are also similarly relatively small, and are moreover attenuated in the large wetlands and slow flowing depositional areas of the upper Zambezi, and
- the site where EF Site 2 is located is only moderately sensitive to changes in sediment and flow due to the widespread resistant bedrock outcrops alongside and within the channel.

There has been a minor degradation of the geomorphology at EF Site 2, but this is due to on-site (non-flow related) bank disturbances associated with landuse activities. The small pockets of riparian agriculture on the Zambian side and recreational/residential encroachment in to the upper riparian areas on the Zimbabwean side would have very slightly reduced the integrity of the riparian vegetation and bank stability.

3.7 FIELD DATA COLLECTION AND ANALYSIS

The EF sites were visited in September 2014. At each site, key alluvial morphological features were linked to surveyed cross sections and notes on the general condition of the site and reach, and likely issues with regard to habitat and channel maintenance, were made from these field observations. Google Earth and historical topographical maps were used to aid in the assessment of potential for change and dynamics of the geomorphology at the sites.

3.7.1 Determining flows to maintain channel morphology

Flow requirements for the maintenance of channel form, or geomorphology, can generally be determined using one, or a combination, of two possible approaches. The first relies on specialist knowledge and experience to identify alluvial morphological cues at the site and within the reach which are associated with regular flooding return frequencies (such as active, seasonal and ephemeral paired benches and terraces). The second approach uses the catchment hydrology and site-specific hydraulic characteristics to model the long term potential bed sediment movement within the river to identify geomorphologically effective discharges. These are ranges of flows which are responsible for a disproportionately large amount of the long term sediment transport (geomorphic work) which is happening at the site.

3.7.1.1 Morphological Cues

The rivers in this study area are not alluvial depositional systems. The EF sites have limited alluvia features present within their incised channels; with the channels themselves flowing along the underlying bedrock of the area. The development of morphological cues, usually associated with depositional alluvial environments, is thus limited. However, some key physical habitat types wee identified and these morphological features, such as backwaters, sedimentary bars and secondary channels, were used in conjunction with local site hydraulics and sediment data (such as the velocities required to activate or move sediments), as cues for the flows and floods required to maintain the channels.

3.7.1.2 Sediment Transport and Geomorphologically Effective Flows

The form (morphology) of a river channel is dependent on the interaction between the supply of sediment from its catchment, and the capacity of that section of the river to transport the sediment it is supplied with. The ability of the river to move sediment is referred to as its sediment transport capacity. Sediment supply and sediment transport capacity interact such that:

- where sediment supply is less than the sediment transport capacity, there is an excess of erosive energy, resulting in net erosion, causing the river channel to erode its bed/banks and incise; but
- where sediment supply is greater than sediment transport capacity, there is an excess of sediment, resulting in net deposition and the development of an aggrading river.

The interactions described above are generally considered over very long timescales. The rivers in this study are primarily erosional river systems, meaning that, in the very long term (hundreds of years), sediment supply is less than the transport capacity of the river channel. Over shorter timescales, which are of more interest to river managers (years and decades in southern Africa), studies in eastern southern African rivers have demonstrated that rivers experience periods of metastability or quasi-stability interrupted by periods of rapid change (Rountree et al. 2001; Rountree and Rogers 2004; Parsons *et al.* 2006). During these timescales, it is the discharge of water and sediment supply that determines channel form. Where changes in these driving factors occur, the channel form will adjust in sympathy with the imposed change. This is of significance as the channel form provides the physical habitat for riverine biota.

Geomorphologically effective flows are those discharges that, over the longer term, are responsible for transporting disproportionately larger proportions of the sediment load (relative to their duration). These are essentially the flows that do the most "work" in determining the sediment transport capacity of the channel, and therefore influencing its form. The calculation of these flows is essentially the sediment transport potential of a particular flow event, multiplied by its duration, which yields its potential contribution to the sediment transport of the system in the long term. The theoretical position taken in these methods is that two sets of discharges are significant in maintaining channel form in southern African rivers:

- a set of geomorphologically effective discharges in the 5-0.1% range on the 1-day daily flow duration curve, which transport a disproportionately large volume of the sediment in the longer term, and
- larger 're-set' flood events such as the flood events of 2000, which can reshape the channel and remove vegetation from the banks and floodplain.

These methodologies for determining channel maintenance flows have been used in ecological flow assessment studies in South Africa, Mozambique, Namibia, Angola, Zambia, Sudan, Peru and Pakistan. The theoretical basis for these assumptions is presented in Dollar and Rowntree (2003).

3.7.1.3 Methods used to identify geomorphologically effective flows

The methods employed to determine geomorphologically effective flows are described below. The long term observed daily flows, regional slope, rating curves (provided by the hydraulician) and sediment characteristics for the site were used to model potential bed material transport at each site over the observed flow record, using Yang's (Yang 1973) total load equations to determine the effectiveness of discharges. This modelling technique assumes:

- The bed material sampled at the site is representative of the supply of bed material to the channel.
- Bed material sampling can be averaged at each EWR site and used to represent the cross-section.
- The supply of bed material to each EWR site is based on the existing bed material and its size distribution, and is available for transport at all discharges.
- Average conditions can be used.

The maintenance of bed sediment characteristics (river bed habitats) is important for instream biota. Bed sediment usually comprise a mix of boulders, cobbles, gravels sands and finer material which have been transported and deposited by the river channel at the site. Some bed sediment is derived *in situ* (in this case, from the cliffs of the gorge) and these very large bed elements are not indicative of the flow regime nor are they related to sediment transport patterns of the river. Only the mobile component of the bed material at this site – the boulders, cobbles, gravels and sands that overlay the bedrock/fixed boulder bed and are transported by contemporary flow regime. Potential Bed Material Transport (PBMT) modelling of these sediments is then undertaken at the EF sites, averaged for the duration of the flow record to provide indications of long term patterns. This method allows for geomorphologically effective flows for the maintenance of channel conditions to be determined. A full, detailed description of the technique can be found in Dollar and Rowntree (2003).

3.7.2 Likely impacts of the proposed Batoka HPP on downstream sediments

The proposed Batoka gorge will alter the flow patterns and sediment delivery to the downstream reaches and their representative EF sites. At EF Site 1 we anticipate a critical reduction in bedload and suspended sediments, with some minor amelioration at EF Site 2 due to inputs from tributaries (Table 3.4). Flushing of the reservoir is unlikely to be undertaken due to the relatively low sediment loads, but if seasonal flushing were to be contemplated, then this should be undertaken in the high flow season to mimic the naturally higher sediment loads of that flow season.

Table 3.4 Estimated changes in sediment delivery expected at EF Site 1 and 2 (as a percentage of Present Day levels, which is at 100%).

% sediment delivered to EF site	Fine suspended sediments (silts and clays)				Coarse suspended sediments (sands and larger)			
	Median		Maximum		Median		Maximum	
Flow season:	Flood	Dry	Flood	Dry	Flood	Dry	Flood	Dry
EF 1: PD	100	100	100	100	100	100	100	100
EF 1: Dam, no flushing	30	20	40	20	15	10	15	10
EF 1: Dam with flushing, flush in wet season	40	20	120	20	15	10	15	10
EF 1: Dam with flushing, Flush in dry season	30	30	40	300	15	10	15	10
EWR 2: PD	100	100	100	100	100	100	100	100
EF 2: Dam, no flushing	40	20	40	20	20	15	20	15
EF 2: Dam with flushing, flush in wet season	50	20	100	20	20	15	20	15
EF 2: Dam with flushing, flush in dry season	40	30	40	200	20	15	20	15

The reduced sediment loads and altered flow patterns, especially those associated with possible peak power generation, can be expected to cause changes in the availability of some types of physical habitats downstream. Indicators of the key habitat types were selected to be able to describe the processes upon which they are dependent in order to make predictions of the expected changes of these habitat types in response to altered flow and sediment regimes.

3.8 IDENTIFICATION OF INDICATORS

3.8.1 Indicator list for Geomorphology

The geomorphology features and their reason for selection as indicators in the EF assessments are given in Table 3.5. The expected responses to flow changes are outlined in Table 3.6.

Table 3.5 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Rock exposures at low flow	Low elevation rock exposures adjacent to and within the low flow active channel are important for Rock Pranticoles, a rare locally endemic bird species which is dependent on these features during the dry season for nesting.
Lengths of cut banks	The extent of cut banks can be used to indicate channel incision and to indicate the potential for marginal vegetation to establish along the banks. Where dams are being considered, the reduced sediment availability downstream generally causes increases in erosion and the extent of cut banks.
Active channel bed sediment condition	Bed sediment size distribution indicates the condition of the instream physical habitat of the main channel bed
Backwater bed sediment condition	Bed sediment size distribution indicates the condition of the instream physical habitat of the backwaters and marginal channel areas. These are important refugia for many species in that they provide lower velocity areas.
Area of backwaters and secondary channels	Secondary channels and the marginal backwaters represent important instream habitats and offer refugia during high flow conditions.
Vegetated mid-channel bars	The sandy banks and open patches of large, stable vegetated bars are utilised by crocodiles for breeding. This is important around EF Site 2 where many crocodile breeding locations were pointed out within the study reach.
Depth of pools	The depth of pools indicates the extent of low flow/drought instream habitat refugia
Sand bars	Shallow, low elevation sand bars are dynamic and there is constant turnover of sediment. These shallowly inundated and exposed bars are the main habitat for bivalves (freshwater shellfish) and therefore are an important feeding area for wading birds which prey upon them.

Table 3.6 List of geomorphology indicators and their predicted direction of response to flow changes.

Indicator	Definition	Predicted change	Source of information
Rock exposures at low flow	The area of rocks exposed within the channel during the low flow season.	Reduced dry season flows would increase the area of rocks exposed. Increased dry season flows, or peaking power releases, would decrease habitat availability.	Hydraulics rating curves and field observations at the EF sites.
Lengths of cut banks	The length of cut (vertical) banks along the low flow channel.	Reduced sediment supply and peaking power releases would both result in an increase in the extent of cut banks due to increased erosion and bank slumping respectively.	Field observations on bank structure and susceptibility to erosion and slumping, Rountree (2009).
Active channel bed sediment condition	The proportion of sediment sizes, and extent of embeddedness, of the low flow active channel.	Increased baseflows and/or reduced sediments and/or peak power generation would lead to a reduction in fines and gravels within the active channel.	
Backwater bed sediment condition	The proportion of sediment sizes, and extent of embeddedness, of the backwaters and marginal areas during the low flow period.	Increased baseflows and/or reduced sediments and/or peak power generation would lead to a reduction in fines and gravels within the backwaters.	
Area of backwaters and secondary channels	Backwaters and secondary channels are areas of low velocity and shallow depth that provide refugia from predators and the fast velocities of the main channel.	Increased baseflows and/or peak power generation would lead to a reduction in this type of habitat, through either increased depths/velocities, or through increased flushing, making the habitat effectively unavailable as a refuge.	Hydraulics rating curves and field observations at the EF sites.
Vegetated mid-channel bars	Large bars and islands which are vegetated. The presence of vegetation indicates the morphological stability and higher elevation of these features relative to the lower lying, more dynamic sand bars.	Reduced sediment supply and peaking power releases would result in an increase in erosion and bank slumping respectively. Both processes could be expected to reduce the area of vegetated id-channel bars.	Hydraulics rating curves, field observations at the EF sites, Rountree *et al*, (2001), Rountree (2009).
Depth of pools	The average depth of the in-channel (active channel) pools along the river reach.	Reduced sediment supply may very slightly increase pool depth due to increased net scour. Similarly, peak power generation could slightly increase pool depth due to increased flood frequencies.	Analysis of hydrological records, hydraulic rating curves, Rountree (2009)
Sand bars	The area of low elevation sand bars exposed during the low flow season.	Reduced sediment supply and peaking power releases would result in an increase in erosion and bank slumping respectively, causing a loss of mobile sands.	

3.8.2 Description and location of indicators

This section describes the geomorphological indicators selected for the evaluation and prediction of changes linked to the proposed dam and hydropower generation.

3.8.2.1 Rock exposures at low flow

The rocky areas that become exposed during the low flow season are critically important for Rock Praticoles (*Glareola nuchalis*). These rare, localised migratory birds use these rocky exposures for nesting in August through November, preferring sites in the river with deep, fast-flowing water around the rock outcrops as such sites provide protection from most predators (Hockey *et al.* 2005). Eggs are laid on a rock edge, under overhangs or in recesses or slight hollows, or on flat, exposed rock, just above the low flow water level. The nest may have a thin lining of plant debris, sand or dried mud.

Figure 3.6 Rocky areas that become exposed during the low flow season

3.8.2.2 Active channel bed sediment condition

This indicator provides an estimate of the bed sediment conditions within the active channel. Table 3.7 provides a description of the bed conditions linked to percentage of present day scores.

Table 3.7 Active channel bed sediment condition descriptions

% of PD condition	Description of the active channel bed condition
0	Surface is dominated by sand and silts, almost all cobbles are embedded
25	50% more embeddedness than the PD condition, extensive fine deposits
50	25% more embeddedness than the PD condition
75	10% more embeddedness than the PD condition
100	Conditions of the river bed as observed in September 2014
150	Doubling of the cobble bars with more, larger interstitial spaces, fewer fines.
200	The channel bed is dominated by boulders, cobbles and bedrock (no fines, very few, very small gravel deposits).
250	The active channel has a bedrock/large boulder bed.

1.1.1.1 Backwater bed sediment condition

This indicator provides an estimate of the bed sediment conditions within the backwaters and slow-flowing marginal areas of the channel. In the field it was discovered that deposits of fine sediments, of approximately 2 cm or more depth, allowed for a high diversity of invertebrate taxa to persist in the backwater habitats (Ewart-Smith, *pers. comm.*). Table 3.8 provides a description of the bed conditions linked to percentage of present day scores.

Table 3.8 Description of bed sediment conditions in the backwaters.

% of PD condition	Description of bed sediment conditions
0	All surfaces are covered by sand and silts
25	Extensive fines with 50% more embeddedness than the PD condition.
50	More extensive fines with 25% more embeddedness than the PD condition
75	More extensive fines with 10% more embeddedness than the PD condition
100	Conditions of the backwaters as observed in September 2014 - more than 50% of the backwater areas have silt/sand drapes.
150	25% reduction of the areas of fines in the backwaters
200	50% reduction of the areas of fines in the backwaters
250	Backwaters are clean bedrock - no sands, gravels and few cobbles/boulders

3.8.2.3 *Area of backwaters and secondary channels*

This indicator reflects the availability of inundated, low velocity, shallow marginal (at EWR1) and/or secondary channels (at EWR 2) and backwaters which provide critical hydraulic habitat refugia in the form of low or no velocity areas in the river. These shallow, low velocity areas are important for many species of fish and aquatic invertebrates. When peaking is in operation, these areas of the channel are scored as being unavailable since the several metres daily water level fluctuations would increase the velocities so much on these marginal areas that they would be rendered unsuitable as refugia.

3.8.2.4 *Lengths of cut banks*

Cut marginal banks are associated with the more alluvial sections of EF Site 2. The marginal banks are associated with the edges of the active channel and the lower extent of marginal vegetation. Where these banks are cut, this indicates important deeper slow flowing inchannel habitat which is usually associated with vegetation and therefore provides good cover. Extensive cut banks would also indicate increasing undercutting of the marginal vegetation.

3.8.2.5 *Depth of pools*

This indicator provides an estimate of the pool depth changes within the active channel. Due to limited sediment loads and the deep, confined and high velocity nature of the channel, this indicator should not show a great variation in depth through most scenarios as the potential for infilling (sedimentation) is very small.

3.8.2.6 *Vegetated mid-channel bars*

This indicator reflects large, stable, vegetated mid-channel bars. These sandy sedimentary features, found in the reach around EF Site 2, would almost always overlie a bedrock base. These larger sedimentary bars and banks are very important crocodile nesting sites.


3.8.2.7 *Sand bars*

At EF Site 1, these are higher elevation features that comprise sand deposits draped over underlying bedrock gorge slopes or the lower banks, usually in the lee of large rock outcrops or in the turbulence eddies at high flows. At EF Site 2, the sand bars are typically smaller scale, low elevation features which are partially exposed during the low flow season. These sandy areas are important bivalves (freshwater shellfish) and other aquatic fauna which are found here and the wading birds which feed on them.

3.8.3 Linked indicators

There are no linked indicators in the geomorphology suite of ecosystem indicators. All the geomorphology indicators link directly to the drivers (flow and sediment inputs).

3.8.4 Integrity weighting of indicators between sites

The weightings of indicators used in the calculation of integrity at the two sites are provided in Table 3.9.

Table 3.9 The weighting of indicators at the two sites

Indicator	Weight		Motivation
	EF Site 1	EF Site 2	
Rock exposures at low flow	1	1	These are morphologically very stable habitat features as they are formed from bedrock.
Active channel bed sediment condition	1	1	The condition of the channel bed is an important indicator of habitat conditions for most instream biota, and is thus generally weighted high.
Backwater bed sediment condition	3	3	The condition of the backwater bed is an important indicator of habitat conditions for most instream biota, and is thus generally weighted high.
Area of backwaters and secondary channels	2	2	Secondary channels provide important instream habitat, especially at EF 2 where more backwaters, and secondary channels, are present in the reach.
Lengths of cut banks	1	1	Cut banks are associated with deeper instream areas. Some instream species, as well as marginal vegetation, are associated with these areas where they are present.
Vegetated mid-channel bars	n/a	1	These are proportionally small features but important for crocodile breeding and for cover of riparian and, during the flood season, aquatic species.
Depth of pools	1	1	These are morphologically very stable habitat features as they largely controlled by the bedrock base of the channel.
Sand bars	1	1	These are proportionally small features but important for wading birds and some aquatic biota.

3.9 ASSUMPTIONS AND LIMITATIONS

DRIFT is a powerful scenario evaluation tool that enables decision makers to evaluate the consequences for the downstream river ecosystem of numerous flow scenarios related to water relsource development. The model and subsequent predictions of change are highly dependent on the available modelled hydrology and the assumption that, in general, the median flow indicators accurately represent median Present Day flow conditions in the river. Modelled hydrology sometimes does not match well with observed flows, but there can equally be problems with observed flow data from gauges, such as where floods drown out the recorder and are therefore underestimated by the flow gauge. For this study, the hydrological record is deemed to provide an accurate and longer term reflection of real flow patterns.

Predictions of change to physical habitats based on hydrology alone will not take in to account the impacts of new dams if these are to be considered for future scenarios. To account for dams, an indicator of suspended sediment (representing all sediment inflows) to each site has been included in the DRIFT model. The values of this indicator should be adjusted if new dams are considered in the scenarios, with the degree of adjustment dependent on the proximity of the dam to the EF site.

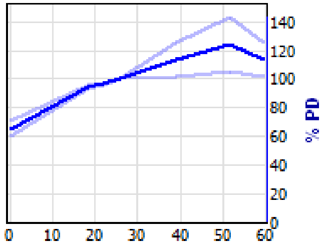
3.10 *MOTIVATIONS FOR RESPONSE CURVES*

3.10.1 Rock exposures at low flow

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Dry season ave daily vol [D season]

<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>18.29</td><td>-0.300</td></tr>
<tr><td></td><td>22.01</td><td>-0.200</td></tr>
<tr><td>Median</td><td>25.73</td><td>0.000</td></tr>
<tr><td></td><td>38.78</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>51.83</td><td>1.500</td></tr>
<tr><td>Max</td><td>59.61</td><td>1.000</td></tr>
</table>



</td><td>At this site, higher dry season flows would create more cut off bedrock bars. These habitats are important for rock pranticole breeding (Hockey et al. 2005). Median and lower than median dry season flows cause limited change because the flows are primarily confined to a single channel, but increases above median flows cause wide areas of the primarily rocky lateral zones to be inundated.</td></tr>
<tr><td>

☑ Dry within day range [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.000</td></tr>
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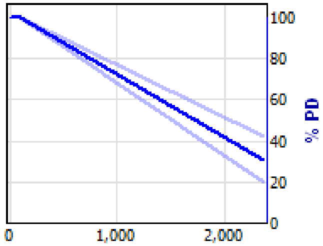

</td><td>Hydraulic rating curves for the EF sites show that high intra-daily flow variations (potentially up to several metres of water level variation twice per day) would render rock exposures unavailable as breeding habitat (in the sense that they would not be exposed for long enough periods for breeding purposes) and therefore very high within daily ranges would drown most rock exposures.</td></tr>
<tr><td>

☑ T1 within day range [T1 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.000</td></tr>
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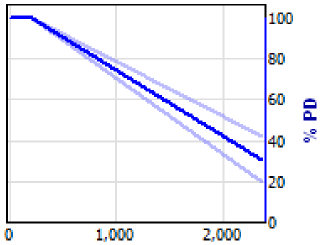
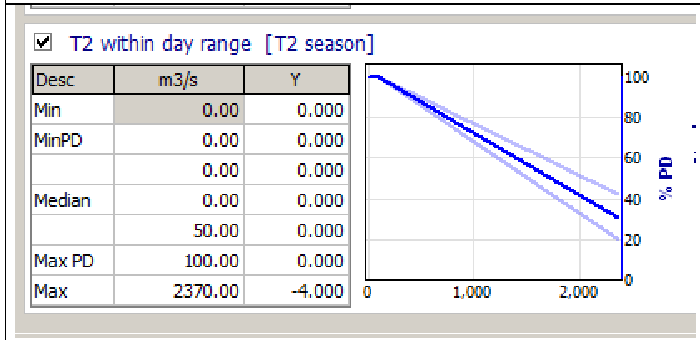


</td><td>Hydraulic rating curves for the EF sites show that high intra-daily flow variations (potentially up to several metres of water level variation twice per day) would render rock exposures unavailable as breeding habitat (in the sense that they would not be exposed for long enough periods for breeding purposes) and therefore very high within daily ranges would drown most rock exposures.</td></tr>
</table>

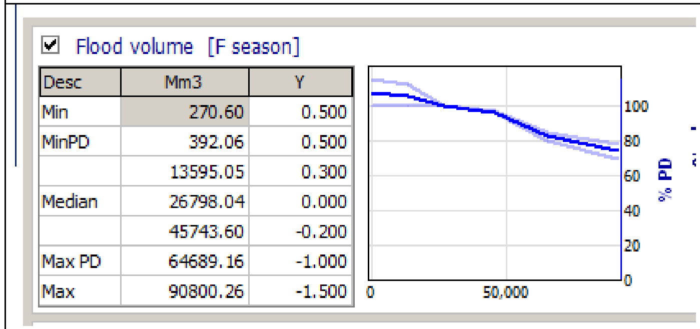
Response curve	Explanation
	Hydraulic rating curves for the EF sites show that high intra-daily flow variations (potentially up to several metres of water level variation twice per day) would render rock exposures unavailable as breeding habitat (in the sense that they would not be exposed for long enough periods for breeding purposes) and therefore very high within daily ranges would drown most rock exposures.

T2 within day range [T2 season]

Desc	m3/s	Y
Min	0.00	0.000
MinPD	0.00	0.000
	0.00	0.000
Median	0.00	0.000
	50.00	0.000
Max PD	100.00	0.000
Max	2370.00	-4.000

References	Hockey, P.A.R., Dean, W.R.J. and Ryan, P.G. (Eds) 2005. Rock Pratincole. In: *Roberts Birds of Southern Africa,* VIIth ed. The Trustees of the John Voelcker Bird Book Fund, Cape Town.

3.10.2 Active channel bed sediment indicator

Response curve	Explanation
	Applying the sediment transport analyses methods of Dollar and Rowntree (2003), important flow classes for sediment movement were identified. These results have been used to develop the relationship between bed sediment condition and max flood. Very large floods, associated with high rainfall years, would be associated with high sediment inflows and large amounts of sediment reworking of the bed. Larger floods would redistrubute more sediment across the channel (and in to the backwaters, creating finer habitats), whereas smaller flood years, associated with reduced local tributary inputs, would scour the channel and backwaters and could be expected to reduce the area of deposited fines.

Flood volume [F season]

Desc	Mm3	Y
Min	270.60	0.500
MinPD	392.06	0.500
	13595.05	0.300
Median	26798.04	0.000
	45743.60	-0.200
Max PD	64689.16	-1.000
Max	90800.26	-1.500

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Dry season ave daily vol [D season]

<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>18.29</td><td>0.000</td></tr>
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<tr><td>Max</td><td>59.61</td><td>0.500</td></tr>
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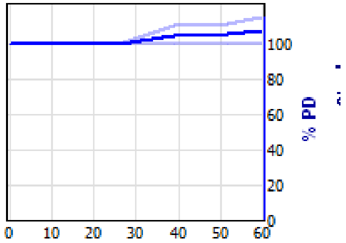

</td><td>Lower average dry season flows would be associated with lower velocities and therefore more opportunities for fine sediments settling out on to the bed of the backwater habitats. Higher dry season discharges would flush the backwaters more effectively, thus reducing the areas of bed sediments.</td></tr>
<tr><td>

☑ Wet: mean Fine suspended sediment [F season]

<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>2.000</td></tr>
<tr><td></td><td>50.00</td><td>1.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.300</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.500</td></tr>
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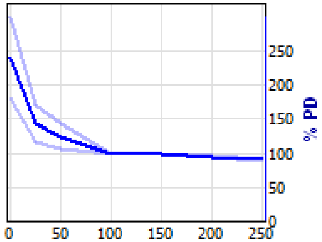

</td><td>The mean suspended sediment load would be correlated with the area and depth of sediments deposited in the deep sections of the active channel.</td></tr>
<tr><td>

☑ Wet: max Fine suspended sediment [F season]

<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.200</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.200</td></tr>
<tr><td></td><td>50.00</td><td>0.050</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.200</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.300</td></tr>
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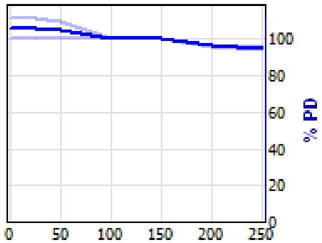

</td><td>The peak suspended sediment load would play a minor role in the deposition of sediments in the main channel. Most fine sediment would however remain in suspension due to inchannel high velocities.</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
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☑ Dry within day range [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
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<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>1.000</td></tr>
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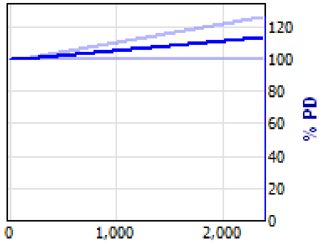

</td><td>A widely fluctuating daily range of discharges will scour out sediments from the margins of the channel, and the twice-daily flood peaks associated with peaking power generation would quickly erode finer sediments from the bed and banks (Rountree 2009), resulting in a clean, increasingly bedrock-dominated channel bed and bank.</td></tr>
<tr><td>

☑ T1 within day range [T1 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>0.000</td></tr>
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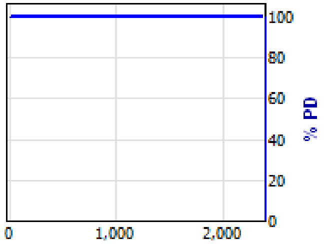
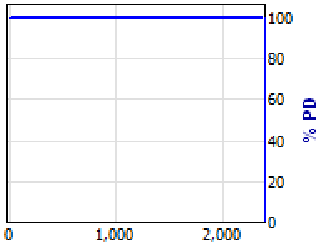


</td><td>A widely fluctuating daily range of discharges will scour out sediments from the margins of the channel, and the twice-daily flood peaks associated with peaking power generation would quickly erode finer sediments from the bed and banks (Rountree 2009), resulting in a clean, increasingly bedrock-dominated channel bed and bank.</td></tr>
<tr><td>

☑ T2 within day range [T2 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>0.000</td></tr>
</table>



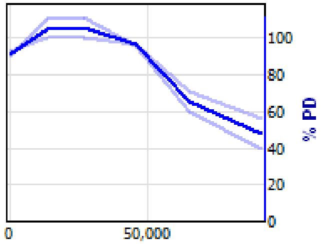
</td><td>A widely fluctuating daily range of discharges will scour out sediments from the margins of the channel, and the twice-daily flood peaks associated with peaking power generation would quickly erode finer sediments from the bed and banks (Rountree 2009), resulting in a clean, increasingly bedrock-dominated channel bed and bank.</td></tr>
<tr><td>References</td><td>Dollar, E.S.J and Rowntree, K.M. (2003). Geomorphological Research for the Conservation and Management of Southern African Rivers. Volume 2: Managing Flow Variability: the geomorphological response. Water Research Commission Report No. 849/2/04, Pretoria.
Rountree, M. W. 2009. Assessing bank stability along the lower Kafue River, in Birkhead A.L., Rountree M., Rowlston, B. and Louw D (eds). Kafue Gorge Lower Hydropower Project, Zambia. Assessing hydraulic behaviour and bank stability along the lower Kafue River in response to peaking releases from the proposed Kafue Gorge Lower Hydropower Project. Prepared for the International Finance Corporation, August 2009.</td></tr>
</table>

3.10.3 Backwater bed sediment condition indicator

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Flood volume [F season]

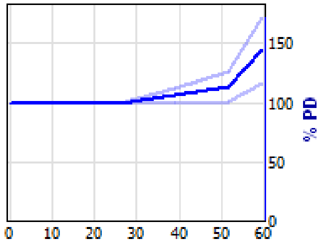
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y</th></tr>
<tr><td>Min</td><td>270.60</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>392.06</td><td>-0.500</td></tr>
<tr><td></td><td>13595.05</td><td>0.100</td></tr>
<tr><td>Median</td><td>26798.04</td><td>0.200</td></tr>
<tr><td></td><td>45743.60</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>64689.16</td><td>-2.000</td></tr>
<tr><td>Max</td><td>90800.26</td><td>-3.000</td></tr>
</table>



</td><td>Very large floods, associated with high rainfall years, would be associated with high sediment inflows and large amounts of sediment reworking of the bed. Very large floods would thus introduce many fines to the backwater areas. Median/moderate floods would do some scouring each year, but very small floods would not scour the backwaters, resulting in increasingly finer conditions developing.</td></tr>
<tr><td>

☑ Dry season ave daily vol [D season]

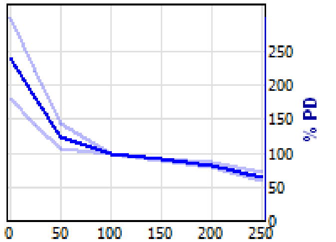
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>18.29</td><td>0.000</td></tr>
<tr><td></td><td>22.01</td><td>0.000</td></tr>
<tr><td>Median</td><td>25.73</td><td>0.000</td></tr>
<tr><td></td><td>38.78</td><td>0.300</td></tr>
<tr><td>Max PD</td><td>51.83</td><td>1.000</td></tr>
<tr><td>Max</td><td>59.61</td><td>2.000</td></tr>
</table>



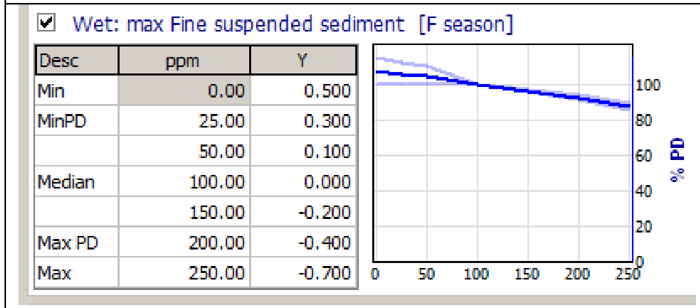
</td><td>Lower average dry season flows would be associated with lower velocities and therefore more opportunities for fine sediments settling out on to the bed of the backwater habitats. Higher dry season discharges would flush the backwaters more effectively, thus reducing the areas of bed sediments.</td></tr>
<tr><td>

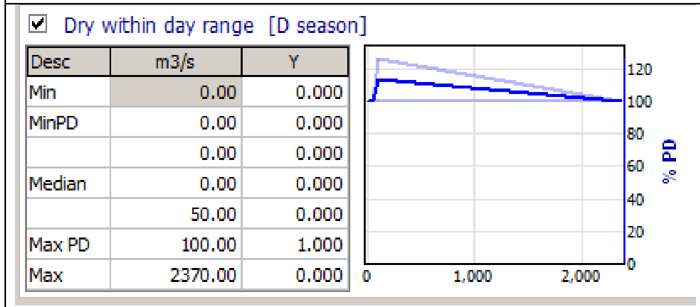
☑ Wet: mean Fine suspended sediment [F season]

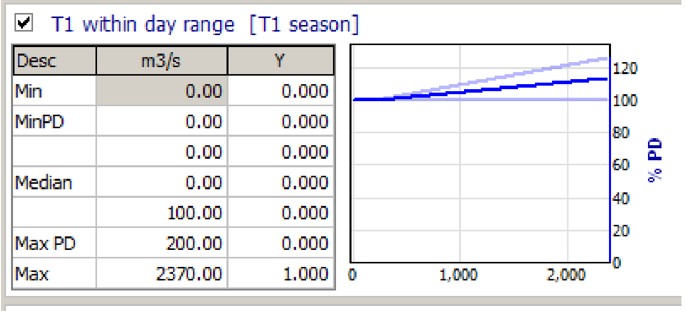
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>2.500</td></tr>
<tr><td></td><td>50.00</td><td>1.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>-2.000</td></tr>
</table>



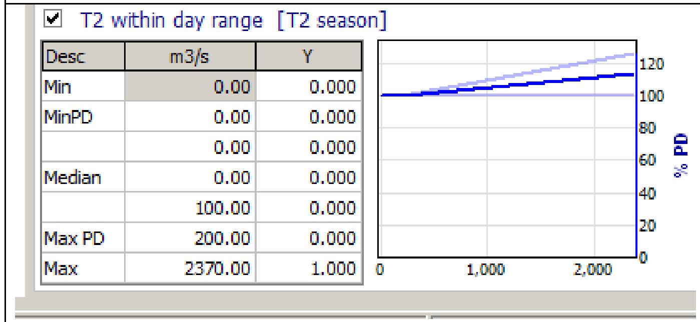
</td><td>The mean suspended sediment load would be directly correlated with the area and depth of fines deposited in the slow velocity backwaters during the dry season.</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.300</td></tr>
<tr><td></td><td>50.00</td><td>0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.400</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.700</td></tr>
</table></td><td>The peak suspended sediment load would be weakly, but directly, correlated with the area and depth of fines deposited in the slow velocity backwaters during the dry season.</td></tr>
<tr><td>

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>0.000</td></tr>
</table></td><td>A widely fluctuating daily range of discharges will scour out fines from the backwaters and increasingly result in a clean, bedrock surface (Rountree 2009).</td></tr>
<tr><td>

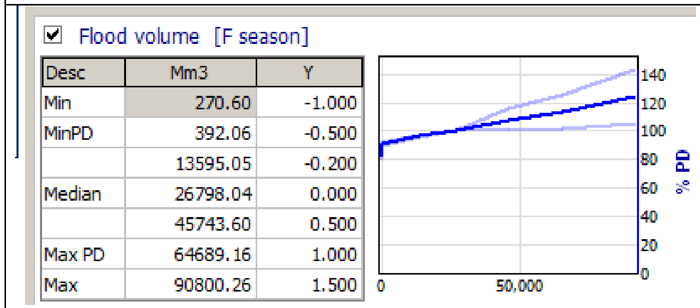
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>1.000</td></tr>
</table></td><td>A widely fluctuating daily range of discharges will scour out fines from the backwaters and increasingly result in a clean, bedrock surface (Rountree 2009).</td></tr>
</table>

Response curve	Explanation
	A widely fluctuating daily range of discharges will scour out fines from the backwaters and increasingly result in a clean, bedrock surface (Rountree 2009).

Desc	m3/s	Y
Min	0.00	0.000
MinPD	0.00	0.000
	0.00	0.000
Median	0.00	0.000
	100.00	0.000
Max PD	200.00	0.000
Max	2370.00	1.000

References	
References	Rountree, M. W. 2009. Assessing bank stability along the lower Kafue River, in Birkhead A.L., Rountree M., Rowlston, B. and Louw D (eds). Kafue Gorge Lower Hydropower Project, Zambia. Assessing hydraulic behaviour and bank stability along the lower Kafue River in response to peaking releases from the proposed Kafue Gorge Lower Hydropower Project. Prepared for the International Finance Corporation, August 2009.

3.10.4 Area of backwaters and secondary channels

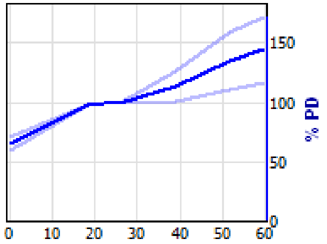
Response curve	Explanation
	Although the channel and backwaters are largely bedrock controlled, and therefore only small adjustments in area can occur in response to erosion and deposition, very large floods could be expected to be associated with higher sediment inflows. The large floods, and higher sediment loads, would scour lateral areas and slightly build the channel bed. Large floods would thus increase secondary channels and backwater areas in rives with bedrock controls (Rountree et al. 2001, Parsons et al. 2006). Very small floods would fail to inundate or replenish much of the marginal zone, making them unavailable for instream biota.

Desc	Mm3	Y
Min	270.60	-1.000
MinPD	392.06	-0.500
	13595.05	-0.200
Median	26798.04	0.000
	45743.60	0.500
Max PD	64689.16	1.000
Max	90800.26	1.500

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

Dry season ave daily vol [D season]

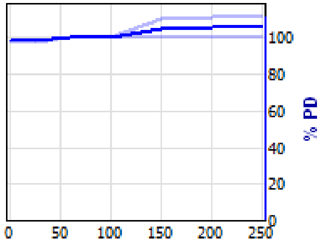
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>18.29</td><td>-0.100</td></tr>
<tr><td></td><td>22.01</td><td>0.000</td></tr>
<tr><td>Median</td><td>25.73</td><td>0.000</td></tr>
<tr><td></td><td>38.78</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>51.83</td><td>1.800</td></tr>
<tr><td>Max</td><td>59.61</td><td>2.000</td></tr>
</table>



</td><td>This is the most important variable - the average dry season Q primarily determines the area of backwaters which are created in the low flow season. At zero flow, there would be few backwaters, and this increases as dry season average flows increase have been related to the consequent increases in width and associated areas of backwaters/slow marginal zones.</td></tr>
<tr><td>

Wet: mean Coarse suspended sediment [F season]

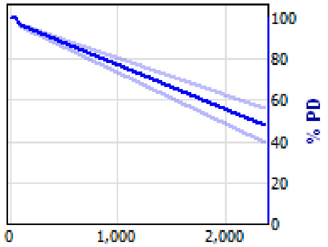
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.100</td></tr>
<tr><td></td><td>59.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.200</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.200</td></tr>
</table>



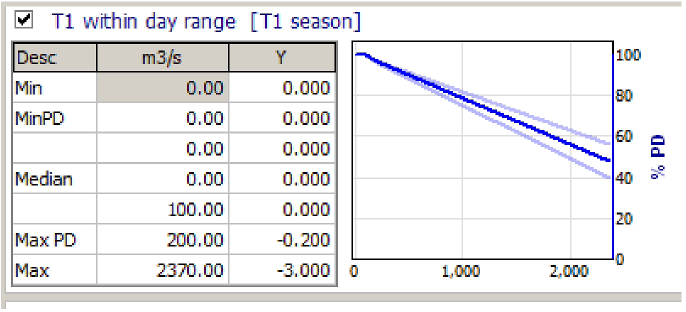
</td><td>The increase of sediment would create, through raised channel bed levels, a slight increase in backwaters/marginal habitat, but the impact of reduced sediment loads would be small as the underlyng channel morphology is primarily bedrock controlled and therefore not able to freely adjust (incise) when sediment is limiting.</td></tr>
<tr><td>

Dry within day range [D season]

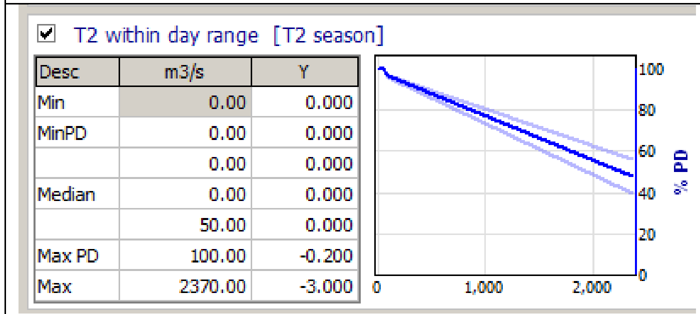
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>-0.200</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>



</td><td>A widely fluctuating daily range of discharges will create a zone of high disturbance between the low and peak flows (Rountree 2009). When this water level fluctuation is very high, of up to a few metres per day, this would create a highly disturbed, scoured and fast velocity (associated with the rise and fall of the peaks) zone, effectively rendering the backwater refugia unavailable for most instream biota. With a more moderate fluctuation, some of the habitat can be expected to still be available.</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>


Desc	m3/s	Y
Min	0.00	0.000
MinPD	0.00	0.000
	0.00	0.000
Median	0.00	0.000
	100.00	0.000
Max PD	200.00	-0.200
Max	2370.00	-3.000

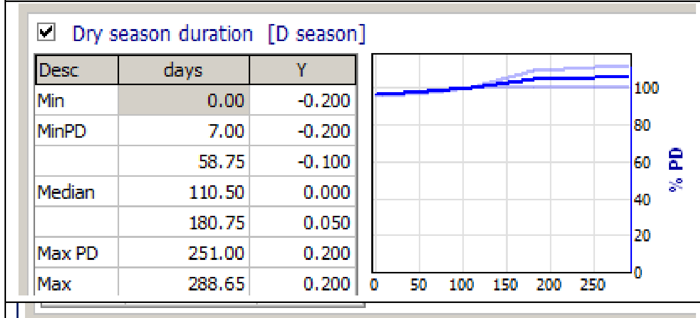
</td><td>A widely fluctuating daily range of discharges will create a zone of high disturbance between the low and peak flows (Rountree 2009). When this water level fluctuation is very high, of up to a few metres per day, this would create a highly disturbed, scoured and fast velocity (associated with the rise and fall of the peaks) zone, effectively rendering the backwater refugia unavailable for most instream biota. With a more moderate fluctuation, some of the habitat can be expected to still be available.</td></tr>
<tr><td>


Desc	m3/s	Y
Min	0.00	0.000
MinPD	0.00	0.000
	0.00	0.000
Median	0.00	0.000
	50.00	0.000
Max PD	100.00	-0.200
Max	2370.00	-3.000

</td><td>A widely fluctuating daily range of discharges will create a zone of high disturbance between the low and peak flows (Rountree 2009). When this water level fluctuation is very high, of up to a few metres per day, this would create a highly disturbed, scoured and fast velocity (associated with the rise and fall of the peaks) zone, effectively rendering the backwater refugia unavailable for most instream biota. With a more moderate fluctuation, some of the habitat can be expected to still be available.</td></tr>
<tr><td>References</td><td>Rountree, M. W. 2009. Assessing bank stability along the lower Kafue River, in Birkhead A.L., Rountree M., Rowlston, B. and Louw D (eds). Kafue Gorge Lower Hydropower Project, Zambia. Assessing hydraulic behaviour and bank stability along the lower Kafue River in response to peaking releases from the proposed Kafue Gorge Lower Hydropower Project. Prepared for the International Finance Corporation, August 2009.
Rountree, M.W., Heritage, G.L. and Rogers, K.H. 2001. In-channel metamorphosis in a semi-arid, mixed bedrock/alluvial river system: Implications for Instream Flow Requirements In M.C. Acreman (ed) Hydro-ecology, IAHS Publ. no. 26.
Parsons, M., McLoughlin, C. A., Rountree, M. W. and Rogers, K. H. (2006). The biotic and abiotic legacy of a large infrequent flood disturbance in the Sabie River, South Africa. River Research and Applications, 22:187-201.</td></tr>
</table>

3.10.5 Length of cut banks

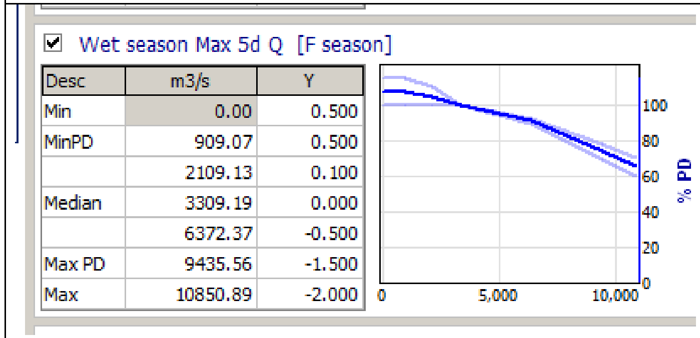
Response curve	Explanation



Dry season duration [D season]

Desc	days	Y
Min	0.00	-0.200
MinPD	7.00	-0.200
	58.75	-0.100
Median	110.50	0.000
	180.75	0.050
Max PD	251.00	0.200
Max	288.65	0.200

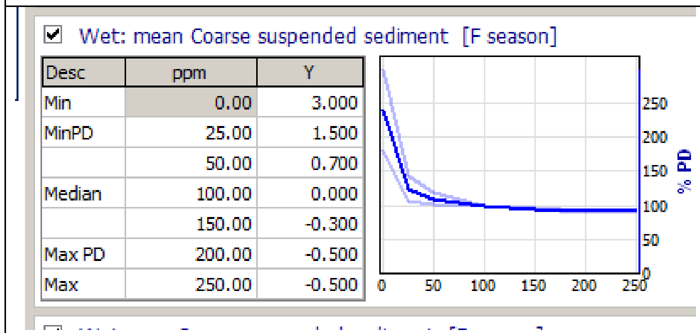
Long dry seasons will promote incision of the low flow channel, creating more cut banks on the alluvial sections of the banks. Very short dry durations will not reset much of the wet season sediment deposits and may result in a net decrease in cut banks relative to median conditions.



Wet season Max 5d Q [F season]

Desc	m3/s	Y
Min	0.00	0.500
MinPD	909.07	0.500
	2109.13	0.100
Median	3309.19	0.000
	6372.37	-0.500
Max PD	9435.56	-1.500
Max	10850.89	-2.000

Very large floods erode the lateral zones and redistribute sediment across the channel floor, resulting in a small widening (and often shallowing) of the active channels (Parsons et al. 2006; Rountree et al. 2001, Tooth 2000; Rountree et al. 2000; Gupta et al. 1999; Bourke and Pickup 1999; Kochel 1988; Nanson, 1986; Baker 1977). This would actually flatten the banks and reduce the extent of cut/vertical banks in the marginal zone. Average floods could be expected to have little net impact, and very low floods may cause some incision of the low channel and undercut the marginal areas, increasing the extent of cut banks.



Wet: mean Coarse suspended sediment [F season]

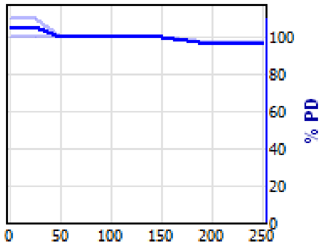
Desc	ppm	Y
Min	0.00	3.000
MinPD	25.00	1.500
	50.00	0.700
Median	100.00	0.000
	150.00	-0.300
Max PD	200.00	-0.500
Max	250.00	-0.500

Lower sediment loads will promote channel incision and therefore result in an increase in the extent of cut banks. Very large reductions in sediment supply will not however result in enormous increases in the extent of cut banks, since the bars associated with cut banks will begin to decline also. Increases in sediment supply have a relatively small impact since the river is largely sediment starved.

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Wet: max Coarse suspended sediment [F season]

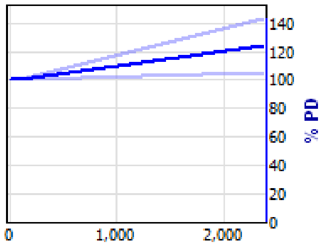
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.010</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.050</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.010</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.200</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.200</td></tr>
</table>



</td><td>Lower sediment loads will promote channel incision and therefore result in an increase in the extent of cut banks, although the peak sediment load alone would only have a minor impact relative the average sediment load values.</td></tr>
<tr><td>

☑ Dry within day range [D season]

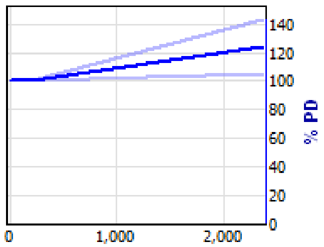
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>1.500</td></tr>
</table>



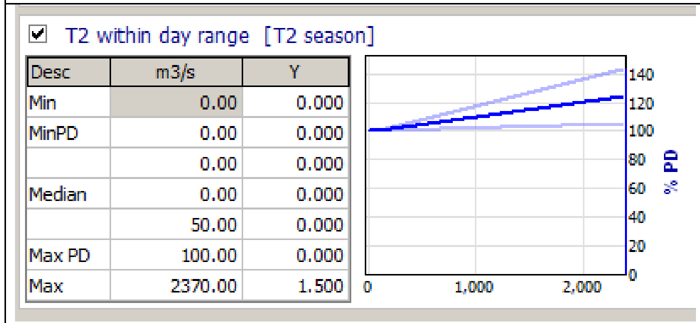
</td><td>Large fluctuations in the daily flow will rapidly cause bank slumping, bank retreat and rapidly increase the extent of cut banks along the channel margins (Rountree 2009).</td></tr>
<tr><td>

☑ T1 within day range [T1 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>1.500</td></tr>
</table>



</td><td>Large fluctuations in the daily flow will rapidly cause bank slumping, bank retreat and rapidly increase the extent of cut banks along the channel margins (Rountree 2009).</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>
</td><td>Large fluctuations in the daily flow will rapidly cause bank slumping, bank retreat and rapidly increase the extent of cut banks along the channel margins (Rountree 2009).</td></tr>
</table>

References

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Rountree, M.W., Rogers, K.H. and Heritage, G.L. 2000. Landscape change in the semi-arid Sabie River in response to flood and drought. *South African Geographical Journal*, 82(3): 173-181.

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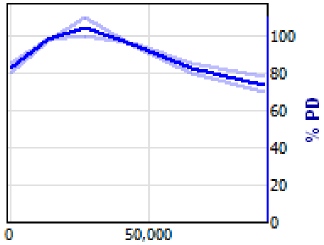
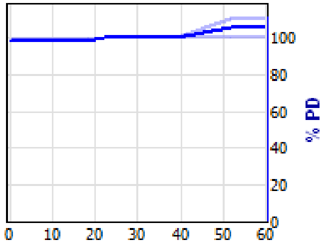
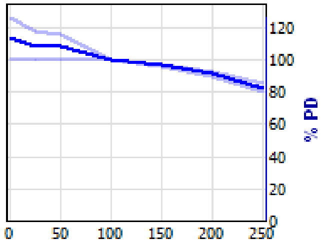
Tooth, S. 2000. Process, form and change in dryland rivers: a review of recent research. *Earth Surface Reviews*, 51: 67-107.

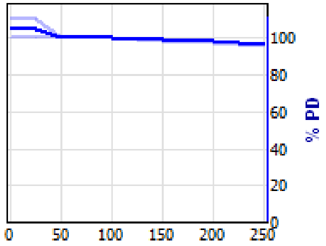
3.10.6 Depth of pools

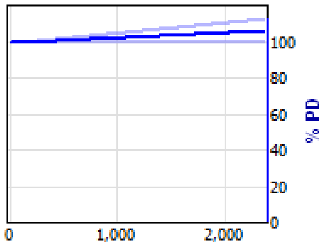
<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Flood volume [F season]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y</th></tr>
<tr><td>Min</td><td>270.60</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>392.06</td><td>-1.000</td></tr>
<tr><td></td><td>13595.05</td><td>-0.100</td></tr>
<tr><td>Median</td><td>26798.04</td><td>0.100</td></tr>
<tr><td></td><td>45743.60</td><td>-0.300</td></tr>
<tr><td>Max PD</td><td>64689.16</td><td>-1.000</td></tr>
<tr><td>Max</td><td>90800.26</td><td>-1.500</td></tr>
</table>


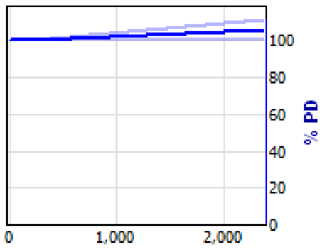
</td><td>The hysteresis of stage-discharge curves associated with large flood pulse systems indicates the buildup of the bed (from flood sediments) and subsequent incision of channel beds during the late wet and dry seasons. Pool beds in the main channel must therefore aggrade, with increasing aggradation in larger flood seasons due to higher sediment loads. These processes have been observed and measured by means of repeat cross-sectional surveys in river systems after very large floods (Rountree, unpublished data). Very small flood seasons could result in pool aggradation due to low velocities and lack of scour.</td></tr>
<tr><td>
☑ Dry season ave daily vol [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>18.29</td><td>-0.100</td></tr>
<tr><td></td><td>22.01</td><td>0.000</td></tr>
<tr><td>Median</td><td>25.73</td><td>0.000</td></tr>
<tr><td></td><td>38.78</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>51.83</td><td>0.100</td></tr>
<tr><td>Max</td><td>59.61</td><td>0.150</td></tr>
</table>


</td><td>Lower dry season flows will result in a decrease in pool depth in the dry season. AT EF Site 1 the range of maximum pool depth on the cross section only ranges from 18.4 to 20 metres for 212 to 690 m3/s - the minimum and maximum average dry season baseflows respectively.</td></tr>
<tr><td>
☑ Wet: mean Coarse suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.600</td></tr>
<tr><td></td><td>50.00</td><td>0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>-1.000</td></tr>
</table>


</td><td>Higher sediment inputs would result in greater deposition and lower pool depths, and conversely lower sediment inputs would result in less deposition and therefore deeper pools (due to less infilling).</td></tr>
</table>

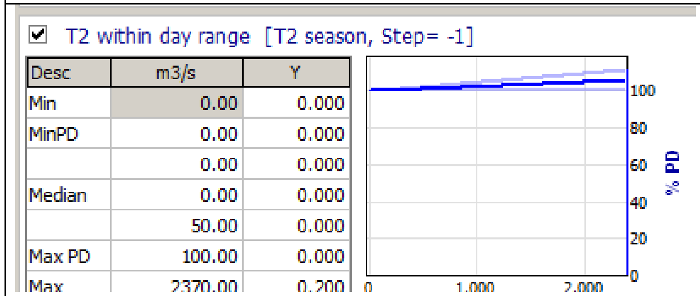
<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Wet: max Coarse suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.200</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.100</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.050</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.100</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.200</td></tr>
</table>


</td><td>Peak sediment inputs will have a small impact on deposition and pool depth: large peaks would infill pools and lower sediment peaks could be expected to be associated with net scour.</td></tr>
<tr><td>
☑ Dry within day range [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>0.300</td></tr>
</table>


</td><td>High variations in water levels would initially result in increased bank erosion and infilling of pools as the marginal sediments are eroded and brought in to the main channel. However, this would only be a temporary impact, since the twice-daily flood peaks would increase sediment transport capacity of the channel and result in overall enhanced flushing of sediments and deeper pools.</td></tr>
<tr><td>
☑ T1 within day range [T1 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>0.200</td></tr>
</table>


</td><td>High variations in water levels would initially result in increased bank erosion and inilling of pools as the marginal sediments are eroded and brought in to the main channel. However, this would only be a temporary impact, since the twice-daily flood peaks would increase sediment transport capacity of the channel and result in overall enhanced flushing of sediments and deeper pools.</td></tr>
</table>

Response curve



☑ T2 within day range [T2 season, Step= -1]

Desc	m3/s	Y
Min	0.00	0.000
MinPD	0.00	0.000
	0.00	0.000
Median	0.00	0.000
	50.00	0.000
Max PD	100.00	0.000
Max	2370.00	0.200

Explanation

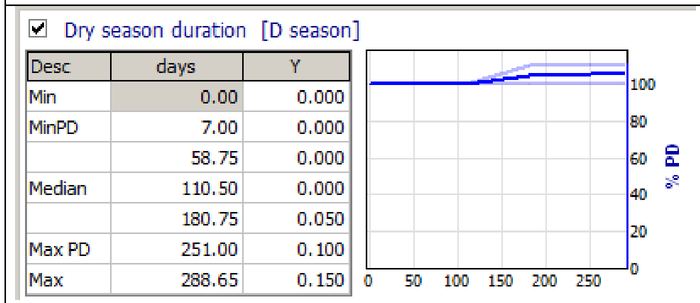
High variations in water levels would initially result in increased bank erosion and inilling of pools as the marginal sediments are eroded and brought in to the main channel. However, this would only be a temporary impact, since the twice-daily flood peaks would increase sediment transport capacity of the channel and result in overall enhanced flushing of sediments and deeper pools.

References

Rountree, unpublished data. Cross-sectional survey data of the Sabie and Letaba rivers in the Kruger National Park, South Africa, following extreme floods in 2000.

3.10.7 Table 3.10Area of vegetated mid-channel bars

Response curve



☑ Dry season duration [D season]

Desc	days	Y
Min	0.00	0.000
MinPD	7.00	0.000
	58.75	0.000
Median	110.50	0.000
	180.75	0.050
Max PD	251.00	0.100
Max	288.65	0.150

Explanation

Long dry seasons would promote vegetation encroachment in to the channel, as well as increasing mid-channel bar stabilisation through vegetation growth (Carter and Rogers 1995).

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Wet season Max 5d Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>0.200</td></tr>
<tr><td></td><td>2109.13</td><td>0.050</td></tr>
<tr><td>Median</td><td>3309.19</td><td>0.000</td></tr>
<tr><td></td><td>6372.37</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>9435.56</td><td>-3.000</td></tr>
<tr><td>Max</td><td>10850.89</td><td>-3.000</td></tr>
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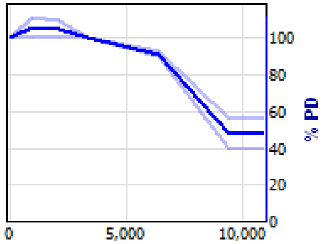
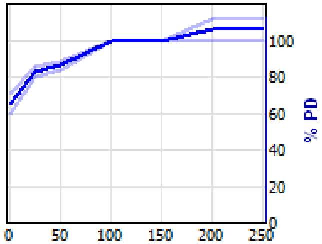


</td><td>Extremely large floods will scour the channel and remove vegetation from the river banks and bars. Small floods would, due to reduced velocities and flow depths, promote vegetation establishment and encroachment in to the channel (Rountree et al. 2000, Rountree et al. 2001, Parsons et al. 2006).</td></tr>
<tr><td>
☑ Wet: mean Coarse suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.800</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.200</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.300</td></tr>
</table>


</td><td>Reduced sediment supply could be expected to reduce the extent of vegetated bars over time, since sediment eroded from the bars would no longer be completely replaced due to further limitations in sediment supply.</td></tr>
<tr><td>
☑ Wet: max Coarse suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.200</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.005</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.100</td></tr>
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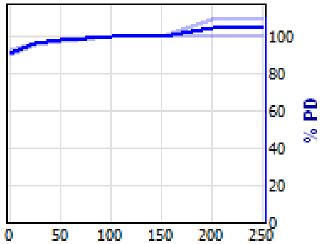
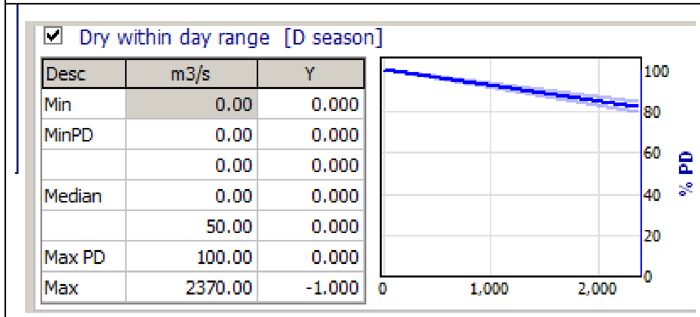
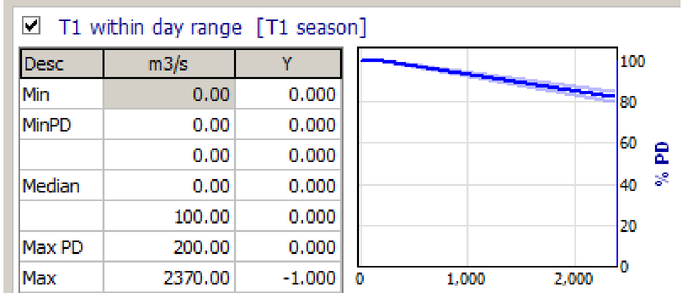
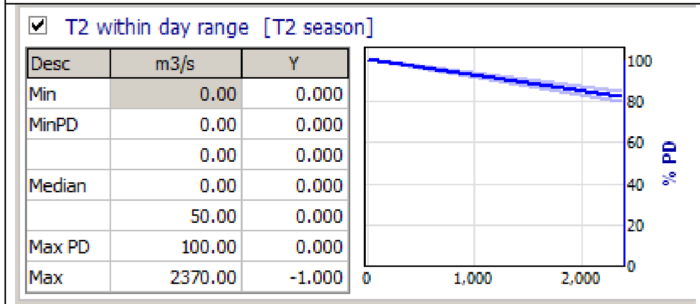


</td><td>Reduced sediment supply peaks could be expected to slightly reduce the extent of vegetated bars over time, since sediment eroded from the bars would no longer be completely replaced due to further limitations in sediment supply. The peak sediment supply could have otherwise replenished some of the sediments eroded over the course of the flow season.</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>
</td><td>Large fluctuations in the daily flow will, at alluvial sections of the bank, rapidly cause bank slumping and bank retreat and would undercut and/or erode marginal vegetation from the banks and bars (Rountree 2009)</td></tr>
<tr><td>
</td><td>Large fluctuations in the daily flow will, at alluvial sections of the bank, rapidly cause bank slumping and bank retreat and would undercut and/or erode marginal vegetation from the banks and bars (Rountree 2009)</td></tr>
<tr><td>
</td><td>Large fluctuations in the daily flow will, at alluvial sections of the bank, rapidly cause bank slumping and bank retreat and would undercut and/or erode marginal vegetation from the banks and bars (Rountree 2009)</td></tr>
<tr><td>References</td><td>Carter, A.J. and Rogers, K.H. 1995. A markovian approach to investigating landscape change in the KNP rivers. Report no. 2/95, CWE, University of the Witwatersrand, Johannesburg.
Rountree, M. W. 2009. Assessing bank stability along the lower Kafue River, in Birkhead A.L., Rountree M., Rowlston, B. and Louw D (eds). Kafue Gorge Lower Hydropower Project, Zambia. Assessing hydraulic behaviour and bank stability along the lower Kafue River in response to peaking releases from the proposed Kafue Gorge Lower Hydropower Project. Prepared for the International Finance Corporation, August 2009.
Rountree, M.W., Rogers, K.H. and Heritage, G.L. 2000. Landscape change in the semi-arid Sabie River in response to flood and drought. South</td></tr>
</table>

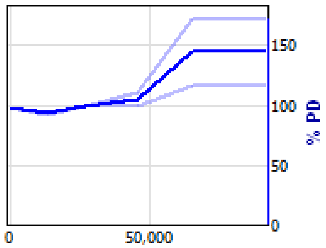
Response curve	Explanation
	African Geographical Journal, 82(3): 173-181. Rountree, M.W., Heritage, G.L. and Rogers, K.H. 2001. In-channel metamorphosis in a semi-arid, mixed bedrock/alluvial river system: Implications for Instream Flow Requirements In M.C. Acreman (ed) Hydro-ecology, IAHS Publ. no. 26. Parsons, M., McLoughlin, C. A., Rountree, M. W. and Rogers, K. H. (2006). The biotic and abiotic legacy of a large infrequent flood disturbance in the Sabie River, South Africa. *River Research and Applications*, 22:187-201.Tooth, S. 2000. Process, form and change in dryland rivers: a review of recent research. *Earth Surface Reviews*, 51: 67-107.

3.10.8 Area of sand bars

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Flood volume [F season]

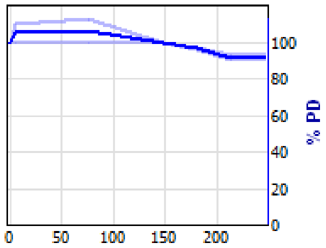
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y</th></tr>
<tr><td>Min</td><td>270.60</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>392.06</td><td>-0.100</td></tr>
<tr><td></td><td>13595.05</td><td>-0.400</td></tr>
<tr><td>Median</td><td>26798.04</td><td>0.000</td></tr>
<tr><td></td><td>45743.60</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>64689.16</td><td>2.000</td></tr>
<tr><td>Max</td><td>90800.26</td><td>2.000</td></tr>
</table>



</td><td>Very large floods cause more sediment to be delivered to the channel, and would therefore be associated with the creation of larger sand deposits in the gorge (Baker, 1977; Carter and Rogers 1995; Kochel, 1988; Nanson, 1986; Rountree et al. 2000; Rountree et al. 2001, Parsons et al. 2006). The higher sediment loads would tend to be associated with the rising limb of the flood. Lower than average floods probably cause a net loss of sand bars, but very small (failed) wet seasons may cause some sand bars to be lost to vegetation encroachment.</td></tr>
<tr><td>

☑ Wet season duration [F season]

<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>0.100</td></tr>
<tr><td></td><td>76.00</td><td>0.300</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>246.10</td><td>-0.500</td></tr>
</table>



</td><td>Long wet seasons erode progressively more of the deposited sand bars (as sediment deposition generally predominantly associated with the early wet season). Short, fast wet seasons could be expected to result in greater than median sand bar areas, but very short wet seasons may not cause any change.</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Dry season ave daily vol [D season]

<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.000</td></tr>
<tr><td>MinPD</td><td>18.29</td><td>0.300</td></tr>
<tr><td></td><td>22.01</td><td>0.000</td></tr>
<tr><td>Median</td><td>25.73</td><td>0.000</td></tr>
<tr><td></td><td>38.78</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>51.83</td><td>-0.300</td></tr>
<tr><td>Max</td><td>59.61</td><td>-0.300</td></tr>
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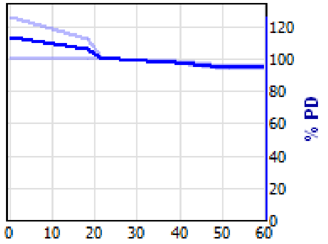

</td><td>The flows in the dry season have low sediment loads and are erosive, albeit only at the points where they are in contact with the sand bars. Higher dry season flows will inundate and erode more sand bars and lower flows would expose more sand bars.</td></tr>
<tr><td>

☑ Wet: mean Coarse suspended sediment [F season]

<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-2.500</td></tr>
<tr><td></td><td>50.00</td><td>-1.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.000</td></tr>
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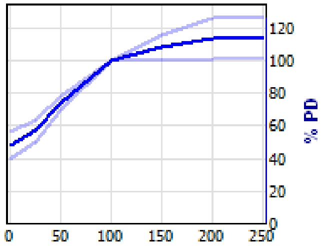

</td><td>Higher sediment inputs would result in the creation of more sand bars, and reduced sediment inputs would result in net erosion of sand bars. Reduced sediment supply would, due to the relative sediment starvation of the reach, quickly result in a decline in area of sand bars.</td></tr>
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☑ Wet: max Coarse suspended sediment [F season]

<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.200</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.100</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.100</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.200</td></tr>
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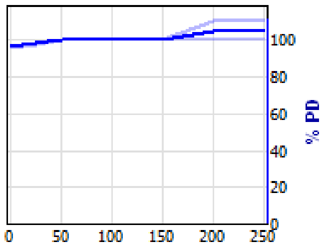

</td><td>Peak sediment inputs will have a small impact on sand bars: large peaks would create more sand bars and lower sediment peaks could be expected to be associated with fewer sand bars.</td></tr>
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<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
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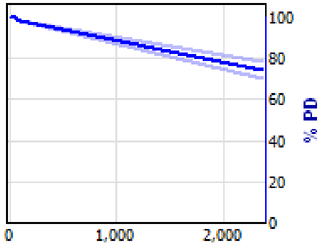
☑ Dry within day range [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>-0.100</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-1.500</td></tr>
</table>



</td><td>High intra-daily flow variations (potentially up to several metres of water level variation twice per day) would cause a very rapid loss of sand bars from the river (Rountree 2009).</td></tr>
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☑ T1 within day range [T1 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.150</td></tr>
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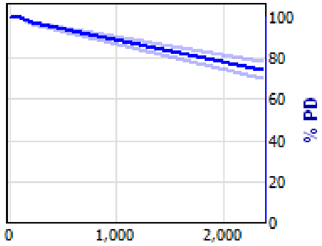

</td><td>High intra-daily flow variations (potentially up to several metres of water level variation twice per day) would cause a very rapid loss of sand bars from the river (Rountree 2009).</td></tr>
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☑ T2 within day range [T2 season]

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<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>0.000</td></tr>
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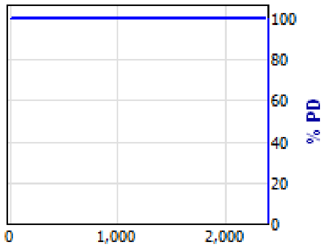

</td><td>High intra-daily flow variations (potentially up to several metres of water level variation twice per day) would cause a very rapid loss of sand bars from the river (Rountree 2009).</td></tr>
</table>

References

Baker, V.R. 1977. Stream-channel response to floods, with examples from central Texas. *Geol. Soc. Am. Bull.*, 88: 1057-1071.

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Nanson, G.C. 1986. Episodes of vertical accretion and catastrophic stripping: a model of disequilibrium flood-plain development. Geol. Soc.

Response curve	Explanation
	Am. Bull., 97: 1467-1475. Rountree, M. W. 2009. Assessing bank stability along the lower Kafue River, in Birkhead A.L., Rountree M., Rowlston, B. and Louw D (eds). Kafue Gorge Lower Hydropower Project, Zambia. Assessing hydraulic behaviour and bank stability along the lower Kafue River in response to peaking releases from the proposed Kafue Gorge Lower Hydropower Project. Prepared for the International Finance Corporation, August 2009. Rountree, M.W., Rogers, K.H. and Heritage, G.L. 2000. Landscape change in the semi-arid Sabie River in response to flood and drought. South African Geographical Journal, 82(3): 173-181. Rountree, M.W., Heritage, G.L. and Rogers, K.H. 2001. In-channel metamorphosis in a semi-arid, mixed bedrock/alluvial river system: Implications for Instream Flow Requirements In M.C. Acreman (ed) Hydro-ecology, IAHS Publ. no. 26. Parsons, M., McLoughlin, C. A., Rountree, M. W. and Rogers, K. H. (2006). The biotic and abiotic legacy of a large infrequent flood disturbance in the Sabie River, South Africa. *River Research and Applications*, 22:187-201.

4 *VEGETATION: SPECIALIST REPORT*

4.1 *OBJECTIVES OF THE VEGETATION STUDY*

The main objective of the vegetation study was to identify the relationship between riparian and aquatic vegetation features and flow level changes, and to predict what impacts, if any, will occur with changes to the present-day flow regimes.

For the vegetation component of the EF assessment, 17 days were allocated to undertaking a literature review of previous information, a site visit, data analysis of the site information collected in the field, prediction of impacts (response curves) and report writing.

This report follows the ToR provided by Southern Waters *viz*.:

- Familiarise yourself to the extent possible with the study area, including:
  - The character of the Zambezi River in the study area.
  - Delineation of homogenous areas based on geology, reach slope, and vegetation.
  - The character of the reaches encompassing the proposed sites.
- Prepare a coarse-level reach analysis for the study river, focussing on the study area.
- Provide detailed information for two EF sites.
- Attend the field visit with the rest of the team to:
  - Ensure that the hydraulic cross-section surveys record whatever information you require for your analyses.
  - Record at each site, where relevant, (i) the dominant and sub-dominant vegetation, (ii) the arrangement of the vegetation relative to inundation and /or flow velocities, (iii) the nature and extent of instream or overhead cover (for fish).
  - Identify plant specimens collected, to species level where possible.
- If necessary, undertake one additional field visit to collect water level and discharge data for Dr Birkhead (2 days allocated).
- Take responsibility for the adequacy of the data collected and provided for the vegetation component of the EFA.
- Select key aspects as indicators for the DRIFT assessment, in liaison with the other specialists, and provide/develop information on:
  - changes in vegetation with changes in the flow regime;
  - any other relevant data as your experience suggests;
  - any other available information relevant to flow assessments;
  - relevant scientific references.
- Select linked indicators that can be used to explain flow-related changes for each of your indicators.
- Attend the DRIFT Workshop(s), prepared to populate the DRIFT response curves for your selected indicators and linked indicators.

- Compile a vegetation chapter for inclusion in the EFA Report, with particular reference to response curve motivation tables.
- Adhere to standard formatting, font and layout specifications provided for written submissions.

4.2 *LAYOUT OF THIS SECTION*

This Section comprises the summary report for vegetation, and provides:

- Literature review focused on riparian vegetation;
- For the EF sites:
    - Ecoclassification assessments for your discipline, with supporting evidence;
    - the DRIFT indicators chosen, and reasons therefor;
    - the relationships between the chosen indicators and flow or other, with referenced, supporting motivations.

Since flows from Batoka HPP are expected to impact on aquatic and riparian vegetation but not so much terrestrial vegetation, focus is directed to aquatic and riparian communities.

4.3 *LITERATURE REVIEW*

The majority of plants in the gorge and downstream of the gorge are terrestrial. In general, there are few aquatic macrophytes and the riparian area is very narrow. Since terrestrial plants grow away from the influence of the river and are not likely to be impacted by fluctuations in river stage due to the Batoka HPP, this review focusses on aquatic and riparian plant communities. All the terrestrial plant communities of the gorge area were competently reviewed in the updated feasibility studies completed by ZRA (1998).

First, a description of aquatic and riparian plant communities of Batoka Gorge is provided. This is followed by a description of flow related aspects of aquatic and riparian plant communities. The review concludes with a description of the effects of hydropower peaking on aquatic and riparian plants.

Aquatic vegetation is the riverine plant community sustained by perennial river flow within the confines of an active channel. This includes submerged species, such as unicellular (diatoms) and filamentous algae, and emergent species, such as mosses (Bryophtes) or macrophytes, such as lilies. Riparian vegetation, on the other hand, is the riverine plant community sustained by river flow or groundwater, or generally moist conditions along river margins, and is typically distinctly different in species composition from adjacent terrestrial communities. Typically, riparian vegetation consists of a mixture of graminoids, herbaceous perennials, annuals, shrubs and trees.

Both aquatic and riparian vegetation play a central role in the functioning of riverine ecosystems. Aquatic algae provide an important component of the diets of aquatic macroinvertebrates and fish and are important processors of nutrients in the water column.

Bryophytes and other emergent vegetation contribute toward better habitat quality for aquatic macroinvertebrates and fish. Riparian vegetation help reduce bank erosion through armouring; maintain water quality through trapping of sediment, nutrients and other contaminants, and shading regulates river water temperature and thus primary productivity; food is provided for riparian animals in the form of fruits, nuts and leaves, and for aquatic macroinvertebrates in the form of leaf litter; the plants themselves offer a diverse array of habitats as well as a corridor for the movement of migratory terrestrial and semi-aquatic animals (Prosser 1999, Terrill 1999). The riparian vegetation also acts as a moderator of water flow and sediment transport by intercepting precipitation and runoff; increasing infiltration; reducing soil moisture, water levels in alluvial aquifers and river flow through evapotranspiration; effecting changes to soil nutrient cycles by leaf litter inputs; and also altering channel structure through inputs of large woody debris.

The nature and extent of the aquatic and riparian vegetation is intimately linked to river channel structure and the occurrence of moisture, including: river water; groundwater, and; soil moisture. Aquatic vegetation is also particularly responsive to changes in water quality, such as changes in nutrient status, temperature and turbidity, which affects light penetrability and the depth of the photic zone in which aquatic plants may grow. Riparian vegetation, sediment transport and water flow interact and influence the kinds of plants suited to a particular river channel shape and water regime. Consequently, changes in the flow regime and its knock-on effects illicit a response in the nature and extent of aquatic and riparian vegetation.

4.3.1 River vegetation of Batoka Gorge

ZRA (1998) provided a comprehensive account of vegetation communities in the gorge of which five communities were described as aquatic/riparian and another five as terrestrial. The five aquatic/riparian communities are summarised in Table 4-1 and a short description of these (summarised from ZRA 1998) follows. In the table, reference is made to their dependence on river habitats, which was assigned on the basis of their habitat characteristics (Coates-Palgrave 1977, Curtis and Manheimer 2005, van Wyk and van Wyk 2009) as follows:

- species common on or near seeps, rivers and watercourses are obligate riparian (wet) species;
- species described as occurring in bush, woodland or forests and/or associated with water courses are facultative riparian (wet/dry) species;
- those occurring on rocky slopes and outcrops or mountain slopes are incidental upland (dry) species.

Categorising plants in this way helps us predict how plants are expected to respond to changes in habitat and/or flow. For example, if incidental species are found in wet environments it may mean their presence there is temporary or it could mean the nature of the wet environment has changed and become drier.

Table 4.1 Vegetation species expected in the gorge, separated by habitat and indicating dependence on river habitats as O = obligate, F = facultative, I = incidental and A = alien (ZRA 1998).

Pools	Bars	Main stem	Gorge Tribs	Scree slopes
Naja horribilis (O)	*Cyperus maculatus (O)*	*Diospyros mespiliformis (O)*	*Diospyros mespiliformis (O)*	*Acacia nigrescens (I)*
Potamogeton spp. (O)	*Ficus capreifolia (O)*	*Garcinia livingstonei (O)*	*Ficus sur (O)*	*Afzelia quanzensis (I)*
Vallisineria spiralis (O)	*Fimbristylis spp. (O)*	*Lonchocarpus capassa (O)*	*Garcinia livingstonei (O)*	*Boscia albitrunca (I)*
	Garcinia livingstonei (O)	*Phyllanthus reticulatus (O)*	*Minusops zeyheri (O)*	*Combretum apiculatum (I)*
	Mimosa pigra (A)	*Strychnos potatorum (O)*	*Nuxia opposotifolia (O)*	*Combretum mossambicense (I)*
	Sesbania sesban (A)		*Olax dissiflora (O)*	*Commiphora mossambicensis (I)*
	Panicum repens (O)	*Ficus ingens (F)*	*Olea europea (O)*	*Cordia pillosissima (I)*
		Flueggia virrosa (F)	*Oncoba spinosa (O)*	*Croton gratissimus (I)*
		Manilkara mochisia (F)	*Syzygium cordatum (O)*	*Croton meynhartii (I)*
			Trichelia emetica (O)	*Diospyros quiloensis (I)*
		Acacia nigrescens (I)		*Elephantorrhiza goetzei (I)*
		Afzelia quanzensis (I)	*Antidesme venosum (F)*	*Grewia flavescens (I)*
		Combretum mossambicense (I)	*Clerodendrum myricoides (F)*	*Kirkia acuminata (I)*
		Croton meynhartii (I)	*Erythroplyhlum zambeziacum (F)*	*Lannea schweinfurthiana (I)*
		Diospyros quiloensis (I)	*Ficus thonnongii (F)*	*Panicum maximum (I)*
		Grewia flavescens (I)	*Manilkara mochisia (F)*	*Sterculia africana (I)*
			Acacia nigrescens (I)	
			Combretum mossambicense (I)	
			Cordia pillosissima (I)	
			Diospyros quiloensis (I)	

Aquatic macrophytes, such as *Vallisineria spiralis, Potamogeton thunbergii, P. octandrus* and *Naja horribilis,* were said to occur in slow-flow pools. Given the strength of flows through the gorge and depth of the river channel, both in stark contrast to the slow/no flow and relatively shallow water depth preferred by aquatic macrophytes (Cheruvelil and Soranno 2008), these species were expected to form a small/insignificant component of the gorge vegetation overall.

Lateral alluvial sand bars were observed in places along the lower parts of the gorge and were more prevalent on the edges of the river, within the median annual flood line, downstream of the gorge. In the gorge the vegetation on these sand banks was sparse and tended to be patchy but consisted of the small trees *Mimosa pigra, Sesbania sesban, Garcinia livingstonei, Ficus capreifolia* and the grasses *Panicum repens* and *Cynodon dactylon.* Downstream of the gorge the common reed *Phragmites australis* and Cape willow *Salix mucronata* were more common on lateral sand bars and around the vegetated islands; both species well adapted to regular inundation during the wet season being flexible and reproducing sexually and vegetatively via plant fragments that root (Karrenberg et al. 2002).

The river channel was fringed by a narrow, riparian woodland inhabited by trees and shrubs. This riparian area varied in width along the river, was patchy in the gorge and better established downstream of the gorge. This woodland community was situated just above the median flood line on shallow rocky soils and will be inundated during large floods. Common tree species included *Diospyros mespiliformis, Acacia nigrescens, Ficus ingens, Afzelia quanensis* and *Garcinia livingstonei*. Characteristic shrubs included *Phyllanthus reticulatus, Flueggia virosa and Grewia flavescens* and the most common grass was *Panicum maximum.* There were some disturbances to this community in the gorge at the river rafting pick-up/drop-off points and downstream of the gorge there had been some clearing/harvesting for wood and fire as well as to create grazing areas with *Cynodon dactylon.*

Some of the perennial tributaries were also inhabited by a variant of the riparian woodland community with some of the common trees being *Ficus thonningii, Olea europea, Trichelia emetica, Diospyros mespiliformis, Garcinia livingstonei, Acacia nigrescens, Nuxia oppositifolia* and *Ficus sur.* Smaller trees and shrubs included *Syzigium cordatum, Cordia pillosissima, Combretum mossambicense* and *Antidesme venosum.*

The scree slopes of the gorge were inhabited by a *Commiphora-Sterculia africana* mixed woodland; an open, tall, dry, deciduous woodland on basaltic soils. Large trees included leadwoods such as *Combretum mossambicense* and *C. apiculatum* and the knob-thorn tree *Acacia nigrescens,* which occurred with smaller trees and shrubs such as *Diospyros quiloensis* and *Grewia flavescens.* *Panicum maximum* was the major grass species found in this community.

4.3.2 Flow related aspects of river vegetation

Flow is considered to influence the distribution of aquatic and riparian plants in three main ways (Van Coller 1992):

- as a resource necessary for growth and reproduction;
- as an agent of disturbance (floods); and
- as a stressor during periods of prolonged low flow.

Aquatic vegetation is an important component of the river food web as diatoms, filamentous green algae and aquatic macrophytes convert dissolved nutrients into a food source for aquatic organisms (Biggs 1996). Periphyton (diatoms, filamentous green algae) form an important component of the diet of snails (Rosemund et al. 1993), aquatic macroinvertebrates (Steinman et al. 1991), crustaceans (Pringle et al. 1993), tadpoles (Petersen and Boulton 1999) and fish (Power and Mathews 1983). Periphyton communities are dynamic and respond primarily to seasonal changes in flow and nutrients (Biggs and Close 1989). Rivers with seasonal floods that have periods of stability longer than 1 month with moderate supplies of nutrients and light allow for different successional phases of periphyton to develop (Yang et al. 2009). Periods of low flow are favourable for the proflieration of diatoms and filamentous green algae. Green algae are favoured over diatoms by higher light and nutrient conditions (Hill 1996). At the start of the wet season increased flows flush nutrients from the river bed and increase opportunities for growth (Larned et al. 2004). The disturbance of floods however overrides growth opportunities of light and nutrients (Biggs 1995) by turning over benthic substrata to which algae are attached (Holomuzki and Biggs 2006), by entraining suspended sediments that scour benthic algae from the surfaces of rocks (Grimm and Fisher 1989) and by shear stress (Biggs and Thomsen 1995). Flood reset algal communities between seasons and favour different species and ratios of diatoms/green algae between years (Ewart-Smith 2012). Diatoms are better adapted to regular high flows and turn over more rapidly than green algae, which tend to proliferate when nutrients and temperatures are higher (Larned 2010).

Riparian vegetation communities are dynamic and the relative dominance of species changes from river source to river mouth. Areas of broadly similar physical habitat contain broadly similar communities, but the species composition and density at any one site is affected by changes in soil moisture, nutrient status and topography (Van Coller 1992); the frequency and intensity of droughts and floods, fire, plant disease and grazing, biogeographical distributions (Naiman *et al.* 2005); and species interactions (Francis 2006).

Localised maintenance of populations and persistence depends upon site stability, site suitability for germination and establishment, and favourable ambient environmental conditions until the age of reproduction (Hupp and Osterkamp 1996). Successful recruitment depends upon (1) availability of seed or propagules, (2) colonisable habitat, (3) a recruitment window where moisture favours establishment and (4) resilience to high (floods) and low (drought) flow periods (Tabacchi *et al.* 1998). Sufficient flows are required seasonally to recharge ground water levels at the end of the dry season and also to facilitate vegetation recruitment (dispersal, germination and seedling growth), which usually occurs as floods recede. Some specialist riparian species release seed to coincide with flood recession because moist seedbeds become available for colonisation (Naiman *et al.* 2008). Plants cued to release seed in this way are reproductive specialists that require specific conditions in order for recruitment to be successful. These reproductive specialists are the most sensitive to alterations in the flow regime, and may be subject to recruitment failure if the flow regime is altered. Scouring floods clear new areas for recruitment and newly established seedlings expand their roots to maintain contact with the gradually receding water table (Rood *et al.* 1999). Other riparian plants may be less specific in their response, flowering and setting seed over many months of the year, or in response to periods of high flow only. These generalists are often pioneers and the first species to colonise new habitat (alluvial deposits), as their seedlings are able to germinate on a variety of habitats and are less prone to recruitment failure as a result of changes to the flow regime.

There is a growing body of knowledge on the distribution and nature of vegetation along river banks and across floodplains. Naiman *et al*. (2005) reviewed much of this, describing how the vegetation changes with distance from the river's edge in a series of lateral zones. The primary drivers of zonation are usually seen as two-fold. Arguably, the main one of these is river flow, with the magnitude and timing of flow (Poff *et al.* 1997), the area of land it inundates, and the velocity, depth and duration of inundation all influencing what plant species can live where. The geomorphological nature of the river channel and surrounding land is also important, as is the nature of the soils, dictating where water can reach and for how long. Through the interplay of flows and landscape, river banks are inundated and exposed at different times of the year, providing a range of conditions that are exploited by different plant species.

River vegetation may be separated out into five zones that are variously inundated and inhabited by species that differ in their dependence on river habitats for their survival (Figure 4-1):

- the aquatic zone, inhabited by obligate diatoms, filamentous green algae and aquatic macrophytes;
- the marginal one, inhabited by obligate trees and shrubs;
- the lower zone, inhabited by facultative trees and shrubs;
- the upper zone, inhabited by a mixture of facultative and incidental trees and shrubs; and
- the terrestrial zone, inhabited by incidental and terrestrial species.

The lower and upper zones are sometimes grouped into a non-marginal zone (Kleynhans et al. 2007), which reduces the number of zones to four.

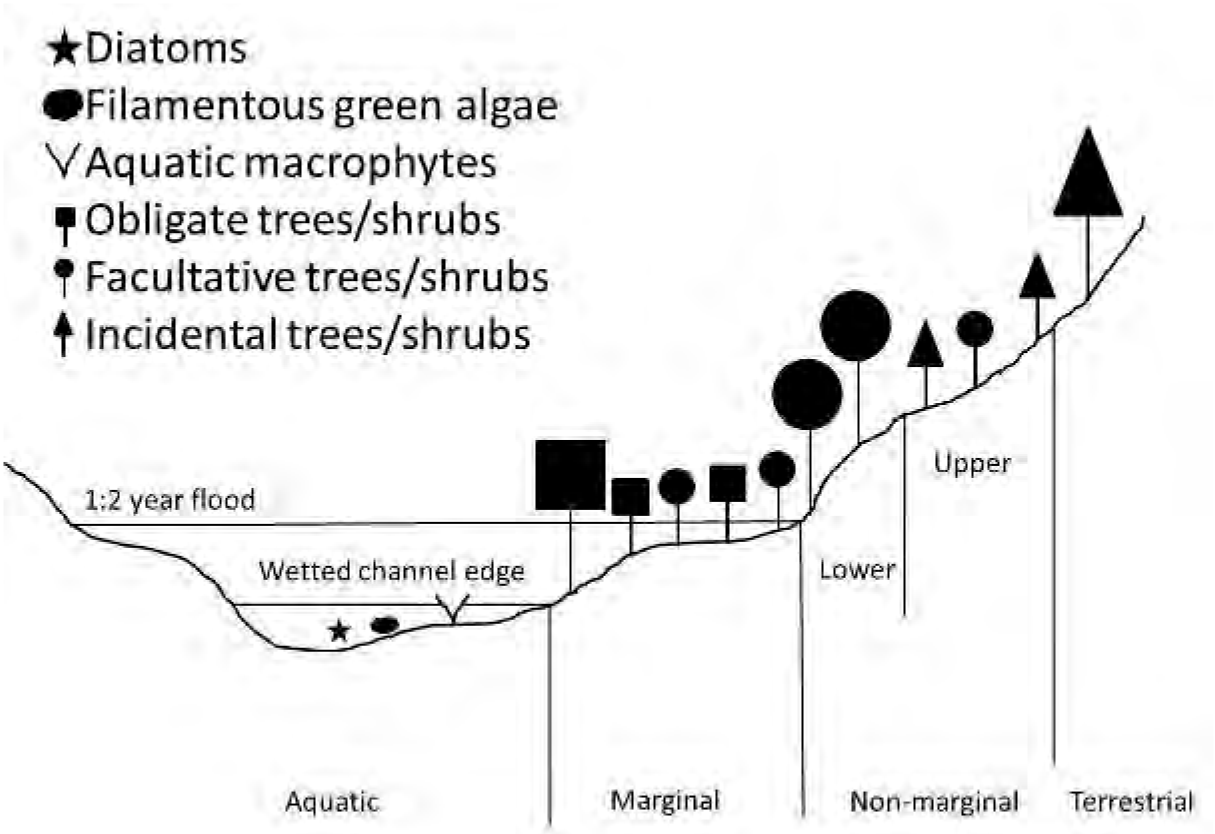


Figure 4.1 **Stylised river vegetation zones.**

In general, water availability decreases laterally away from the river channel as the depth to groundwater increases and the frequency of flooding and inundation duration of flood events decreases (Naiman *et al.* 2005). Inundation duration influences vegetation structure, with permanent to frequently inundated areas generally dominated by herbaceous perennials and graminoids, while those less frequently inundated are dominated by shrubs and trees and an understory of herbaceous perennials and graminoids (Toner and Keddy 1997, Merrit et al. 2010). The combination of a decrease in water availability and in the frequency of being flooded equates to a higher probability of experiencing a water shortage higher up the bank.

The life history strategies of species occupying the marginal, lower and upper zones differ. The life histories of marginal zone plants are more intimately linked with the flow regime than upper zone plants although the roles of density dependence, competition and other interactions between riparian plants are more important higher up the bank (Francis 2006).

4.3.3 Effects of hydropower flow regime alterations on river vegetation

Changes to vegetation communities downstream of dams are well documented (Carter Johnson 2002) and result from alterations to the natural flow regime. Upstream effects include habitat loss resulting from inundation and also the formation of new riparian zones (Richter and Thomas 2007). These are not considered here as the focus of this report is downstream effects. Generally, downstream effects include a reduction in flow, and therefore a reduction in stream power and related sediment-transport capacity, as a result of storage abstraction and by evaporation from the water surface (Brandt 2000). As flows upstream of the dam are slowed suspended sediments drop out into the dam. As a result, water released from the dam is supply limited and thus highly erosive. Erosion of river banks, channel widening and down-cutting are common changes to river channel structure immediately downstream of dams (Grant et al. 2003). At some point, if there is sufficient sediment supply in the river basin downstream, equilibrium will again be reached as suspended sediment loads are replenished. Reduced base flows are particularly damaging during the low flow season and are usually coupled with a reduction in freshes (small dry season floods). Together these sustain groundwater levels during the dry season that lower and upper riparian species rely upon and also maintain the marginal riparian species that are less drought tolerant. The aquatic community is particularly sensitive to changes in flow during the dry season as this is their season of active growth and reproduction (Yang et al. 2009). Diatoms and algae increase in abundance during the dry season as disturbance to benthic substrata is reduced, nutrients are more readily available and temperatures are higher (Yang et al. 2009). Reduced flows in the dry season decrease the inundated/benthic habitat available for their proliferation.

Peak discharges are also commonly reduced (Potyondy and Andrews 1999). Peak discharges disturb benthic communities and this may reset the succession of aquatic plant, diatom and algal communities (Ewart-Smith 2012). Riparian species are also not favoured. Some riparian species are cued to high flows at particular times of the year, flowering, setting and dispersing seed over the period of the long-term average flood peak (Rood et al. 2005). These species suffer recruitment failure should the timing of this flood peak change. Others species increase growth, flowering and seed production in response to high flows and thus maintain sustained recruitment over decades of alternate wet and dry years. Should high flows be reduced, growth, reproductive success and recruitment in both of these groups of plants will be suppressed or fail.

Another impact of reduced peak discharges relates to a reduction in the capacity of the river downstream to transport sediment. Some riparian species require sediment of a large calibre (cobbles, boulders) or are adapted to grow on bedrock. Sedimentation will reduce the availability of these rocky habitats and will favour other species adapted to finer sediment. Reduced sediment transport may also favour the growth and persistence of aquatic species as coarse suspended sediments in the water column act like scours removing benthic diatoms, algae and bryophytes from rocks (Grimm and Fisher 1989).

Besides changed water quantities (storage effects) the release of water can create completely altered diurnal and seasonal patterns of flow (Brandt 2000). Diurnal changes may occur as more water is used during the day time for the generation of electricity. Seasonal (annual) changes may occur as water is stored during the rainy season as reservoirs are filled for use during the dry season. Another characteristic of many regulated rivers is the sudden fluctuation of discharge that takes place during peaking (Renofalt et al. 2010).

Changes in the hydrological regime have predictable consequences on aquatic and riparian plant species since they are arranged along a gradient of inundation duration (Nilsson and Breggren 2000). In humid environments, inundation duration has been interpreted as a predictor of the degree to which roots are exposed. However, in more arid environments, it is correlated with a whole suite of environmental variables. These include shear stress, sediment deposition and erosion, soil moisture and depth to groundwater, in addition to soil oxygen concentration (Auble 1994).

Riparian plants are adapted to seasonally changing hydrological regimes. Aquatic species that are totally submerged tend to reproduce during the low flow season, when flowering plants of the plant emerge beyond the water's surface to be pollinated. Elevated base flows during the low-flow season may result in failure of these species to reproduce. Marginal zone species tend to be either graminoids or multi-stemmed shrubs adapted to withstand the force of regular annual floods. They generally reproduce sexually and asexually (via vegetative growth). Many of these soft and fleshy wet bank plants are able to disperse as vegetative diaspores, plant fragments that are able to root themselves. The fast rates of growth and their multi-reproductive strategy and dispersal mechanisms allows these wet bank plants to adapt to changes in the flow regime more quickly and easily than the woody trees and shrubs that dominate the dry bank. The woody trees and shrubs of the dry bank are more drought tolerant and able to withstand prolonged periods of no flow, provided that ground water levels remain. These plants are typically phreatophytic and rely on ground water to sustain their survival during periods of low flow and low soil moisture. Since many rely on periods of high flow to initiate flowering and seed production, and flood-recession for seed dispersal, over an annual cycle, changes that disrupt annual seasonality of flow may result in recruitment failure. Generalist species that flower and set seed aseasonally may not be as susceptible to recruitment failure by a change in the annual flood peak for example, but will still be susceptible to difficulties in seedling establishment if there are no periods of low flow over which seedlings may establish themselves in the absence of scouring floods.

Stabilisation of flows will prevent plants that require periods of low or high flow to complete some part of their life cycle from reproducing successfully. Similarly constant rapid fluctuations in discharge will mean that only the most robust, generalist and rapidly growing plant may survive.

4.4 DESCRIPTION OF THE EF SITES

EF Site 1 was located in the gorge while EF Site 2 was located downstream out of the gorge. The gorge differed in having extremely steep and rocky banks and also with very little/no alluvial sandy habitats in the marginal riparian area. Once out of the gorge the valley was wider and the river banks shallower. At EF Site 2 there was still much bedrock habitat available in the marginal zone but this was balanced by an increase in the availability of alluvial sand in the lateral bars of the marginal zone (Table 4-2). Due to this there was a greater abundance of marginal zone species, such as *Phragmites mauritianus, Cyperus maculatus, Cynodon dactylon, Ficus capreifolia* and *Salix mucronata* at EF Site 2. The only common and prolific member of the marginal zone at EF Site 1 was the shrub *Stropanthus cf. speciosus,* which was present at EF Site 2 but at a reduced abundance. Trees common at both sites were *Cobretum imberbe, Diospyros mespiliformis, Garcinia livingstonei* and *Gymnosporia senegalensis.*

4.4.1 EF Site 1, Batoka Gorge

The riparian area along the gorge was narrow (Figure 4-2) and approximately 25 metres in width (Figure 4-3).

Figure 4.2 The riparian area at EF Site 1, L = left bank, R = right bank.

Table 4.2 Cover abundance of all species at EF Sites 1 and 2, m=marginal, l=lower and u=upper zone.

SITE	1						2					
BANK	Left			Right			Left			Right		
ZONE	m	l	u	m	l	u	m	l	u	m	l	u
Bedrock	50			45			20			50	10	
Boulder	20	70	40	35	60	60	15			10	10	
Cobble	20	20	40	15	30	30	5	10		5		30
Gravel	5	10	20	5	10	10		10			80	20
Sand	5						60	80	100	35		50
NON-TREES												
Bryophyta sp1	10									2		
Cynodon dactylon							30			20		
Cyperus maculatus										3		
Ehrharta sp1	1									1		
Panicum maximum		1	20				3			5		
Panicum repens							5			10		
Pentashistis sp1	11			7			2			2		
Phragmites mauritianus							25			10		

Sesbania sesban							4					
Stropanthus cf. speciosus	14	2		4	2		3			2		
TREES												
Acacia nigrescens			3			5		18	10			
Adansonia digitata									5			
Afzelia quanensis											2	
Antidesma venosum					5							
Bridelia cathartica		15										
Colophospermum mopane									10			5
Combretum imberbe			12			22		15	15		25	
Combretum imberbe juv												2
Cordia pillosissima			15			5					2	
Diospyros mespiliformis		2	10		20			15			5	
Diospyros mespiliformis juv		3					1					
Diospyros quiloensis						5						
Ficus capreifolia							2					
Ficus ingens				15	2							
Garcinia livingstonei		12					3	2			15	
Garcinia livingstonei juv	1	1										
Gymnosporia senegalensis		12			12						10	
Gymnosporia senegalensis juv		4			5			5				
Salix mucronata										1		
Salix mucronata juv										5		
Syzigium guineense juv					5			2				
Trichelia emetica			20			10						

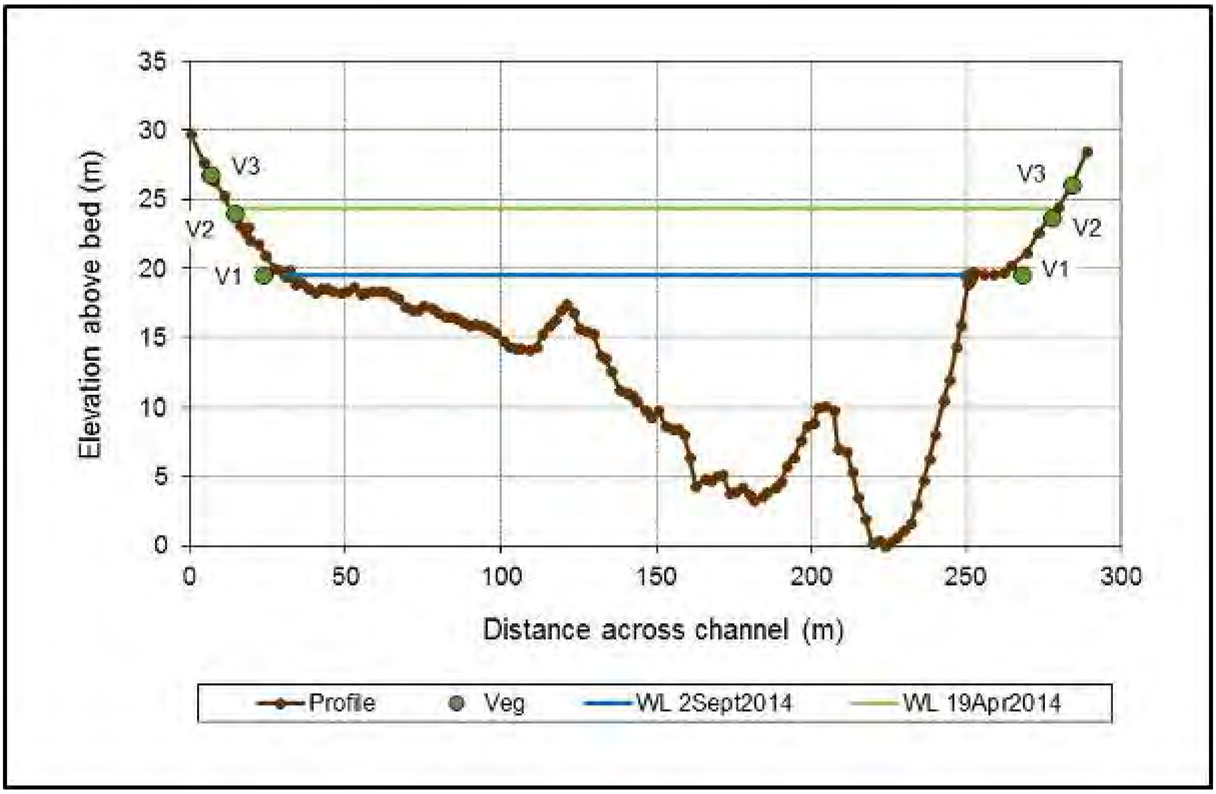


Figure 4.3 **Vegetation zones at both banks of EF Site 1. Lower limits of zones are: 1 = marginal, 2 = lower and 3 = upper.**

The marginal zone comprised bedrock, boulders and cobbles and was sparsely populated. The dominant vegetation was Bryophyta sp1 at the interface of the aquatic and marginal zones and *Stropanthus cf. speciosus* in the marginal zone. The lower and upper zones were narrow and patchy next to a scant terrestrial community.

4.4.2 EF Site 2, upstream of Kariba

The riparian area downstream of the gorge was patchy and narrow but considerably better vegetated (Figure 4-4) and wider, when compared to EF Site 1, being 100 metres in width on the left bank and 500 metres in width on the right bank (Figure 4-5).

Figure 4.4 **The riparian area at EF Site 2, L = left bank, R = right bank.**

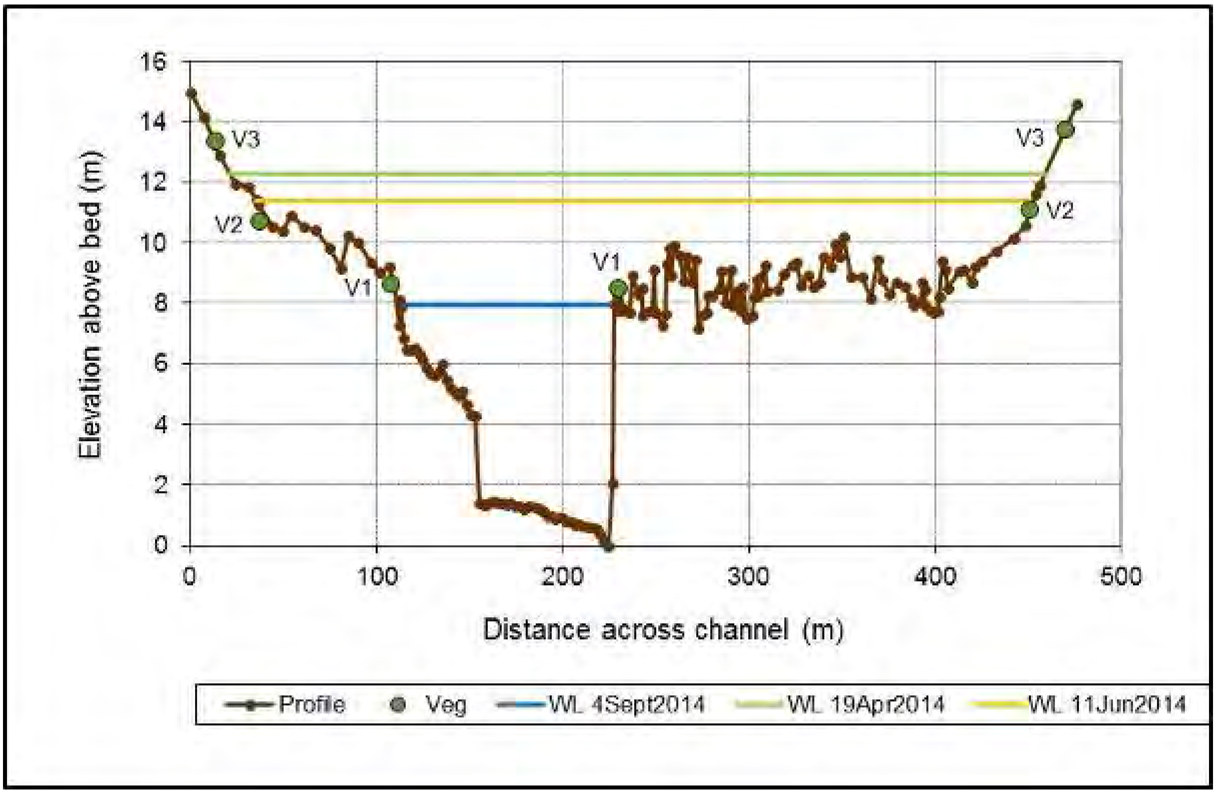


Figure 4.5 **Vegetation zones at both banks of EF Site 2. Lower limits of zones are: 1 = marginal, 2 = lower and 3 = upper.**

The left bank and right bank differed in that the left bank comprised a sandy alluvial lateral bar in between stands of *Phragmites mauritianus.* The right bank comprised a bedrock backwater area from the channel edge for a distance of *c.* 200 metres before a sandy alluvial lateral bar was found once the bank gradient had steepened. The lower and upper zones were narrow and better established on the left bank of the river. The adjacent terrestrial community was considerably more extensive than that of the gorge area.

4.5 *ECOCLASSIFICATION OF RIVER REACHES REPRESENTED BY THE EF SITES*

The Vegetation Response Assessment Index (VEGRAI) (Kleynhans et al. 2007) was used to assess the condition of the riparian vegetation at each EF Site[1]. The method compares the present day condition to that which would be expected under natural (reference) conditions, and considers how past impacts may have influenced the ecological condition over time. The reference condition (Section 4.3.1) was taken from ZRA (1998).

A level 3 assessment was conducted that assesses the impacts on two riparian zones; a marginal zone and a non-marginal zone. Riparian species expected in these two zones are listed for *bars* and *main channel* (Table 4-1) respectively. In the application of DRIFT the broader non-marginal zone was further separated into a lower and upper zone (Figure 4-1).

[1] Please note: this method does not take plants of the aquatic zone into account.

Each EF Site is discussed and the main influences on the ecological condition are compared between sites. Descriptions of the ecological categories used to describe the ecological condition are provided in Table 4-3.

Table 4.3 The ecological categories are used to describe the ecological condition of rivers (adapted from Kleynhans et al. 2007).

Ecological Category	PES % Score	Description of the habitat
A A/B	92-100% 87-92%	Still in a Reference Condition.
B B/C	82-87% 77-82%	Slightly modified from the Reference Condition. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C C/D	62-77% 57-62%	Moderately modified from the Reference Condition. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D D/E	42-57% 37-42%	Largely modified from the Reference Condition. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E E/F	22-37% 17-22	Seriously modified from the Reference Condition. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	0-17%	Critically/Extremely modified from the Reference Condition. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.

4.5.1 EF Site 1, Batoka Gorge

There were no obvious disturbances to the ecological condition of the riparian area at EF Site 1, which scored 90%. This means the riparian area was very close to the reference condition (Table 4-3) and in an Ecological Category A/B. At this EF Site the riparian area was narrow and patchily distributed along the edge of the gorge. The marginal zone normally comprises a mixture of graminoids (such as reeds and sedges) and small trees (such as figs or willows) but here the marginal zone was sparse. There were however some marginal graminoids present on lateral bars (of alluvial sand) downstream of this EF Site but overall these constituted a small proportion of the gorges riparian flora. The non-marginal zone was narrow and comprised a mixture of trees, shrubs and their saplings, indicative of healthy relationship between the natural flow regime and the life histories of the plants (see 4.3.2).

Table 4.4 VEGRAI 3 scores and Ecological Condition (EC) for EF Site 1.

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	93.3	46.7	3.3	2.0	100.0	Both zones are equally important.
NON MARGINAL	86.7	43.3	3.3	1.0	100.0	
	2.0				200.0	
LEVEL 3 VEGRAI (%)				90.0		
VEGRAI EC				A/B		
AVERAGE CONFIDENCE				3.3		

Table 4.5 VEGRAI scores and Ecological Condition (EC) for EF Site 2.

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	86.7	43.3	3.3	2.0	100.0	Both zones are equally important.
NON MARGINAL	86.7	43.3	3.3	1.0	100.0	
	2.0				200.0	
LEVEL 3 VEGRAI (%)				86.7		
VEGRAI EC				B		
AVERAGE CONFIDENCE				3.3		

4.5.2 EF Site 2, upstream of Kariba

There were few disturbances to the ecological condition of the riparian area at EF Site 2, which scored 86.7%. This means the riparian area was slightly modified from the reference condition (Table 4-3) and in an Ecological Category of B. In contrast to EF Site 1, both the marginal and non-marginal zones of the riparian area were well established. The marginal zone comprised a mixture of marginal graminoids (such as reeds and sedges) and small trees (such as figs or willows) up- and downstream of the EF Site. The population of trees and shrubs of the non-marginal zone comprised a mixture of adults and saplings, indicative of a healthy relationship between the natural flow regime and the life histories of these plants (see 4.3.2). The only visible impacts were slight and related to use of woody plants, for firewood or construction material; grazing of saplings or reeds in the marginal area; and the presence of one alien species (*Mimosa pigra)*.

4.6 FIELD DATA COLLECTION AND ANALYSIS

Data collection occurred during low-flow conditions in September 2014.

4.6.1 Data collection

Vegetation data were collected from both banks at both EF Sites. Data were collected in belt-transects that were 10 m in length (longitudinally down the bank). The width of each plot differed according to the width of the zone being sampled. Zones were identified upfront on the basis of growth form characteristics and indicator species (Kleynhans et al. 2007, Kemper and Boucher 2008). Plots were laid out contiguously up the bank laterally through the extent of the riparian zone. The presence of terrestrial species indicated the outer boundary of the riparian zone. The centre of each vegetation transect was aligned along the hydraulic cross-sections surveyed by Dr Andrew Birkhead. The boundaries of each sample plot (for each lateral zone; marginal, lower and upper) were surveyed in on the cross-sections so that the location of each lateral zone could be related to flow using stage-discharge relationships.

The data on the structure of the vegetation community in each transect included:

- the number of lateral zones present;
- plant cover, estimated visually as a percentage for each plant species and maximum height of each species present in each zone;
- the number of woody trees in two height classes (<2.0 m saplings and >2.0 m trees); and
- the percentage frequency of the dominant substratum types in each vegetation plot.

Any species that could not be identified in the field was collected, pressed and submitted to the CE Moss Herbarium at the University of the Witwatersrand, South Africa for identification.

4.6.2 Data analysis

To facilitate comparison of the sparsely populated vegetation community data between EF sites, the percentage cover for each species recorded in each transect was converted to a percentage of the total cover recorded for that site. This allowed a ranking by cover per species, which was comparable across sites. The location of each lateral zone was transposed onto the cross sections and the upper and lower discharge limit of each zone determined using the rating curves and associated hydraulic data.

4.7 *RESULTS*

4.7.1 EF Site 1

Stropanthus cf. speciosus was the most commonly encountered and abundant shrub at EF Site 1. This shrub was situated in the rocky marginal area of the marginal zone that is inundated during the wet season. The next most abundant trees were *Diospyros mespiliformis, Combretum imberbe* and *Trichelia emetica,* all situated in the lower and upper zones above the median flood line.

Table 4.6 Dominant species by cover (T = total cover per species as a percentage of the total vegetation cover) and frequency of occurrence (F). Data are cover percentages per sample plot per species. L = left bank, R = right bank. m = marginal, l = lower and u = upper zone, sap = sapling.

Species	T	F	L-m	L-l	L-u	R-m	R-l	R-u
Stropanthus cf. speciosus	8	67	14	2		4	2	
Diospyros mespiliformis	11	50		2	10		20	
Combretum imberbe	12	33			12			22
Trichelia emetica	10	33			20			10
Gymnosporia senegalensis	8	33		12			12	
Panicum maximum	7	33		1	20			
Pentashistis sp1	7	33	11			9		
Cordia pillosissima	7	33			15			5
Ficus ingens	6	33				15	2	
Gymnosporia senegalensis sap	3	33		4			5	
Syzigium guineense sap	2	33				1	5	
Garcinia livingstonei sap	1	33	1	1				
Bridelia cathartica	5	17		15				
Garcinia livingstonei	4	17		12				
Bryophyta sp1	3	17	10					
Antidesma venosum	2	17					5	
Diospyros quiloensis	2	17						5
Diospyros mespiliformis sap	1	17		3				
Phyllanthus reticulatus	0	17	1					
Ehrharta sp1	0	17	1					

4.7.2 EF Site 2

Combretum imberbe and *Garcinia livingstonei* were the most frequently encountered trees at EF Site 2 and *C. imberbe,* along with *Cynodon dactylon,* were the most abundant species present, followed by *Phragmites mauritianus* and *Acacia nigrescens. P. mauritianus* and *C. dactylon* were situated in the marginal zone, *G. livingstonei* in the marginal and lower zones and the other species mentioned found in the lower or upper zone.

Table 4.7 Dominant species by cover (T = total cover per species as a percentage of the total vegetation cover) and frequency of occurrence (F). Data are cover percentages per sample plot per species. L = left bank, R = right bank. m = marginal, l = lower and u = upper zone, sap = sapling.

	T	F	L-m	L-l	L-u	R-m	R-l	R-u
Combretum imberbe	18	50		15	15		25	
Garcinia livingstonei	7	50	3	2			15	
Cynodon dactylon	17	33	30			20		
Phragmites mauritianus	12	33	25			10		
Acacia nigrescens	9	33		18	10			
Diospyros mespiliformis	7	33		15			5	
Panicum repens	5	33	5			10		
Colophospermum mopane	5	33			10			5
Stropanthus cf. speciosus	2	33	3			2		
Pentashistis sp1	1	33	2			2		
Gymnosporia senegalensis	3	17					10	
Gymnosporia senegalensis sap	2	17		5				
Adansonia digitata	2	17			5			
Salix mucronata sap	2	17				5		
Sesbania sesban	1	17	4					
Panicum maximum	1	17	3					
Cyperus sp1	1	17				3		
Bryophyta sp1	1	17				2		
Combretum imberbe sap	1	17						2
Cordia pillosissima	1	17					2	
Syzigium guineense sap	1	17		2				
Ficus capreifolia	1	17	2					
Triplochiton zambesiacus	1	17	2					
Afzelia quanensis	1	17					2	
Ehrharta sp1	0	17				1		
Diospyros mespiliformis sap	0	17	1					
Salix mucronata	0	17				1		

There were three discriminant species for each of the three zones (Table 4-8). Of these, the most common marginal zone graminoid *Phragmites mauritianus,* the marginal shrub

Stropanthus speciosus, the lower zone tree *Diospyris mespiliformis* and the upper zone tree *Combretum imberbe* were selected as indicators.

Table 4.8 Discriminating taxa for the three vegetation zones at both EF Sites.

Marginal zone	Lower zone	Upper zone
Phragmites mauritianus	***Diospyros mespiliformis***	***Combretum imberbe***
Cynodon dactylon	*Gymnosporia senegalensis*	*Colophospermum mopane*
Stropanthus cf. speciosus	*Garcinia livingstonei*	*Trichelia emetica*

4.8 *IDENTIFICATION OF INDICATORS*

Biophysical indicators are discipline-specific attributes of the river system that respond to a change in river flow by changing in their:

- abundance;
- concentration; or
- extent (area).

The indicators are used to characterise the current situation and changes that could occur with development-driven flow changes.

Within any one biophysical discipline, key attributes can be grouped if they are expected to respond in the same way to the flow regime of the river. For example, plant species that are tolerant of submersion and respond to increased moisture with increased growth rates and seed production may be grouped together as they would be expected to react to changes in the flow regime in the same way as one another. The discriminating taxa for the three vegetation zones determined in the vegetation analysis are provided in Table 4-8. From this, four species were chosen to represent four riparian indicators: marginal graminoids represented by *Phragmites australis* (common reed); marginal shrubs represented by *Stropanthus speciosus* (common poison rope); lower zone trees represented by *Diospyros mespiliformis* (Jackal-berry tree) and upper zone trees represented by *Combretum imberbe* (Leadwood tree).

Four other aquatic vegetation indicators were selected, in discussion with the other specialists, to provide linked indicators for important food sources of fish and macroinvertebrates. These were organic detritus, single-celled diatoms, filamentous green algae and Bryophyta sp1 (aquatic rock moss).

4.8.1 Indicator list for vegetation

There are eight vegetation indicators for this EF assessment and six of these were present in abundance at both EF Sites. *Phragmites mauritianus* was not observed at EF Site 1 but is expected to occur in the lower reaches of the gorge and so marginal graminoids were modelled in the same was using DRIFT as at EF Site 2; on the basis of their position and how this relates to discharge on the cross-sections. Bryophyta sp1 was scant at EF Site 2 and therefore not considered an important food source and so was not modelled there using DRIFT.

A list of species/features and their reason for selection as indicators in the EF assessments is given in Table 4-9. Their expected responses to flow changes are outlined in Table 4-10.

Table 4.9 Indicators and reasons for their selection.

Indicator (site)	Reasons for selection as indicator
Organic detritus	Organic detritus provides food for a number of fish species, especially *Labeo* spp.
Single-celled diatoms	Single-celled diatoms are an important food source for aquatic macroinvertebrates and fish.
Filamentous green algae	Filamentous green algae affect the quality of aquatic macroinvertebrate habitat and also provide an important food source for fish.
Bryophyta sp1. (aquatic rock moss)	Rock moss was prolific at EF Site 1 and would provide important habitat/holdfasts for aquatic macroinvertebrates during the wet season and may also provide a food source for fish.
Marginal graminoids (*Phragmites mauritianus*)	There were few marginal graminoids in the gorge but this group of plants were well established at EF Site 2 and provide important habitat for aquatic macroinvertebrates and crocodiles as well as cover for fish from predators.
Marginal shrubs (*Stropanthus cf. speciosus*)	Marginal shrubs were present at both EF Sites and also provide important habitat for aquatic macroinvertebrates and cover from predators for fish.
Lower zone trees (*Diospyros mespiliformis*)	Lower zone trees form the majority of the riparian zone at both EF Sites and occur with a mixture of shrubs. Many will provide fruit, woody and leaf material for a variety of terrestrial and aquatic organisms as well as providing nesting sites for birds.
Upper zone trees (*Combretum imberbe*)	Upper zone trees occur with terrestrial species on the outer edge of the riparian area and also provide fruit, woody and leaf material for a variety of terrestrial and aquatic organisms as well as providing nesting sites for birds.

Table 4.10 List of vegetation indicators and their predicted direction of response to flow changes.

Indicator	Definition	Predicted change	References
Organic detritus	Organic detritus comprises plant material such as leaves, twigs, bark, flowers and fruits, that fall in from the riparian canopy, or which are washed or blown in from surrounding landscapes.	The dam will trap detritus transported from the Barotse flood plain reducing that available in the gorge. A decrease in the abundance reduces food available to fish and macroinvertebrates.	Davies and Day 1998.

Indicator	Definition	Predicted change	References
Single-celled diatoms	Unicellular algae (Bacillariophyta) that are enclosed in a frustule made of silica.	Peaking flows will flush diatoms from the benthos retarding growth, preventing succession and reducing their abundance. A decrease in abundance reduces food available to fish and macroinvertebrates.	Bell 1992, Grimm and Fisher 1989, Holomuzki and Biggs 2006.
Filamentous green algae	Colonial green algae (Chlorophyta) that contain chloroplasts with chlorophyll a and b and have cellulose cell walls.	The dam will trap nutrients transported from the Barotse flood plain. Peaking flows will flush green algae from the benthos retarding growth. A decrease in abundance reduces food available to fish.	Bell 1992, Biggs and Thomsen 1995, Ewart-Smith 2012.
Bryophtya sp1. (aquatic rock moss)	Small flowerless plants that do not have vascular tissue and grow in dense clumps/mats on rocks at the water's edge.	Rock moss grows slowly and when wet. Peaking flows are expected to increase the abundance of Bryophyta sp1. An increase in abundance provides habitat for macroinvertebrates.	Chambers et al. 1991, Bell 1992, Englund 1991, Vanderpoorten and Klein 2000.
Marginal graminoids (*Phragmites mauritianus*)	Graminoids (grasses, sedges and rushes) that grow in the marginal zone of the riparian area (Figure 4-1). These plants are reliant upon regular (seasonal) inundation.	Marginal graminoids are dormant in the dry season but grow in response to wetting in other seasons. Peaking flows (alone) will favour their growth if the lateral bars upon which they grow remain in place. An increase in extent provides habitat for fish and macroinvertebrates.	Kotschy et al. 2000, Kotschy and Rogers 2008, Reinecke 2013.
Marginal shrubs (*Stropanthus cf. speciosus*)	Woody plants (trees and shrubs) that grow in the marginal zone of the riparian area (Figure 4-1). These plants are reliant upon regular (seasonal) inundation.	Marginal shrubs grow in response to wetting. Peaking flows (alone) will favour their growth if the lateral bars upon which they grow remain in place. An increase in extent provides habitat for fish and macroinvertebrates.	Goldblatt and Manning 2000, Coates Palgrave 1977, Reinecke 2013.
Lower zone trees (*Diospyros mespiliformis*)	Woody plants that grow in the lower zone of the riparian area (Figure 4-1). These plants are favoured by regular inundation but not reliant upon it.	Lower zone trees grow in response to wetting and an increase in nutrient supply from floods. Peaking is expected to favour their growth. An increase in extent provides cover and browsing for terrestrial vertebrates.	Curtis and Manheimer 2005, van Wyk and van Wyk 2009, Reinecke 2013.

Indicator	Definition	Predicted change	References
Upper zone trees (*Combretum imberbe*)	Woody plants that grow in the upper zone of the riparian area (Figure 4-1). These plants are dessication tolerant and can grow just as well in a terrestrial environment.	Upper zone trees would be favoured by increased wetting but peaking is not expected to reach into this zone. No changes are expected.	Curtis and Manheimer 2005, van Wyk and van Wyk 2009, Reinecke 2013.

4.8.2 Description and location of indicators

4.8.2.1 Organic detritus

Organic detritus comprises plant material such as leaves, twigs, bark, flowers and fruits, that fall in from the riparian canopy, or which are washed or blown in from surrounding terrestrial vegetation (Davies and Day 1995). Organic detritus breaks down and provides nutrients for the growth of diatoms and filamentous green algae (Larned et al. 2004) but also is a food source for grazing fish such as *Labeo* species (Tweddle pers. comm.). A large supply of organic detritus is picked up through the Barotse flood plain during the wet season and transported into the gorge. During flood-onset this organic detritus, along with other localised supplies from gorge trees and shrubs, are transported through the gorge and deposited into the channel, backwater areas, pools and or other marginal aquatic habitats.

4.8.2.2 Single celled diatoms

Diatoms are unicellular algae (Bacillariophyta) that are enclosed in a frustule made of silica (Bell 1992). Together with other algae (see below) they form a component of the periphyton that grown on benthic substrata in the aquatic zone of the river channel (Ewart-Smith 2012). Diatoms convert dissolved nutrients into a food source for other aquatic organisms (Biggs 1996) and are grazed by snails (Rosemund et al. 1993), aquatic macroinvertebrates (Steinman et al. 1991), crustaceans (Pringle et al. 1993), tadpoles (Petersen and Boulton 1999) and fish (Power and Mathews 1983). Diatoms grow well under conditions of low nutrients, light and temperature and are primarily controlled by changes in flow (Ewart-Smith 2012). Floods disturb diatoms in a number of ways. They turn over benthic substrata upon which diatoms grow (Grimm and Fisher 1989); they entrain suspended sediments that scour diatoms from the surface of benthic rocks (Webb et al. 2006) and shear stress directly scours diatoms from the rock surfaces (Biggs and Thomsen 1995). In this way, flood disturbance overrides any positive effects of nutrients, temperature or light. Diatoms proliferate during the dry season when current velocities are low and if these periods persist for longer than 1 month different successional communities of diatom may develop (Yang et al. 2009). A low but constant biomass can persist under conditions of frequent flooding (up to 10 days) as diatoms are constantly scoured/flushed away and thus prevented from accruing biomass (Biggs 1995).

4.8.2.3 *Filamentous green algae*

Filamentous green algae (Chlorophyta) are colonial and contain chloroplasts with chlorophyll a and b and have cellulose cell walls (Bell 1992). Like diatoms, they form a component of the periphyton that converts available nutrients into a food source for a range of aquatic organisms and proliferate when velocities are lower in the dry season (see above). Unlike diatoms, they are favoured under conditions of increased light, temperature and/or nutrients (Hill 1996, Wilde and Tilly 1981) and are slower to recover from the disturbances associated with floods (Ewart-Smith 2012).

4.8.2.4 *Bryophyta sp1.*

Bryophytes are small flowerless plants that do not have vascular tissue and grow in dense clumps/mats on rocks (Bell 1992) at the water's edge. Aquatic bryophytes are well adapted to the forces of flowing water (Miler et al. 2012) and tend to dominate in habitats characterised by high flow velocities (Vanderpoorten and Klein 2000). The frequency of inundation at the bankfull discharge does not influence bryophytes (Suren and Duncan 1999) rather their distribution is associated with substrate stability, the key driver separating habitats for bryophtyes versus those suited to aquatic macrophytes (Chambers et al. 1991). Bryophytes attach directly to large substrates and require long periods of substrate stability to establish (Englund 1991).

4.8.2.5 *Marginal graminoids (Phragmites mauritianus)*

Marginal graminoids (grasses, sedges and rushes) grow in the marginal zone of the riparian area (Figure 4-1) and are reliant upon regular (seasonal) inundation (Reinecke 2013). *Phragmites mauritianus* is an obligate riparian plant with an extensive root system, which consolidates and maintains bank stability (Kotschy and Rogers 2008). It is also known for its aggressive and persistent survival strategies, which include vegetative growth through creeping runners that root at regular intervals (Brown et al. 2005). Dispersal occurs most successfully via vegetative diaspores (stem fragments) broken from the plant during flood events. The diaspores are able to root on sandy banks or newly cleared/disturbed areas (Kotschy et al. 2000). *P. mauritianus* will tolerate seasonal drying, is dormant during the dry season (Cross and Fleming 1989), can extend vegetative stems rapidly towards new areas of moisture and flowers in late spring and fruits in autumn (Fanshawe 1972).

Figure 4.6 ***Phragmites mauritianus*, selected indicator for marginal zone graminoids.**

4.8.2.6 Marginal shrubs (Stropanthus cf. speciosus)

Marginal woody plants (trees and shrubs) grow in the marginal zone of the riparian area (Figure 4-1) and are reliant upon regular (seasonal) inundation. *Stropanthus cf. speciosus* was the dominant shrub at EF Site 1 growing in the bare rock of the marginal zone. This plant is common at forest margins (van Wyk and van Wyk 2009) and flowers from September to October thereafter releasing wind-dispersed seeds (Coates Palgrave 1977). At EF Site 2, this shrub was present on the alluvial lateral bars and co-occurred with *Salix mucronata* and *Ficus capreifolia,* both pioneering riparian trees that are also well adapted to the regular inundation of their marginal zone habitats by being flexible (Reinecke 2013), good bank stabilisers (Karrenberg et al. 2002) and being able to disperse asexually via vegetative diaspores (Nilsson and Svedmark 2002).

Figure 4.7 ***Stropanthus cf. speciosus*, selected indicator for marginal woody plants.**

4.8.2.7 *Lower zone trees (Diospyros mespiliformis)*

Diospyros mespiliformis is a woody plant that grows in the lower zone of the riparian area (Figure 4-1). These plants are favoured by regular inundation but not reliant upon it (Reinecke 2013). *Diospyros mespiliformis* grows in the lower zone on the edge of lateral bars, which consist of cobbles and a surface layer of alluvial washed fines or sand (van Wyk and van Wyk 2009). *Diospyros mespiliformis* is a tall tree, found on the banks of rivers and on floodplains, that flowers from August to January during the dry season and into flood-onset and fruits over flood recession (Curtis and Manheimer 2005). The plants respond to increased soil moisture by increasing flowering and seed set (Curtis and Mannheimer 2005). Livestock, game and humans eat the fruits and the twigs and the bark is used medicinally (Coates Palgrave 1977, Van Wyk and van Wyk 1997).

Figure 4.8 ***Diospyros mespiliformis*, selected indicator for lower zone trees.**

4.8.2.8 *Upper zone trees (Combretum imberbe)*

Combretum imberbe is a woody tree that grows in the upper zone of the riparian area (Figure 4-1). These plants are desiccation tolerant and can grow just as well in a terrestrial environment (van Wyk and van Wyk 2009) as they are found growing in bushveld, alluvial sands along perennial and ephemeral rivers. It is tolerant of a wide range of soil conditions and flowers from November to February, fruiting all year round but mostly from December to June (Curtis and Manheimer 2005). This species also responds to increases in moisture by increasing seed production, such as during rainy periods. *Combretum imberbe* is utilised for fuel and construction materials in many parts of Africa.

Figure 4.9 *Combretum imberbe*, **selected indicator for upper zone trees.**

4.8.3 Linked indicators

Motivation for all linked indicators is provided in Table 4-11.

Table 4.11 Linked indicators and motivations

Indicator	Linked indicator	Motivation
Organic detritus	Dry duration Dry min 5-d Q Wet duration Wet average daily volume Dry within day range T1 within day range T2 within day range Q Wet mean fine suspended sediments	Deciduous leaves enter the river in the dry season. High flows in the dry season pick up riparian detritus. More detritus transported over a longer wet season. High flows in the wet season pick up riparian detritus. Continuous peaking scours and denudes detritus. Continuous peaking scours and denudes detritus. Continuous peaking scours and denudes detritus. Organic detritus is suspended at similar discharges.

Indicator	Linked indicator	Motivation
Single-celled diatoms	Dry duration Dry min 5-d Q Wet duration Wet average daily volume Dry within day range T1 within day range T2 within day range Q Wet mean coarse suspended sediments Wet mean fine suspended sediments Nutrients	Benthic diatoms proliferate in the dry season. High flows inundate more marginal habitat for growth. More diatoms are scoured over longer wet seasons. High flows disturb inundated rocks and scour diatoms. Continuous peaking scours and denudes diatoms. Continuous peaking scours and denudes diatoms. Continuous peaking scours and denudes diatoms. Coarse suspended sediments scour diatoms. Fine suspended sediments increase water turbidity. Nutrients influence growth of diatoms.
Filamentous green algae	Dry duration Dry min 5-d Q Wet duration Wet average daily volume Dry within day range T1 within day range T2 within day range Q Wet mean coarse suspended sediments Wet mean fine suspended sediments Temperature Nutrients	Filamentous green algae proliferate in the dry season. High flows inundate more marginal habitat for growth. More greens are scoured over longer wet seasons. High flows disturb inundated rocks and scour greens. Continuous peaking scours and denudes greens. Continuous peaking scours and denudes greens. Continuous peaking scours and denudes greens. Coarse suspended sediments scour greens. Fine suspended sediments increase water turbidity. Temperature influences growth of filamentous greens Nutrients influence growth of filamentous greens.
Bryophyta	Dry duration Dry min 5-d Q Wet duration Wet max 5-d Q Dry within day range T1 within day range T2 within day range Q Wet mean coarse suspended sediments Wet mean fine suspended sediments	Rock moss is exposed and dries out in the dry season. Higher flows inundate rock moss and it grows. More rock moss is scoured over a long wet season. High flows scour rock moss. Continuous peaking favours growth. Continuous peaking favours growth. Continuous peaking favours growth. Coarse suspended sediments scour rock moss. Fine suspended sediments increase turbidity.
Marginal graminoids	Dry duration Dry min 5-d Q Wet duration Wet max 5-d Q Dry maximum instantaneous Q T1 maximum instantaneous Q T2 maximum instantaneous Q Wet mean fine suspended sediments Length cut banks Vegetated mid-channel bars	Plants are dormant in the dry season. Plants incur desiccation stress in the dry season. More flushing takes place over a longer wet season. High flows flush marginal graminoids from the banks. Continuous peaking does not favour growth (dormant). Continuous peaking favours growth. Continuous peaking favours growth. Fine sediments carry nutrients that boost plant growth. Marginal graminoids inhabit lateral bars. Marginal graminoids inhabit vegetated bars.
Marginal shrubs	Dry duration Dry min 5-d Q Wet duration Wet max 5-d Q	Less stress occurs over a shorter dry season. Plants incur desiccation stress in the dry season. More flushing takes place over a longer wet season. High flows flush marginal shrubs/trees from the banks.

Indicator	Linked indicator	Motivation
	Dry maximum instantaneous Q T1 maximum instantaneous Q T2 maximum instantaneous Q Wet mean fine suspended sediments Length cut banks Vegetated mid-channel bars	Continuous peaking favours growth. Continuous peaking favours growth. Continuous peaking favours growth. Fine sediments carry nutrients that boost plant growth. Marginal shrubs/trees inhabit lateral bars. Marginal shrubs/trees inhabit vegetated bars.
Lower zone trees	Dry duration Wet duration Wet max 5-d Q Dry maximum instantaneous Q T1 maximum instantaneous Q T2 maximum instantaneous Q Wet mean fine suspended sediments	Less stress occurs over a shorter dry season. More flushing takes place over a longer wet season. High flows flush saplings from the banks. Continuous peaking favours growth slightly. Continuous peaking favours growth slightly. Continuous peaking favours growth slightly. Fine sediments carry nutrients that boost plant growth.
Upper zone trees	Wet max 5-d Q Wet duration	Growth and reproduction favoured by high flows. More wetting takes place over longer wet season.

4.9 *ASSUMPTIONS AND LIMITATIONS*

The study was limited in the extent to which observations could be made in the gorge as most of the gorge was inaccessible. The Google Earth imagery for the lower parts of the gorge were also of poor quality and this limited the extent to which generalisations about plant distribution and habitat types could be made along the gorges length. This was especially important for the assumptions about the extent to which marginal graminoids were present in the lower gorge and absent from the upper gorge.

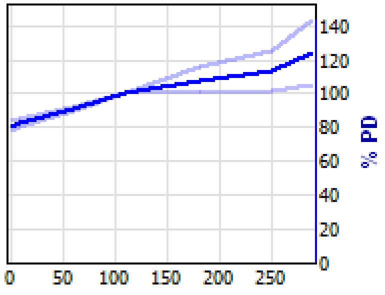
4.10 *MOTIVATIONS FOR RESPONSE CURVES: EF SITE 2*

4.10.1 Organic detritus

<table>
<tr><td colspan="2">Organic detritus</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry season duration [D season]

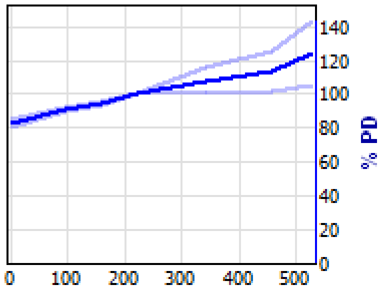
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.100</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>-1.000</td></tr>
<tr><td></td><td>58.75</td><td>-0.500</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>1.500</td></tr>
</table>



</td><td>Many terrestrial and some riparian trees are deciduous and lose their leaves during the dry season when they enter growth dormancy (Davies and Day 1998). A longer dry season will contribute more leaf fine/coarse particulate matter into the river.</td><td>3</td></tr>
<tr><td>

☑ Dry season Min 5d Q [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-0.500</td></tr>
<tr><td></td><td>157.39</td><td>-0.300</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>1.000</td></tr>
<tr><td>Max</td><td>527.41</td><td>1.500</td></tr>
</table>

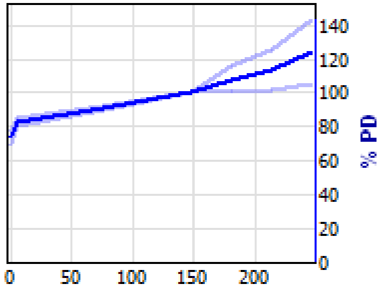


</td><td>The marginal zone is inundated at discharges between 480-2500 cumecs. Inundation of the marginal zone will pick up fine/coarse particulate matter from the riparian area and transport it into the river channel (Naiman et al. 2005). Greater discharges will lift coarse/fine particulate matter from channel bed and into the water column. Smaller discharges will not entrain fine/coarse particulate matter.</td><td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Organic detritus</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Wet season duration [F season]

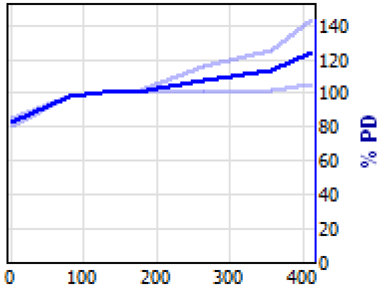
Desc	days	Y
Min	0.00	-1.500
MinPD	5.00	-1.000
	76.00	-0.500
Median	147.00	0.000
	180.50	0.500
Max PD	214.00	1.000
Max	246.10	1.500



</td><td>A longer wet season will carry/scour more particulate matter from the riparian area (Naiman et al. 2005). A shorter wet season will result in less particulate matter being delivered into the channel.</td><td>3</td></tr>
<tr><td>

Wet season ave daily vol [F season]

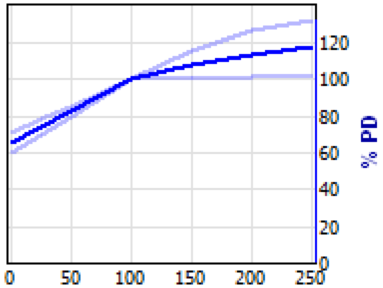
Desc	Mm3/d	Y
Min	0.00	-1.000
MinPD	78.41	-0.100
	124.02	0.000
Median	169.63	0.000
	263.51	0.500
Max PD	357.40	1.000
Max	411.01	1.500



</td><td>Inundation of the riparian area picks up and delivers fine/coarse particulate matter to the river (Naiman et al. 2005). Greater discharges reach further into the riparian area covering a larger area and providing more particulates. Lower than median will reduce that available compared to PD.</td><td>4</td></tr>
<tr><td>

Wet: mean Fine suspended sediment [F season]

Desc	ppm	Y
Min	0.00	-2.000
MinPD	25.00	-1.500
	50.00	-1.000
Median	100.00	0.000
	150.00	0.500
Max PD	200.00	1.000
Max	250.00	1.200

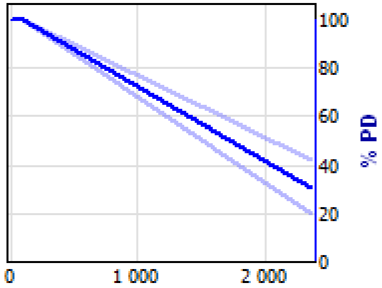


</td><td>Detritus is transported along with suspended sediments in the water column. A reduction in suspended fines correlates to a reduction in detritus.</td><td>2</td></tr>
</table>

<table>
<tr><td colspan="2">Organic detritus</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Dry within day range [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.000</td></tr>
</table>



</td><td>Peaking during the dry season at 2,500 cumecs inundates the entire marginal zone. Continuous inundation of the marginal zone will flush all organic particulate matter downstream leaving little available as a food source for biota.</td><td>3</td></tr>
<tr><td>

T1 within day range [T1 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.000</td></tr>
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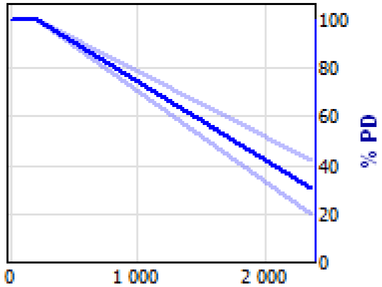

</td><td>Peaking during the T1 season at 2,500 cumecs inundates the entire marginal zone. Continuous inundation of the marginal zone will flush all organic particulate matter downstream leaving little available as a food source for biota.</td><td>3</td></tr>
<tr><td>

T2 within day range [T2 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
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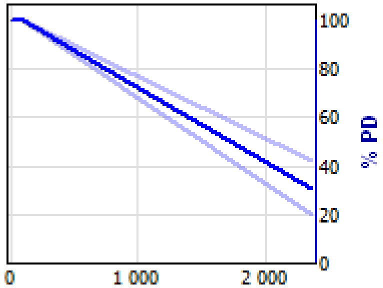
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.000</td></tr>
</table>



</td><td>Peaking during the T2 season at 2,500 cumecs inundates the entire marginal zone. Continuous inundation of the marginal zone will flush all organic particulate matter downstream leaving little available as a food source for biota.</td><td>3</td></tr>
</table>

4.10.2 Single-celled diatoms

<table>
<tr><td colspan="2">Single-celled diatoms</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Dry season duration [D season]

<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
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<tr><td>Max PD</td><td>251.00</td><td>1.500</td></tr>
<tr><td>Max</td><td>288.65</td><td>2.000</td></tr>
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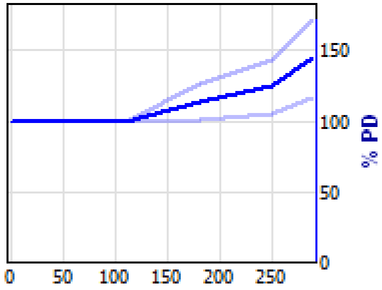

</td><td>Benthic diatoms grow best in the dry season (Ewart-Smith 2012), a longer dry season favours growth. Diatoms grow rapidly and turn over growth cycles within years.</td><td>4</td></tr>
<tr><td>

Dry season Min 5d Q [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-1.500</td></tr>
<tr><td></td><td>157.39</td><td>-0.500</td></tr>
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<tr><td>Max PD</td><td>458.62</td><td>2.000</td></tr>
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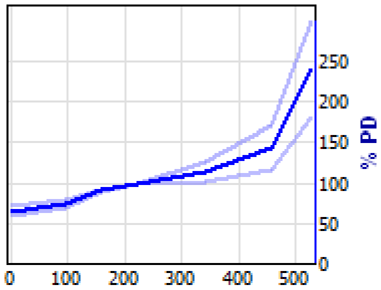

</td><td>Diatoms grow in the aquatic zone (Biggs 1996) and larger discharges inundate more rocky benthic habitat upon which they grow. Lower discharges reduce the habitat available. Reduced flow reduces disturbance and favours a shift from edible unicellular diatoms to filamentous inedible diatoms.</td><td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Single-celled diatoms</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>☑ Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.000</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>1.500</td></tr>
<tr><td></td><td>76.00</td><td>1.000</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
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<tr><td>Max PD</td><td>214.00</td><td>-2.000</td></tr>
<tr><td>Max</td><td>246.10</td><td>-3.000</td></tr>
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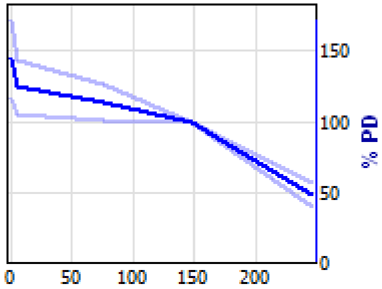
</td><td>Floods scour diatoms from the benthic rocks upon which they grow (Biggs and Thomsen 1995). The period over which flood scour exerts an influence is minimised over a short wet season and maximised over a longer wet season. Diatom growth is favoured by shorter wet seasons.</td><td>4</td></tr>
<tr><td>☑ Wet season ave daily vol [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.000</td></tr>
<tr><td>MinPD</td><td>78.41</td><td>0.500</td></tr>
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<tr><td>Median</td><td>169.63</td><td>0.000</td></tr>
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<tr><td>Max PD</td><td>357.40</td><td>-1.500</td></tr>
<tr><td>Max</td><td>411.01</td><td>-2.000</td></tr>
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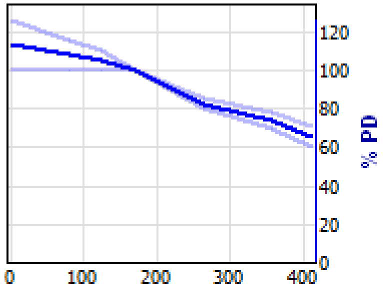
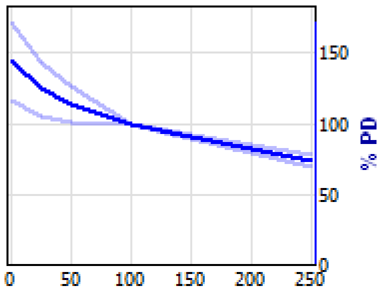

</td><td>Floods scour diatoms from the benthic rocks upon which they grow (Biggs and Thomsen 1995). The period over which flood scour exerts an influence is minimised over a short wet season and maximised over a longer wet season. Diatom growth is favoured by shorter wet seasons.</td><td>4</td></tr>
<tr><td>☑ Wet: mean Coarse suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>1.500</td></tr>
<tr><td></td><td>50.00</td><td>1.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>-1.500</td></tr>
</table>

</td><td>Suspended coarse sediments act like sand paper scouring benthic diatoms from the surface of inundated rocks (Grimm and Fisher 1989). An increase in suspended coarse sediments will reduce benthic diatom abundance. A decrease in suspended coarse sediments favours the growth of diatoms.</td><td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Single-celled diatoms</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>☑ Wet: mean Fine suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>1.000</td></tr>
<tr><td></td><td>50.00</td><td>0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>-1.500</td></tr>
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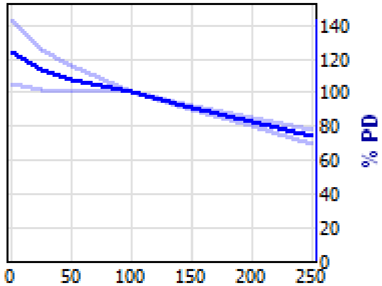
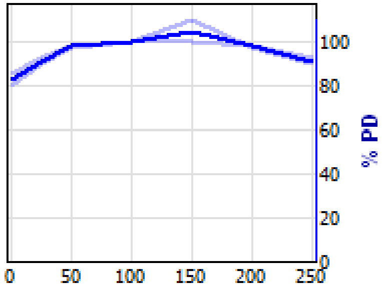
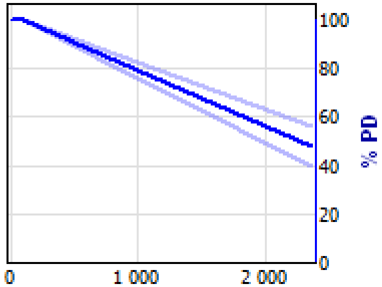
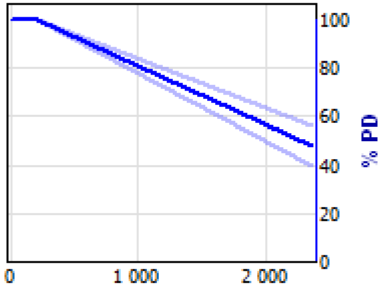
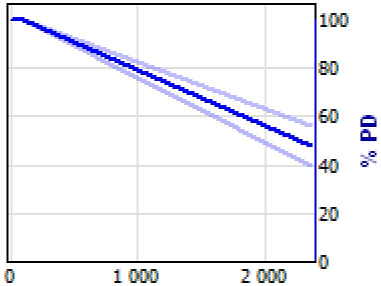

</td><td>Fine suspended sediments increase water turbidity which decreases light penetration, reduced light into the water column decreases diatom growth (Hill 1996). Reduced turbidity favours growth of diatoms.</td><td>2</td></tr>
<tr><td>☐ Nutrients [All seasons]
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.100</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.500</td></tr>
</table>

</td><td>CAN BE SWITCHED ON IF AVAILABLE. An increase in nutrients will favour diatom growth up to a point beyond which the surplus of nutrients favours green algae over diatoms (Ewart-Smith 2012). A reduction in nutrients will reduce the abundance of unicellular diatoms.</td><td>2</td></tr>
<tr><td>☑ Dry within day range [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>

</td><td>Diatoms require stable substrata upon which to grow (Holomuzki and Biggs 2006) and are scoured from rocks by shear stress (Biggs and Thomsen 1995). Continual inundation during the dry season disturb and flush diatoms downstream reducing their abundance.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Single-celled diatoms</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>T1 within day range [T1 season]
<table>
<tr><td>Desc</td><td>m3/s</td><td>Y</td></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>


</td><td>Diatoms require stable substrata upon which to grow (Holomuzki and Biggs 2006) and are scoured from rocks by shear stress (Biggs and Thomsen 1995). Continual inundation during the transitional season 1 disturbs and flushes diatoms downstream reducing their abundance.</td><td>3</td></tr>
<tr><td>T2 within day range [T2 season]
<table>
<tr><td>Desc</td><td>m3/s</td><td>Y</td></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>


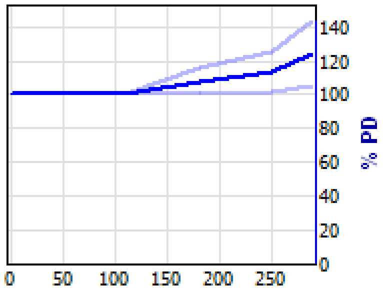
</td><td>Diatoms require stable substrata upon which to grow (Holomuzki and Biggs 2006) and are scoured from rocks by shear stress (Biggs and Thomsen 1995). Continual inundation during the transitional season 2 disturbs and flushes diatoms downstream reducing their abundance.</td><td>3</td></tr>
</table>

4.10.3 Filamentous green algae

<table>
<tr><td colspan="2">Filamentous green algae</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Dry season duration [D season]

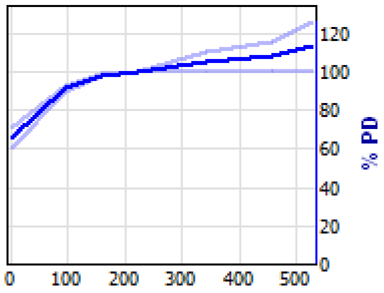
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>0.000</td></tr>
<tr><td></td><td>58.75</td><td>0.000</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>1.500</td></tr>
</table>



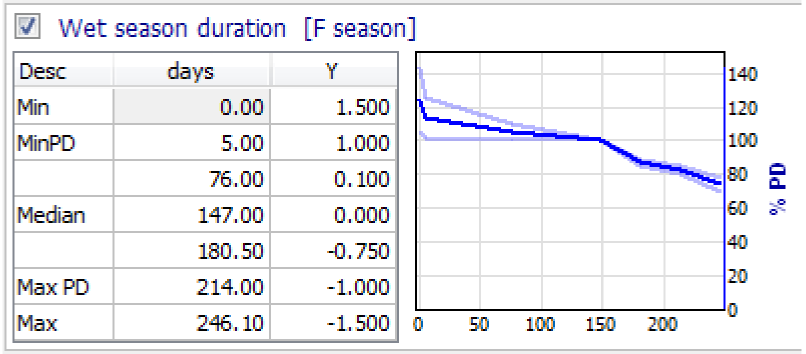
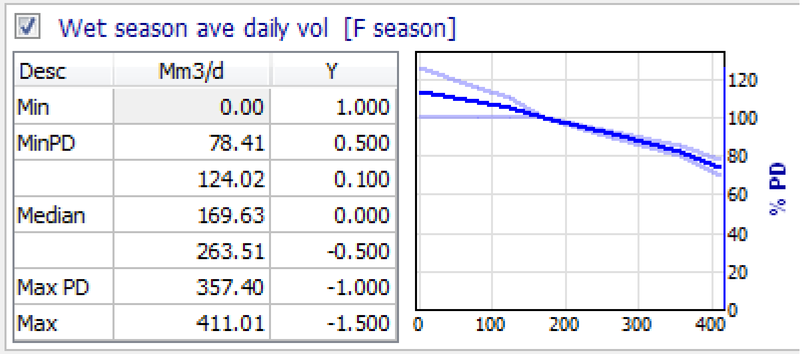
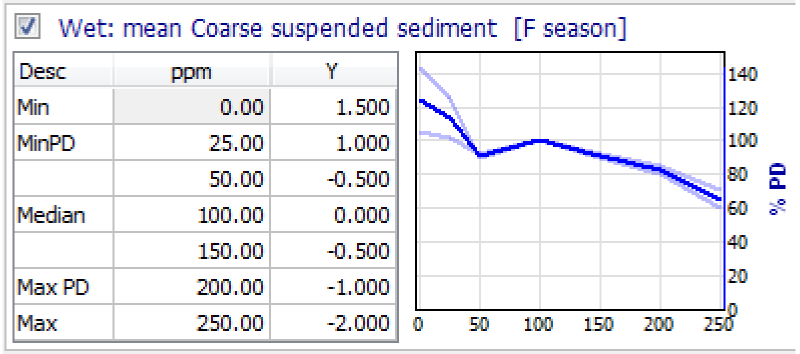
</td><td>Green algae grow best in the dry season (Ewart-Smith 2012) when flows are low; a longer dry season favours growth.</td><td>4</td></tr>
<tr><td>

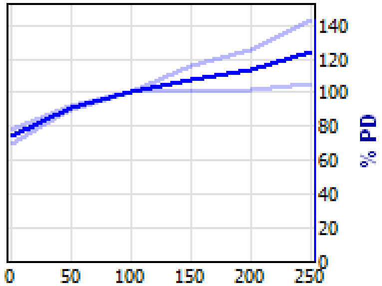
Dry season Min 5d Q [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-0.500</td></tr>
<tr><td></td><td>157.39</td><td>-0.100</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>0.500</td></tr>
<tr><td>Max</td><td>527.41</td><td>1.000</td></tr>
</table>



</td><td>Green algae grow on benthic (inundated) rocks (Biggs 1996). At lower discharges a smaller area of benthic substrata are inundated. Greater dry season discharges inundate a wider area of benthic substrata upon which green algae may grow.</td><td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Filamentous green algae</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
</td><td>Floods scour algae from the benthic rocks upon which they grow (Biggs and Thomsen 1995). The period over which flood scour exerts an influence is minimised over a short wet season and maximised over a longer wet season. Growth of green algae is favoured by shorter wet seasons.</td><td>4</td></tr>
<tr><td>
</td><td>At discharges lower than 1000 cumecs, the marginal area is inundated providing a greater area of benthic substrata upon which green algae may grow. At higher discharges bed sediments turn over disturbing algal communities and also scouring them from the rocks (Biggs and Thomsen 1995).</td><td>4</td></tr>
<tr><td>
</td><td>Suspended coarse sediments act like sand paper scouring green algae from the surface of inundated rocks (Grimm and Fisher 1989). An increase in suspended coarse sediments reduced algal abundance. A decrease in suspended coarse sediments favours the growth of algae.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Filamentous green algae</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Wet: mean Fine suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.500</td></tr>
</table>


</td><td>Fine suspended sediments increase water turbidity which decreases light penetration, reduced light into the water column decreases diatom growth (Hill 1996). Reduced turbidity favours growth of algae.</td><td>2</td></tr>
<tr><td>
Temperature [All seasons]
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.500</td></tr>
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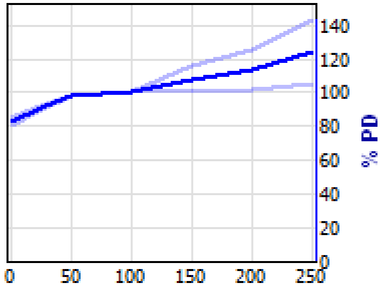
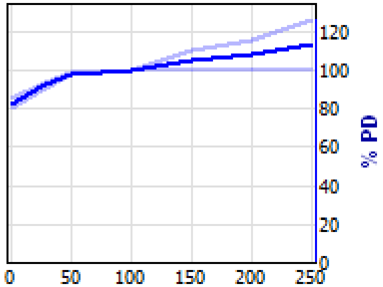
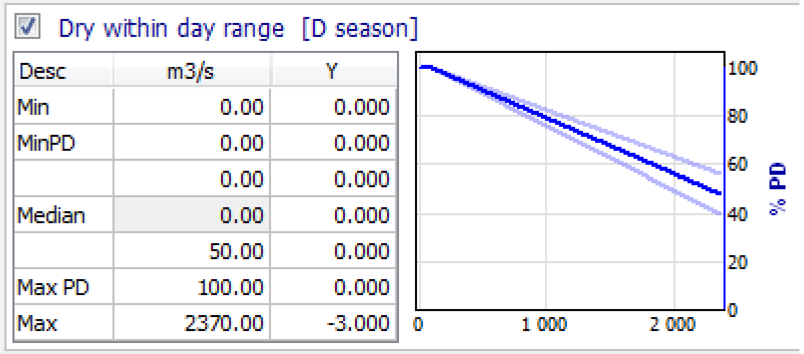
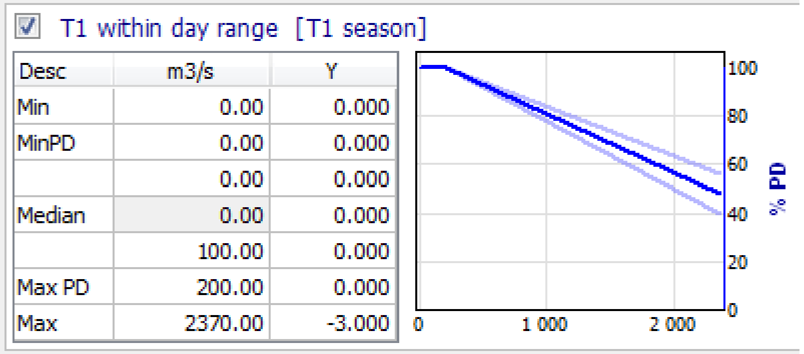
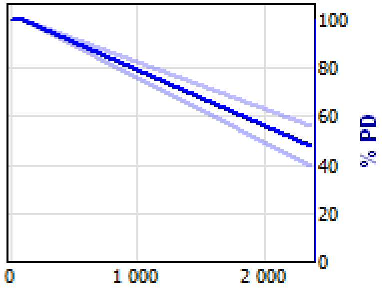


</td><td>CAN BE SWITCHED ON IF REQUIRED. Increases in temperature favour growth of green algae (De Nicola 1996). Growth is hindered at lower temperatures.</td><td>2</td></tr>
<tr><td>
Nutrients [All seasons]
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.000</td></tr>
</table>


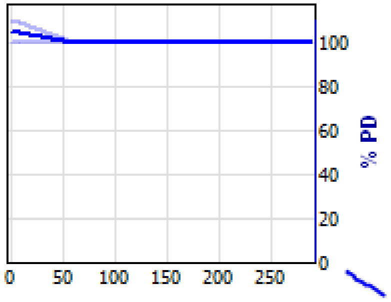
</td><td>CAN BE SWITCHED ON IF REQUIRED. An increase in nutrients will favour algal growth (Ewart-Smith 2012). A reduction in nutrients will reduce the abundance of green algae.</td><td>2</td></tr>
</table>

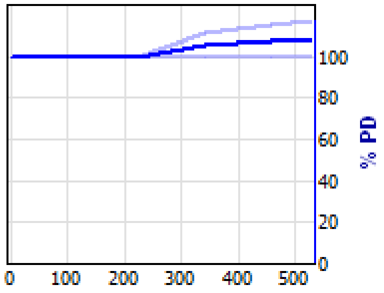
<table>
<tr><td colspan="2">Filamentous green algae</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td></td><td>Green algae require stable substrata upon which to grow (Holomuzki and Biggs 2006) and are scoured from rocks by shear stress (Biggs and Thomsen 1995). Continual inundation during the dry season disturbs and flushes algae downstream reducing their abundance.</td><td>3</td></tr>
<tr><td></td><td>Green algae require stable substrata upon which to grow (Holomuzki and Biggs 2006) and are scoured from rocks by shear stress (Biggs and Thomsen 1995). Continual inundation during the T1 season disturbs and flushes algae downstream reducing their abundance.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Filamentous green algae</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
T2 within day range [T2 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>


</td><td>Green algae require stable substrata upon which to grow (Holomuzki and Biggs 2006) and are scoured from rocks by shear stress (Biggs and Thomsen 1995). Continual inundation during the T2 season disturbs and flushes algae downstream reducing their abundance.</td><td>3</td></tr>
</table>

4.10.4 Bryophta sp1. (EF Site 1 only)

<table>
<tr><td colspan="2">Bryophyta sp1.</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.100</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>0.050</td></tr>
<tr><td></td><td>58.75</td><td>0.000</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>0.000</td></tr>
</table>


</td><td>This moss is adapted to drying out and is dormant during the dry season (pers. obs). Rock mosses growth and reproduction is favoured over a shorter dry season.</td><td>2</td></tr>
<tr><td>
Dry season Min 5d Q [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>0.000</td></tr>
<tr><td></td><td>157.39</td><td>0.000</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>0.500</td></tr>
<tr><td>Max</td><td>527.41</td><td>0.600</td></tr>
</table>


</td><td>The rock moss is inundated between 200-600 cumecs. The moss dries out and is dormant when dry (pers. obs.). Growth and reproduction takes place when inundated. The moss grows slowly and spreads slowly mainly by vegetative reproduction (Bell 1992).</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Bryophyta sp1.</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Wet season Max 5d Q [F season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>0.500</td></tr>
<tr><td></td><td>2109.13</td><td>0.100</td></tr>
<tr><td>Median</td><td>3309.19</td><td>0.000</td></tr>
<tr><td></td><td>6372.37</td><td>-1.000</td></tr>
<tr><td>Max PD</td><td>9435.56</td><td>-1.500</td></tr>
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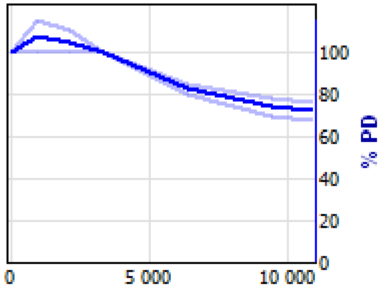
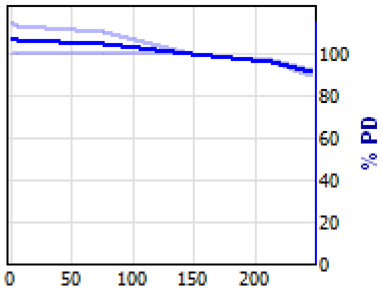


</td><td>The rock moss is inundated between 200-600 cumecs. Growth and reproduction takes place when inundated (Bell 1992). The force of a large flood scours the moss from the rocks and turns rocks over which disturb the moss (Suren and Duncan 1999).</td><td>3</td></tr>
<tr><td>

Wet season duration [F season]

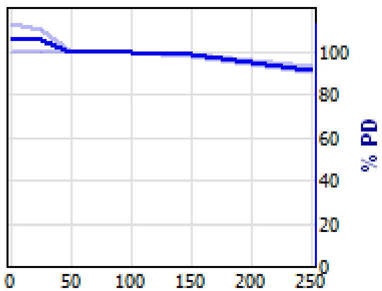
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.500</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>0.400</td></tr>
<tr><td></td><td>76.00</td><td>0.100</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>-0.200</td></tr>
<tr><td>Max</td><td>246.10</td><td>-0.500</td></tr>
</table>



</td><td>Rock moss are scoured from the rocks during high flows (Suren and Duncan 1999). Less scouring takes place occurs over a shorter wet season and more scouring takes place during a longer wet season.</td><td>3</td></tr>
<tr><td>

Wet: mean Coarse suspended sediment [F season]

<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.300</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.100</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.300</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.500</td></tr>
</table>



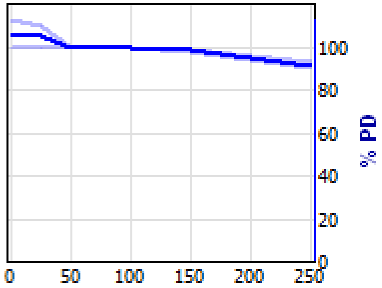
</td><td>Coarse suspended sediment particles act like sandpaper and increase the scouring force of the floods (Suren and Duncan 1999). Greater coarse suspended sediment loads = greater scouring force. Less coarse sediment favours growth.</td><td>3</td></tr>
</table>

Bryophyta sp1.

Response curve | **Explanation** | **Confidence**

☑ Wet: mean Fine suspended sediment [F season]

Desc	ppm	Y
Min	0.00	0.300
MinPD	25.00	0.100
	50.00	0.000
Median	100.00	0.000
	150.00	-0.100
Max PD	200.00	-0.300
Max	250.00	-0.500

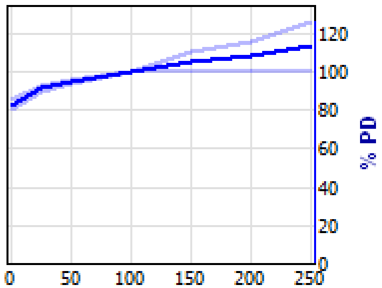


Explanation: Suspended fines make water turbid so an increase in the suspended sediment load will limit light penetrating into the water column (Hill 1996). Reduced light will hinder growth of inundated rock moss. Less suspended sediment will favour growth of inundated rock moss.

Confidence: 2

☐ Nutrients [All seasons]

Desc	%baseline	Y
Min	0.00	-1.000
MinPD	25.00	-0.500
	50.00	-0.300
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	0.500
Max	250.00	1.000

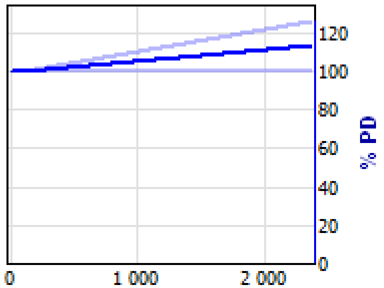


Explanation: MAY BE TURNED ON IF BECOME AVAILABLE. Increased nutrients stimulate growth of the rock moss (Larned et al. 2004). A surplus of nutrients will favour rock moss growth. A decrease in nutrients will hinder rock moss growth.

Confidence: 2

☑ Dry within day range [D season]

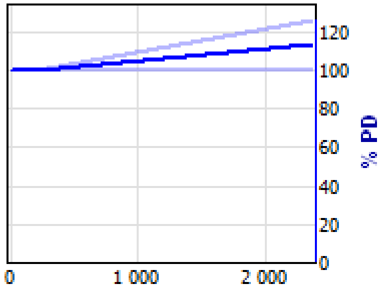
Desc	m3/s	Y
Min	0.00	0.000
MinPD	0.00	0.000
	0.00	0.000
Median	0.00	0.000
	50.00	0.000
Max PD	100.00	0.000
Max	2370.00	1.000

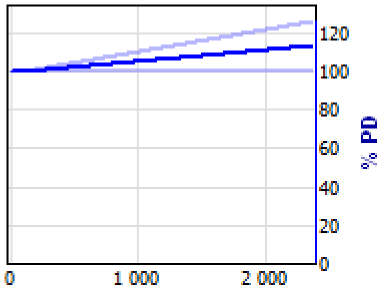


Explanation: Continual wetting of rock moss favours growth (Bell 1992). Peaking at 2,500 cumecs inudates most of the marginal zone (upper limit 3000 cumecs) that consists of rocks available as benthic habitat for the rock moss. This discharge is not large enough to effect scouring. Continual inundation favours growth of the rock moss.

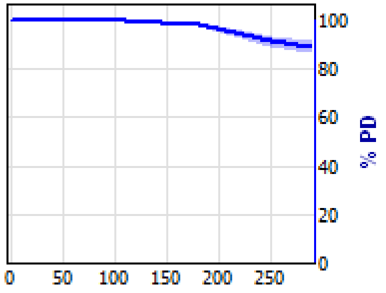
Confidence: 3

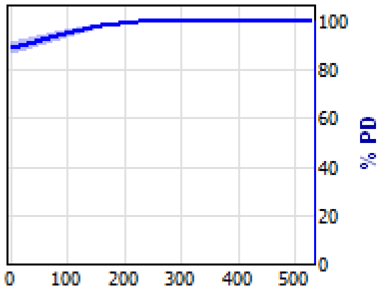
<table>
<tr><td colspan="2">Bryophyta sp1.</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>T1 within day range [T1 season]

Desc | m3/s | Y
Min | 0.00 | 0.000
MinPD | 0.00 | 0.000
 | 0.00 | 0.000
Median | 0.00 | 0.000
 | 100.00 | 0.000
Max PD | 200.00 | 0.000
Max | 2370.00 | 1.000
</td><td>Continual wetting of rock moss favours growth (Bell 1992). Peaking at 2,500 cumecs inudates most of the marginal zone (upper limit 3000 cumecs) that consists of rocks available as benthic habitat for the rock moss. This discharge is not large enough to effect scouring. Continual inundation favours growth of the rock moss.</td><td>3</td></tr>
<tr><td>T2 within day range [T2 season]

Desc | m3/s | Y
Min | 0.00 | 0.000
MinPD | 0.00 | 0.000
 | 0.00 | 0.000
Median | 0.00 | 0.000
 | 50.00 | 0.000
Max PD | 100.00 | 0.000
Max | 2370.00 | 1.000
</td><td>Continual wetting of rock moss favours growth (Bell 1992). Peaking at 2,500 cumecs inudates most of the marginal zone (upper limit 3000 cumecs) that consists of rocks available as benthic habitat for the rock moss. This discharge is not large enough to effect scouring. Continual inundation favours growth of the rock moss.</td><td>3</td></tr>
</table>

4.10.5 Marginal graminoids

<table>
<tr><td colspan="2">Marginal graminoids</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>0.000</td></tr>
<tr><td></td><td>58.75</td><td>0.000</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>288.65</td><td>-0.600</td></tr>
</table>


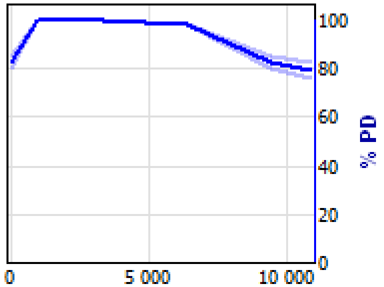
</td><td>Extended dry season prolongs desiccation stress that may cause mortality. Marginal graminoids are dormant during the dry season (Cross and Fleming 1989) and so not favoured when this is shorter.</td><td>2</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>
Dry season Min 5d Q [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.600</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-0.300</td></tr>
<tr><td></td><td>157.39</td><td>-0.100</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>0.000</td></tr>
<tr><td>Max</td><td>527.41</td><td>0.000</td></tr>
</table>


</td><td>The marginal zone is inundated between 480-2500 cumecs. Marginal species are dormant during the dry season (Cross and Fleming 1989) so little growth and no reproduction takes place in response to increased discharge. Persistent lower discharge may cause some mortality as wetting of marginal zone reduced.</td><td>2</td></tr>
</table>

<table>
<tr><td colspan="2">Marginal graminoids</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Wet season Max 5d Q [F season]

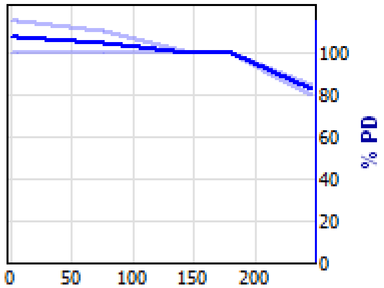
<table>
<tr><td>Desc</td><td>m3/s</td><td>Y</td></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>0.000</td></tr>
<tr><td></td><td>2109.13</td><td>0.000</td></tr>
<tr><td>Median</td><td>3309.19</td><td>0.000</td></tr>
<tr><td></td><td>6372.37</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>9435.56</td><td>-1.000</td></tr>
<tr><td>Max</td><td>10850.89</td><td>-1.200</td></tr>
</table>



</td><td>Marginal zone is inundated between 480-2500 cumecs. Discharges < 500 cumecs don't reach into the marginal area and hinder growth/reproduction. Plants grow and reproduce in response to wetting (Kotschy et al. 2000). Extreme floods cause stem snap or uproot root culms (Kotschy and Rogers 2008).</td><td>4</td></tr>
<tr><td>

Wet season duration [F season]

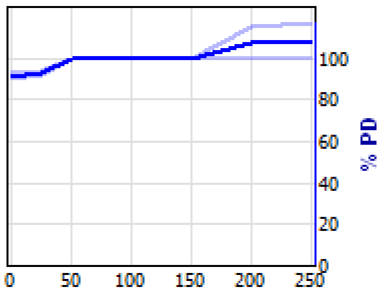
<table>
<tr><td>Desc</td><td>days</td><td>Y</td></tr>
<tr><td>Min</td><td>0.00</td><td>0.500</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>0.500</td></tr>
<tr><td></td><td>76.00</td><td>0.100</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>246.10</td><td>-1.000</td></tr>
</table>



</td><td>Extreme floods cause stem snap or uproot root culms (Kotschy and Rogers 2008). Extended wet season flushes the marginal area for a longer period and more damage (stem snap, uprooting) takes place over a longer wet season. Less flushing out of graminoids takes place over a shorter wet season.</td><td>4</td></tr>
<tr><td>

Wet: mean Fine suspended sediment [F season]

<table>
<tr><td>Desc</td><td>ppm</td><td>Y</td></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.400</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.600</td></tr>
</table>

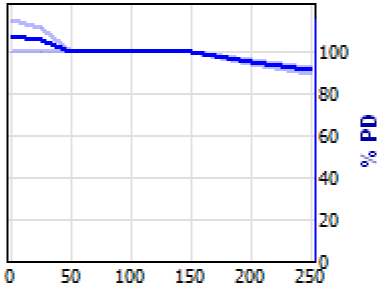


</td><td>Suspended fines carry nutrients that boost plant growth in the otherwise nutrient poor alluvial (washed) sands they inhabit (Naiman et al. 2005). An increase in suspended fines boost plant growth and vitality that increases reproductive output.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Marginal graminoids</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Lengths of cut marginal banks [All seasons]

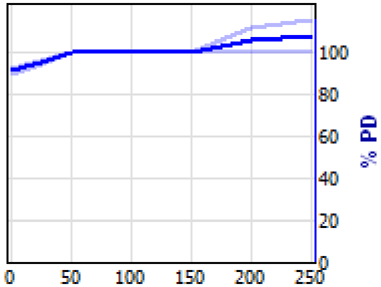
Desc	%baseline	Y
Min	0.00	0.500
MinPD	25.00	0.250
	50.00	0.000
Median	100.00	0.000
	150.00	0.000
Max PD	200.00	-0.250
Max	250.00	-0.500



</td><td>Marginal graminoids inhabit the edge of the active channel (van Ginkel et al. 2010). A reduction in the extent of the active channel edge will reduce the extent of marginal graminoids. Cut banks comprise c. 20% of the marginal habitat available to graminoids.</td><td>3</td></tr>
<tr><td>

Vegetated midchannel bars [All seasons]

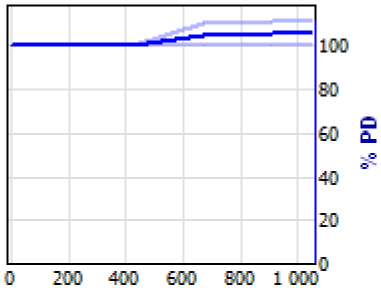
Desc	%baseline	Y
Min	0.00	-0.500
MinPD	25.00	-0.250
	50.00	0.000
Median	100.00	0.000
	150.00	0.000
Max PD	200.00	0.250
Max	250.00	0.500



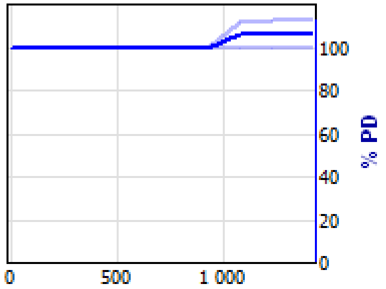
</td><td>Marginal graminoids inhabit the vegetated mid-channel bars (van Ginkel et al. 2010). An increase in extent of mid-channel bars provides more habitat for marginal graminoids. A reduced extent of mid-channel bars reduces marginal habitat for graminoids.</td><td>3</td></tr>
<tr><td>

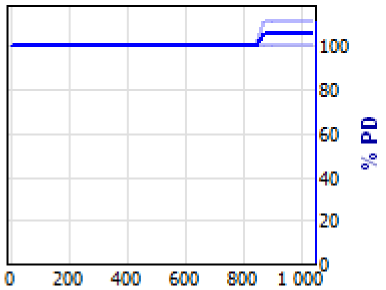
Dry season max instantaneous Q [D season]

Desc	m3/s	Y
Min	0.00	0.000
MinPD	410.70	0.000
	417.71	0.000
Median	424.72	0.000
	666.90	0.100
Max PD	909.07	0.200
Max	1045.43	0.200



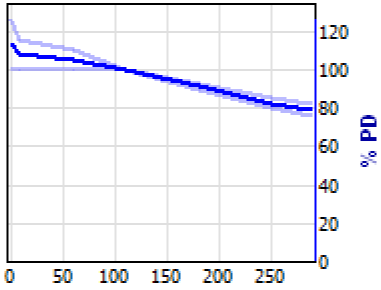
</td><td>Marginal graminoids are dormant during the dry season (Cross and Fleming 1989) so are not favoured by increased wetting.</td><td>2</td></tr>
</table>

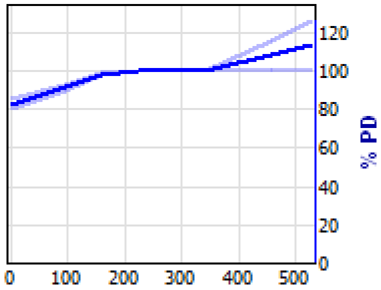
<table>
<tr><td colspan="2">Marginal graminoids</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>T1 max instantaneous Q [T1 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>0.000</td></tr>
<tr><td></td><td>916.74</td><td>0.000</td></tr>
<tr><td>Median</td><td>924.41</td><td>0.000</td></tr>
<tr><td></td><td>1076.73</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>1229.04</td><td>0.300</td></tr>
<tr><td>Max</td><td>1413.40</td><td>0.300</td></tr>
</table>


</td><td>The marginal zone is inundated at discharges between 500-2500 cumecs. Increased wetting favours growth (Kotschy et al. 2000).</td><td>3</td></tr>
<tr><td>T2 max instantaneous Q [T2 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>400.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>844.62</td><td>0.000</td></tr>
<tr><td></td><td>873.04</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>901.46</td><td>0.200</td></tr>
<tr><td>Max</td><td>1036.67</td><td>0.200</td></tr>
</table>


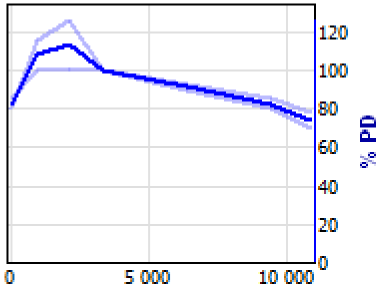
</td><td>The marginal zone is inundated at discharges between 500-2500 cumecs, increased wetting favours growth (Kotschy et al. 2000).</td><td>3</td></tr>
</table>

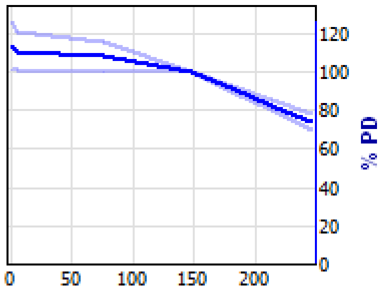
4.10.6 Marginal shrubs

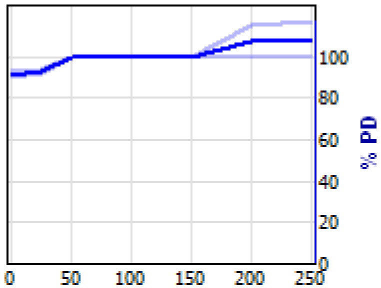
<table>
<tr><td colspan="2">Marginal shrubs</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.000</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>0.500</td></tr>
<tr><td></td><td>58.75</td><td>0.100</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>-1.200</td></tr>
</table>


</td><td>Extended dry season prolongs dessication stress that may cause mortality (Naiman et al. 2005). Marginal shrubs are favoured over a shorter dry season.</td><td>4</td></tr>
<tr><td>
Dry season Min 5d Q [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-0.500</td></tr>
<tr><td></td><td>157.39</td><td>-0.100</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>0.500</td></tr>
<tr><td>Max</td><td>527.41</td><td>1.000</td></tr>
</table>


</td><td>The marginal zone is inundated between 480-2500 cumecs. Growth and reproduction take place in response to increased water availability (Karrenberg et al. 2002). Persistent lower discharge may cause some mortality as wetting of marginal zone reduced.</td><td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Marginal shrubs</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Wet season Max 5d Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>0.500</td></tr>
<tr><td></td><td>2109.13</td><td>1.000</td></tr>
<tr><td>Median</td><td>3309.19</td><td>0.000</td></tr>
<tr><td></td><td>6372.37</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>9435.56</td><td>-1.000</td></tr>
<tr><td>Max</td><td>10850.89</td><td>-1.500</td></tr>
</table>


</td><td>The marginal zone is inundated between 480-2500 cumecs. Growth and reproduction take place in response to increased discharge (Karrenberg et al. 2002). Persistent lower discharge may cause some mortality as wetting of marginal zone reduced. Stem snap and flushing takes place at higher discharges (Karrenberg et al. 2002).</td><td>4</td></tr>
<tr><td>
Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.000</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>0.800</td></tr>
<tr><td></td><td>76.00</td><td>0.500</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>246.10</td><td>-1.500</td></tr>
</table>


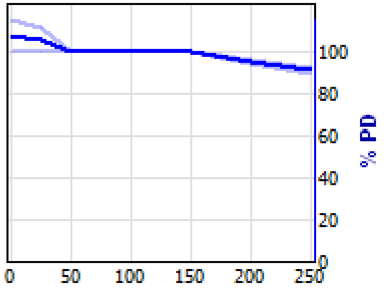
</td><td>Stem snap and flushing takes place at higher discharges (Karrenberg et al. 2002). Less uprooting and stem snap takes place over a shorter wet season. A longer wet season causes more damage to marginal zone plants.</td><td>4</td></tr>
<tr><td>
Wet: mean Fine suspended sediment [F season]
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.400</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.600</td></tr>
</table>


</td><td>Suspended fines carry nutrients that boost plant growth when deposited in the riparian area (Naiman et al. 2005). An increase in suspended fines increases vitality and reproductive output. Reduced nutrient delivery hinders growth and reproductive output.</td><td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Marginal shrubs</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Lengths of cut marginal banks [All seasons]

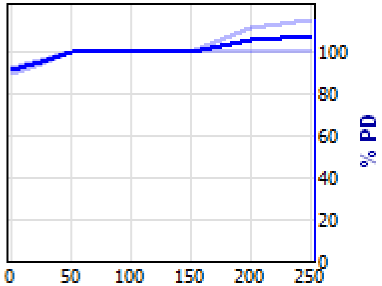
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.250</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.250</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.500</td></tr>
</table>



</td><td>Marginal shrubs inhabit the edge of the active channel (Reinecke 2013). A reduction in the extent of the active channel edge will reduce the extent of marginal shrubs. Cut banks comprise c. 20% of the marginal habitat available to marginal shrubs.</td><td>3</td></tr>
<tr><td>

Vegetated midchannel bars [All seasons]

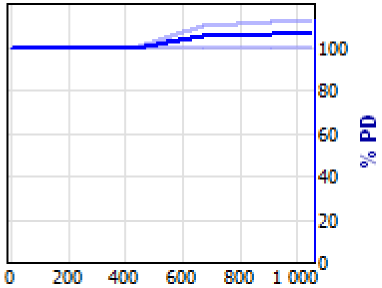
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.250</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.250</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.500</td></tr>
</table>



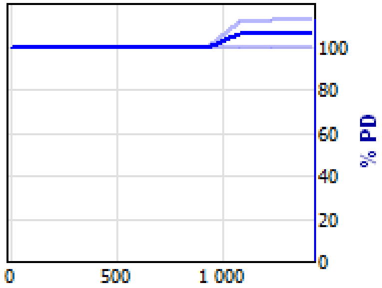
</td><td>Marginal shrubs inhabit the vegetated mid-channel bars (pers. obs). An increase in extent of mid-channel bars provides more habitat for marginal shrubs. A reduced extent of mid-channel bars reduces marginal habitat for shrubs.</td><td>3</td></tr>
<tr><td>

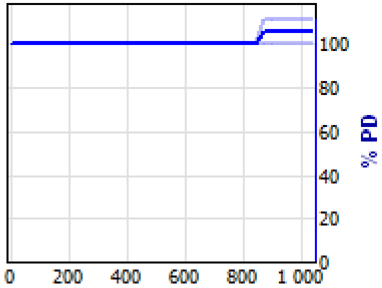
Dry season max instantaneous Q [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>410.70</td><td>0.000</td></tr>
<tr><td></td><td>417.71</td><td>0.000</td></tr>
<tr><td>Median</td><td>424.72</td><td>0.000</td></tr>
<tr><td></td><td>666.90</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>909.07</td><td>0.200</td></tr>
<tr><td>Max</td><td>1045.43</td><td>0.300</td></tr>
</table>



</td><td>The marginal zone is inundated at discharges between 500-2500 cumecs. Increased wetting favours growth (Karrenberg et al. 2002).</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Marginal shrubs</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
T1 max instantaneous Q [T1 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>0.000</td></tr>
<tr><td></td><td>916.74</td><td>0.000</td></tr>
<tr><td>Median</td><td>924.41</td><td>0.000</td></tr>
<tr><td></td><td>1076.73</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>1229.04</td><td>0.300</td></tr>
<tr><td>Max</td><td>1413.40</td><td>0.300</td></tr>
</table>


</td><td>The marginal zone is inundated at discharges between 500-2500 cumecs. Increased wetting favours growth (Karrenberg et al. 2002).</td><td>3</td></tr>
<tr><td>
T2 max instantaneous Q [T2 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>400.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>844.62</td><td>0.000</td></tr>
<tr><td></td><td>873.04</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>901.46</td><td>0.200</td></tr>
<tr><td>Max</td><td>1036.67</td><td>0.200</td></tr>
</table>


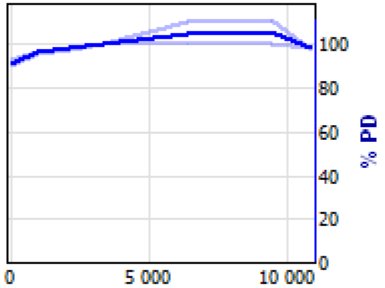
</td><td>The marginal zone is inundated at discharges between 500-2500 cumecs, increased wetting favours growth (Karrenberg et al. 2002).</td><td></td></tr>
</table>

4.10.7 Lower zone trees

<table>
<tr><td colspan="2">Lower zone trees</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Wet season Max 5d Q [F season]

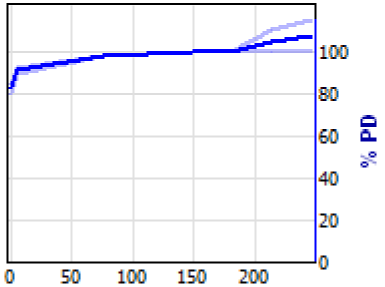
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>-0.200</td></tr>
<tr><td></td><td>2109.13</td><td>-0.100</td></tr>
<tr><td>Median</td><td>3309.19</td><td>0.000</td></tr>
<tr><td></td><td>6372.37</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>9435.56</td><td>0.200</td></tr>
<tr><td>Max</td><td>10850.89</td><td>-0.100</td></tr>
</table>



</td><td>Lower zone is inundated between 2500-4900 cumecs. Plants grow and reproduce in response to wetting (Curtis and Manheimer 2005). Discharges lower than median don't flood the lower zone and hinder growth/reproduction. Extreme floods may uproot saplings (Parsons et al. 2005).</td><td>3</td></tr>
<tr><td>

☑ Wet season duration [F season]

<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>-0.500</td></tr>
<tr><td></td><td>76.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>0.100</td></tr>
<tr><td>Max</td><td>246.10</td><td>0.500</td></tr>
</table>

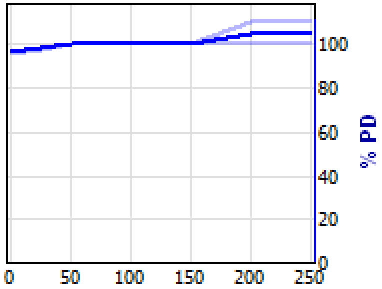


</td><td>Wet season floods inundate the lower zone and provides water for growth and reproduction (Curtis and Manheimer 2005). Shorter wet seasons deliver less water and longer wet seasons deliver more.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Lower zone trees</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Wet: mean Fine suspended sediment [F season]

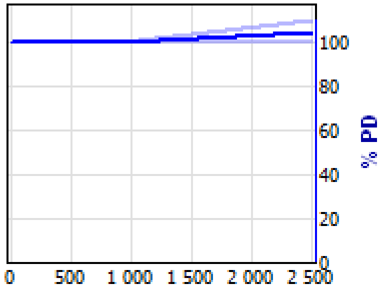
<table>
<tr><th>Desc</th><th>ppm</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.200</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.100</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.100</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.200</td></tr>
</table>



</td><td>Suspended fines carry nutrients available to boost plant growth in the riparian area (Naiman et al. 2005). An increase in suspended fines increases plant vitality and stimulates reproductive output.</td><td>3</td></tr>
<tr><td>

Dry season max instantaneous Q [D season]

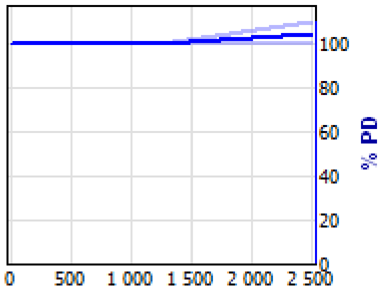
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>410.70</td><td>0.000</td></tr>
<tr><td></td><td>417.71</td><td>0.000</td></tr>
<tr><td>Median</td><td>424.72</td><td>0.000</td></tr>
<tr><td></td><td>666.90</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>909.07</td><td>0.000</td></tr>
<tr><td>Max</td><td>2500.00</td><td>0.100</td></tr>
</table>



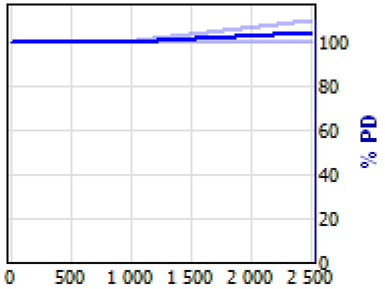
</td><td>Lower zone is inundated between 2500-4900 cumecs. Wetting favours plant growth. Continual wetting below this threshold may favour growth slightly by boosting ground water recharge but this will be minimal.</td><td>3</td></tr>
<tr><td>

T1 max instantaneous Q [T1 season]

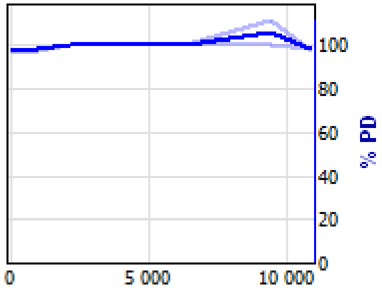
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>0.000</td></tr>
<tr><td></td><td>916.74</td><td>0.000</td></tr>
<tr><td>Median</td><td>924.41</td><td>0.000</td></tr>
<tr><td></td><td>1076.73</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1229.04</td><td>0.000</td></tr>
<tr><td>Max</td><td>2500.00</td><td>0.100</td></tr>
</table>

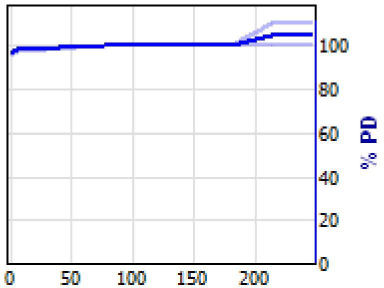


</td><td>Lower zone is inundated between 2500-4900 cumecs. Wetting favours plant growth. Continual wetting below this threshold may favour growth slightly by boosting ground water recharge but this will be minimal.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Lower zone trees</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>T2 max instantaneous Q [T2 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>400.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>844.62</td><td>0.000</td></tr>
<tr><td></td><td>873.04</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>901.46</td><td>0.000</td></tr>
<tr><td>Max</td><td>2500.00</td><td>0.100</td></tr>
</table>

</td>
<td>Lower zone is inundated between 2500-4900 cumecs. Wetting favours plant growth. Continual wetting below this threshold may favour growth slightly by boosting ground water recharge but this will be minimal.</td>
<td>3</td></tr>
</table>

4.10.8 Upper zone trees

<table>
<tr><td colspan="2">Upper zone trees</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Wet season Max 5d Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.150</td></tr>
<tr><td>MinPD</td><td>909.07</td><td>-0.100</td></tr>
<tr><td></td><td>2109.13</td><td>0.000</td></tr>
<tr><td>Median</td><td>3309.19</td><td>0.000</td></tr>
<tr><td></td><td>6372.37</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>9435.56</td><td>0.200</td></tr>
<tr><td>Max</td><td>10850.89</td><td>-0.100</td></tr>
</table>


</td><td>The upper zone is inundated at discharges greater than 4900 cumecs. Upper zone trees are dessication tolerant (Curtis and Manheimer 2005). Plant growth and reproduction is favoured by wetting. Extreme floods may uproot saplings (Parsons et al. 2005).</td><td>3</td></tr>
<tr><td>
Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.200</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>-0.100</td></tr>
<tr><td></td><td>76.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>0.100</td></tr>
<tr><td>Max</td><td>246.10</td><td>0.200</td></tr>
</table>


</td><td>Extended wet season provides water for growth and reproduction (Curtis and Manheimer 2005). Less growth/reproduction occurs over a shorter wet season and more seeds are dispersed into the riparian area over a longer wet season.</td><td>3</td></tr>
</table>

5 *MACROINVERTEBRATES: SPECIALIST REPORT*

5.1 OBJECTIVES OF THE MACROINVERTEBRATE STUDY

For the macroinvertebrate component of the EFA assessment, 17 days were allocated to a site visit, data analysis of the site information collected in the field, prediction of impacts (response curves) and report writing.

The Terms of Reference provided were:

- Familiarise yourself to the extent possible with the study area, including:
  - the character of the Zambezi River in the study area;
  - the character of the macroinvertebrate communities.
- Provide detailed information for two EF sites.
- Attend the field visit with the rest of the team to:
  - ensure that the hydraulic cross-section surveys record whatever information you require for your analyses;
  - record at each site, where relevant, (i) the dominant and sub-dominant invertebrates, (ii) the arrangement of the invertebrate habitat relative to inundation and /or flow velocities.
- Identify invertebrate specimens collected, to the lowest taxonomic level relevant for the EF assessments.
- Take responsibility for the adequacy of the data collected and provided for the macroinvertebrate component of the EFA.
- Select key aspects as indicators for the DRIFT assessment, in liaison with the other specialists, and provide/develop information on:
  - changes in invertebrate populations with changes in the flow regime;
  - any other relevant data as your experience suggests;
  - any other available information relevant to flow assessments;
  - relevant scientific references.
- Select linked indicators that can be used to explain flow-related changes for each of your indicators.
- Attend the DRIFT Workshop(s), prepared to populate the DRIFT response curves for your selected indicators and linked indicators.
- Compile a macroinvertebrate chapter for inclusion in the EF Report, with particular reference to response curve motivation tables.
- Adhere to standard formatting, font and layout specifications provided by the Southern Waters for written submissions.

5.1.1 Layout of this Section

This Section comprises the summary report for macroinvertebrates, and provides:

- Ecoclassification assessments for macroinvertebrates, with supporting evidence;
- the DRIFT indicators chosen, and reasons therefore;

- the relationships between the chosen macroinvertebrate indicators and flow or other drivers, with referenced supporting motivations.

5.2 *DESCRIPTION OF THE STUDY AREA, WITH THE FOCUS ON MACROINVERTEBRATES*

The study area falls within an area described in most literature as the Middle Zambezi, which extends from Victoria Falls to Cahora Bassa. This study area therefore fall within the upper extent of the Middle Zambezi, immediately downstream of Victoria Falls where the Zambezi flows as a series of rapids within the Batoka Gorge before it widens further downstream and opens into the Kariba Dam. As a 'flood-pulse' system, the Zambezi is characterised by a single large flood event over the wet season. Within the Batoka gorge itself, lateral movement of flows is limited by the steep gorge and therefore, during high flows, most of the channel would be hostile for habitation by macroinvertebrates. Although fast flowing, deep rapids are still characteristic of the gorge during low flow periods, marginal slower flowing habitats play an important role in providing habitat for aquatic macroinvertebrates over this period.

Near the upstream extent of the Kariba Dam, the Zambezi River is no longer confined by the gorge and the slope is more gentle and typical of a large foothill river. The system widens into a broad channel with a diversity of habitats ranging from fast flowing rapids, to riffles and runs and slow flowing marginal habitats including vegetation and sand bars. During the flood season, flows can spread laterally into these floodplain areas thus creating refuge habitat for macroinvertebrates that is less prevalent (or absent) in the gorge.

5.3 *LITERATURE REVIEW*

Macroinvertebrates play a key role in the ecological functioning of rivers through processing organic matter, either by breaking down detritus or grazing algal biofilms. Macroinvertebrates are in turn food for fish and birds and are therefore important in the transport of energy along the stream channel both longitudinally and laterally into both floodplain and terrestrial habitats (Boulton and Lake 2008).

The flow regime is a fundamental part of rivers to which macroinvertebrates are acutely adapted (Hildrew and Giller 1997; Poff et al. 1997; Poff and Zimmerman 2010). Floods in particular are disturbance events that are important in regulating macroinvertebrate populations (Death 2008). There are many examples in the literature of life-history, morphological and behavioural adaptations of riverine macroinvertebrates to the frequency, timing, rate of change and magnitude of floods as a natural feature of rivers (e.g. Hart and Finelli 1999; Bunn and Arthington 2002; Lytle and Poff 2004; Konrad et al. 2008). It is not surprising therefore, that even small changes in the pattern of flooding can lead to significant shifts in macroinvertebrate community structure and a consequent change in the ecological functioning of a river.

Besides flood events, low flows are an important component of the natural habitat that support macroinvertebrate communities in rivers (Statzner et al. 1988; Statzner and Borchardt 1994; Hildrew and Giller 1994; Bunn and Arthington 2002). Habitat can be described as a combination of the flow characteristics and the substratum type, which together constitutes the hydraulic biotopes to which macroinvertebrates are adapted (Wadeson 1995). Whereas some taxa may be adapted to fast flow over cobbles or boulders typical of riffles, others are found only in backwaters where flow velocities are slow or zero and the substratum may be sandy or stony. By contrast, other taxa are only found on marginal vegetation typical of the channel margins. Changes in the flow regime can therefore affect the availability and diversity of different habitats which ultimately affects species richness and community structure of macroinvertebrates (Poff and Zimmerman 2010).

Considering that dams can affect the pattern of flooding and the heterogeneity of hydraulic habitats through changes in low flow conditions in rivers, major changes in macroinvertebrate communities and ecosystem functioning are often a consequence of dams constructed in rivers. Besides these direct impacts to macroinvertebrates, dams also have indirect impacts on community structure by altering water quality (e.g. temperature and dissolved oxygen), suspended sediment loads, organic matter from upstream, food quality (through changes in benthic algal biomass and composition) and changes in predation from fish species (King et al. 2000; Lytle 2008).

Macroinvertebrates of the middle reaches of the Zambezi River and their adaptations to the flow regime are largely unstudied. Taxonomic collections of Odonata (dragonflies and damselflies) have been undertaken in the Katombora to Victoria Falls section of the Zambezi River by Pinhey (1984) and Fitzpatrick (2000), while the freshwater molluscs of the upper Zambezi were studied by Appleton (1996). Freshwater snail diversity in the Middle Zambezi Basin was investigated by Mubita (2008) but her study focused on the main tributaries of the Zambezi River. More recently, Suhling et al. (2004) published a paper on the taxonomy of Odonata in southwestern Africa, which included collections from the 'swamps of the middle Zambezi basin', including the floodplains of the Zambezi River itself. In 2009, Suhling et al. (2009) reported on the status and distribution of dragonflies as part of a broader series by the IUCN on freshwater biodiversity of Southern Africa. Their report states that the middle reaches of the Zambezi are rich in dragonfly species, and both Suhling et al. (2004) and Suhling et al. (2009) emphasise the importance of the middle Zambezi River for the conservation of Odonata diversity. While Suhling et al. (2009) indicate that little is known about Odonata diversity and ecology of the Zambezi, it is evident that this statement is true for aquatic macinvertebrate community of the middle Zambezi as a whole. Despite the lack of knowledge of the distribution and ecology of the macroinvertebrates of the middle Zambezi River between Victoria Falls and Lake Kariba, the construction of large in channel dams is indicated as the biggest threat to macroinvertebrate diversity (with reference largely to Odonata).

5.4 *DESCRIPTION OF THE EF SITES*

See Section 1.4 for a map showing the location of the study sites.

5.4.1 EF Site 1

5.4.1.1 Hydraulic biotopes:

- Large cascades and rapids are a key feature of the Zambezi in the Batoka Gorge at EF Site 1. These habitats are characterised by fast-flowing, turbulent, clear water, which is highly oxygenated. For safety reasons, these areas could not be sampled in this study.

Figure 5.1 Relatively small cascades and riffles over boulders and large cobbles sampled along the edge of the main channel. The large cascades were inaccessible.

- Small cascade/riffles: characterise the margins of the cascades within the main channel and include fast-flowing, highly oxygenated broken water over boulders with some large cobble and bedrock (Figure 5.1).
- Runs: Moderately deep (> 70 cm), fast flowing areas over bedrock sheets covered with Bryophytes (aquatic moss). The main flow type in these areas was Smooth Boundary Turbulent (SBT) with areas of rippled surface flow (RSF) where the substratum was dominated by boulders.
- Secondary channels (backwaters) adjacent to the main channel which is recharged during the high flow season. At the time of sampling in September 2014, these seasonal channels were characterised as wide shallow backwaters or slackwaters (mean depth between 40-60 cm) with no or very slow flow. The substratum in these channels is predominantly bedrock sheets, covered by a fine layer of sand/silt in places or single celled diatoms in others. Oxygen levels tend to be low in such habitats and temperatures highly stratified.

- Sandy slackwaters along the margins of the main channel are characterised by turbulent, flickering flow over sands and gravel ranging in depth from about 40 cm to 60 cm.

5.4.2 EF Site 2

5.4.2.1 Hydraulic biotopes:

- Riffles: areas of shallow (mean depth between 20-40 cm), fast flowing broken water over cobbles. At the time of sampling in September 2014, riffles were found in the main channel.
- Runs: Included a range of depths from about 20-60 cm of rippled surface flow (RSF) over large cobbles embedded in finer material along the edge of the main channel (Figure 5.2).

Figure 5.2 RSF flow over cobbles embedded in finer sediments was characteristic of the runs sampled at EF Site 2 in September 2014.

- Secondary channels (backwaters) adjacent to the main channel which is recharged during the high flow season. In September 2014, the backwaters included isolated pools with no flow over cobbles embedded in fine material, as well as slow flowing slackwaters over cobbles and boulders (Figure 5-3).
- Sandy slackwaters along the margins of the main channel are characterised by turbulent, flickering flow over sands and gravel ranging in depth from about 40 cm to 60 cm (Figure 5.3).
- Sandbars: Most of the instream portion of the Zambezi River in the study area is characterised by highly mobile sandbars. The sands bars are characterised by slow-flowing, clear, good quality water. Faunal biodiversity is low, and is characterised by large populations of filter-feeding bivalves.

Figure 5.3 **Cobble backwaters with no flow - characteristic of the secondary channel at the time of sampling**

Figure 5.4 **Sandy slackwaters - characteristic of the channel margin in areas at EF Site 2**

- Vegetation-out-of-current: the channel margins are characterised by an abundance of emergent and submerged aquatic plants that grow in slow-moving water on the margins of the active channels. The marginal vegetation includes a diversity of structures such as stems and leaves of different sizes and densities and therefore this habitat supports a high diversity of aquatic fauna.
- Vegetation-in-current (Figure 5.5): clumps of sedges within the channel itself are characterised largely as stems with fast flowing unbroken water, typically Smooth Boundary Turbulent (SBT) or Rippled Surface Flow (RSF).

Figure 5.5 **(a) Vegetation-in-current (VIC) was characterised by clumps of vegetation in fast flowing water within the channel; (b) Vegetation-out-of-current (VOOC) characterised the channel margins at EF Site 2.**

5.5 *ECOCLASSIFICATION OF RIVER REACHES REPRESENTED BY THE EF SITES*

Aquatic macroinvertebrates were collected and identified to family level according to the Zambian Scoring System (ZISS) biomonitoring method (Lowe 2013). The ZISS method was developed specifically for aquatic macroinvertebrates expected in streams and rivers in Zambia. The ZISS method is essentially the same as the South African Scoring System version 5 (SASS5; Dickens and Graham 2002), but some of the sensitivity scores were adjusted and some additional molluscs were included to account for the taxa typical of more tropical rivers expected in this region.

This method provides an excellent index of species richness and water quality in perennial rivers with relatively natural habitats. The protocol allocates a predetermined score for each taxon according to its sensitivity to water quality perturbation. Sensitive taxa are allocated high weighting (maximum of 15) while taxa more common to degraded/disturbed systems receive low weightings. ZISS sampling was done separately for each available biotope (defined by flow and substratum characteristics). A description of the biotopes sampled for calculation of the ZISS scores is given in Section 5.4 above.

ZISS scores, Average Scores Per Taxon (ASPTs)[2] – calculated by dividing the ZISS score by the number of taxa - and total number of taxa were calculated for each biotope.

Essentially, an assessment of Present Ecological State for aquatic invertebrates was based on an assessment and interpretation of these data using the guidelines provided in Table 5.1.

Table 5.1 Definitions of Present Ecological State categories for aquatic macroinvertebrates applied in this study.

Category	Description
A	*Unimpaired*
	• Natural diversity of taxa, and;
	• numerous sensitive taxa, and;
	• abundance as expected under natural conditions, and;
	• no taxon dominating the fauna for extended periods.
B	*Slightly Impaired*
	• As above, but with fewer sensitive taxa and slightly lower diversity.
C	*Moderately Impaired*
	• Moderate diversity of taxa relative to diversity expected under natural conditions, or;
	• moderate numbers of sensitive taxa, or;
	• moderate reduction in abundance of some or all taxa relative to that expected under natural conditions.
D	*Considerably Impaired*
	• Low diversity of taxa relative to diversity expected under natural conditions, and;
	• mostly tolerant taxa, and;
	• considerable reduction in abundance of some or all taxa relative to that expected under natural conditions, or;
	• more than one taxon dominating the fauna for extended periods.
E	*Severely Impaired*
	• Very low diversity of taxa relative to diversity expected under natural conditions, and;
	• only tolerant taxa present, or;
	• severe reduction in abundance of some or all taxa relative to that expected under natural conditions, or;
	• only one taxon dominating the fauna for extended periods.
F	*Very Severely Impaired*
	• As above, but with Very Severe reduction in diversity and abundance.

[2] ASPTs are particularly useful as indicators of water quality of an aquatic system, as a low score will indicate that the community is dominated by species resistant to anthropogenic perturbations such as pollution, while high scores indicate the occurrence of more sensitive and, often rare, species, that would be expected to occur in undisturbed systems.

5.5.1 EF Site 1

In total, 21 taxa were recorded within the Batoka Gorge (EF Site 1) in September 2014. The "stones" habitat included riffles and cascades over boulder and large cobble, deep runs over bedrock and backwater pools over bedrock with no flow. The "Gravel-Sand-Mud" biotope included slackwaters with moderate flow over sands and gravels and sand and silt over bedrock in the backwaters. No vegetation was available for sampling at the time of the site visit and thus it was excluded from the ZISS assessment. Under lower flow conditions typical of the dry season, it is likely that more cobble habitat may have been available for sampling and thus the sample collected in September is likely to be an under representation of the taxa present in the Gorge.

The ephemeroptera were the most common fauna found at EF Site 1 with moderate numbers of baetid mayflies of which seven different species were identified. Moderate numbers of caenid mayflies as well as the Dipteran larvae, chironomidae and ceratopogonidae were also recorded. Taxa that are highly sensitive to water quality impairment included the Oligoneuridae, Heptageniidae and Baetidae, as well as the Trichopteran, Polycentropodidae. With an ASPT score of 6.81, this site supports a high proportion of moderately to highly sensitive taxa (Table 5.2). Also, no single taxon was particularly dominant. Nevertheless, the recorded number of taxa was lower than expected under natural conditions. Although this may, to some extent, be a consequence of the time of sampling when access to some habitats was limited, the data suggest a slight impairment from natural. Therefore, in terms of macroinvertebrates, the Present Ecological State of the Zambezi in the Batoka Gorge is rated as a Category A/B (Table 5.1).

Table 5.2 ZISS results for EF Site 1 sampled in September 2014

EF Site 1: Batoka Gorge	Stones	Veg	GSM	TOTAL
ZISS	123		57	143
Total number of families	16		11	21
ASPT	7.69		5.18	6.81

5.5.2 EF Site 2

In total, 33 taxa were recorded at EF Site 2 upstream of the Kariba Dam in September 2014. The "stones" habitat included riffles, runs and backwaters over large and small cobbles, either embedded in fine sediments (predominantly in the backwaters) or loosely moveable cobbles. The "Gravel-Sand-Mud" biotope included slackwaters with moderate flow over sands and silt either along the channel margin or mid-channel sand bars. Vegetation, both "in-current" and "out-of-current" was sampled at EF Site 2. The vegetation-in-current included clumps of *Cyperus* within the channel with moderate flow. Vegetation-out-of current included a mix of stalked vegetation such as *Phragmites* sp. as well as leafy vegetation such as *Salix* sp. and *Persacaria* sp.

Twenty two of the total macroinvertebrates taxa were recorded in the “stones” biotope and the majority of families present belong to the order ephemeroptera or mayflies.

As with EF Site 1, ephemeroptera were the most dominant group in terms of the number of taxa and overall abundance. Of these, six families are highly sensitive to water quality impairment and included stoneflies (Perlidae), Hepetegeniidae, Oligoneuridae, Polymitarcyidae, Prosopistomatidae and seven species of baetidae. Also, the sensitive Trichopteran, Philopotamidae were also found at this site. No single taxon was particularly dominant, although taxa that were moderately abundant included the freshwater shrimp (atydae) found only in the vegetation-out-of-current, some of the mayflies, the Dipertan, Simuliidae and bivalves (including mostly Sphaeiidae) which were highly productive in the sandbars and sandy channel margins. This site as a similar ASPT score to EF Site 1, but the total number of taxa is considerably higher (Table 5.3). Habitat heterogeneity was greater at EF Site 2, relative to EF Site 1, which could account for the high ZISS score. Also, no specific group was particularly dominant. There may however be a very slight impairment to the macroinvertebrate community structure due to slight water quality impairment because a higher ASPT score would be expected with a ZISS score of 224 as recorded in September 2014. In terms of macroinvertebrates, therefore, the Present Ecological State of the Zambezi upstream of the Kariba Dam at EF Site 2 is considered a category A/B.

Table 5.3 ZISS results for EF Site 2 sampled in September 2014

EF Site 1: Batoka Gorge	Stones	Veg	GSM	TOTAL
ZISS	167	140	33	224
Total number of families	22	21	9	33
ASPT	7.59	6.67	3.67	6.79

5.6 FIELD DATA COLLECTION AND ANALYSIS

Macroinvertebrate samples were collected in September 2014 at both EF sites 1 and 2 using a kick-sampling technique prescribed by the ZISS protocol (see section 1.6). The technique involves disturbing the streambed so that invertebrates are dislodged from the substratum and vegetation using a 1 mm mesh net with an aperture of 30 x 30 cm. Samples were collected from five separate biotopes at ef Site 1 and seven separate biotopes at Site 2. Kick sampling was undertaken for a total of 10 minutes within each hydraulic biotope.

Each sample was preserved in 70% ethanol and then, with the exception of Baetidae, sorted to family level back in the laboratory. Baetid mayflies were sorted to species level because this family was present in most hydraulic biotopes, although on visual inspection in the field, it was evident that specific baetid species were restricted to specific hydraulic biotopes. Understanding the diversity of this group therefore contributed to an understanding of habitat heterogeneity and macroinvertebrate species richness in this system. All taxa were enumerated in the laboratory to provide an indication of the relative abundance of each taxonomic group.

5.7 *RESULTS OF DATA COLLECTION*

5.7.1 EF Site 1

A total of 30 taxa, identified mostly to family level (see Appendix A for a list of all taxa) were recorded at EF Site 1 in the Batoka Gorge in September 2014 (Table 5.4). The Ephemeroptera (Mayflies) represented the largest number of families (i.e. 6 families), with seven baetid species. The Ephemeroptera were also the most abundant taxon, represented largely by the baetids (Table 5.4; Figure 5-7). The Diptera (flies) were the second most speciose order, represented by four families (Table 5.4). Chironomids (midge larvae) were the most abundant taxon within this order.

The snails (Gastropoda) and bivalves (Pelecypoda) were relatively rare at EF Site 1, probably because there is little refuge habitat during the flood season for taxa that do have an adult phase. Similarly, Plecoptera and Trichoptera (caddis flies) were not abundant at EF Site 1 within the gorge. Neither group is particularly resistant to disturbance, particularly the caddis flies. Taxa typical of zero flow conditions in marginal vegetation such as shrimps (Atyidae) and ostracods were absent from the gorge, most likely due to a lack of favourable habitat.

Table 5.4 Summary of the number of families by order (with the number of baetid species in parenthesis) recorded at EF Site 1 in September 2014

Order	EF Site 1
Ephemeroptera	1
Plecoptera	2
Trichoptera	3
Odonata	3
Coleoptera	4
Diptera	2
Hemiptera	1
Oligochaeta	1
Gastropoda	1
Pelecypoda	0
Ostracoda	0
Atyidae	1
Total	30

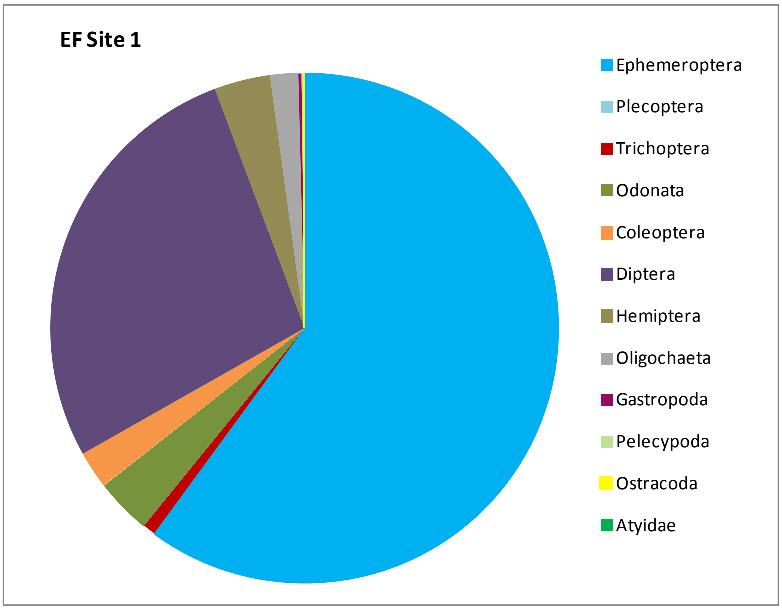


Figure 5.6 **Proportional representation of macroinvertebrate orders by number of individuals at EF Site 1 in September 2014.**

The relative proportion of macroinvertebrate abundance in each hydraulic biotope (Figure 1.7) shows a clear distinction in the dominant taxa between different biotopes as well as the overall abundance of macroinvertebrates within each biotope (Figure 5-8f).

In particular:

- the stones-in-current (SIC) biotopes (Figure 5-8a and b) were dominated by Ephemeroptera, although Diptera were far more abundant in the runs, compared to the riffles possibly due to the covering of bryophytes on the bedrock within the runs that provides refuge habitat for Diperan larvae, particularly Chironomids. Also, the refuge value offered by the thick bryophytes may account for the high overall abundance of macroinvertebrates recorded the SIC–run biotope (Figure 5-8f).
- the stones-out-of-current (SOOC) biotope was dominated by Diptera although Ephemeroptera were fairly abundant (Figure 5-8c).
- the SOOC with sand biotope (Figure 5-8d), like the SOOC without sand (Figure 5-8c), was dominated by Diptera with Ephemeroptera as the second most abundant taxon but Oligochaetes were far more prevalent in the backwaters with sand (Figure 5-8c and d).
- Ephemeroptera were completely absent from the sand and gravel slackwaters along the channel margin (Figure 5-8e), which were dominated by Oligochaetes and a relatively high proportion of both Odonata and Dipteran larvae. Although the overall abundance of macroinvertebrates was particularly low along these sandy margins. It is likely that the substratum along these margins is highly mobile and therefore offers little in the way of refuge from changes in discharge.

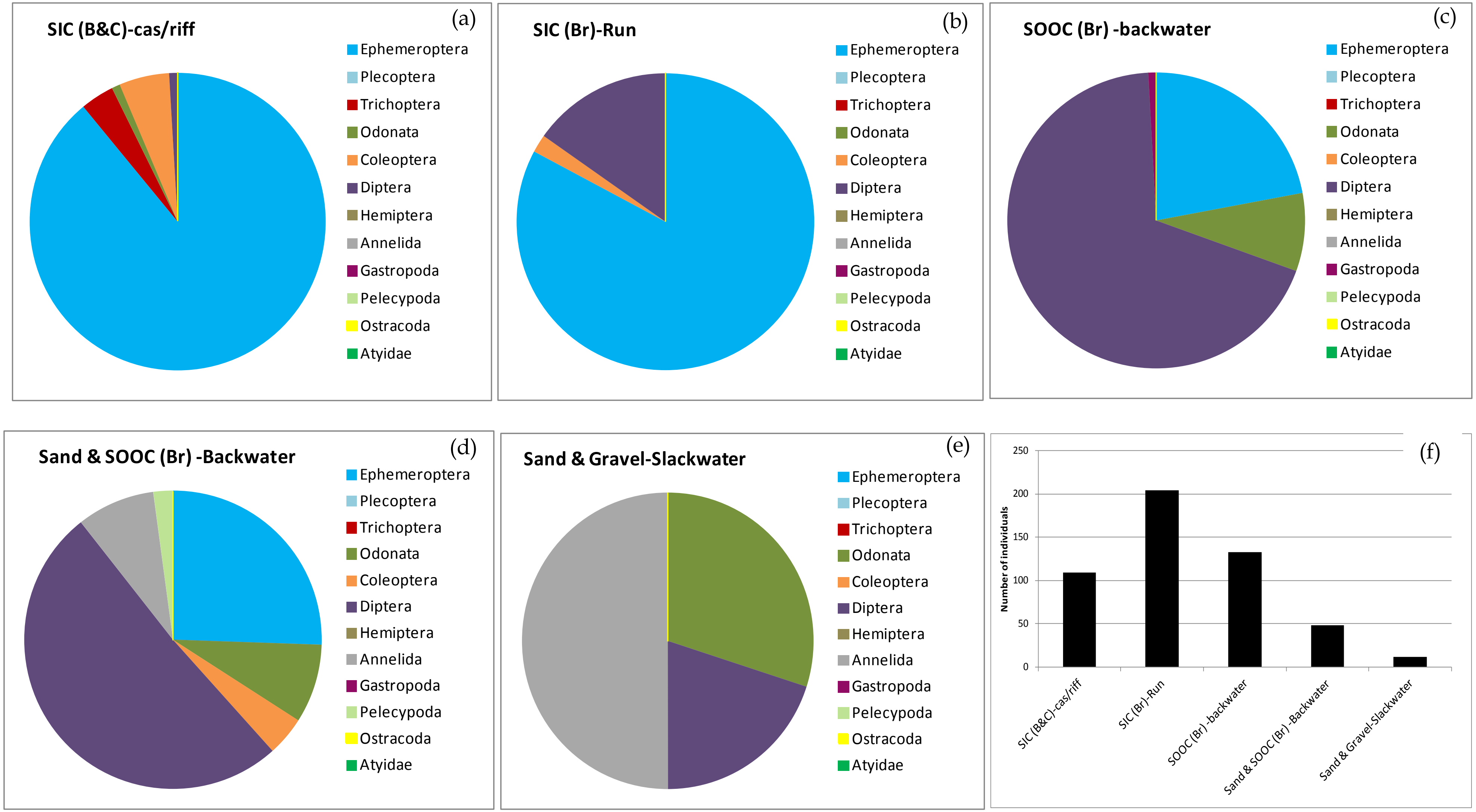


Figure 5.7 **Proportional representation of macroinvertebrate orders by number of individuals recorded in each hydraulic biotope sampled at EF Site 1 in September 2014.**

The overall Shannon-Wiener Diversity Index (H') for EF Site 1 was 2.5, although diversity varied between the different hydraulic biotopes ranging from 2.3 and 2.4 in the SIC-riffle biotope and SOOC with sand biotopes respectively, to 1.6 in the sand/gravel slackwaters (Figure 5-8). Considering the low taxonomic resolution of this study, these data indicate a system that is highly diverse in terms of macroinvertebrate fauna, with all hydraulic biotopes contributing to the overall diversity.

Macroinvertebrate community structure and the taxa driving the difference in community structure between each hydraulic biotope was analysed using multivariate statistical analyses in PRIMER 6.1. Three distinct communities were identified at EF Site 1, namely the Stones-in-current (SIC) community, the Stones-out-of-current (SOOC) community, and the Sand community (Figure 5-9). The percentage dissimilarity between these groups given in Table 5.5 indicates that the SIC and Sand communities were most dissimilar at 94% dissimilarity, while the SOOC and Sand communities were the least dissimilar, yet still distinct from each other at 73% dissimilarity.

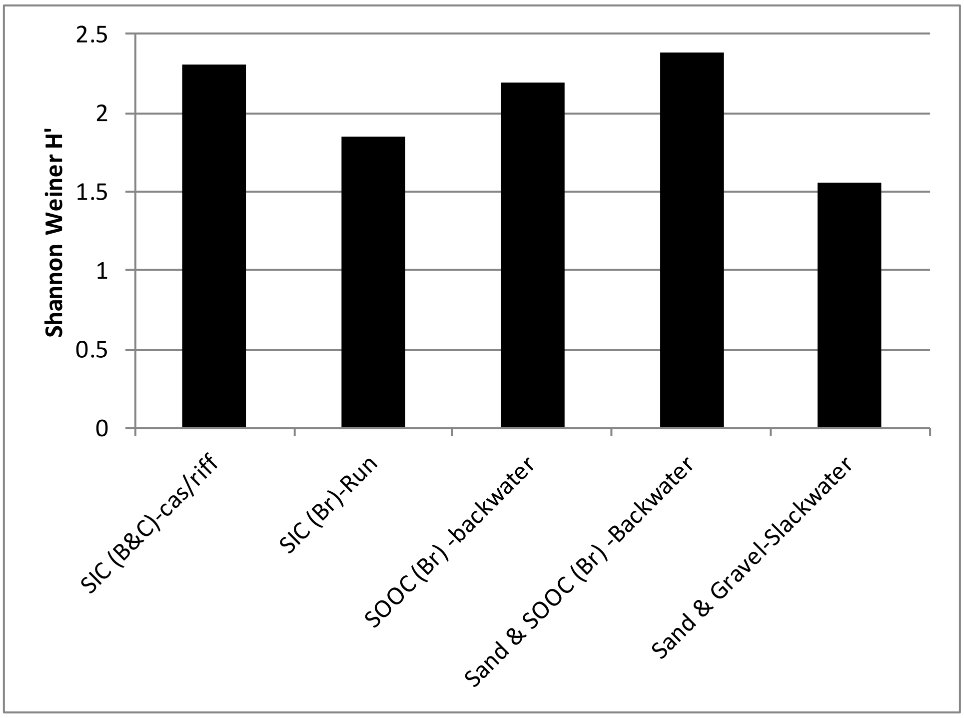


Figure 5.8 **Shannon-Weiner Diversity Index (H') calculated for each hydraulic biotope sampled in September 2014 at EF 1.**

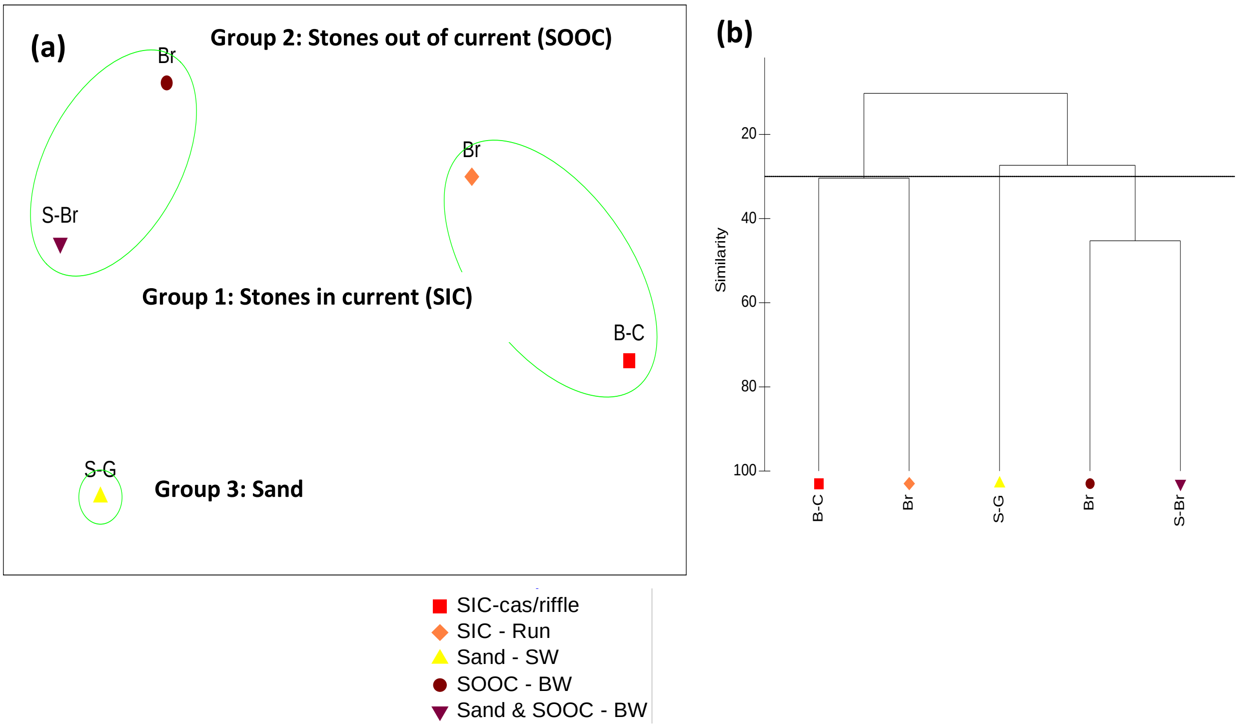


Figure 5.9 a) Multi-dimensional Scaling (MDS) plot and b) Cluster analysis of the macroinvertebrate communities within each hydraulic biotope sampled at EF Site 1 in September 2014.

Table 5.5 Percentage dissimilarity in community structure between the three broad macroinvertebrates determined by the multivariate analyses shown in Figure 1.9

	SIC	SOOC	Sand
SOOC	88		
Sand	94	73	

The SIMPER routine in PRIMER between these three communities showed that:

- The abundance of certain ephemeroptera taxa, including various baetid species and Trichorythidae in the SIC community and their absence in the SOOC and Sand communities accounted for the distinction of the SIC community at this site (Table 5.6a and b).
- The abundance of the Diperan larvae, Chironomidae is the main taxon that distinguishes the SOOC community from the others at this site (Table 5.6c).
- The abundance of Oligochaeta in the Sand community and the absence of Ephemeroptera made this community distinct from the other two (Table 5.6b and c).

Although these biotopes may group together under unaltered flow conditions, an alteration in flow and habitat characteristics may result in the shift in the communities represented by

Table 5.6 **SIMPER results from the multivariate analysis of (a) the Stones-in-current (SIC) and the Stones-out-of-current (SOOC) groups (b) The SIC and Sand groups; (c) the SOOC and Sand groups. % Diss = the % dissimilarity for a given taxon. Cum % diss = the cumulative % dissimilarity for each consecutive taxon.**

(b)

	SIC	SOOC		
Taxon	mean Abund.	mean Abund.	% Diss.	Cum.% diss.
Baetidae sp4	50.98	0.00	12.31	14.02
Tricorythidae	19.36	0.00	7.69	22.78
Chironomidae	10.50	29.27	6.18	29.82
Baetidae sp2	7.84	0.00	4.86	35.35
Baetidae sp6	7.51	0.00	4.81	40.84
Dipteran pupa	0.00	6.35	4.26	45.69
Corixidae	0.00	5.95	4.01	50.26
Elmidae	4.93	0.00	3.87	54.67
Ceratopogonidae	0.00	3.76	3.67	58.85
Caenidae	0.25	6.40	3.59	62.94
Cordulidae	0.00	4.37	3.58	67.01
Baetidae sp1	0.00	4.00	3.48	70.97

(c)

	SIC	Sand		
Taxon	mean Abund.	mean Abund.	% Diss.	Cum.% diss.
Baetidae sp4	50.98	0.00	18.31	19.53
Tricorythidae	19.36	0.00	11.50	31.8
Baetidae sp2	7.84	0.00	7.24	39.51
Baetidae sp6	7.51	0.00	7.23	47.22
Oligochaete	0.00	5.02	5.80	53.41
Elmidae	4.93	0.00	5.78	59.58
Chironomidae	10.50	1.99	5.73	65.69
Gomphidae	0.00	2.99	4.49	70.48

	SOOC	Sand		
Taxon	mean Abund.	mean Abund.	% Diss.	Cum.% diss.
Chironomidae	29.27	1.99	10.60	14.58
Caenidae	6.40	0.00	7.71	10.61
Diptera pupa?	6.35	0.00	7.19	9.89
Ceratopogonidae	3.76	0.00	6.68	9.19
Cordulidae	4.37	0.00	6.09	8.38
Baetidae sp1	4.00	0.00	5.98	8.23
Baetidae sp5	4.75	0.00	5.52	7.60
Corixidae	5.95	1.00	3.64	5.01

these biotopes as more flow sensitive taxa are lost. Therefore, SIMPER was used to assess the taxa that may account for any differences between the assemblages represented by each hydraulic biotope within each group.

The analysis showed that:

- The key difference between the communities found in the sandy backwaters covering stones-out-of-current (i.e. Sand and SOOC - BW) and the SOOC backwater with no sand (i.e. SOOC –BW) is the presence of the Dipteran larvae, Ceratopogonidae present in the latter (Table 5.7a). Ceratopogonidae flourish in still waters with fine sediments.
- Besides differences in the abundance of different baetid species between the cascade/riffle (SIC-cas/riffles) community and the Run (SIC – Run) community, particularly sensitive Ephemeroptera taxa, namely the Oligoneuridae and Heptageniidae were only found in the broken water biotope at EF Site 1 (Table 5.7b).

Table 5.7 SIMPER results from the multivariate analysis of (a) the stony backwater (SOOC-BW) and the sandy backwater covering stones (Sand and SOOC – BW) samples and the cascade/riffle (SIC – cas/riffle) and run (SIC-Run) samples. % Diss = the % dissimilarity for a given taxon. Cum. % diss = the cumulative % dissimilarity for each consecutive taxon.

	SOOC - BW	Sand & SOOC-BW		
Taxon	**mean Abund.**	**mean Abund.**	**% Diss.**	**Cum.% diss.**
Chironomidae	8.37	2.45	11.02	20.14
Baetidae sp5	4.36	0.00	8.12	34.98
Ceratopogonidae	0.00	3.87	7.21	48.16
Corixidae	3.87	1.00	5.35	57.94
Oligochaete	0.00	2.00	3.73	64.74
Baetidae sp7	1.73	0.00	3.23	70.64

(b)

	SIC-cas/riffle	SIC - Run		
on	**mean Abund.**	**mean Abund.**	**% Diss.**	**Cum.% diss.**
Baetidae sp4	2.24	12.04	15.73	22.59
Baetidae sp6	5.48	0.00	8.79	35.22
Chironomidae	1.00	5.48	7.18	45.53
Tricorythidae	6.56	2.24	6.93	55.49
Baetidae sp7	0.00	3.46	5.56	63.47
Oligoneuridae	2.83	0.00	4.54	69.99
Heptageniidae	2.24	0.00	3.59	75.14

5.7.2 EF Site 2

A total of 42 taxa, identified mostly to family level (see Appendix A for a list of all taxa) were recorded at EF Site2 upstream of the Kariba Dam during September 2014 (Table 1.8). The Ephemeroptera (Mayflies) were the most speciose order with a total of eight families, including six baetid species. The Hemiptera (bugs) and Diperta (flies) each included five different families, while four different families each represented the Odonata (dragonflies and damselflies) and Trichoptera (Caddisflies; Table 5.8).

In terms of abundance, 60% of the macroinvertebrates belong to the Ephemeroptera, which were mostly baetid mayflies although Trichorythidae and Oligoneuridae also occurred in significant numbers at this site. Plecoptera (Stoneflies) were relatively abundant at this site (Figure 6.x). Similar to EF Site 2, the Dipterans were relatively abundant although besides Chironomids, Simulids were also significantly abundant within this group.

Although absent at EF Site 1, Atyidae (shimps) were found within the overhanging vegetation along the channel margins in significant numbers at EF Site 2 (Figure 5-10). Also, molluscs were far more abundant at this site compared to EF Site 1, particularly the bivalves (Pelecypoda) which favoured the sandbars and sandy channel margins typical of this site.

Table 5.8 Summary of the number of families by order (with the number of baetid species in parenthesis) recorded at EF Site 2 in September 2014.

Order	EF Site 1
Atyidae	1
Annelida	1
Coleoptera	3
Diptera	5
Ephemeroptera	13(6)
Gastropoda	1
Hemiptera	5
Odonata	4
Ostracoda	1
Pelecypoda	3
Plecoptera	1
Trichoptera	4
Total	42

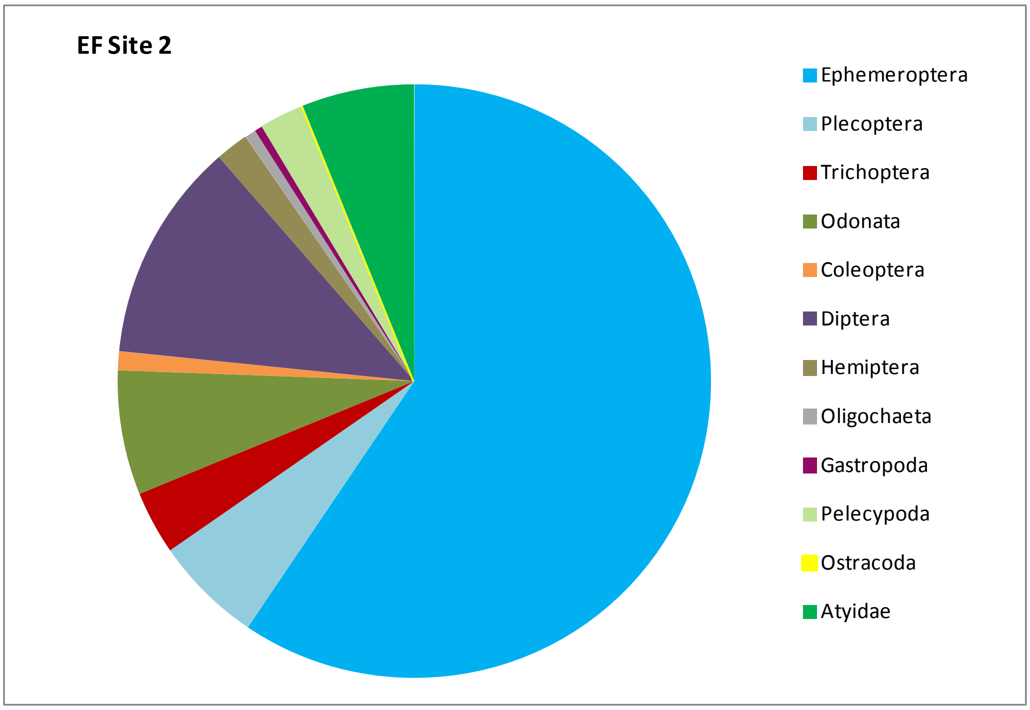


Figure 5.10 Proportional representation of macroinvertebrate orders by number of individuals at EF Site 2 in September 2014.

Both the relative proportion of macroinvertebrates (Figure 5-11a to g) and the overall macroinvertebrate abundance (Figure 5-11h) varied considerably between the seven different hydraulic biotopes sampled at EF Site 2. In particular it is evident that:

- Both the stones-in-current (SIC) and stones-out-of-current (SOOC) biotopes (Figure 1.11a to d) were dominated by Ephemeroptera, particularly the SOOC biotope with 91% of the overall macroinvertebrates belonging to this order (Figure 5-11d). Nevertheless, the overall abundance was relatively low in the SOOC (Figure 6.xh).
- Unlike the SOOC community, the SIC communities, particularly the riffle (Figure 6.xa) and fast run (Figure 5-11b) included a relatively high proportion of Plecoptera (stoneflies), particularly in the fast run which was the most productive of all the biotopes at this site (Figure 5-11h).
- Although the relative proportion of Ephemeroptera was high in the Vegetation-in-current (Veg-IC) biotope, Diptera were the dominant order, largely due to high numbers of Simuliidae.
- Shrimps (Atyidae) dominated the Vegetation-out-of-current (Veg-OOC) biotope, contributing more than 50% to the overall number of individuals (Figure 5-11f).
- Bivalves (Pelecypoda) were particularly dominant in the Sandbars and sandy, slow moving biotope (Sand-Slackwater) (Figure 5-11g). Other orders represented by the Sand-Slackwater included the Odonates (mostly dragonfly larvae), Dipterans and Gastropods (snails). Unlike all other biotopes at Site EF 2, Ephemeroptera, Trichoptera and Plecoptera were completely absent from the Sand-slackwaters.

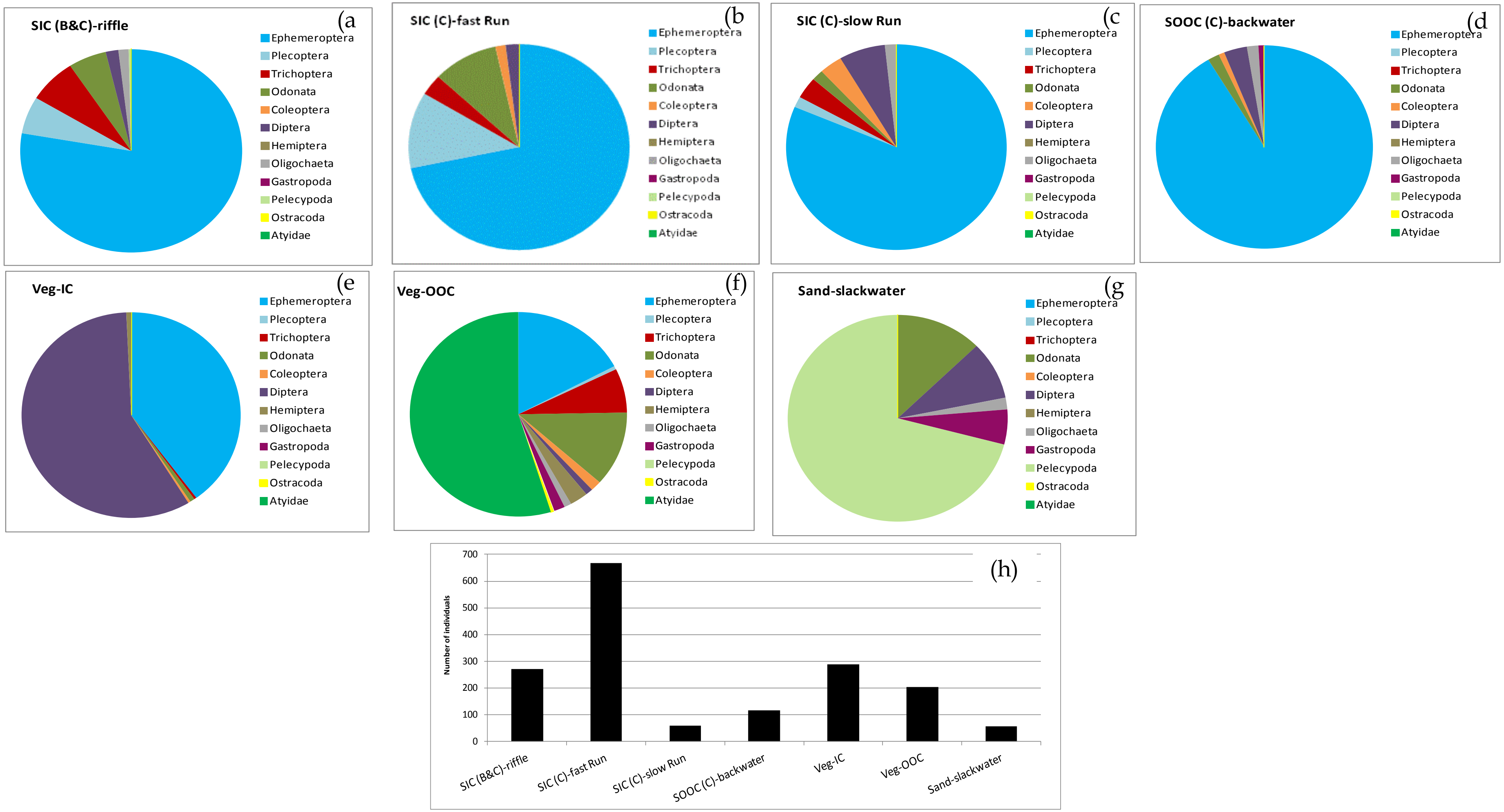


Figure 5.11 **Proportional representation of macroinvertebrate orders by number of individuals recorded in each hydraulic biotope sampled at EF Site 2 in September 2014.**

The overall Shannon-Wiener Diversity Index (H') for EF Site 2 was 3.0, although the index varied between 1.9 in the sand-slackwater, being the least diverse to 2.8 in both the riffle and vegetation-out-of-current biotopes, which were both particularly diverse (Figure 5-12). Evidently, all biotopes sampled at EF Site 2 support communities that contribute to the overall macroinvertebrate diversity.

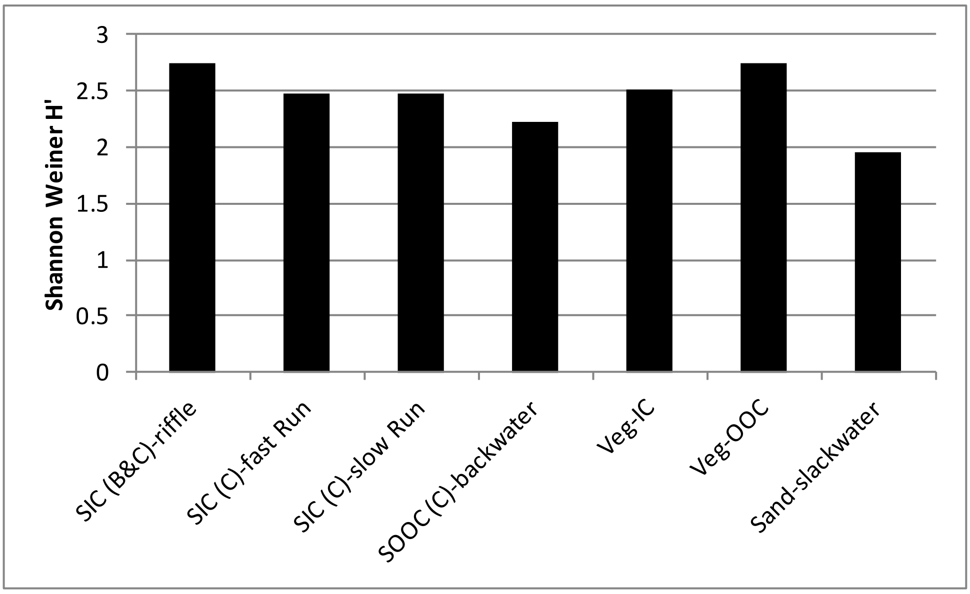


Figure 5.12 Shannon-Weiner Diversity Index (H') calculated for each hydraulic biotope sampled in September 2014 at EF 2.

Analysis of the macroinvertebrate community structure in PRIMER suggested that five macroinvertebrate communities could be identified at EF Site 2 (Figure 5-13a and b). These included the Stones-in-current (SIC) community, the Stones-out-of-current (SOOC) community, the vegetation-in-current (VIC) community, the Vegetation-out-of-current (VOOC) community and the Sand community (Figure 5-13a). The cluster diagram in Figure 5-13b shows that the sand community was the least similar to all others. This distinction is also reflected in the percentage dissimilarity between these groups given in Table 5.9.

Table 5.9 Percentage dissimilarity in community structure between the five broad macroinvertebrate communities determined by the multivariate analyses shown in Figure 5-13 at EF Site 2.

	SIC	SOOC	VIC	VOOC
SOOC	76			
VIC	71	74		
VOOC	81	85	71	
Sand	85	81	91	85

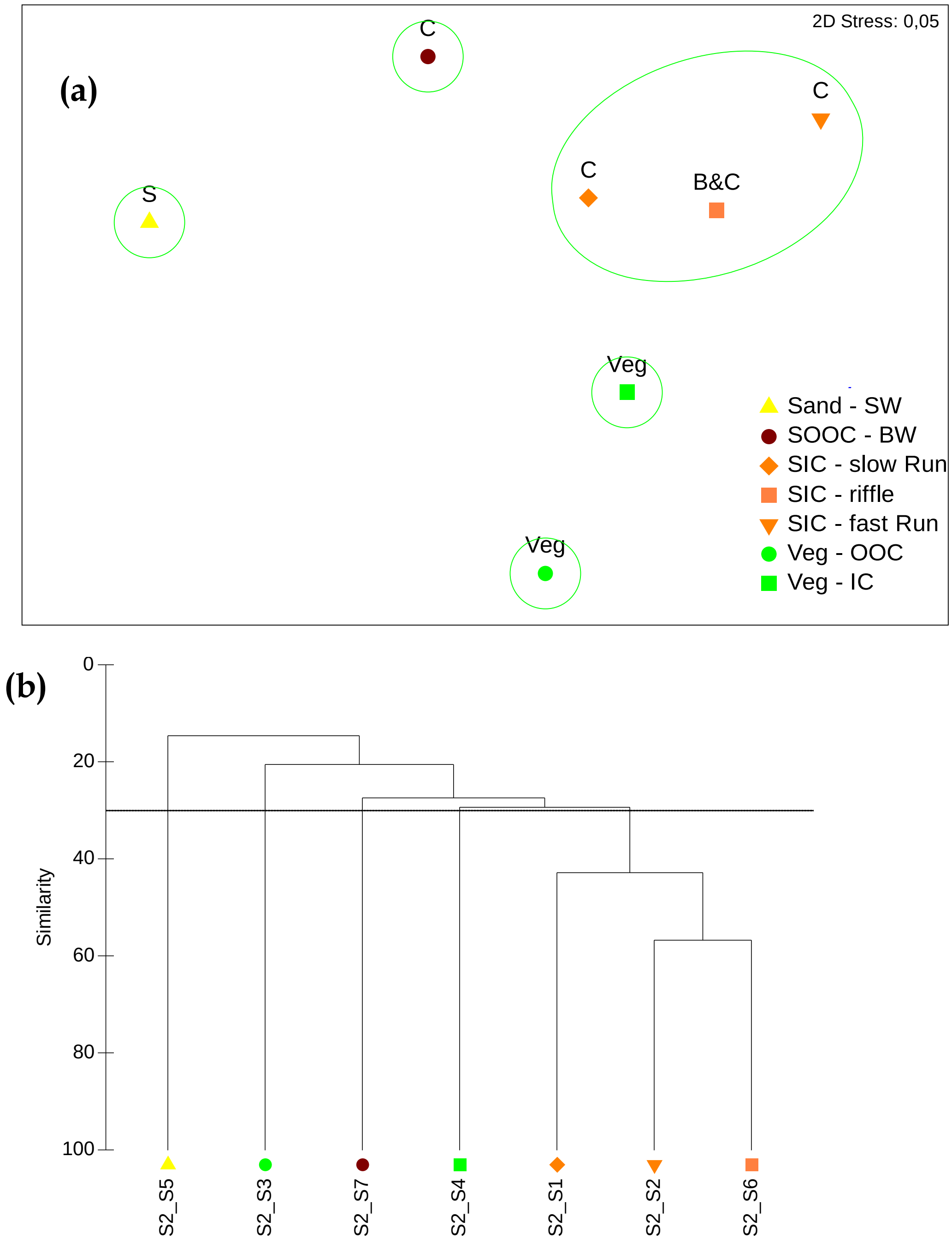
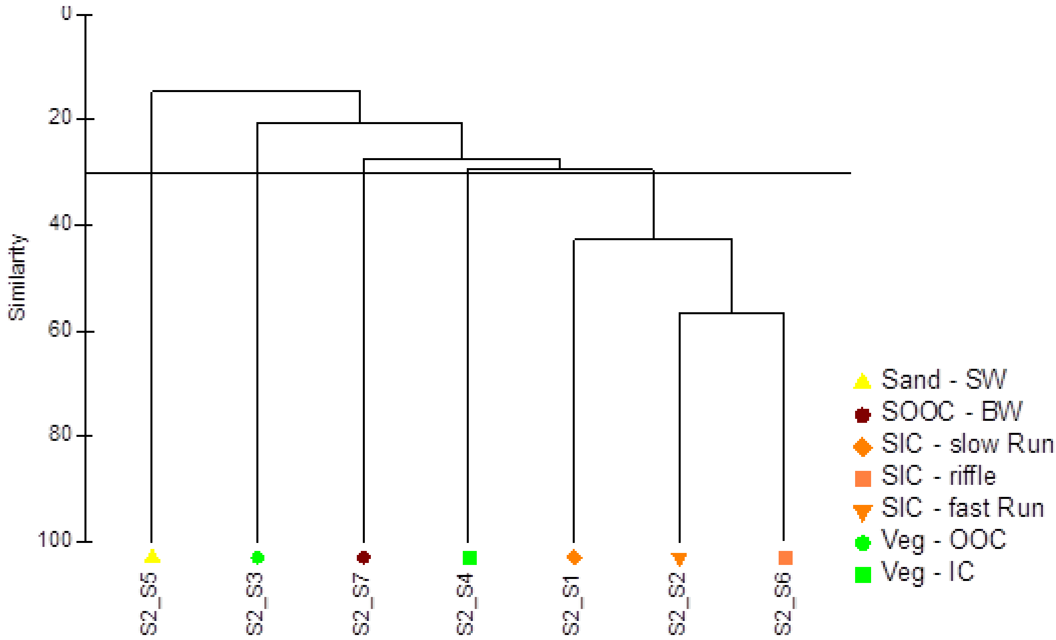


Figure 5.13 **a) Multi-dimensional Scaling (MDS) plot and b) cluster analysis of the macroinvertebrate communities within each hydraulic biotope sampled at EF Site 1 in September 2014.**



The SIMPER routine in PRIMER between these three communities showed that:

- Although the SIC and VIC biotopes were characterised by fast flowing water, certain Ephemeroptera, particularly Trichorythidae and Heptageniidae were far more abundant in the SIC biotope (Table 5.10a).
- Oligoneuridae were found exclusively in the SIC biotope (Table 5.10a and b).
- The VIC biotope was dominated by Simulidae and an unidentified Dipteran pupa (probably Simulidae) and these taxa were most responsible for the distinction of the VIC community from all others at EF Site 2 (Table 5.10a and d).
- The high abundance of the silt tolerant Ephemeropteran, Caenidae in the slow flowing backwaters, was the key contributor to the distinction of the SOOC community from all others (Table 5.10b, c and d).
- Shrimps (Atyidae) were found exclusively in the VOOC biotope in high numbers and this was the key taxon that distinguished the VOOC community from all others (Table 1.10 c and e).
- Bivalves (Pelecopodae) including mostly the Sphariidae and Mutelidae but also some coribulidae were found only in the sand channel margins and sand bars at this site. The abundance of bivalves as a whole made the sand community distinction from the others (Table 5.10d).

Table 5.10 **SIMPER results from the multivariate analysis of (a) the Stones-in-current (SIC) and Vegetation-in-current (VIC); (b) the SIC and Stones-out-of-current (SOOC); (c) the Vegetation-out-of-current (VOOC) and the SOOC; (d) the VOOC and VIC and (e) the Sand and SOOC groups. % Diss = the % dissimilarity for a given taxon. Cum.% diss = the cumulative % dissimilarity for each consecutive taxon.**

(a)

Taxon	SIC mean Abund.	VIC mean Abund.	% Diss.	Cum.% diss.
Dipteran pupa	0.00	100.00	9.76	13.81
Simuliidae	0.00	60.06	7.56	24.50
Baetidae sp5	0.00	35.05	5.77	32.67
Tricorythidae	54.76	5.02	4.24	38.68
Heptageniidae	59.60	9.00	4.01	44.35
Perlidae	21.62	0.00	3.82	49.76
Baetidae sp2	0.22	17.98	3.72	55.03
Oligoneuridae	17.89	0.00	3.45	59.91
Baetidae sp4	10.24	36.97	3.12	64.32
Leptophlebiidae	25.50	2.99	2.82	68.31
Baetidae sp6	13.84	1.00	2.49	71.84

(b)

Taxon	SIC mean Abund.	SOOC mean Abund.	% Diss.	Cum.% diss.
Caenidae	0.22	72.93	10.46	14.47
Tricorythidae	54.76	0.00	8.01	25.56
Heptageniidae	59.60	1.99	7.32	35.69
Perlidae	21.62	0.00	4.89	42.46
Baetidae sp6	13.84	0.00	4.6	48.83
Oligoneuridae	17.89	0.00	4.41	54.92
Philopotamidae	7.18	0.00	3.17	59.31
Libellulidae	9.99	0.00	3.04	63.51
Leptophlebiidae	25.50	22.00	2.68	67.21
Simuliidae	0.00	4.00	2.66	70.89

(c)

Taxon	VOOC mean Abund.	SOOC mean Abund.	% Diss.	Cum.% diss.
Shrimps	102.01	0.00	13.33	15.76
Caenidae	0.00	72.93	11.28	29.09
Leptophlebiidae	0.00	22.00	6.19	36.41
Coenagrionidae	22.00	0.00	6.19	43.72
Baetidae sp5	22.00	1.00	4.87	49.48
Leptoceridae sp1	9.99	0.00	4.17	54.41
Notonectidae	5.02	0.00	2.95	57.9
Veliidae	5.02	0.00	2.95	61.39
Simuliidae	0.00	4.00	2.64	64.51
Corixidae	8.01	1.00	2.41	67.36
Pleidae	2.99	0.00	2.29	70.07

(d)

Taxon	VOOC mean Abund.	VIC mean Abund.	% Diss.	Cum.% diss.
Shrimps	102.01	0.00	9.99	14.04
Dipteran pupa	0.00	100.00	9.89	27.94
Simuliidae	0.00	60.06	7.66	38.71
Baetidae sp4	0.00	36.97	6.02	47.17
Coenagrionidae	22.00	0.00	4.64	53.69
Baetidae sp2	0.00	17.98	4.20	59.59
Leptoceridae sp1	9.99	0.00	3.13	63.99
Notonectidae	5.02	0.00	2.21	67.09
Leptophlebiidae	0.00	2.99	1.71	69.50

(e)

Taxon	Sand mean Abund.	SOOC mean Abund.	% Diss.	Cum.% diss.
Caenidae	0.00	72.93	18.52	22.91
Leptophlebiidae	0.00	22.00	10.17	35.49
Sphaeriidae	19.98	0.00	9.7	47.48
Mutelidae	16.00	0.00	8.67	58.2
Chironomidae	5.02	0.00	4.85	64.2
Simuliidae	0.00	4.00	4.34	69.56
Corbiculidae	2.99	0.00	3.76	74.2

5.8 *IDENTIFICATION OF INDICATORS*

5.8.1 Macroinvertebrate indicators

A list of macroinvertebrate taxa or indices used as indicators in the EF assessment and the reasons of their selection are provided in Table 5.11.

Table 5.11 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Species Richness	Measure of community integrity which would decline with a loss of habitat heterogeneity (both sites)
Ephemeroptera	Important source of food for terrestrial birds (both sites)
Bivalves (Pelecypoda)	Important source of food for open billed storks found only in sandbars and sandy channel margins (EF Site 2)
Oligoneuridae	Indicator of fast flow (broken water) over cobbles and boulders at both sites.
Simuliidae	Indicator of increased suspended organics (both sites)
Chironomidae	Proliferate under reduced flow and elevated algal biomass (both sites)
Shrimps (Atyidae)	Important source of fish food found only in the Marginal Vegetation out of current (EF2)
Ceratopogonidae	Indicator of increased silt and fine sediments (both sites)
Snails (Gastropoda)	Important food source for food for many fish species that may proliferate in the absence of flood disturbance (both sites)

5.8.2 Description and location of indicators

1.1.1.2 Name: Species Richness

Habitat: All habitats sampled at both EF sites 1 and 2 contribute to the diversity and species richness of macroinvertebrates.

Representative species: All taxa, although the distribution of different baetid species in different biotopes provides a good indicator of changes in species richness considering the low taxonomic resolution of the full macroinvertebrate community determined in this study.

Other characteristic species: n/a

Flow-related concerns: Changes in flow conditions (i.e. the duration of the dry season; a reduction in dry season discharge and a change in the pattern of dry season flows) may result in a loss of habitat heterogeneity which provides the template for maintenance of a diverse macroinvertebrate community at both sites.

1.1.1.3 Name: Ephemeroptera

Habitat: Found mostly in habitats with cobble or bedrock substrata.
Representative species: Baetidae, Heptageniidae, Trichorythidae
Other characteristic species: Leptophlebidae.
Flow-related concerns: A loss of habitat with fast flowing broken water (i.e. a reduction in dry season base flows) may result in a reduction in the abundance of Ephemeroptera.

1.1.1.4 Name: Bivalves (Pelecypoda)

Habitat: Sandy channel margins and in-channel sandbars
Representative species: Sphaeriidae and Mutelidae.
Other characteristic species: Corbiculidae
Flow-related concerns: A reduction in discharge and thus in the availability of sand habitat with changes in sediment supply would result in a reduction in the abundance of bivalves.

1.1.1.5 Name: Oligoneuridae

Habitat: Riffles and cascades (broken water) over cobbles and boulders
Representative species: n/a
Other characteristic species: n/a
Flow-related concerns: This taxon is highly sensitive to changes in flow. A loss of suitable habitat (i.e. broken water over stones) with a reduction in discharge would result in a loss of this sensitive taxon.

1.1.1.6 Name: Simuliidae

Habitat: flowing water over stones or through vegetation.
Representative species: n/a.
Other characteristic species: n/a.
Flow-related concerns: As filter feeders, Simuliidae thrive under constant, moderately fast flowing conditions with an increase in suspended organic material. Therefore a loss of flow variability and in increase in phytoplankton from dam releases may result in a proliferation of Simuliidae. A loss of flood disturbance would also promote the proliferation of Simuliidae.

1.1.1.7 Name: Chironomidae

Habitat: Generalists that occur in almost all habitats.
Representative species: n/a.
Other characteristic species: n/a.
Flow-related concerns: A reduction in flow and an increase in backwater conditions would favour the proliferation of Chironomidae at the expense of more sensitive taxa. Also, as generalists, Chironomidae can proliferate if water quality deteriorates which may be a consequence of a change in flow conditions.

1.1.1.8 Name: Shrimps (Atyidae)

Habitat: Marginal Vegetation-out-of-current (VOOC).
Representative species: n/a.
Other characteristic species: n/a.
Flow-related concerns: A loss of suitable habitat either through a reduction in base flows or an indirect flow related loss of marginal vegetation would result in a reduction in the abundance of this taxon.

1.1.1.9 Name: Ceratopogonidae

Habitat: Stagnant or slow flowing backwaters with silt and find sediments
Representative species: n/a.
Other characteristic species: n/a.
Flow-related concerns: A reduction in baseflows and a loss of flood disturbance would favour the proliferation of this taxon. The deposition of fine sediments (organic or inorganic) as a result of a dam would also exacerbate the potential proliferation of this taxon.

1.1.1.10 Name: Gastropoda

Habitat: Sand either in or out of current
Representative species: Thiaridae and Viviparidae
Other characteristic species: n/a.
Flow-related concerns: The loss of flood disturbance and an increase in backwater areas would promote the proliferation of this taxon. Also, an increase in benthic algae in the absence of flood disturbance would increase the food supply and thus productivity of these grazers.

5.8.3 Linked indicators

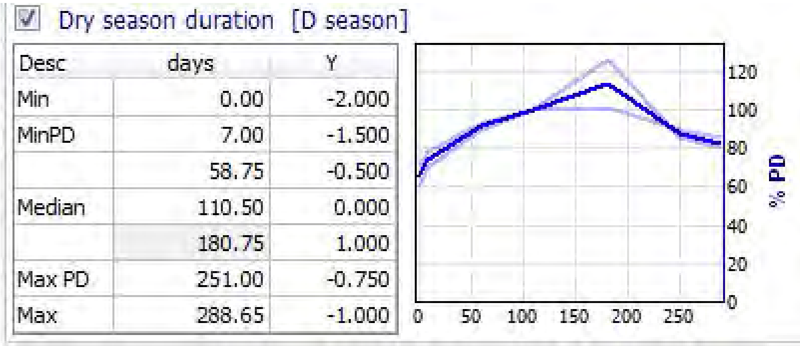
See Section 5.10.

5.9 ASSUMPTIONS AND LIMITATIONS

No background information on the macroinvertebrate communities of the Zambezi River within the study area and therefore many of the links are based on extrapolation from other areas. Data collection was limited to the collection of a single sample in September 2014 and therefore the data presented in this study is a ‘snap shot’ of the macroinvertebrate community in the middle Zambezi River. Temporal changes in community structure could therefore not be quantified. Also, this study was limited to the identification of macroinvertebrate to family level. While a greater level of taxonomic resolution (e.g to genera or species) would have provided a better understanding of species richness and the structure and function of macroinvertebrate communities, this was beyond the scope of this study.

5.10 *MOTIVATIONS FOR RESPONSE CURVES*

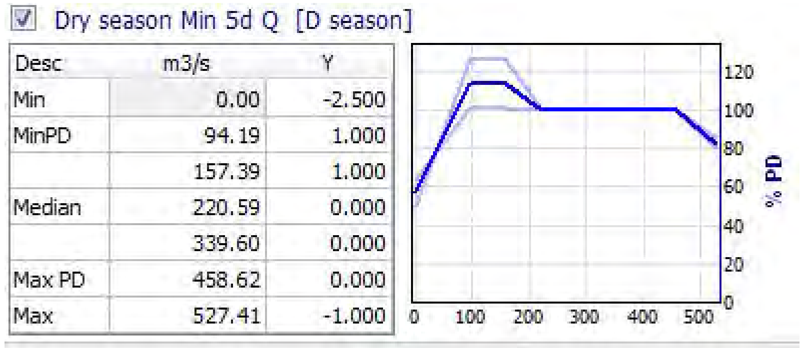
5.10.1 Indicator 1: Species Richness

<table>
<tr><td colspan="2">Species Richness</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>-1.500</td></tr>
<tr><td></td><td>58.75</td><td>-0.500</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>-0.750</td></tr>
<tr><td>Max</td><td>288.65</td><td>-1.000</td></tr>
</table></td><td>Many aquatic macroinvertebrates, particularly aquatic insects that contribute significantly to the diversity of the macroinvertebrate community in rivers, have evolved life history strategies that respond to seasonal cues associated with the dry season such as temperature changes, change in water depth and hydraulic conditions which trigger hatching and growth of individuals over this period and emergence prior to the onset of the wet season (Lytle and Poff 2004; Lytle 2008).

A reduction in the duration of the dry season would mean a shorter season for breeding, growth and emergence of many macroinvertebrates, particularly the aquatic insects that rely on dry season conditions during their larval phase. A disruption of the life cycle of many species will result in the loss of some sensitive species and a reduction in the abundance of others (Poff and Zimmerman 2010).

The wet season or disturbance period is a harsh, inhospitable environment for many macroinvertebrates and discharges in the transitional seasons reduce the availability of suitable habitat. Therefore, a slight increase in the length of the dry season may increase species richness marginally. However,</td><td>High</td></tr>
</table>

Species Richness		
Linked indicator response curve	Explanation	Confidence
	the longer the duration of the dry season, particularly if the duration extends over the hot period in February through to April typical of the middle reaches of the Zambezi River, conditions will favour the proliferation of hardy taxa and thus a loss in species (Grimm 1994).	
	Many aquatic macroinvertebrates rely on highly oxygenated broken water typical of riffles and shallow cascades while others thrive in smooth fast unbroken flows associated with runs (Schael 2005). A complete loss of flows in the dry season would result in the loss of the riffles and cascades and runs. Many of the flow sensitive taxa (mostly within the Ephemeroptera, Trichoptera and Plecoptera) would therefore disappear and therefore species richness would decline. However, considering that about 50% of all taxa were found in the slow flowing backwaters and slackwaters associated with the secondary channels, this would result in only a low decline in the species richness. Because the main channel is a harsh, inhospitable habitat for macroinvertebrates i.e. deep pools, rapids and cascades, an increase in the dry season minimum would result in the loss of some of these shallower runs and riffles/cascades that are characteristic of the secondary channel and a consequent reduction in species richness. Nevertheless, these habitats would only be lost at around 700m^3/s (at EF Site 1).	High

<table>
<tr><td colspan="2">Species Richness</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>-0.500</td></tr>
<tr><td></td><td>76.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>-0.250</td></tr>
<tr><td>Max</td><td>246.10</td><td>-1.500</td></tr>
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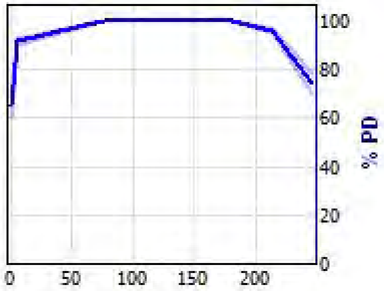

</td><td>Physical disturbance typical of the wet season acts differentially to remove macroinvertrates across the channel (Hildrew and Giller 1994) with certain taxa being morphologically adapted to withstand disturbance, others are behaviourally adapted through emergence strategies that are synchronised to avoid the wet season or find refuge in interstitial spaces in certain habitats (Lytle 2002, Lytle 2008).

Flood disturbance therefore reduces the abundance of hardy macroinvertebrate species that proliferate under stable conditions and therefore maintains species richness. Therefore a reduction in the wet season duration to zero days means a complete loss of flood disturbance in the system, a proliferation of hardy taxa which outcome more sensitive taxa which would result in the loss of species diversity (Hildrew and Giller 1994). An extended wet season would however increase the length of hostile conditions and thus reduce the length of time for breeding, feeding and thus completion of the aquatic phase of the life cycle for many aquatic insects. This would therefore result in a loss of these taxa and a reduction in species richness.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Species Richness</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
Wet season ave daily vol [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>78.41</td><td>0.000</td></tr>
<tr><td></td><td>124.02</td><td>0.000</td></tr>
<tr><td>Median</td><td>169.63</td><td>0.000</td></tr>
<tr><td></td><td>263.51</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>357.40</td><td>0.000</td></tr>
<tr><td>Max</td><td>411.01</td><td>-0.500</td></tr>
</table>


</td><td>Disturbance acts to reduce the abundance of macroinvertebrates (Konrad et al. 2008, Bunn and Arthington 2002). Depending on their adaptation to flows, floods will act differentially on different taxa and thus preventing dominance by certain taxa (Hildrew and Giller 1994). A reduction in flood size may allow certain hardy taxa to withstand being flushed from the system and may therefore out-compete more sensitive taxa resulting in a slight reduction in species richness.

An increase in flood size beyond PD would however reduce any available refuge for taxa that do not emerge over the wet season and naturally survive through the disturbance period. Also, increases in the volume of the wet season would increase sheer stress on the bed and therefore species that are morphologically adapted to survive under natural levels of sheer stress associated with natural disturbance events may not survive extreme events beyond the natural range. Excess flood size would therefore result in the loss of species and a reduction in species richness.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Species Richness</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Single-celled diatoms [D season]

<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.010</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>-1.000</td></tr>
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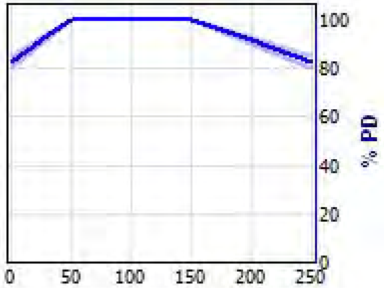


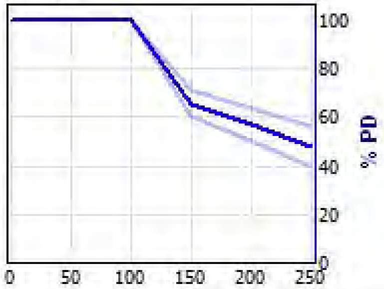
</td><td>Single celled diatoms are the major food source for many aquatic macroinvertebrates (Ewart-Smith and King 2012).

Therefore a loss of diatoms may lead to a reduction and or loss of species that feed exclusively by grazing or scraping diatoms from the substratum.

Conversely, an excessive increase in diatoms would reduce the quality of available habitat for macroinvertebrates (Biggs and Kilroy 2000) and could result in the loss of species that are sensitive to habitat quality.</td><td>HIgh</td></tr>
<tr><td>

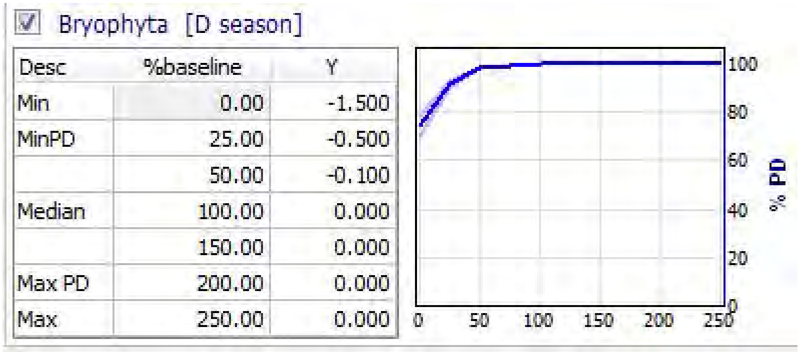
Filamentous green algae [All seasons]

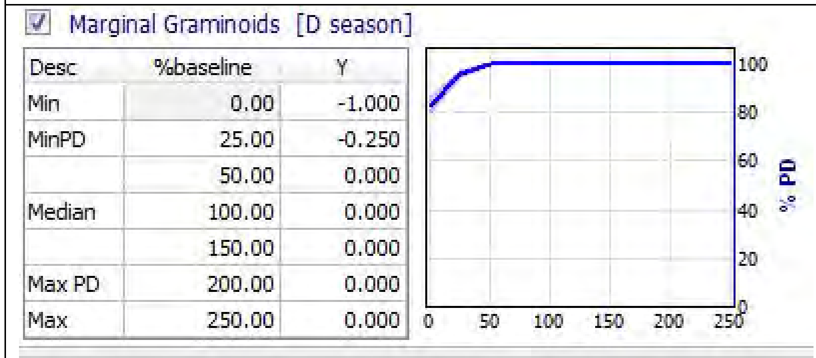
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-2.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-2.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>-3.000</td></tr>
</table>



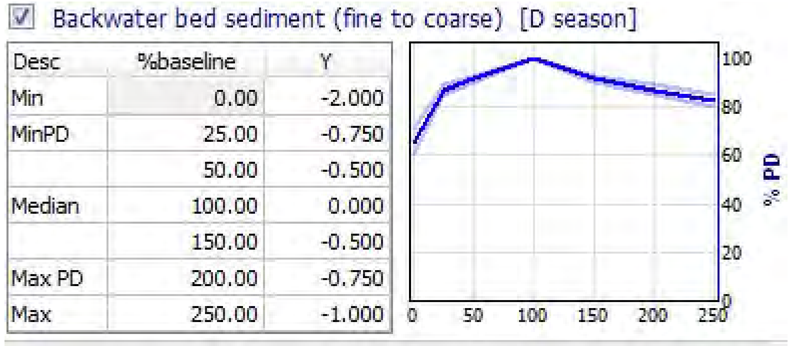
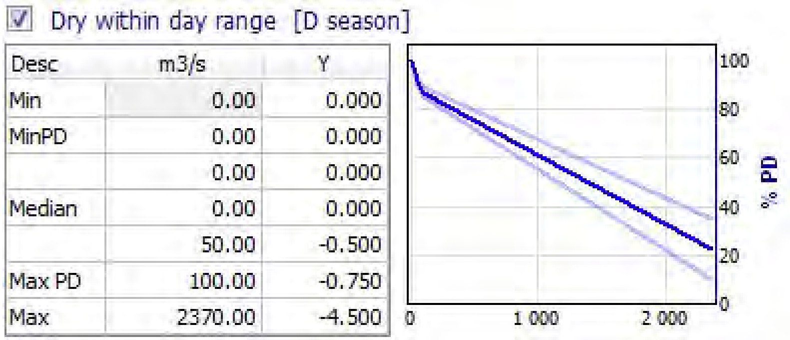
</td><td>Green algae are not a favoured source of food for most grazers and scrapers in river ecosystems, although specific taxa, such as gastropods may eat the basal cells of green algae (Stevenson et al. 1998).

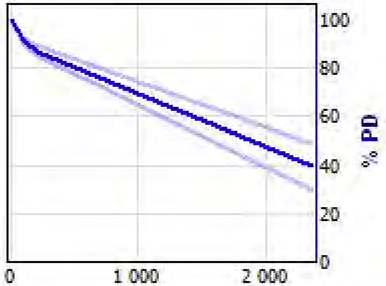
An increase in green algae would cause a reduction in food quality (through a reduction in the relative proportion of diatoms as green algal abundance increases), which may favour the growth and productivity of hardy taxa that can feed on green algae. This would result in a reduction in species diversity.
Also, the proliferation of green algae would reduce habitat quality for many macroinvertebrate taxa, particularly in the stony substrata (cobbles, bedrock, boulders) (Stevenson et al.</td><td>High</td></tr>
</table>

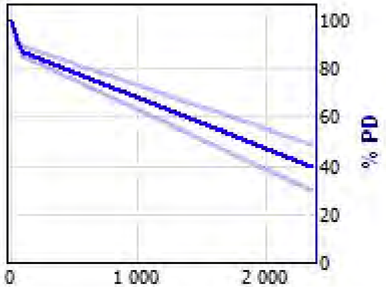
<table>
<tr><td colspan="2">Species Richness</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td></td><td>1998.)</td><td></td></tr>
<tr><td>
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.000</td></tr>
</table>
</td><td>Bryophytes growing mainly on bedrock sheets in the runs within the secondary channel at EF Site 1 have a complex structure that provides refuge habitat for many taxa that were found exclusively in the run biotope. The loss of Bryophytes would therefore result in a reduction in habitat quality through the loss of refuge from very high shear stress during flood events. This would result in the loss of taxa that are behaviourally adapted to these habitats for survival through flood disturbance.

Therefore, a loss of Bryophytes would result in a decrease in species richness at EF Site 1.</td><td>Moderate</td></tr>
<tr><td>
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.250</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.000</td></tr>
</table>
</td><td>This is an important habitat for a number of species that were found only in the marginal vegetation at EF Site 2, such as the Odonates, Coenagrionidae, certain Baetid species and Atyidae (shrimps) (Thirion 2007).

A loss of graminoids in the water column, or a loss of diversity of form (i.e. stalks and leaves) would therefore result in the loss of habitat quality and a loss of species.</td><td>High</td></tr>
</table>

Species Richness		
Linked indicator response curve	Explanation	Confidence
	Some taxa rely on bedrock or boulders without very fine silt in the slow flowing or stagnant biotopes for their growth and productivity, particularly some of the more sensitive aquatic insects that require gill respiration such as the Ephemeroptera (e.g specific baetids species were found only in silt free backwaters at EF Site 1) and Trichoptera (Lytle 2008). Therefore if all backwaters are covered in silt and sands, then species richness will decline as silt sensitive taxa are lost but many taxa will still be found in the flowing biotopes. Some taxa were found only in these fine sediments under PD conditions and therefore a loss of habitats with fine silts may also result in the loss of a few taxa.	High
	Many aquatic macroinbertebrates have life history strategies that are adapted to the stable low flow conditions associated with the dry season (Lytle and Poff 2004; Lytle 2008). Excessive daily range in discharge would create an unstable, high disturbance environment during the dry season which is naturally a stable environment. Macroinvertebrates are therefore vulnerable to rapid diurnal changes in flow and regulated river reaches below hydroelective dams with erratic flow patterns generally have macroinvertebrate communities with a very low diversity (Munn and Brusven 1991).	High

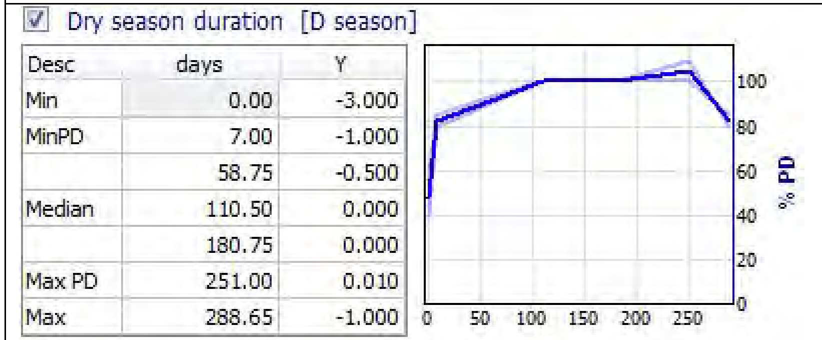
<table>
<tr><td colspan="2">Species Richness</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td></td><td>Thus, the excessive daily range in discharge would flush out most macroinvertebrates that are not adapted to survival under extreme flood disturbance events (Munn and Brusven 1991; Bunn and Arthington 2002). This would result in the loss of species and thus a reduction in species richness.</td><td></td></tr>
<tr><td>T1 within day range [T1 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.750</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.500</td></tr>
</table>

</td><td>Although many aquatic macroinvertebrates have life history strategies that are adapted to the stable low flow conditions associated with the dry season (Lytle and Poff 2004; Lytle 2008) when most of them complete the aquatic part of their life cycle, some multivoltile taxa that may still breeding and feeding in the system towards the end of the dry season and into the transitional season. These species may be vulnerable to flushing by excessive daily range in flows over this period.

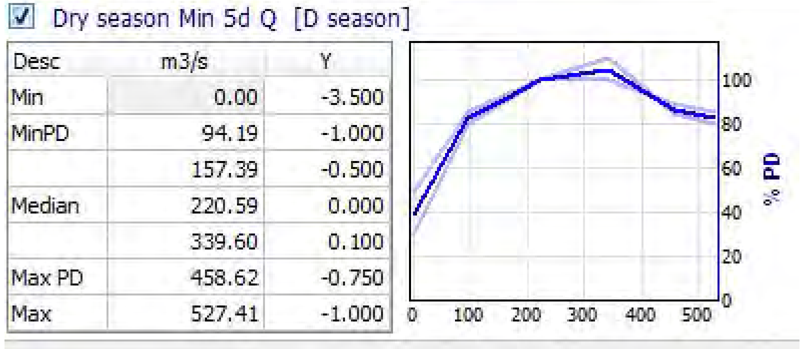
Nevertheless the effect on species richness would be less extreme than would be in the dry season when many more taxa may not yet have emerged.</td><td>Moderate</td></tr>
<tr><td>T2 within day range [T2 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>-0.750</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.500</td></tr>
</table>

</td><td>Although many aquatic macroinvertebrates have life history strategies that are adapted to the stable low flow conditions associated with the dry season (Lytle and Poff 2004; Lytle 2008) when most of them complete the aquatic part of their life cycle, some multivoltile taxa that lay eggs in the system as the flood recedes may be flushed out.

However, fewer taxa would be affected by massive daily</td><td>Moderate</td></tr>
</table>

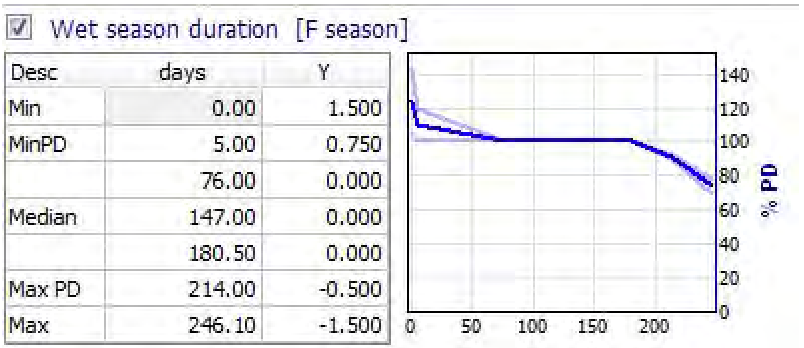
<table>
<tr><td colspan="2">Species Richness</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td></td><td>fluctuations than in T1 because fewer taxa would be dependent on the river at this time, relative to T1.</td><td></td></tr>
</table>

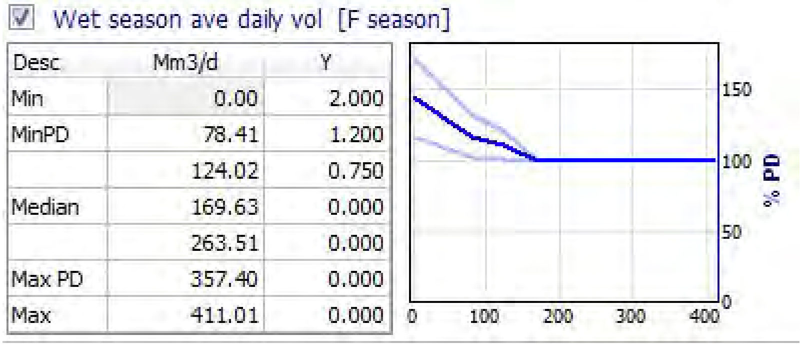
5.10.2 Indicator 2: Ephemeroptera

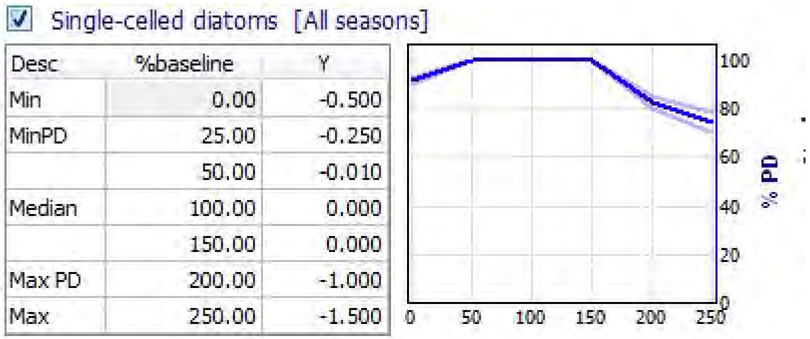
<table>
<tr><td colspan="2">Ephemeroptera</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
</td><td>A reduction in the duration of the dry season would mean a shorter season for breeding, growth and emergence of many Ephemeroptera taxa that rely on dry season conditions during their larval phase and therefore a reduction in abundance.

An extended dry season would promote proliferation of hardy taxa at the expense of sensitive taxa, many of which are Ephemeroptera.</td><td>High</td></tr>
<tr><td>
</td><td>A complete loss of flows in the dry season would result in the loss of flowing water habitats, particularly riffles, cascades and runs. Most of the mayflies (Ephemeroptera) are reliant on flowing water and therefore, a loss of habitat will result in a loss of Ephemeropteran abundance.

An increase in the dry season discharge would increase the availability of suitable habitat for mayflies. The main channel is</td><td>High</td></tr>
</table>

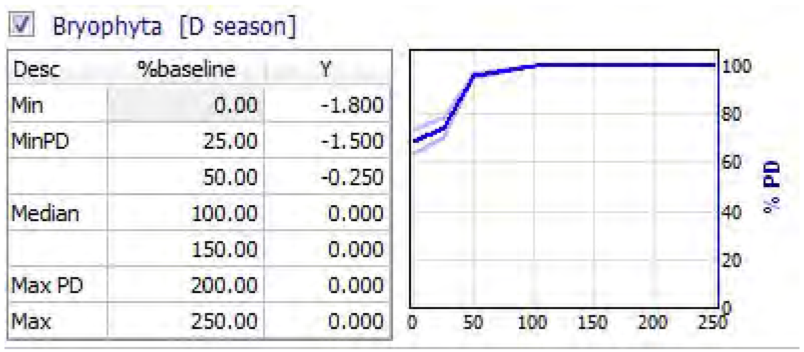
Ephemeroptera		
Linked indicator response curve	Explanation	Confidence
	less suitable habitat for mayflies relative to the secondary channels which provides a range of different habitat types with its heterogeneity in bed sediment size. A discharge of 527m^3/s would not inundate the secondary channel and so an increase in the dry season minimum would not result in a massive loss in mayfly abundance, although some loss may be evident as shear stresses increase in the main channel and available habitat becomes unsuitable.	
	Flood disturbance reduces the abundance of hardy macroinvertebrate species that proliferate under stable conditions. Therefore a reduction in the wet season duration to zero days means a complete loss of flood disturbance in the system and a proliferation of hardy taxa which out-compete more sensitive taxa (Hildrew and Giller 1994). Under zero flood conditions, certain mayflies like the Trichorythidae or more hardy Baetid species may flourish and thus Ephemeroptera abundance would increase slightly. An extended wet season would however increase the length of disturbance conditions that do not favour the growth and survival of most Ephemeroptera taxa that rely on stable dry season conditions to complete their life cycle.	High

<table>
<tr><td colspan="2">Ephemeroptera</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
</td><td>The loss of flood disturbance will result in an increase in the abundance of Ephemeroptera in the riffles and cascades and runs where many mayfly taxa are able to thrive.

Most aquatic insects such as the Ephemeroptera have life history cycles that are adapted to floods through emergence prior to the onset of a disturbance event (Lytle 2008). Therefore flood size is irrelevant to most Ephemeroptera taxa as would be reduced by the PD floods any way and thus an increase in flood size would have a negligible effect on the ephemeroptera abundance.</td><td>High</td></tr>
<tr><td>
</td><td>Many of the Ephemeroptera are either filter feeders (e.g. Oligoneuridae) or deposit feeders (e.g. Caenidae, Leptophlebidae) and therefore are not reliant on diatoms as a food source (Schael 2005). Nevertheless, some baetid species as well as Heptageniidae feed on diatoms.

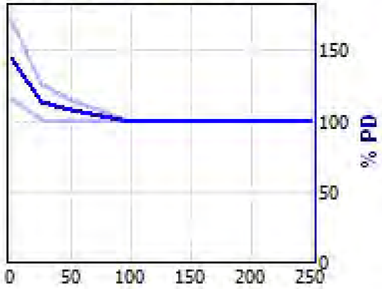
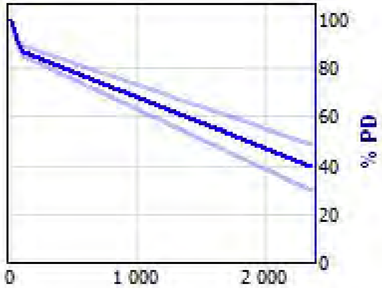
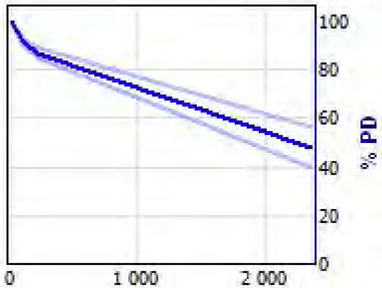
Therefore the loss of diatom biomass could have some effect on Ephemeroptera abundance as a whole but the effect would be low.

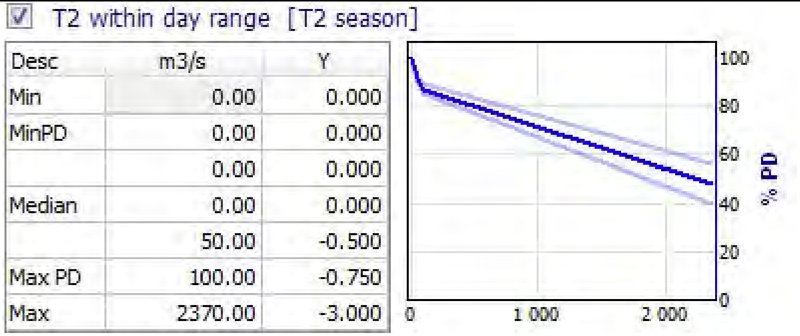
An excessive increase in diatoms would however reduce habitat quality (Biggs and Kilroy 2000) and thus result in a loss of Ephemeroptera.</td><td>HIgh</td></tr>
</table>

<table>
<tr><td colspan="2">Ephemeroptera</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td></td><td>Aquatic moss (Bryophyta) was a common feature of the macrofaunal habitat in the run biotopes at EF Site 1. The highest diversity of Baetid species and the greatest abundance of Ephemeroptera were found in this habitat. This suggests that Bryophyta provides and important refuge habitat for Ephemeroptera within a habitat that would otherwise be largely inhospitable due to high shear stress.

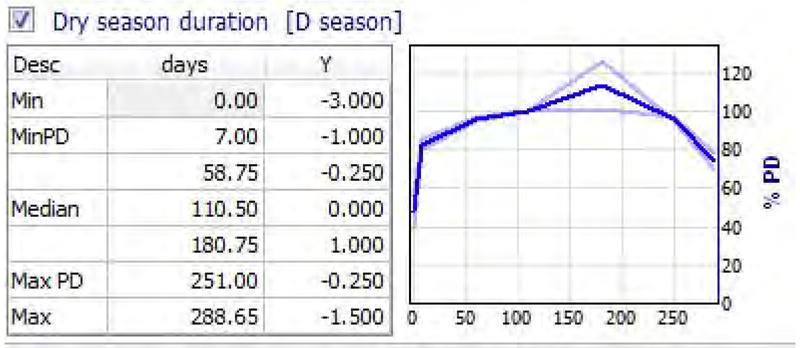
Therefore, a loss of Bryophyta would result in a loss of Ephemeroptera.</td><td>High</td></tr>
<tr><td></td><td>Some of the Baetid species were only found in the VOOC biotope, suggesting that certain Ephemeroptera taxa rely on this habitat for their survival.

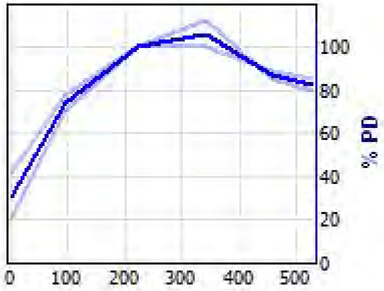
Therefore, a loss of Marginal Graminoids and therefore a loss of habitat would result in a reduction in the abundance of certain ephemeroptera. However, the habitat is so small relative to other available habitat in the gorge and thus the effect will be very small at EF Site 1.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Ephemeroptera</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>☑ Backwater bed sediment (fine to coarse) [D season]
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>1.000</td></tr>
<tr><td></td><td>50.00</td><td>0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.000</td></tr>
</table>

</td><td>Caenids favour fine silt and thus flourish under increased sediments loads (Corbin and Goonan 2010). Therefore, an increase in fine sediments in the backwaters would result in an increase in the overall abundance of mayflies.</td><td>High</td></tr>
<tr><td>☑ Dry within day range [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>-0.750</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.500</td></tr>
</table>

</td><td>Ephemeroptera (like most macroinvertebrates) are vulnerable to rapid diurnal changes in flow (Bunn and Brusven 1991). Excessive daily range in discharge in the dry season would flush out most macroinvertebrates which rely on more benign conditions associated with the dry season for breeding.</td><td>High</td></tr>
<tr><td>☑ T1 within day range [T1 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.750</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>

</td><td>Excessive daily range in discharge in the transitional season would flush out most Ephemperoperta that are still breeding and feeding in the system towards the end of the dry season.</td><td>Moderate</td></tr>
</table>

Ephemeroptera		
Linked indicator response curve	Explanation	Confidence
	Excessive daily range in discharge in the transitional season would flush out most Ephemeroptera that are still breeding and feeding in the transitional season.	Moderate

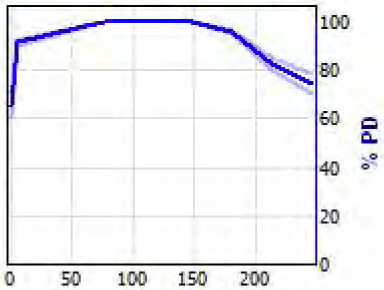
5.10.3 Indicator 3: Oligoneuridae

Oligoneuridae		
Linked indicator response curve	Explanation	Confidence
	A reduction in the duration of the dry season would mean a shorter season for breeding and emergence of Oligoneuridae which rely on the duration of the dry season to complete their life cycle (Campbell 1986). Because the wet season is a harsh, inhospitable environment, and discharges in the transitional seasons reduce the availability of suitable habitat, a slight increase in the length of the dry season may increase Oligoneuridae abundance slightly. An extension of the dry season duration, particularly if the duration extends over the hot period in February through to April, the better conditions will be for the proliferation of	High

<table>
<tr><td colspan="2">Oligoneuridae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td></td><td>hardy taxa at the expense of sensitive taxa</td><td></td></tr>
<tr><td>Dry season Min 5d Q [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-4.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-1.500</td></tr>
<tr><td></td><td>157.39</td><td>-0.750</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.250</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>-0.750</td></tr>
<tr><td>Max</td><td>527.41</td><td>-1.000</td></tr>
</table>


</td><td>A complete loss of flows in the dry season would result in the loss of the riffles and cascades and runs. Oligoneuridae are wholly dependent on the riffles and cascades.

Therefore, a loss of these habitats would result in a significant loss of Oligoneuridae with a loss of these habitats.

Because the main channel is a harsh, inhospitable habitat for macroinvertebrates i.e. deep pools, rapids and cascades, an increase in the dry season minimum would result in the loss of some of the shallower runs and riffles/cascades that are characteristic of the secondary channel and thus a reduction in Oligoneuridae. Nevertheless, these habitats would only be lost at around 700m³/s.</td><td>High</td></tr>
<tr><td>Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>-0.500</td></tr>
<tr><td></td><td>76.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>-0.250</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>246.10</td><td>-1.500</td></tr>
</table>


</td><td>A loss of the wet season would result in the loss of flood disturbance and other hardy taxa would flourish at the expense of Oligoneuridae under these conditions.

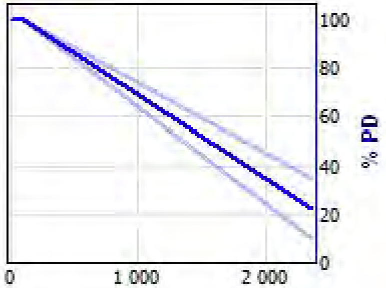
Therefore, Oligoneuridae would decline in abundance if the wet season duration was reduced to zero.

An extended wet season would however increase the length of hostile conditions and thus reduce the length of time for breeding, etc.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Oligoneuridae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Dry within day range [D season]

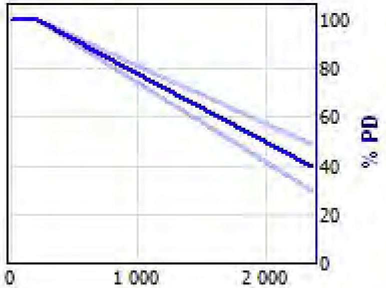
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.500</td></tr>
</table>



</td><td>Oligoneuridae are vulnerable to rapid diurnal changes in flow (Bunn and Brusven 1991). .Excessive daily range in discharge in the dry season would flush out most Oligoneuridae.</td><td>High</td></tr>
<tr><td>

T1 within day range [T1 season]

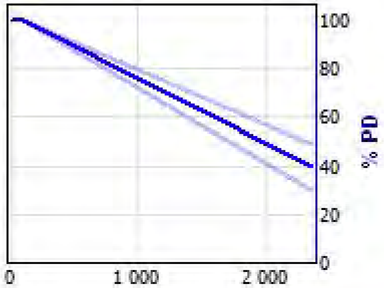
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.500</td></tr>
</table>



</td><td>Oligoneuridae are vulnerable to rapid diurnal changes in flow (Bunn and Brusven 1991). Excessive daily range in discharge in the transitional season would flush out most individuals, although the effect would not be as great as during the dry season which is the main breeding period.</td><td>Moderate</td></tr>
<tr><td>

T2 within day range [T2 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.500</td></tr>
</table>



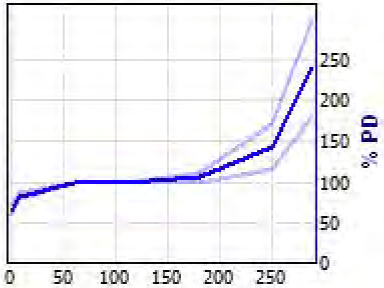
</td><td>Oligoneuridae are vulnerable to rapid diurnal changes in flow (Bunn and Brusven 1991). Excessive daily range in discharge in the transitional season would flush out most individuals, although the effect would not be as great as during the dry season which is the main breeding period.</td><td>Moderate</td></tr>
</table>

5.10.4 Indicator 4: Chironomidae

<table>
<tr><td colspan="2">Chironomidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry season duration [D season]

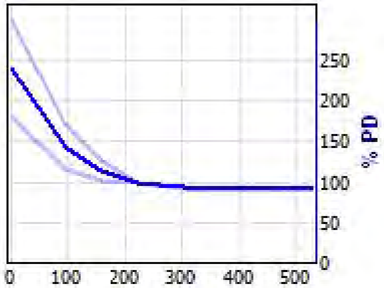
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>-1.000</td></tr>
<tr><td></td><td>58.75</td><td>0.000</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>2.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>3.000</td></tr>
</table>



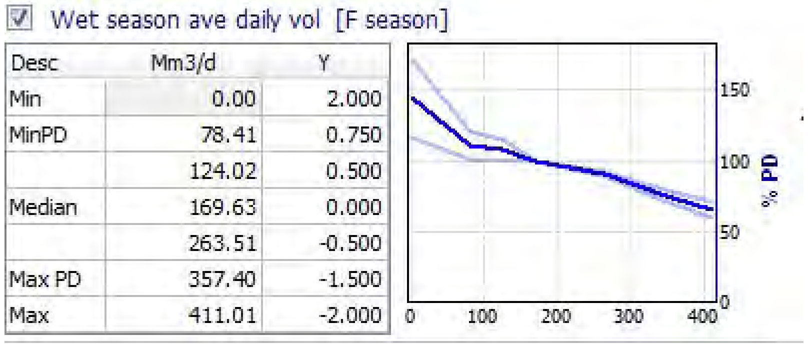
</td><td>Chironomids tend to proliferate in systems that are under stress (Mackay and Cyrus 2001). Therefore, an extended dry season would result in the proliferation of this taxon because large wetted backwaters would remain.</td><td>High</td></tr>
<tr><td>

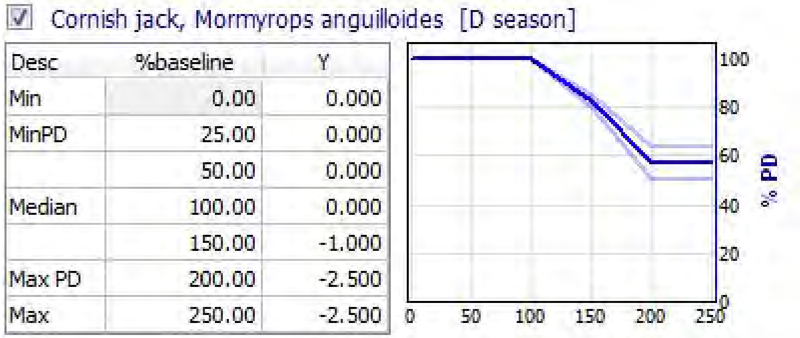
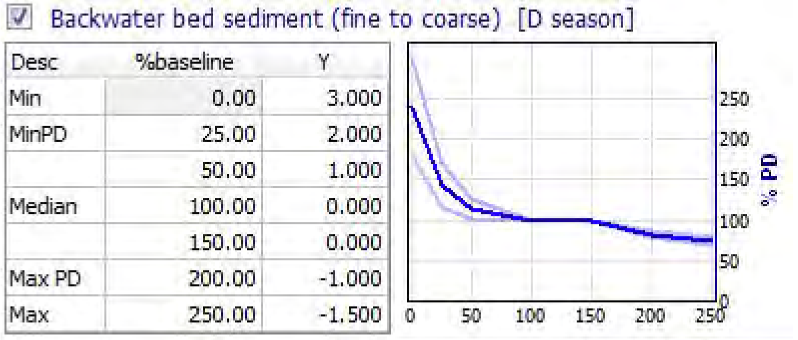
☑ Dry season Min 5d Q [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>3.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>2.000</td></tr>
<tr><td></td><td>157.39</td><td>1.000</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>-0.500</td></tr>
<tr><td>Max</td><td>527.41</td><td>-0.500</td></tr>
</table>



</td><td>Chironomids would proliferated under low flow conditions as they are able to withstand stress (increase in temperatures and a range of velocities) (Munn and Brusven 1991). Chironomidae would proliferate in the backwater pools over bedrock that would be extensive under these conditions</td><td>High</td></tr>
</table>

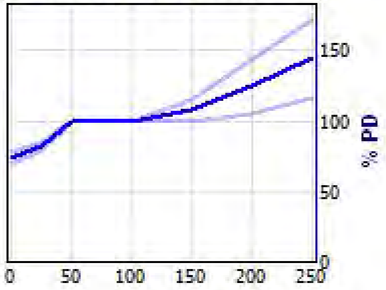
<table>
<tr><td colspan="2">Chironomidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
</td><td>Chironomids would increase in abundance with zero wet season discharge to flush them out as they flourish in low flow condition.

However, any discharge larger than the median would reduce their abundance from PD, although not excessively as Chironomids can withstand these conditions to some extent (Munn and Brusven 1991).</td><td>High</td></tr>
<tr><td>
</td><td>Fish predation would cause a decline in Chironomids in the backwaters but chironomids are also found in other biotopes so they would not be completely diminished.</td><td></td></tr>
<tr><td>
</td><td>Chironomids are generalists that occur across a range of different substratum types (Thirion 2007). They are hardy taxa that can proliferate in fine sediments (Munn and Brusven 1991).</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Chironomidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Area of backwaters and secondary channels [D season]

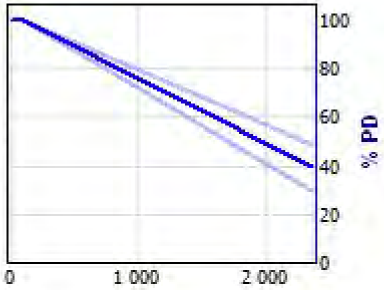
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.050</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>2.000</td></tr>
</table>



</td><td>An increase in the area of backwaters and secondary channels would favour the proliferation of hardy taxa like Chironomids</td><td></td></tr>
<tr><td>

Dry within day range [D season]

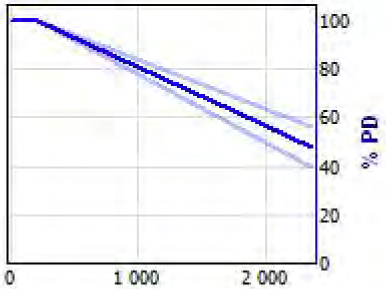
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.500</td></tr>
</table>



</td><td>Chironomids can probably tolerate some increase in daily range because they are generally hardy and can take refuge in interstitial spaces but they will be scoured out as the bed moves with particularly high flows</td><td>High</td></tr>
<tr><td>

T1 within day range [T1 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>

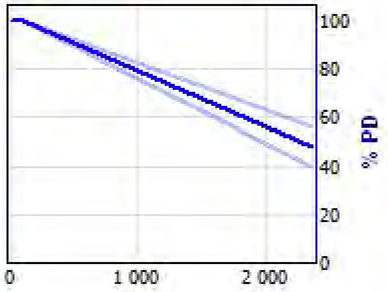


</td><td>Chironomids can probably tolerate some increase in daily range because they are generally hardy and can take refuge in interstitial spaces but they will be scoured out as the bed moves with particularly high flows.</td><td>Moderate</td></tr>
</table>

<table>
<tr><td colspan="2">Chironomidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ T2 within day range [T2 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-3.000</td></tr>
</table>



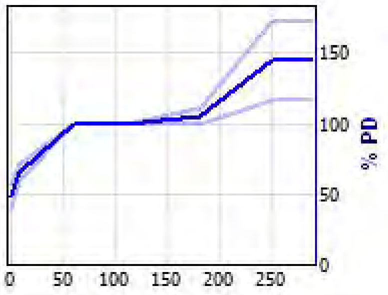
</td><td>Chironomids can probably tolerate some increase in daily range because they are generally hardy and can take refuge in interstitial spaces but they will be scoured out as the bed moves with particularly high flows.</td><td>Moderate</td></tr>
</table>

5.10.5 Indicator 5: Ceratopogonidae

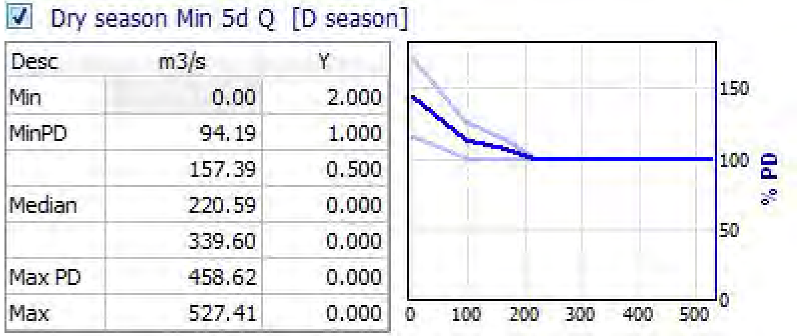
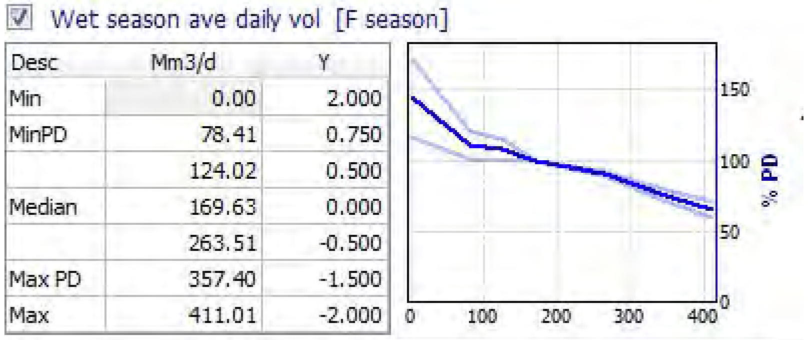
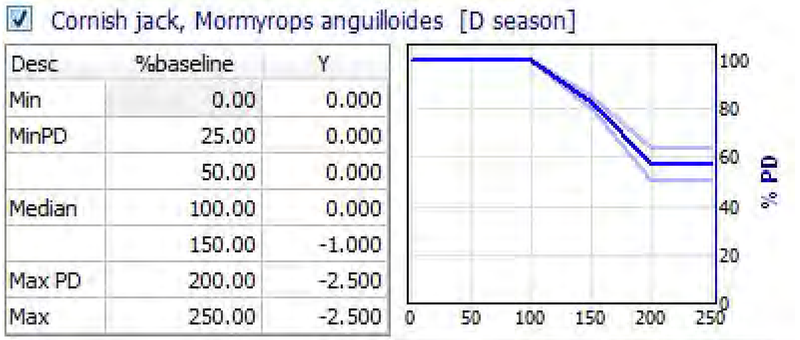
<table>
<tr><td colspan="2">Ceratopogonidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry season duration [D season]

<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>-2.000</td></tr>
<tr><td></td><td>58.75</td><td>0.000</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>2.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>2.000</td></tr>
</table>



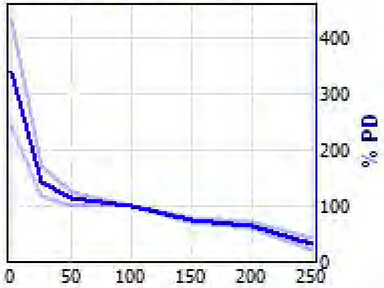
</td><td>Ceratopogonids were found only in the Sand covering bedrock in the secondary channel backwaters. They are susceptible to flooding but would proliferate under low flow conditions, provided the habitat remains wetted.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Ceratopogonidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
</td><td>Ceratopogonids would tolerate low flow (no flow conditions; Thirion 2007) and may even increase slightly at the expense of other more sensitive taxa.</td><td>High</td></tr>
<tr><td>
</td><td>Ceratopogonids would increase in abundance with zero wet season discharge to flush them out as they flourish in low flow conditions. However, any discharge larger than the median would reduce their abundance from PD.</td><td>High</td></tr>
<tr><td>
</td><td>Fish predation will cause a reduction in Ceratopogonidae abundance if fish abundance increases.</td><td>Moderate</td></tr>
</table>

<table>
<tr><td colspan="2">Ceratopogonidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Backwater bed sediment (fine to coarse) [D season]

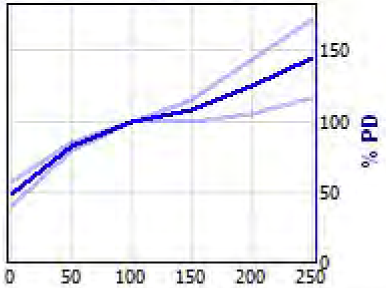
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>3.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>2.000</td></tr>
<tr><td></td><td>50.00</td><td>1.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-1.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-2.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>-4.000</td></tr>
</table>



</td><td>Ceratopogonidae like the fine sediments and are not found elsewhere like the Chironomidae (Benke et al.1984). Therefore a loss of fines will result in a significant reduction in the abundance of this taxon.</td><td>Moderate</td></tr>
<tr><td>

Area of backwaters and secondary channels [D season]

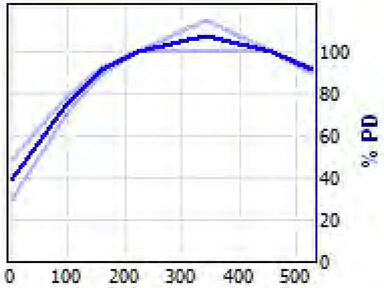
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-2.000</td></tr>
<tr><td></td><td>50.00</td><td>-1.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>2.000</td></tr>
</table>

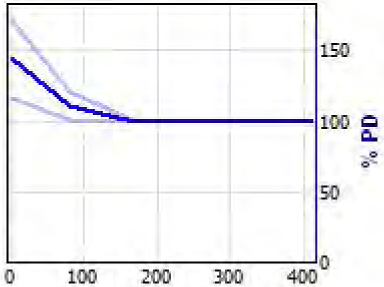


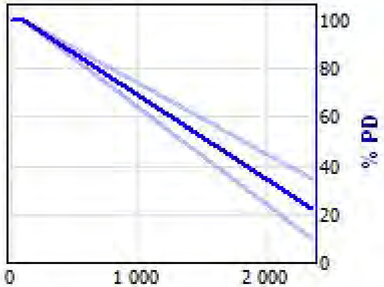
</td><td>Ceratopogonidae were only found in the backwaters but can be found in flowing (run) habitats (moderate flow), usually where cobbles are embedded as they favour the soft sediments. Therefore a loss of slow to moderately flowing habitats would result in a reduction in the abundance of this taxon.</td><td>Moderate</td></tr>
</table>

5.10.6 Indicator 6: Simuliidae

Simuliidae		
Linked indicator response curve	Explanation	Confidence

<table>
<tr><td colspan="2">Simuliidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry season Min 5d Q [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.500</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-1.500</td></tr>
<tr><td></td><td>157.39</td><td>-0.500</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>0.000</td></tr>
<tr><td>Max</td><td>527.41</td><td>-0.500</td></tr>
</table>


</td><td>Filter feeders like Simuliidae cannot survive without flowing water (about 0.5 m/s) because of the requirements for particles moving past in the water column to feed (McNair et al. 1997). An increase in the dry season minimum may increase abundance when velocities go beyond 1 m/s (Rivers Moore and de Moor 2008). Eventually though further increases would result in a drowning of riffles but Simuliidae would be able to withstand the cascades to some extent but would eventually be flushed out as the velocities increased further</td><td>High</td></tr>
<tr><td>
☑ Wet season ave daily vol [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.000</td></tr>
<tr><td>MinPD</td><td>78.41</td><td>0.750</td></tr>
<tr><td></td><td>124.02</td><td>0.200</td></tr>
<tr><td>Median</td><td>169.63</td><td>0.000</td></tr>
<tr><td></td><td>263.51</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>357.40</td><td>0.000</td></tr>
<tr><td>Max</td><td>411.01</td><td>0.000</td></tr>
</table>


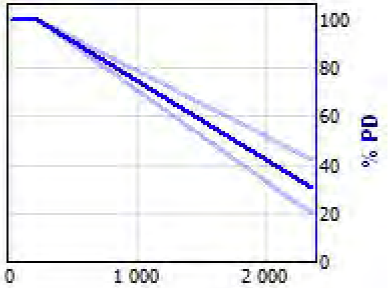
</td><td>The loss of flood disturbance will result in an increase in the abundance of Simuliidae in the riffles and cascades and runs.</td><td>High</td></tr>
<tr><td>
☑ Dry within day range [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.500</td></tr>
</table>


</td><td>Although Simuliidae can tolerate relatively high velocities, excessive daily range in discharge in the dry season would flush out most groups which rely on more benign conditions associated with the dry season for breeding.</td><td>Moderate</td></tr>
</table>

<table>
<tr><td colspan="2">Simuliidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

T1 within day range [T1 season]

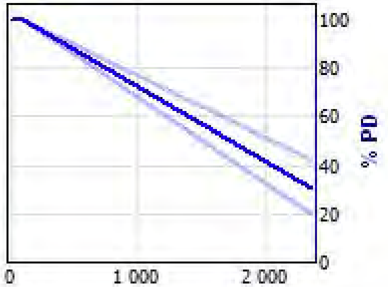
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.000</td></tr>
</table>



</td><td>Although Simuliidae can tolerate relatively high velocities, excessive daily range in discharge in the dry season would flush out most groups which rely on more benign conditions associated with the transitional season for breeding.</td><td>Moderate</td></tr>
<tr><td>

T2 within day range [T2 season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>2370.00</td><td>-4.000</td></tr>
</table>



</td><td>Although Simuliidae can tolerate relatively high velocities, excessive daily range in discharge in the dry season would flush out most groups which rely on more benign conditions associated with the transitional season for breeding.</td><td>Moderate</td></tr>
<tr><td>

Zoo and phytoplankton [All seasons]

<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-4.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-3.000</td></tr>
<tr><td></td><td>50.00</td><td>-1.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>2.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>3.000</td></tr>
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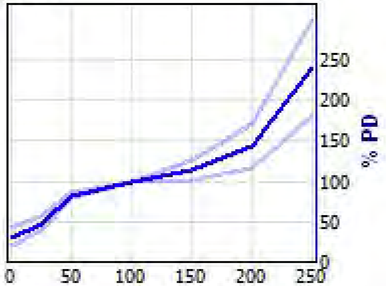


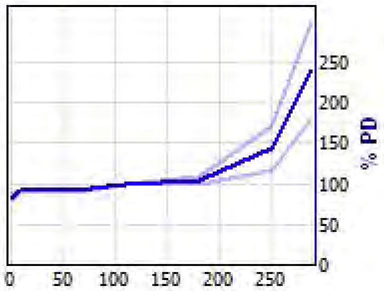
</td><td>As filter feeders, the abundance of Simuliidae is dependent on the concentration of food particles in the water column which will increase with the dam (De Moor 1986)</td><td>Moderate</td></tr>
</table>

5.10.7 Indicator 6: Gastropoda (snails)

<table>
<tr><td colspan="2">Gastropoda (snails)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

Dry season duration [D season]

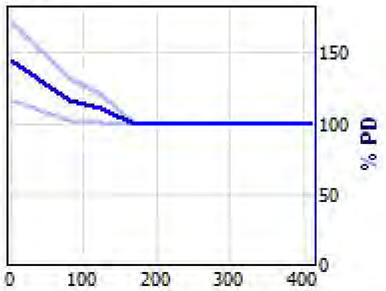
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>-0.500</td></tr>
<tr><td></td><td>58.75</td><td>-0.500</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>0.050</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>2.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>3.000</td></tr>
</table>



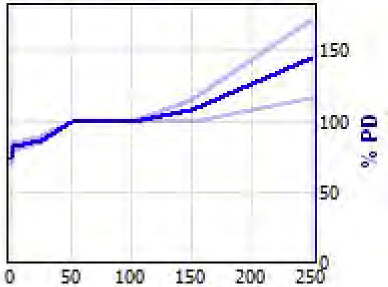
</td><td>Gastropods flourish in slow or no flow conditions and therefore, an extended dry season would result in the proliferation of this taxon because large wetted backwaters would remain.</td><td>High</td></tr>
<tr><td>

Wet season ave daily vol [F season]

<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.000</td></tr>
<tr><td>MinPD</td><td>78.41</td><td>1.200</td></tr>
<tr><td></td><td>124.02</td><td>0.750</td></tr>
<tr><td>Median</td><td>169.63</td><td>0.000</td></tr>
<tr><td></td><td>263.51</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>357.40</td><td>0.000</td></tr>
<tr><td>Max</td><td>411.01</td><td>0.000</td></tr>
</table>



</td><td>Snails would increase in abundance with zero wet season discharge to flush them out as they flourish in low flow conditions. However, any discharge larger than the median would reduce their abundance from PD because they are vulnerable to increased flood disturbance.</td><td>High</td></tr>
</table>

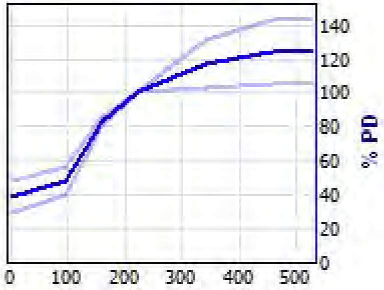
<table>
<tr><td colspan="2">Gastropoda (snails)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>Area of backwaters and secondary channels [D season]
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>1.00</td><td>-1.000</td></tr>
<tr><td></td><td>25.00</td><td>-0.750</td></tr>
<tr><td>Median</td><td>50.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>150.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>2.000</td></tr>
</table>


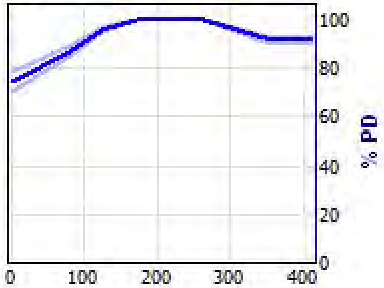
</td><td>An increase in the area of backwaters and secondary channels would favour the proliferation of snails which proliferate in areas of minimal flow disturbance</td><td></td></tr>
<tr><td colspan="3"></td></tr>
</table>

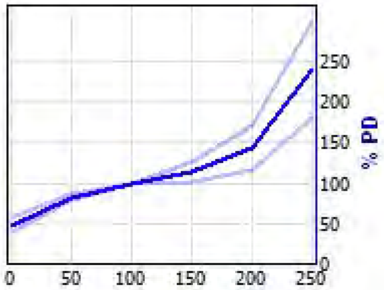
5.10.8 Indicator 7: Pelecypoda (Bivalves)

<table>
<tr><td colspan="2">Pelecypoda (Bivalves)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>7.00</td><td>-0.010</td></tr>
<tr><td></td><td>58.75</td><td>0.000</td></tr>
<tr><td>Median</td><td>110.50</td><td>0.000</td></tr>
<tr><td></td><td>180.75</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>251.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>288.65</td><td>0.000</td></tr>
</table>


</td><td>Bivalves would burrow during the high flow period and therefore would be less affected by the loss of a dry season.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Pelecypoda (Bivalves)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>Dry season Min 5d Q [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.500</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-3.000</td></tr>
<tr><td></td><td>157.39</td><td>-1.000</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>1.200</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>1.500</td></tr>
<tr><td>Max</td><td>527.41</td><td>1.500</td></tr>
</table>


</td><td>A massive reduction in flows would reduce the area sand bars and sandy margins available for bivalves and thus would result in reduction in biomass. An increase in baseflows would result in an increase in biomass as the area of sandy habitat would increase.</td><td>High</td></tr>
<tr><td>Wet season ave daily vol [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>78.41</td><td>-0.750</td></tr>
<tr><td></td><td>124.02</td><td>-0.250</td></tr>
<tr><td>Median</td><td>169.63</td><td>0.000</td></tr>
<tr><td></td><td>263.51</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>357.40</td><td>-0.500</td></tr>
<tr><td>Max</td><td>411.01</td><td>-0.500</td></tr>
</table>


</td><td>Bivalves would burrow as flows increased but a reduction in winter flows to zero would reduce the area of wetted habitat. excessively high flows may make these habitats less favourable though and would cause a decline in abundance</td><td></td></tr>
<tr><td>Sand bars [All seasons]
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-2.000</td></tr>
<tr><td></td><td>50.00</td><td>-1.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>2.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>3.000</td></tr>
</table>


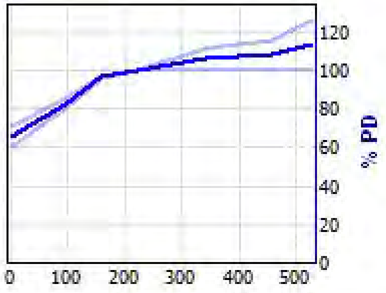
</td><td>A reduction in the availability of sand bars would result in a significant reduction in the bivalves because they are wholly reliant on relatively deep sands as habitat.</td><td></td></tr>
</table>

5.10.9 Indicator 8: Atyidae (Shrimps)

<table>
<tr><td colspan="2">Atyidae (Shrimps)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry season Min 5d Q [D season]

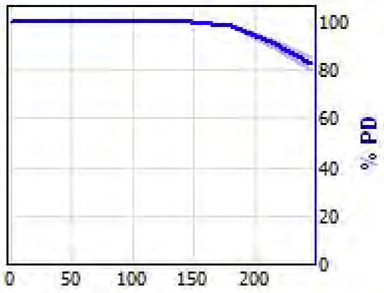
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>94.19</td><td>-1.000</td></tr>
<tr><td></td><td>157.39</td><td>-0.200</td></tr>
<tr><td>Median</td><td>220.59</td><td>0.000</td></tr>
<tr><td></td><td>339.60</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>458.62</td><td>0.500</td></tr>
<tr><td>Max</td><td>527.41</td><td>1.000</td></tr>
</table>



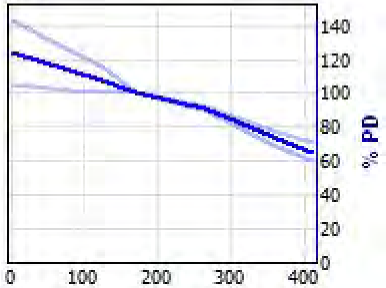
</td><td>A reduction in discharge will lead to less available habitat and thus a reduction in abundance whereas an increase in discharge will increase the area of wetted vegetation and thus increase the abundance.</td><td>High</td></tr>
<tr><td>

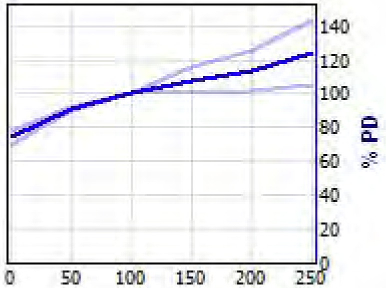
☑ Wet season duration [F season]

<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>5.00</td><td>0.000</td></tr>
<tr><td></td><td>76.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>147.00</td><td>0.000</td></tr>
<tr><td></td><td>180.50</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>214.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>246.10</td><td>-1.000</td></tr>
</table>



</td><td>An increase in the duration of the wet season will reduce the time available for breeding and feeding of shrimps which rely on vegetation that is out of current.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Atyidae (Shrimps)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Wet season ave daily vol [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.500</td></tr>
<tr><td>MinPD</td><td>78.41</td><td>1.000</td></tr>
<tr><td></td><td>124.02</td><td>0.500</td></tr>
<tr><td>Median</td><td>169.63</td><td>0.000</td></tr>
<tr><td></td><td>263.51</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>357.40</td><td>-1.500</td></tr>
<tr><td>Max</td><td>411.01</td><td>-2.000</td></tr>
</table>


</td><td>A reduction in wet season volumes would promote VOOC habitat and thus increase abundance whereas an increase would reduce favourable habitat</td><td></td></tr>
<tr><td>
☑ Marginal Graminoids [All seasons]
<table>
<tr><th>Desc</th><th>%baseline</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.500</td></tr>
</table>


</td><td>Shrimps are obligate vegetation dwellers and thus the quality and quantity of marginal vegetation is important for this group (Thirion 2007). A diversity of leaf types promotes habitat heterogeneity and food quality with an impact on shrimp abundance</td><td></td></tr>
</table>

6 *FISH: SPECIALIST REPORT*

6.1 OBJECTIVES OF THE FISH STUDY

The main objective of the fish study was to identify the relationship between fish and flow level changes, and to predict what impacts, if any, will occur with changes to the present day flow regime.

For the fish component of the EF assessment, 24.75 days were allocated to undertaking a literature review of previous information, a site visit, data analysis of the site information collected in the field, prediction of impacts (response curves) and report writing.

The ToR provided were:

- Familiarise yourself to the extent possible with the study area, including:
  - The character of the fish communities of the rivers in the Zambezi River, with particular reference to the reach between Victoria Falls and Lake Kariba.
  - The character of the fish in the reaches encompassing the proposed EF sites.
  - The fisheries of Lake Kariba.
- Provide detailed information for two EF sites.
- Attend the field visit with the rest of the team to:
  - Ensure that the hydraulic cross-section surveys record whatever information you require for your analyses.
  - Record at each site, where relevant and possible, (i) the dominant and sub-dominant fish species, (ii) the arrangement of the fish species relative to flow velocities, (iii) the nature and extent of instream or overhead cover (for fish).
  - Identify fish specimens collected, to species level where possible.
- Take responsibility for the adequacy of the data collated/collected and provided for the fish component of the EFA.
- For each site, identify a maximum of 10 indicators (preferably no more than five) for the EFA, and provide/develop information on, as available/relevant/known:
  - descriptions of the representative species;
  - distribution and abundance (in particular, flow-related limitations to spatial distribution);
  - habitat requirements in terms of water depth, water velocity and substratum type;
  - life histories (e.g. spawning times);
  - anticipated sensitivity to change in the flow regime;
  - any additional relevant information.
- Attend the DRIFT Workshop(s), prepared to populate the DRIFT response curves for your selected indicators and linked indicators.
- As a separate exercise, evaluate the potential impacts of a hydropower station at Batoka Gorge (based on the scenarios evaluated at the EF workshop) on the fisheries

at Lake Kariba using existing data, in particular work that links kapenta stocks with inflow into Lake Kariba (e.g., Karenga and Kolding 1995; Kolding et al. 2003; Kolding and Songore 2003).

- Compile a fish ecology chapter for inclusion in the EFA Report, with particular reference to response curve motivation tables.
- Adhere to standard formatting, font and layout specifications provided by the Southern Waters for written submissions.

6.1.1 Layout of this Section

This Section comprises the summary report for fish, and provides:

- An overview of the study area, with focus on delineation of homogenous areas;
- For the EF sites:
  - Ecoclassification assessments for fish, with supporting evidence;
  - the DRIFT indicators chosen, and reasons therefore;
  - the relationships between the chosen fish indicators and flow or other drivers with referenced, supporting motivations.
- Ecospecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to fish.

6.2 *DESCRIPTION OF THE STUDY AREA, WITH THE FOCUS ON FISH*

This upper section of the Middle Zambezi River extends for approximately 170 km (127 km in a straight line) from the base of the Victoria Falls to the inflow to Lake Kariba. The Victoria Falls is a zoogeographical boundary between the Upper Zambezi and Middle Zambezi fish faunas. The study area includes the 100 km long Batoka Gorge, where the river flows as a series of rapids interspersed with pools with depths of up to 20-100 m according to Minshull (2010). The river is confined by the steep walls of the gorge, before opening out between the end of the gorge and the inflow to the lake (a distance of 60-70 km) into a series of rapids, riffles, islands, sand bars and extensive shallows, where slower flow allows for the development of a greater variety of littoral fish habitats.

The Batoka Gorge cuts through horizontal layers of flow basalt (Minshull 2010). The layering of vesicular and columnar basalt results in a heterogeneity of habitats along the water's edge that offers protection to small fish. This includes small protected bays, overhangs, springs and seepages, and results in a greater variety of small fishes than might be expected (Minshull 2010). Nevertheless, in the Batoka Gorge, the resident fish population is restricted to fish species adapted to living in rapids and in deep river pools (but see Literature Review, Section 1.2.).

Between the Batoka Gorge and Lake Kariba, the river provides greater diversity of fish habitat, although there are still no extensive floodplain habitats such as those seen in the Upper Zambezi that result in much greater fish species diversity. Thus over 80 fish species occur in the stretch between Victoria Falls and Katima Mulilo rapids about 150 km upstream (Tweddle 2014), compared to only 28 reported to occur in the Middle Zambezi by Jackson (1961) before Lake Kariba came into existence. The habitats available in the 60-70 km stretch of river include fast-flowing rapids, riffles and runs over cobble and gravel substrata, and slow flowing littoral habitats, Marginal vegetation that provides habitat for small fish species and juveniles of larger species includes reedbeds, grasses and riparian shrubs and trees. Areas of floodplain and peripheral lagoons are minimal.

6.3 LITERATURE REVIEW

6.3.1 Fish species distribution

Few publications exist on the fishes of the section of the Middle Zambezi between Victoria Falls and its inflow to Lake Kariba. Jubb (1953) was the first author to draw a distinction between the Upper Zambezi and Middle Zambezi fish fauna. Prior to the completion of Kariba dam and thus the establishment of Lake Kariba, the fish fauna of the Middle Zambezi was surveyed by Jackson (1961). Jackson described the fish fauna as depauperate, attributing this to the sandbank nature of the river. Only 28 fish species were listed from the Middle Zambezi system, of which 26 were collected by Jackson (1961) in about two tonnes of fish caught in four surveys in the intensive sampling programme using gillnets, seines, various handnets, hook and line, and dynamite.

Much of the existing literature concerns speculation on whether fish can survive the drop over the falls, where Jubb (1976a; 1976b; 1977) refuted suggestions by Balon (1974a; 1974b) that fish could survive the drop. Jubb stated that fish were more likely to have entered the gorge via the Victoria Falls hydroelectric power stations. Minshull (2010) presented results of limited rotenone surveys of the Batoka Gorge and summarised the arguments for and against the possibility of fish surviving the drop.

Several species of Upper Zambezi origin have been recorded in Lake Kariba (Balon 1974b; Zengeya and Marshall 2008; Marshall 2011) but few have become established. Minshull (2010) suggested 19 Upper Zambezi species in total have been recorded from the Middle Zambezi since the establishment of Lake Kariba, but several of these were probably overlooked earlier. Some, for instance, have relict populations in the headwaters of the Matetsi and Deka tributaries of the Middle Zambezi (Marshall 2011), probably reflecting their Upper Zambezi links prior to the erosion that created the Batoka Gorge.

Minshull (2010) showed that small juveniles of Upper Zambezi fish species could survive in the Batoka Gorge, but his sampling also demonstrated that their appearance was ephemeral, thus for instance, 23 species were recorded at Dibu Dibu in August 1990 but only 13 at the same site two months later.

6.3.2 Lake Kariba fisheries in relation to potential impacts of Batoka Gorge Dam

In the early days of Lake Kariba, there was a considerable amount of speculation on the potential impacts of lake level fluctuations caused by manipulation of the dam to optimise electricity production and to manage the level to accommodate the influx of annual floods. For example, Jackson (1966) recommended that "for the establishment of a fishery, the ideal man-made lake might best have its waters concerned as much as possible all the year round, so as to preserve at all times the maximum height of water". Jackson (1966) also suggested that an annual draw-down in most impoundments has a deleterious impact on fisheries due to inhibition of permanent growth of aquatic vegetation in littoral areas of dams. Harding (1966) and Coche (1974) agreed with Jackson (1966), drawing conclusions from a limited amount of data when the lake's hydrology and fisheries were still in very early stages of succession.

Since that time, a large amount of information has been gathered on productivity and fisheries in new, large man-made lakes, and also on fluctuations in productivity and fisheries in natural African lakes that vary enormously in size and volume over time, e.g. Lake Chilwa in Malawi (Furse *et al*. 1979) and Lake Liambezi in Namibia (van der Waal 1974; Peel 2012). It is now understood that new man-made lakes and ephemeral natural lakes that have refilled after drought periods benefit greatly but temporarily from high productivity due to availability of nutrients from flooded terrestrial areas. Even in lakes of relative stability in level, small annual changes in level can have measurable impact on fish stocks and yields (Tweddle and Magasa 1989, for the Lake Malawi tilapia fishery; Kolding 1992, for Lake Turkana).

With the benefit of a much longer series of catch and hydrology data for Lake Kariba, Karenge and Kolding (1995a) examined the relationship between catch and lake level. They concluded that there is no evidence supporting the general notion that fluctuating lake levels in Lake Kariba have severe adverse effects on the fisheries. They stated that a suitably timed draw-down is a necessary pre-requisite for subsequent flooding and inundation which appear to have highly beneficial effects on the productivity of the lake.

Karenge and Kolding (1995a) stated that this conclusion was of importance in relation to the proposed Batoka Gorge Dam, which they believed will increase the rates and amplitudes of lake fluctuations in Lake Kariba.

6.4 DESCRIPTION OF THE EF SITES

See Section 1.4 for a map showing the location of the study sites.

6.4.1 EF Site 1

The river here is characterised mainly by large rapids and fast-flowing counter-currents. These could not be sampled by the methods available, and time constraints precluded the use of fishing methods suitable for these habitats, i.e. angling, longlines and possibly fyke nets. In addition, there are extensive areas of fast-flowing runs over bedrock that provide limited fish habitat.

Secondary channels provide varied habitat suitable for a range of fish species, and thus such a side channel was targeted as the major fish sampling site in this study (Figure 6.1a). The chosen site consisted of a still pool 5-10 m wide and up to 1.2 m deep with a bottom mainly of bedrock but bordered by an undercut ridge. Parts of the bottom were covered by silt and unicellular diatoms (Figure 6.1b). From this a small stream riffled down through a bed of boulders over gravel (Figure 6.1c) into another pool approximately 10 m long, where the bottom was primarily rocks and cobbles (Figure 6.1d). The site was treated with the piscicide rotenone, with a large pool immediately downstream of the lower pool providing sufficient dilution to limit the impact of the piscicide to the sampled area only.

	
a	b
	
c	d

Figure 6.1 **Sampling site EF Site 1. (a) View of the gorge as a whole showing the secondary channel above the sampling site. (b) The uppermost sampled pool. (c) The small riffle through boulders between the two pools. (d) View from the top of the small riffles down to the lower pool at top of picture.**

Some (limited) electric fishing was also done at the margins of the main channel (Figure 6-2).

Figure 6.2 **The electric fishing sampling site at EF Site 1.**

6.4.2 EF Site 2

The river at EF Site 2 has a wide variety of habitats, including riffles, runs, secondary channels, backwaters, and sandbars (Figure 6-3). Most notably, in stark contrast to EF Site 1, there is a considerable amount of marginal vegetation in the sampling area. Clumps of reeds and sedges occur in the shallows, and the banks in some areas are lined with shrubs and reeds, providing shelter for small fish species and juveniles of larger species. Nevertheless, there remains an absence of floodplain habitats such as lagoons and deep side channels, and thus, with the large annual fluctuation in river level, the fish species that can be expected to occur are only those adapted solely to large river channels.

a

b

c

d

Figure 6.3 **Representative sample sites at EF Site 2. (a) Clumps of emergent reeds on the island opposite the Hwange Angling and Boating Club, sampled with the D-net. (b) An extensive area of sand/gravel bottomed pools, cobbles/riffles, reeds, etc. sampled using the D-net and the electric fisher. (c) Women and children fishing an isolated pool for small cichlids. (d) Gillnets set alongside a well-vegetated river bank.**

6.5 ECOCLASSIFICATION OF RIVER REACHES REPRESENTED BY THE EF SITES

The fish fauna in the Middle Zambezi River between Victoria Falls and Lake Kariba is naturally depauperate (Jackson 1961; Minshull 2010; Marshall 2011) because of the character of the river. The river flows through the steep-sided rocky Batoka Gorge, and below that it is a 'sandbank' river with marked seasonal flow and a resulting paucity of weed cover. Sampling in the Middle Zambezi River before and during the construction of Kariba Dam yielded only 26 species, with two more known to occur (Jackson 1961), in marked contrast to the 80+ species found in the 'reservoir' type Upper Zambezi River above Victoria Falls (Tweddle 2014). The very limited sampling in the current field survey yielded 19 species, one of which, a species of *Cyphomyrus*, is a new record for the Middle Zambezi and is currently under taxonomic/genetic investigation.

EF Site 1: Minshull (2010) recorded 29 fish species in Batoka Gorge, including small numbers of juveniles of Upper Zambezi species. Of the 29 recorded species, only 12 can be regarded as common 'permanent residents'. Some Upper Zambezi species have become established in the more complex habitats of Lake Kariba, but in general such species can only be regarded as temporary inhabitants in the gorge.

The health of the fish population in Batoka Gorge has to be assessed in terms of the naturally hostile environment in the gorge. Anthropogenic effects are very low. Fishing is restricted to hook and line for predatory fish, tigerfish (*Hydrocynus vittatus*) and vundu (*Heterobranchus longifilis*). Access points are limited and thus fishing mortality is small. Some nutrient enrichment and presence of raised *E. coli* levels are reported from the gorge below the towns of Victoria Falls and Livingstone but at low levels, and thus the fish populations in the gorge can be regarded as near pristine, Category A-B.

EF Site 2: Anthropogenic impacts are much more evident at EF Site 2. Villages border the river and the banks are heavily grazed, either by hippos, cows, or both. Numerous, but small, sand beaches occur wherever there is human habitation, with such sites cleared for water collection and/or washing. Water quality, however, appears to remain healthy.

Fishing activity is evident everywhere, particularly on the Zambian bank. Numerous makoros (dugout canoes) were seen and many monofilament gillnets were observed in makoros, on the river banks and in the water. These monofilament nets are a recent addition to the fishery, and have resulted in serious adverse effects on fish biomass in the Upper Zambezi above Victoria Falls. They are also much more damaging to other fauna than older multifilament nets because (a) they are cheap, easily damaged, not easily repairable, and are thus discarded after use, and (b) they are made of a material that does not lie limply on the ground but instead forms springy bunches of material in which animals of all varieties are trapped and die.

Anthropogenic impacts are not on a scale that impacts on fish diversity, but probably sufficient to lead to changed species abundance ratios. Large cichlids, mainly tilapiines in this area, in particular are most reduced by targeted fishing, while *Labeo altivelis* abundance may be negatively affected by heavy exploitation during breeding migrations (Skelton et al. 1991). Thus, the fish populations in the reach represented by EF Site 2 can be regarded as Category B (slightly modified from natural condition).

6.6 FIELD DATA COLLECTION AND ANALYSIS

At EF Site 1, the piscicide rotenone was used at a low concentration, sufficient to collect all fish at the chosen site but with sufficient dilution in the large pool below to have no impact on the fauna there. Fish were collected as they rose to the surface; tissue samples were taken from representative samples of each species for DNA analysis, and the fish were preserved in formalin for later confirmation of identity.

In addition, electric fishing using a Samus backpack was carried out along the boulder bank in a moderate-swift counter-current. No fish were caught or seen at this site.

At EF Site 2, a variety of habitats was sampled using several gears. Two overnight gillnet sets were made alongside vegetated (reeds and roots of riparian bushes) river banks in stretches of zero to low flow. The net used was the standard fleet of surface set nets with graded mesh sizes as used in fisheries research programmes in the Upper Zambezi system (and other rivers) for the last two decades, designed to sample fish species of all sizes, and also the full size range for each species. Gillnets were made of 6-ply, brown multifilament nylon with manufacturer-quoted stretch mesh sizes of 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm. Each fleet was 110 m long by 2.5 m deep and consisted of eleven randomly distributed 10 m mesh panels.

Gill nets were set in the evening and retrieved between 06:00 and 07:00 the following morning.

Electric fishing using a Samus backpack, supplemented by use of a large, fine-meshed D-net, was carried out along the bank of the island opposite the Hwange Angling and Boating Club, and in the extensive area of riffles, small rapids, pools and patches of reeds adjacent to the transect site.

An isolated pool in a depression on the grassy bank contained a large mixed shoal of palm-sized cichlids when first observed on arrival at EF Site 2. The following day, a group of women and children were fishing in it with hook and line. Their catch was examined, though it was not known how many fish had already been removed before our arrival.

All fish retained for identification and as reference samples were deposited in the South African Institute for Aquatic Biodiversity in Grahamstown (SAIAB), together with DNA tissue samples, preserved in conc. ethanol, for inclusion in SAIAB's genetic barcoding programme.

6.7 *RESULTS*

6.7.1 EF Site 1 and EF Site 2

A list of species recorded at EF sites 1 and 2 in September 2014, with notes on their abundance in the area is provided in Table 6-1.

Table 6.1 Species recorded at EF Sites 1 and 2 in the current survey, with notes on their abundance in the area.

Species	EF Site 1	EF Site 2	Notes
Mormyrops anguilloides	X		Juveniles are abundant in sheltered boulder habitats in Batoka Gorge. Adults occupy deeper water and are considered to be a fairly uncommon species by Marshall (2011).
Cyphomyrus discorhynchus		X	Two specimens were caught together in a gillnet at EF Site 2. The species is widely distributed in the Middle and Lower Zambezi.
Cyphomyrus cf. cubangoensis	X		It was thought until recently that there was only one species of the mormyrid genus Cyphomyrus in the Zambezi system, i.e. Cyphomyrus discorhynchus. This species has now been separated into two different species in the Zambezi by Kramer and van der Bank (2011). Cyphomyrus discorhynchus is now restricted to the Middle and Lower Zambezi systems, while the Upper Zambezi species was linked with the Okavango River species under a resurrected name, C. cubangoensis (Pellegrin, 1936). Kramer and van der Bank (2011) considered Victoria Falls to be the boundary between the two species. During the Batoka survey in September 2014, two species of Cyphomyrus were collected. Cyphomyrus discorhynchus was collected at EF Site 2, but in the gorge itself at the dam site four specimens were collected of a separate species. This species has similar morphometric counts to C. cubangoensis but differs in shape and colouration, even from similar sized specimens from the Upper Zambezi River rapids at Kasane above Victoria Falls. Following the discovery of this species, the photographs of Cyphomyrus in Kramer and van der Bank (2011) were reviewed. The specimen listed as C. discorhynchus from Batoka Gorge is the same as the species caught in the gorge in the present survey, with a marked difference in fin ray counts to the illustrated C. discorhynchus from downstream. Kramer and van der Bank (2011) did not include any specimens between Batoka Gorge and Tete in their analysis and thus did not consider the possibility that the differences between their Batoka and Tete specimens were at the species level rather than geographic variation, despite the clear separation that can be observed in their PCA and DFA graphs. Genetic analysis is now underway, comparing tissue samples from specimens from the Kavango, Kwando, Upper Zambezi Rivers and Batoka Gorge to confirm that these are distinct, although related species.
Opsaridium zambezense		X	A common species in fast-flowing streams and rivers throughout the Zambezi system, particularly over sandy/gravelly bottoms adjacent to rapids areas, and common in Batoka Gorge (Minshull 2010).
Barbus unitaeniatus		X	One of only two small Barbus species recorded at EF Site 2, it was fairly common in all the shallow habitats sampled, particularly in flowing water over sand/gravel.
Barbus fasciolatus		X	The other small Barbus species recorded at EF Site 2, it was also fairly common in all the shallow habitats sampled.
Labeobarbus marequensis	X		An abundant species throughout Batoka Gorge, where adults occupy open water and juveniles frequent the shallows.
Labeo cylindricus	X		Abundant and widespread in all rocky areas of the river, where it grazes

Species	EF Site 1	EF Site 2	Notes
			on filamentous algae and diatoms on the rocks.
Distichodus schenga		X	Described as abundant in the study area by Jackson (1961) and continues to be common in the river (Marshall 2011). Possibly absent from the faster waters in the Batoka Gorge as not recorded by Minshull (2010).
Brycinus imberi		X	Abundant in the river at EF Site 2, where it was the major catch in the survey gillnets. Probably absent from the faster waters in the Batoka Gorge as not recorded by Minshull (2010).
Brycinus lateralis		X	Common throughout the study area.
Micralestes acutidens	X	X	Abundant throughout the study area,
Schilbe intermedius		X	The two specimens caught at EF Ste 2 were of the typical Middle Zambezi form with an adipose fin. Upper Zambezi specimens lack the adipose fin. Regarded as generally sparse or only locally common in the Middle Zambezi by Marshall (2011).
Micropanchax johnstoni		X	Regarded as less abundant in the Middle Zambezi than in the Upper and Lower Zambezi, probably because of the lack of vegetation in the river (Jackson, 1961; Marshall 2011), and only a single specimen was caught by Minshull (2010) in Batoka Gorge. In the present survey, it was caught at several sites at EF Site 2, in shallow areas in emergent reed clumps.
Hemichromis elongatus		X	A single specimen was caught at EF Site 2 by a group of women and children fishing a small isolated pool (Fig.1.3.c). This is a new downstream record for this Upper Zambezi species, although it was recorded in the Batoka Gorge by Minshull (2010).
Pharyngochromis cf. acuticeps	X		Abundant in Batoka Gorge, both in the present sample and in those of Minshull (2010). Reported by Jackson (1961) to inhabit shallow running water in the main stream. This is a species complex, with several distinct species in the Upper Zambezi system and probably more in the Middle Zambezi.
Coptodon rendalli		X	The most abundant species caught at EF Site 2 by a group of women and children fishing a small isolated pool (Fig. 1.3.c), comprising about 80% of the catch.
Oreochromis mortimeri		X	Small Oreochromis specimens caught at EF Site 2 by a group of women and children fishing a small isolated pool (Fig. 1.3.c) are referred to this species, which is the recognised indigenous species of Lake Kariba and the Middle Zambezi system. There is a possibility that the specimen illustrated may be a Nile tilapia hybrid-based on the very faint suggestion of barring on the tail, though this is not as prominent as in known F1 hybrids.
Oreochromis niloticus		X	A single specimen was caught at EF Site 2 by a group of women and children fishing a small isolated pool (Fig. 1.3.c). This is a new upstream record for this alien invasive species.

A summary of fish sampled at each site, with site locality and the number of each species caught or observed is provided in Table 6-2.

Table 6.2 Summary of fish sampled at each site. (A) Site locality. (B) Number of each species caught or observed.

(A) Sites	Coordinates	
Site 1: Rotenone sampling site in Batoka Gorge	17° 55′ 33″S	26° 06′ 47″E
Site 2A: First gillnet site below gorge	18° 04′ 35″S	26° 41′ 22″E
Site 2B: Second gillnet site below gorge	18° 03′ 24″S	26° 37′ 15″E
Site 2C: Pool fished by women and children	18° 03′ 31″S	26° 37′ 48″E
Site 2D: First D-net site below gorge	18° 04′ 40″S	26° 41′ 34″E
Site 2E: Second D-net/ electric fishing site below gorge	18° 03′ 20″S	26° 38′ 45″E

(B) Species	Site 1	Site 2A	Site 2B	Site 2C	Site 2D	Site 2E
Mormyrops anguilloides	12					
Cyphomyrus cf. *cubangoensis*	4					
Cyphomyrus discorhynchus			2			
Barbus fasciolatus					3	1
Barbus unitaeniatus		1				9
Labeobarbus marequensis	4					
Labeo cylindricus	~ 30					
Opsaridium zambezense					1	
Brycinus imberi		10	~15			
Brycinus lateralis		2				
Micralestes acutidens	3	2				
Distichodus schenga		1				
Coptodon rendalli				~20		
Oreochromis mortimeri				3		
Oreochromis niloticus				2		
Hemichromis elongatus				1		
Pharyngochromis cf. *acuticeps*	~ 40					
Micropanchax johnstoni					8	3
Schilbe intermedius					1	1

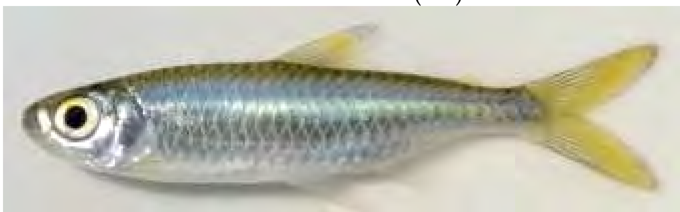
6.7.2 Caught/observed, expected, possible, and historical errors in the occurrence of fish species

The fish species of the study area, divided into four categories: caught/observed, expected, possible, and historical errors are listed in Table 6-3. The **expected** category includes those species that definitely exist in the study area and that would have been caught with a more extended sampling visit and more fishing methods, e.g., hook and line and fyke nets.

Table 6.3 **The fish species of the study area, divided into four categories: caught/observed, expected, possible, and historical errors. Localities of photos other than EF sites as follows: UZ = Upper Zambezi, MZ = Middle Zambezi, LK = Lake Kariba, CB = Cahorra Bassa, Mal = Malawi.**

Species	Recorded	Expected	Possible	Historical errors	Photograph
Mormyrops anguilloides	X				 EF Site 1 © Denis Tweddle
Cyphomyrus discorhynchus	X				 EF Site 2 © Denis Tweddle
Cyphomyrus cf. *cubangoensis*	X				 EF Site 1 © Denis Tweddle
Opsaridium zambezense	X				 © Denis Tweddle (UZ)
Barbus unitaeniatus	X				 © Denis Tweddle (UZ)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Barbus fasciolatus	X				 EF Site 1 © Denis Tweddle
Labeobarbus marequensis	X				 EF Site 1 © Denis Tweddle
Labeo cylindricus	X				 EF Site 1 © Denis Tweddle
Distichodus schenga	X				 EF Site 2 © Denis Tweddle
Brycinus imberi	X				 EF Site 2 © Denis Tweddle

Species	Recorded	Expected	Possible	Historical errors	Photograph
Brycinus lateralis	X				 © Denis Tweddle (UZ)
Micralestes acutidens	X				 © Denis Tweddle (UZ)
Schilbe intermedius	X				 EF Site 2 © Denis Tweddle
Micropanchax johnstoni	X				 EF Site 2 © Denis Tweddle
Hemichromis elongatus	X				 © Denis Tweddle (UZ)
Pharyngochromis cf. *acuticeps*	X				

Species	Recorded	Expected	Possible Historical errors	Photograph
Coptodon rendalli	X			EF Site 1 © Denis Tweddle  © Denis Tweddle (UZ)
Oreochromis mortimeri	X			 EF Site 2 © Denis Tweddle
Oreochromis niloticus	X			 © Roger Bills (UZ – Kabompo)
Mormyrus longirostris		X		 © Roger Bills (CB)
Marcusenius macrolepidotus		X		 © Paul Skelton (LK)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Barbus lineomaculatus		X			 © Denis Tweddle (Mal)
Barbus trimaculatus/B. poechii		X			 © Denis Tweddle (Mal)
Labeo altivelis		X			 © Roger Bills (CB)
Labeo congoro		X			 © Roger Bills (CB)
Distichodus mossambicus		X			 © Roger Bills (CB)

Species	Recorded	Expected	Possible Historical errors	Photograph
Hydrocynus vittatus		X		 © Denis Tweddle (UZ)
*Amphilius uranoscopus**		X		 © Denis Tweddle (UZ)
Clarias gariepinus		X		 © Denis Tweddle (UZ)
Heterobranchus longifilis		X		 © Roger Bills (CB)
Malapterurus shirensis		X		 © Paul Skelton (MZ)
Synodontis nebulosus		X		 © Roger Bills (CB)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Synodontis zambezensis		X			 © Roger Bills (CB)
Pseudocrenilabrus philander		X			 © Denis Tweddle (UZ)
Tilapia sparrmanii		X			 © Denis Tweddle (UZ)
Mastacembelus vanderwaali		X			 © Denis Tweddle (UZ)
Mormyrus lacerda			X		 © Denis Tweddle (UZ)
Marcusenius altisambesi			X		 © Denis Tweddle (UZ)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Petrocephalus cf. *catostoma*			X		 © Denis Tweddle (Mal)
Coptostomabarbus wittei			X		 © Denis Tweddle (UZ)
Barbus bifrenatus			X		 © Denis Tweddle (UZ)
Barbus multilineatus			X		 © Denis Tweddle (UZ)
Barbus afrovernayi			X		 © Denis Tweddle (UZ)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Barbus paludinosus			X		 © Denis Tweddle (UZ)
Nannocharax machadoi			X		 © Denis Tweddle (UZ)
Hepsetus cuvieri			X		 © Denis Tweddle (UZ)
Parauchenoglanis ngamensis			X		 © Denis Tweddle (UZ)
Zaireichthys monomatapa			X		 © Roger Bills
Chiloglanis spp			X		 © Denis Tweddle (UZ)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Micropanchax hutereaui			X		 © Denis Tweddle (UZ)
Sargochromis cf. *codringtonii*			X		 © Roger Bills (CB)
Sargochromis carlottae			X		 © Denis Tweddle (UZ)
Sargochromis giardi			X		 © Denis Tweddle (UZ)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Serranochromis macrocephalus			X		 © Denis Tweddle (UZ)
Serranochromis robustus jallae			X		 © Denis Tweddle (UZ)
Oreochromis macrochir			X		 © Denis Tweddle (UZ)
Ctenopoma multispine			X		 © Denis Tweddle (UZ)
Barbus barotseensis				X	 © Denis Tweddle (UZ)

Species	Recorded	Expected	Possible	Historical errors	Photograph
Labeo lunatus				X	 © Denis Tweddle (UZ)

Table 6-4 provides explanatory notes about fish species occurring in the sampling area that were not sampled in September 2014. Table 6-5 is notes on fish species that possibly occur in the sampling area, and historical recording errors.

Table 6.4 Annotated list of fish species occurring in the sampling area that were not sampled.

Species	Notes
Mormyrus longirostris	The Middle and Lower Zambezi *Mormyrus* species, fairly common but not often caught. Can be targeted by angling with small baited hooks under weedbeds. Marshall (2011) stated that *M. longirostris* and the Upper Zambezi species *M. lacerda* are geographically isolated except for some overlap in Batoka Gorge, quoting Minshull (2010). Marshall then, however, stated that in the 1960s and 1970s *M. longirostris* was less abundant than *M. lacerda* in Lake Kariba, but this is a typographical error as there are no references or museum or even anecdotal records for *M. lacerda* in Lake Kariba.
Marcusenius macrolepidotus	The *Marcusenius* species of the Middle and Lower Zambezi, not collected in the Middle Zambezi before Kariba (Jackson, 1961) and still rather sparse in Lake Kariba (Marshall 2011). Expected to occur in the study area in small numbers.
Barbus lineomaculatus	A widespread species in Zimbabwe (Marshall 2011), but primarily a species of upland streams and scarce in the main Zambezi River. Also subject to misidentification, e.g. the Bulawayo Museum collection of *Barbus lineomaculatus* contained ten different spotted species (DT, pers. obs. in 2003).
Barbus trimaculatus/B. poechii	*Barbus poechii* occur in the Upper Zambezi and *B. trimaculatus* in the Middle and Lower Zambezi. Some *B. poechii* populations have three spots like *B. trimaculatus* and thus they are closely related and may be regarded as synonymous. Minshull (2010) recorded a single specimen of *B. poechii* in Batoka Gorge.

Species	Notes
Labeo altivelis	Reported as the most abundant species in the Middle Zambezi before Kariba (Jackson, 1961). Its importance as a commercial species has declined, like many other African labeos (Skelton et al., 1991), but it remains an important species in the system and a key indicator of ecosystem health.
Labeo congoro	Not as abundant as *L. altivelis*, but still considered an abundant species in the river before Kariba (Jackson, 1961). Marshall (2011) reports that the major populations of *L. congoro* in the Zambezi are in the gorges below Victoria Falls, and dam construction has led to the extirpation of this species in river further south, thus the construction of the Batoka Gorge dam will have a major impact on this species' survival.
Distichodus mossambicus	Common in the Zambezi River above and below Lake Kariba, though less common than *D. schenga*.
Hydrocynus vittatus	The tigerfish is abundant throughout the Upper Zambezi system and is an important angling target species in the project area.
Amphilius uranoscopus	Surprisingly scarce in the Middle Zambezi despite the extensive rocky habitat preferred by this species (the name of which will soon change, following publication of a major review of this group). Recorded by Minshull (2010) from one site in Batoka Gorge, but has not been found elsewhere in the Middle Zambezi (Marshall 2011).
Clarias gariepinus	Common and widespread throughout sub-Saharan Africa. It is absent from the rockier fast-flowing areas such as Batoka Gorge, but found in deeper pools below the gorge in the dry season and in flooded estuaries during the flood season (Marshall 2011).
Heterobranchus longifilis	The vundu is an important angling target in the deeper parts of the Middle and Lower Zambezi including Batoka Gorge because of its very large size, although it is not very abundant.
Malapterurus shirensis	Electric catfish are largely confined to slower moving river sections and are thus likely to be absent from the Batoka Gorge and scarce in the rest of the survey area, but considered by Minshull (quoted in Marshall 2011) to be common in the Olive Beadle camp area of Lake Kariba.
Synodontis nebulosus	Less common than *S. zambezensis* throughout the Middle and Lower Zambezi, *S. nebulosus* was recorded in Batoka Gorge by Minshull (2010).
Synodontis zambezensis	Abundant throughout the Middle Zambezi, including the study area. Regarded as fairly common in the Middle Zambezi pre-Kariba (Jackson, 1961) and found in Batoka Gorge by Minshull (2010).

Species	Notes
Pseudocrenilabrus philander	A widespread and generally abundant species in its favoured habitat of still waters with abundant marginal vegetation (Marshall 2011), but as this habitat was scarce in the Middle Zambezi pre-Kariba, this species was not recorded by Jackson (1961). It is now common in Lake Kariba inshore waters.
Tilapia sparrmanii	Not recorded by Jackson (1961) in the Middle Zambezi pre-Kariba, but Minshull (2010) collected 49 specimens at one site in Batoka Gorge. Increasing in importance in Lake Kariba (Marshall 2011).
Mastacembelus vanderwaali	Not recorded in the Middle Zambezi pre-Kariba (Jackson, 1961), this species is common in Batoka Gorge (Minshull 2009; 2010) and has been found downstream of Lake Kariba (Marshall 2011). It is likely, therefore that the species always occurred in appropriate rocky habitats in the Middle Zambezi and was overlooked in earlier surveys.

Table 6.5 Notes on fish species that possibly occur in the sampling area, and historical recording errors.

Species	Notes
Mormyrus lacerda	A single specimen of this Upper Zambezi species was collected in the Batoka Gorge by Minshull (2010). Identity needs to be verified to confirm it was not *M. longirostris.*
Marcusenius altisambesi	A single specimen of this Upper Zambezi species was collected in the Batoka Gorge by Minshull (2010). Identity needs to be verified to confirm it was not *M. macrolepidotus.*
Petrocephalus cf. *catostoma*	Reported as extremely scarce in the Middle Zambezi, none were caught before Kariba (Jackson, 1961) and the genus has never been recorded from Lake Kariba. *Petrocephalus catastoma* is the Lower Zambezi species, while three species occur above Victoria Falls, only one of which is currently described (*P. longicapitis*).
Coptostomabarbus wittei	An Upper Zambezi species collected in 1989 in the upper reaches of Lake Kariba at Olive Beadle and Masuna camps (Skelton, 1994).
Barbus bifrenatus	An Upper Zambezi species recorded in Batoka Gorge by Minshull (2010) and in the upper reaches of the Matetsi and Deka tributaries (Marshall 2011).
Barbus multilineatus	An Upper Zambezi species collected in 1989 in the upper reaches of Lake Kariba at Olive Beadle and Masuna camps (Skelton, 1994).

Species	Notes
Barbus afrovernayi	An Upper Zambezi species collected in 1989 in the upper reaches of Lake Kariba at Olive Beadle and Masuna camps (Skelton, 1994).
Barbus paludinosus	One of the most abundant and widespread species in southern and eastern Africa but often with localised distribution, It is primarily a pioneer species, thus frequently found abundantly in newly flooded areas and new lakes, and in badly degraded sand rivers. Apparently absent from the main Middle Zambezi River between Victoria Falls and Lake Kariba, both now and pre-Kariba (Jackson, 1961), and scarce in the lake itself (Marshall 2011).
Nannocharax machadoi	An Upper Zambezi species collected in 1989 in the upper reaches of Lake Kariba at Olive Beadle and Masuna camps (Skelton, 1994) and since recorded in kapenta nets in Lake Kariba (Minshull 2010).
Hepsetus cuvieri	Found in the Middle Zambezi at the Deka and Matetsi River mouths and also in the Mlibizi area of Lake Kariba (Minshull 2010; Marshall 2011) and may be in the process of becoming established in Lake Kariba.
Parauchenoglanis ngamensis	An Upper Zambezi species - one specimen caught by an angler at Olive Beadle Camp in Lake Kariba (Minshull 2010).
Zaireichthys monomatapa	The Middle and Lower Zambezi *Zaireichthys* species, surprisingly absent from Jackson's (1961) Middle Zambezi samples and from any museum samples, but found further downstream at Mana Pools (Marshall 2011).
Chiloglanis spp	Surprisingly absent from any samples from the Batoka Gorge and at EF Ste 2, areas with apparent ideal habitat (Minshull 2010 and present survey). Jackson (1961) reported it as abundant in the Sanyanti, and "no doubt present in similar situations in the Zambesi". The genus therefore appears to be absent from the main river but common in tributaries.
Micropanchax hutereaui	An Upper Zambezi species recorded in Batoka Gorge by Minshull (2010) and in the upper reaches of the Matetsi and Deka tributaries (Marshall 2011). It also occurs in the Lower Zambezi (Tweddle and Willoughby, 1978), thus may be present but overlooked elsewhere in the system.
Sargochromis cf. *codringtonii*	An apparently undescribed species of *Sargochromis*, confused with the Upper Zambezi species *S. codringtonii* in all literature (e.g. Marshall 2011). Not particularly numerous in the river pre-Kariba, it has increased enormously in the lake (Marshall 2011).
Sargochromis carlottae	An Upper Zambezi species reported from Lake Kariba by Balon (1974), but none were collected in an extensive 2006 survey (Zengeya and Marshall 2008; Marshall 2011).

Species	Notes
Sargochromis giardi	An Upper Zambezi species reported from Lake Kariba by Balon (1974), but none were collected in an extensive 2006 survey (Zengeya and Marshall 2008; Marshall 2011). There is a distinct possibility of misidentification of the species listed as *S. codringtonii*.
Serranochromis macrocephalus	Abundant and widespread in Lake Kariba, having grown from a small population existing in the western part of the lake in the 1960s, Marshall (2011) believes the species existed in the Middle Zambezi pre-Kariba.
Serranochromis robustus jallae	Widely stocked throughout Zimbabwe, including Lake Kariba (Marshall 2011).
Oreochromis macrochir	An Upper Zambezi species that has been widely stocked throughout Zimbabwe, including Lake Kariba (Marshall 2011).
Ctenopoma multispine	A single specimen of this Upper Zambezi species was caught by an angler at Masuna Camp, Lake Kariba (Minshull 2010). Common in the Lower Shire tributary of the Lower Zambezi (Tweddle and Willoughby, 1978) and therefore possibly present throughout the Zambezi system.
Barbus barotseensis	The record by Jackson (1961) in the Middle Zambezi system was tentative and probably a misidentification.
Labeo lunatus	Recorded in Lake Kariba by Balon (1974) and tentatively by Bowmaker (1973), but these were very small specimens and Marshall (2011) considered them to be misidentifications of *L. cylindricus* as the species has not been recorded by any other survey.

6.8 IDENTIFICATION OF INDICATORS

6.8.1 Indicator list for fish

A list of fish groups used as indicators in the EF assessment and their expected response to flow changes are provided in Table 6-6.

Table 6.6 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Labeo altivelis	A major fisheries target, subject to major fluctuations in abundance, both natural based on breeding success and as a result of fishing.
Redeye labeo, *Labeo cylindricus*	One of the most common fish species in the main Zambezi River channel, it grazes on algae and diatoms from rock surfaces and may therefore be vulnerable to rapid changes in river level that affect food availability.
Cichlids	Most important target of fishers, particularly the tilapiines. Vulnerable to changes in river level when breeding, as they construct sand platform nests in shallow water.
Chessa and Nkupe, *Distichodus* spp	Omnivorous, but with large herbivorous component to diet, large riverine species, important in river fishery.
Synodontis zambezensis	Most widespread demersal, omnivorous species in the system.
Alestids	Three small, abundant, shoaling pelagic species, two of which, *Brycinus lateralis* and *Micralestes acutidens*, occur at both EF sites, while the largest of the three, *Brycinus imberi*, is scarce or absent in the fastest flowing gorge sections.
Barbus spp	Small species characteristic of shallow water environments and thus vulnerable to river level changes, unusually low species diversity in the Middle Zambezi system.
Cornish jack, *Mormyrops anguilloides*	A large species, whose juveniles occupy boulder habitats and may therefore be vulnerable to rapid or frequent changes in river level.
Vundu, *Heterobranchus longifilis*	An iconic, very large but fairly uncommon catfish species that is restricted to deep pools in the main river channels.
Tigerfish, *Hydrocynus vittatus*	The main target of anglers in the system, a highly fecund and wide-ranging species but potentially vulnerable to river level fluctuations when spawning in relatively shallow water.

6.8.2 Description and location of indicators

6.8.2.1 Name: Labeo altivelis

Habitat: Main river channel at EF Site 2.

Representative species: .Representative of riverine algal and detrital grazing species, subject to major fluctuations in abundance, both natural based on breeding success and as a result of fishing

Other characteristic species: *Labeo congoro* is another algal and sediment/ detrital feeder, though more in rocky habitats (Marshall 2011).

Flow-related concerns: *Labeo altivelis* may be affected by dam operation in two important ways. Fluctuations in river level will affect algal and diatom growth in the shallow areas, which may impact on food availability, while short-term fluctuations in river level while the fish are spawning in shallow flooding areas will severely impact spawning success, by alternately exposing eggs laid in shallow water or smothering them in silt generated by slumping of river banks as a result of constant alteration of flow and river level.

6.8.2.2 Name: Redeye labeo, Labeo cylindricus

Habitat: Main river channel on rocky shores.

Representative species: Representative of algal grazing species, primarily in rocky habitats

Other characteristic species: *Labeo congoro* is another rock habitat algal and sediment/ detrital feeder

Flow-related concerns: The labeos may be affected by dam operation in two important ways. Fluctuations in river level will affect algal and diatom growth on rocks in the shallow areas, which will impact on food availability, while short-term fluctuations in river level while the fish are spawning in shallow flooding areas will severely impact spawning success, by alternately exposing eggs laid in shallow water or smothering them in silt generated by slumping of river banks as a result of constant alteration of flow and river level.

6.8.2.3 Name: Cichlids

Habitat: Slower moving waters. In the gorge, the small species *Pharyngochromis* cf. *acuticeps* is the most abundant and only resident cichlid, occupying slow-flowing shallow areas wherever there is suitable cover. Below the gorge tilapiine cichlids dominate, as shown by the shoal of juveniles of several species in an isolated pool on the river bank.

Representative species: *Pharyngochromis* cf. *acuticeps*, *Oreochromis mortimeri*, *O. niloticus*, *Coptodon rendalli*.

Other characteristic species: n/a

Flow-related concerns: Short term fluctuations in level will impact on breeding success because of the cichlids' breeding strategy, in which the male constructs a nest, usually of sand, to which it attracts mates to spawn. Changes in level will disrupt territorial behaviour and nest construction. Extended periods of low flow downstream of the dam when the reservoir is filling will expose the tilapiines to high fishing mortality as the fish are concentrated in smaller areas and lower water volumes. In the gorge, *P.* cf. *acuticeps* will be affected by fluctuating river levels as they will constantly have to move from shelter to shelter and thus be exposed to predation, particularly by tigerfish.

6.8.2.4 Name: Chessa and Nkupe, Distichodus spp

Habitat: Main river channels only
Representative species: Nkupe, *D. mossambicus* and chessa, *D. schenga*
Other characteristic species: n/a
Flow-related concerns: Nkupe in particular is a large-growing species dependent on large rivers. Changes in flow regime will impact on survival.

6.8.2.5 Name: Synodontis zambezensis

Habitat: .main river channel at a wide range of depths.
Representative species: *Synodontis zambezensis*
Other characteristic species: n/a
Flow-related concerns: Chosen as a species that has a wide range of habitat tolerance and a resilience to fishing pressure.

6.8.2.6 Name: Alestids

Habitat: Pelagic zone of river channels, generally close to bank.
Representative species: *Brycinus lateralis*, *B. imberi*, *Micralestes acutidens*
Other characteristic species: n/a
Flow-related concerns: Chosen as a group of pelagic species that are a major part of the prey of predatory species such as tigerfish. Changes in level will destabilise their shoaling patterns, while for *B. imberi* short term level changes will impact on breeding success as they breed in newly flooded shallow areas and temporary streams.

6.8.2.7 Name: Barbus spp

Habitat: Shallow marginal areas.
Representative species: *Barbus fasciolatus, Barbus unitaeniatus*
Other characteristic species: .n/a
Flow-related concerns: Small species characteristic of shallow water environments and thus vulnerable to river level changes, *Barbus* have unusually low species diversity in the Middle Zambezi system.

6.8.2.8 Name: Cornish jack, Mormyrops anguilloides

Habitat: Cover in rocky areas during the day, moving into open water to feed under cover of darkness. Juveniles occur in very shallow water.
Representative species: *Mormyrops anguilloides*

Other characteristic species: .Other mormyrids that are similarly nocturnal include the two *Cyphomyrus* species.

Flow-related concerns: .Short term changes in river level will impact on the juveniles in shallow water, which will be forced to move from cover when the level drops, exposing them to predation. Changes in level will also impact on the macroinvertebrates on which the smaller mormyrids depend for food.

6.8.2.9 Name: Vundu, Heterobranchus longifilis

Habitat: Deeper parts of main river channels, particularly pools

Representative species: *Heterobranchus longifilis*

Other characteristic species: *Clarias gariepinus*

Flow-related concerns: . Low, selected as an iconic large angling target species

6.8.2.10 Name: Tigerfish, Hydrocynus vittatus

Habitat: . pelagic in main river channels

Representative species: *Hydrocynus vittatus*

Other characteristic species: n/a

Flow-related concerns: Short term changes in river level will disrupt breeding success by alternately exposing eggs laid in shallow water to the air or smothering them under layers of silt created by destabilisation of river banks with rapidly changing levels. Upstream migration to suitable spawning areas may also be halted by the dam, reducing potential spawning grounds and thus spawning success.

6.8.3 Linked indicators

See Section 6.9.

6.9 *Motivations for Response Curves*

6.9.1 Indicator 1: Labeo altivelis

Labeo altivelis		
Linked indicator response curve	Explanation	Confidence
Dry season duration [D season]	A short dry season contributes to maintaining high flows and thus improving habitat for the majority of the riverine species in the system, including Labeo altivelis at EF Site 2, whereas a long dry season results in a reduced flow over a longer period and thus restricting habitat and exposing fish to predation. Impacts of dry season length, dry season min 5d Q, and high flood volumes are cumulative.	High
Dry season min 5d Q [D season]	Reducing the flow in the dry season will have a major deleterious impact on Labeo habitat, while maintaining a higher flow will give increased habitat.	High
Flood volume [F season]	Flood volume has a direct impact on survival. High floods extend the period in which newly spawned Labeo fry can find extensive cover from predation in flooded river margins and vegetation. Low floods confine the river more within defined river banks thereby reducing available habitat for fry. Overall habitat for all sizes is also greater at high river volumes.	High
T1 within day range (T1 season)	Peaking at the time of the beginning of the rains and during the naturally rising flood waters will have a major deleterious effect on labeo spawning as eggs laid in the flooding river margins, particularly in flooding vegetation at EF Site 2 will be alternately drying out and being inundated and potentially	High

Labeo altivelis		
Linked indicator response curve	Explanation	Confidence
	smothered in silt.	
Single-celled diatoms (All seasons)	Labeo altivelis is an algal and bottom sediment (organic detritus) feeder. Fluctuations in abundance of sedentary single celled and filamentous diatoms will therefore impact on the health of the Labeo population.	Moderate
Filamentous green algae (All seasons)	Labeo altivelis is an algal and bottom sediment (organic detritus) feeder. Fluctuations in abundance of green algae will therefore impact on the health of the Labeo population.	Moderate
Vegetated midchannel bars [T1 season]	Labeos in general spawn over flooded vegetation. Marshall (2011) reports upstream spawning migrations from Lake Kariba but does not indicate the depth or type of spawning habitat(s). Vegetated midchannel bars, by increasing effective riparian zone, are likely to lead to improved spawning success, though the extent is uncertain.	Moderate
Depth of pools [D season]	At EF Site 2, where the river is generally much broader and shallower than at Site 1, abundance of this relatively large labeo species will depend on the area of deeper habitat availability providing refuge from predation.	Moderate
Fish catches [All seasons]	Labeo altivelis is highly vulnerable to fishing, particularly when undertaking breeding migrations at the beginning of the rainy season. At this time excessive fishing pressure targeting spawning labeos can have major impacts on survival and has been documented to cause complete fisheries collapse (Skelton et al. 1991). This may be mitigated to some extent by upstream migration from Lake Kariba.	High

6.9.2 Indicator 2: Redeye labeo, Labeo cylindricus

Redeye labeo, Labeo cylindricus		
Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will have an adverse impact on redeye labeo habitat, while maintaining a higher flow will give increased habitat. The impact will be greater at EF Site 2, as at EF Site 1 large rocky pools will remain even if there is complete cessation of flow.	Moderate
Flood volume [F season]	Flood volume has a direct impact on survival. High floods extend the period in which newly spawned redeye labeo fry can find extensive cover from predation in flooded rocky river margins, and at EF Site 2 in vegetation. Low floods confine the river more within defined river banks thereby reducing available habitat for fry. Overall habitat for all sizes is also greater at high river volumes.	High
Single-celled diatoms (All seasons)	Redeye labeo graze on diatoms, algae and other organic matter on rocky surfaces, known collectively as aufwuchs, and on the bottom (Marshall 2011), and commonly occur in fast water and riffles. Low flood levels result in greater diatom abundance due to greater areas of backwater and slow flow, but these are unavailable to labeo, and thus higher diatom abundance in backwaters does not benefit labeo that feed in the main river channels. Higher flows slightly increase grazing areas but this is accounted for elsewhere in response to higher flows.	High

Redeye labeo, Labeo cylindricus		
Linked indicator response curve	Explanation	Confidence
Filamentous green algae (All seasons)	Redeye labeo graze on diatoms, algae and other organic matter on rocky surfaces and on the bottom (Marshall 2011), and commonly occur in fast water and riffles. Low flood levels result in greater algal abundance due to greater areas of backwater and slow flow, but these are unavailable to labeo, and thus higher algal abundance does not benefit labeo that feed in the main river channels. Higher flows slightly increase grazing areas but this is accounted for elsewhere in response to higher flows.	High
Area of backwaters and secondary channels (D season)	At both sites there are extensive areas of rocky backwaters and secondary channels. Most are too slow to favour redeye labeo, but there are channels with rapid flow that provide suitable habitat.	Moderate
T1 within day range (T1 season)	Peaking at the time of the beginning of the rains and during the naturally rising flood waters will have a major deleterious effect on labeo spawning as eggs laid in the flooding river margins, particularly in flooding vegetation at EF Site 2 (as directly observed in this species in flooding ephemeral streams flowing into Lake Malawi by D. Tweddle) will be alternately drying out and being inundated and potentially smothered in silt.	High
refs		

6.9.3 Indicator 3: Cichlids

Cichlids		
Linked indicator response curve	Explanation	Confidence
Dry season duration [D season]	A short dry season contributes to maintaining high flows and thus improving habitat for the majority of the riverine species in the system, including the cichlids, whereas a long dry season results in a reduced flow over a longer period and thus restricting habitat and exposing fish to predation. Impacts of dry season length, dry season min 5d Q, and high flood volumes are cumulative.	High
Dry season min 5d Q [D season]	Reducing the flow in the dry season will have a major deleterious impact on the shallow water habitat of *Pharyngochromis* cf. *acuticeps* at EF Site 1, while maintaining a higher flow will give increased habitat.	High
Flood volume [F season]	Flood volume has a direct impact on survival. High floods extend the period in which cichlids can find extensive cover from predation in flooded rocky river margins and vegetation. Low floods confine the river more within defined river banks thereby reducing available habitat for fry. Overall habitat for all es is also greater at high river volumes.	High
Ephemeroptera [All seasons]	Ephemeroptera, together with other insects, are important components of the diet of many species including small cichlids such as *P*. cf. *acuticeps* and juveniles of others.	Moderate
Oligoneuridae [All seasons]	Oligoneuridae, together with other insects, are important components of the diet of many species including small cichlids such as *P*. cf. *acuticeps* and juveniles of others.	Moderate

Cichlids		
Linked indicator response curve	Explanation	Confidence
Chironomidae [All seasons]	Chironomidae are an important component of the invertebrate fauna in backwaters where *P*. cf. *acuticeps*, and juveniles of the other larger cichlids at EF Site 2 feed.	Moderate
Ceratopogonidae [All seasons]	Ceratopogonidae are an important component of the invertebrate fauna in backwaters, particularly in silty areas, where *P*. cf. *acuticeps* feed.	Moderate
Simulidae [All seasons]	Simulidae are not common in backwaters and thus contribute little to *P*. cf. *acuticeps* diet in this area.	Moderate
Shrimps	Shrimps are an important component of the invertebrate fauna in marginal shrub and reed areas at EF Site 2 where *P*. cf. *acuticeps* and juveniles of other cichlid species feed.	Moderate
Marginal Graminoids [D season]	Marginal graminoids are a habitat for juvenile cichlids of all species at EF Site 2.	Moderate
Marginal Shrubs [All seasons]	Marginal shrubs are an important habitat for juvenile cichlids of all species at EF Site 2. Upstream of the Site 2 transect, there are extensive stretches of relatively stable shrub-lined riparian zone that provide diverse nursery habitats.	Moderate
Area of backwaters and secondary channels (D season)	At EF Site 1, backwaters and secondary channels are the only available habitat for cichlids, particularly *P*. cf. *acuticeps*, as flows in the main river channels are too strong for cichlids. The availability of such backwaters is therefore essential for cichlids to survive in the gorge. At EF Site 2, while one would expect the extensive shallow backwaters to be important nursery areas for larger cichlids, few cichlids were seen in the survey, with the exception of a	High

Cichlids		
Linked indicator response curve	Explanation	Confidence
	cut-off backwater that contained a shoal of palm-sized cichlids, the majority being juvenile *Coptodon rendalli*. This suggests that the backwaters do have more significance for cichlids over the full course of the lower flow period than the single sampling visit would suggest.	
Dry within day range [D season]	Daily peaking in the dry season will reduce the area of habitat availability for all cichlid species, particularly the juveniles, as these areas will be alternately dry and covered. Some areas may remain as pools, but the amount of suitable habitat availability in this section of river is high and cichlids are very common in this habitat, thus the negative impact of peaking will be high. The peaking may also have a serious impact on breeding success as the male cichlids establish breeding territories known as nests (Tweddle et al. 1997) in the shallows where they court females, and fluctuating water levels will interfere with this courting behaviour, and, in the case of the commonest cichlid species at EF Site 2, *Coptodon rendalli*, it will also interfere with adults' guarding behaviour of fry in the nesting burrows.	High
T1 within day range [T1 season]	Daily peaking in the transition period will reduce the area of habitat availability for all cichlid species, particularly the juveniles, as these areas will be alternately dry and covered. Some areas may remain as pools, but the amount of suitable habitat availability in this section of river is high and cichlids are very common in this habitat, thus the negative impact of	High

Cichlids		
Linked indicator response curve	Explanation	Confidence
	peaking will be high. The peaking may also have a serious impact on breeding success as the male cichlids establish breeding territories known as nests (Tweddle et al. 1997) in the shallows where they court females, and fluctuating water levels will interfere with this courting behaviour, and, in the case of the commonest cichlid species at EF Site 2, *Coptodon rendalli*, it will also interfere with adults' guarding behaviour of fry in the nesting burrows.	
Fish catches [All seasons]	Current cichlid stocks are considered to be low due to the recent introduction of monofilament gillnets in the Zambian fishery. Reduction or removal of fishing effort would increase stocks.	High

6.9.4 Indicator 4: Chessa and Nkupe, *Distichodus* spp

Chessa and Nkupe, *Distichodus* spp		
Linked indicator response curve	Explanation	Confidence
Dry season duration [D season]	A short dry season contributes to maintaining high flows and thus improving habitat for the majority of the riverine species in the system, including *Distichodus* species, whereas a long dry season results in a reduced flow over a longer period and thus restricting habitat and exposing fish to predation. Impacts of dry season length, dry season min 5d Q, and high flood volumes are cumulative.	High

Chessa and Nkupe, *Distichodus* spp		
Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will have a major deleterious impact on *Distichodus* habitat, while maintaining a higher flow will give increased habitat.	High
Flood volume [F season]	Flood volume has a direct impact on survival. High floods provide more habitat for the fish fry and juveniles for a longer period. Low floods confine the river more within defined river banks thereby reducing available habitat for fry. Overall habitat for all sizes is also greater at high river volumes.	High
Single-celled diatoms [All seasons]	Both *Distichodus* species are primarily herbivorous, feeding on algae, grasses and weeds (Marshall 2011). The proportion of diatoms in the diet is not known but is likely to be low and reduction in diatoms is unlikely to impact on population health.	Moderate
Filamentous green algae [All seasons]	Both *Distichodus* species are primarily herbivorous, feeding on algae, grasses and weeds (Marshall 2011). The proportion of green algae is not known but a reduction in green algae is unlikely to have a major impact on population health.	Moderate
Depth of pools [D season]	At EF Site 2, where the river is generally much broader and shallower than at Site 1, abundance of these relatively large *Distichodus* species will depend on the area of deeper habitat availability providing refuge from predation.	Moderate
Ephemeroptera [All seasons]	Macroinvertebrates form part of the diet of both *Distichodus* species. Cumulative impacts of declines in invertebrates on fish health can be expected, with no single group having an individual impact.	Moderate

Chessa and Nkupe, *Distichodus* spp		
Linked indicator response curve	Explanation	Confidence
Oligoneuridae [All seasons]	Macroinvertebrates form part of the diet of both *Distichodus* species. Cumulative impacts of declines in invertebrates on fish health can be expected, with no single group having an individual impact.	Moderate
Chironomidae [All seasons]	Macroinvertebrates form part of the diet of both *Distichodus* species. Cumulative impacts of declines in invertebrates on fish health can be expected, with no single group having an individual impact.	Moderate
Ceratopogonidae [All seasons]	Macroinvertebrates form part of the diet of both *Distichodus* species. Cumulative impacts of declines in invertebrates on fish health can be expected, with no single group having an individual impact.	Moderate
Simulidae [All seasons]	Macroinvertebrates form part of the diet of both *Distichodus* species. Cumulative impacts of declines in invertebrates on fish health can be expected, with no single group having an individual impact.	Moderate
Shrimps [All seasons]	Macroinvertebrates form part of the diet of both *Distichodus* species. Cumulative impacts of declines in invertebrates on fish health can be expected, with no single group having an individual impact.	Moderate
Gastropods [All seasons]	Gastropods form part of the diet of both *Distichodus* species, and Minshull (reported in Marshall 2011) found chessa stomachs packed with *Melanoides* in the Chalala area of Lake Kariba. As the species are omnivorous and capable of switching between prey items, only a collective reduction in all	Moderate

Chessa and Nkupe, *Distichodus* spp		
Linked indicator response curve	Explanation	Confidence
	prey items would have a major impact on fish populations.	
Bivalves [All seasons]	Macroinvertebrates form part of the diet of both *Distichodus* species. Cumulative impacts of declines in invertebrates on fish health can be expected, with no single group having an individual impact.	Moderate
Alestids [All seasons]	Both species of *Distichodus* are reported to feed on small fishes (Marshall 2011). Given their open water habitats, alestids, particularly the small shoaling species *Micralestes acutidens*, are likely the most common prey items. Absence or great reduction in prey fish would impact on health and success of adult *Distichodus*. Increase in alestid abundance is unlikely to have any impact given current abundance.	Moderate
Marginal Shrubs [All seasons]	Roots of marginal shrubs contribute to cover and protection from predation for juvenile fish, thus loss of this habitat would have some, but very minor, effect on survival of juveniles of the *Distichodus* species.	Moderate
Fish catches [All seasons]	*Distichodus* are targeted by both gillnets and hook and line. The impact of current fishing effort is unknown but likely to be significant. Reduction or removal of fishing effort would increase stocks.	High

6.9.5 Indicator 5: Synodontis zambezensis

Synodontis zambezensis	

Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will reduce Synodontis habitat, while maintaining a higher flow will give increased habitat.	High
Flood volume [F season]	High floods increase overall habitat and boost survival of fry and juveniles. Low floods confine the river more within defined river banks thereby reducing available habitat for fry. Overall habitat for all sizes is also greater at high river volumes.	High
Single-celled diatoms [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Filamentous green algae [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Ephemeroptera [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Oligoneuridae [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Chironomidae [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is	Moderate

Synodontis zambezensis		
Linked indicator response curve	Explanation	Confidence
	given a high rating here, with cumulative effects considered more relevant.	
Ceratopogonidae [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Simulidae [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Shrimps [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Gastropods [All seasons]	While gastropods are an important component of the diet of S. zambezensis in general, they are scarce and thus of minor importance in the diet.	Moderate
Bivalves [All seasons]	The Zambezi squeaker is omnivorous with diet determined by food availability (Marshall 2011). Thus no single food item is given a high rating here, with cumulative effects considered more relevant.	Moderate
Marginal Shrubs [All seasons]	Submerged roots of riparian vegetation make a marginal contribution to habitat for juvenile squeakers, although none were caught in this survey. Increased river levels would create increased shrub-tree habitat diversity at EF Site 2.	Moderate

Synodontis zambezensis		
Linked indicator response curve	Explanation	Confidence
Margibal Graminoids [Al seasons]	Submerged roots of reeds provide habitat for juvenile squeakers. While none were found in this survey, squeakers can be found in small numbers in reedbeds. Decrease in size of in-stream reedbeds, e.g. because of lower river levels, would negatively impact on fish habitat, while increased reed habitat appears unlikely in expected scenarios.	
Fish catches [All seasons]	Squeakers are fairly resistant to general fishing effort, being targeted by fishers only as a last resort when all other species have been heavily overfished.	High

6.9.6 Indicator 6: Alestids

Alestids		
Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will confine alestids in smaller water volumes, thereby increasing predation on them, while maintaining a higher flow will give increased habitat	High
Flood volume [F season]	Flood volume has a direct impact on survival. High floods increase spawning success and reduce predation, whereas low floods confine the river more within defined river banks thereby reducing available habitat and increasing predation.	High
Ephemeroptera [All seasons]	One of the three Middle Zambezi alestids, *B. imberi*, is abundant at EF Site 2, while the other two, *M. acutidens* and *B. lateralis*, also appear to be fairly common. All are opportunistic	Moderate

Alestids		
Linked indicator response curve	Explanation	Confidence
	omnivores (Marshall 2011). No single food item dominates although terrestrial insects are reported to bethe main food items for *B. imberi* in Lake Kariba. Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compenstaed by switching to other prey items. Food availability for alestids is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	
Oligoneuridae [All seasons]	One of the three Middle Zambezi alestids, *B. imberi*, is abundant at EF Site 2, while the other two, *M. acutidens* and *B. lateralis*, also appear to be fairly common. All are opportunistic omnivores (Marshall 2011). No single food item dominates although terrestrial insects are reported to bethe main food items for *B. imberi* in Lake Kariba. Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compenstaed by switching to other prey items. Food availability for alestids is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Chironomidae [All seasons]	One of the three Middle Zambezi alestids, *B. imberi*, is abundant at EF Site 2, while the other two, *M. acutidens* and *B. lateralis*, also appear to be fairly common. All are opportunistic omnivores (Marshall 2011). No single food item dominates although terrestrial insects are reported to bethe main food items for *B. imberi* in Lake Kariba. Opportunistic feeding	Moderate

Alestids		
Linked indicator response curve	Explanation	Confidence
	behaviour means that changes in abundance of one type of prey is likely to be compenstaed by switching to other prey items. Food availability for alestids is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	
Ceratopogonidae [All seasons]	One of the three Middle Zambezi alestids, *B. imberi*, is abundant at EF Site 2, while the other two, *M. acutidens* and *B. lateralis*, also appear to be fairly common. All are opportunistic omnivores (Marshall 2011). No single food item dominates although terrestrial insects are reported to bethe main food items for *B. imberi* in Lake Kariba. Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compenstaed by switching to other prey items. Food availability for alestids is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Simulidae [All seasons]	*Micralestes acutidens* is the most common alestid at Site EF 1. Alestids are opportunistic omnivores (Marshall 2011). No single food item dominates. Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for alestids is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Shrimps [All seasons]	One of the three Middle Zambezi alestids, *B. imberi*, is	Moderate

Alestids		
Linked indicator response curve	Explanation	Confidence
	abundant at EF Site 2, while the other two, *M. acutidens* and *B. lateralis*, also appear to be fairly common. All are opportunistic omnivores (Marshall 2011). No single food item dominates although terrestrial insects are reported to bethe main food items for *B. imberi* in Lake Kariba. Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compenstaed by switching to other prey items. Food availability for alestids is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	
Marginal Graminoids [D season]	Submerged roots of reeds provide habitat for alestids, which can be found adjacent to reedbeds, into which they can retreat to avoid predation. Decrease in size of in-stream reedbeds, e.g. because of lower river levels, would negatively impact on fish habitat, while increased reed habitat appears unlikely in expected scenarios.	Moderate
Marginal Shrubs [All seasons]	Submerged roots of riparian vegetation provide cover for alestids. Increased river levels would create increased shrub-tree habitat diversity at EF Site 2 and thereby more protection from predation.	Moderate
T1 within day range [T1 season]	*Brycinus imberi* makes breeding migrations into flooded rivers (Marshall 2011) and has been observed spawning in shallows of newly-flooding ephemeral rain water channels adjacent to Lake Malawi by D. Tweddle (pers.obs.). *Brycinus lateralis* is also observed to migrate on to floodplains in the Upper Zambezi	High

Alestids		
Linked indicator response curve	Explanation	Confidence
	system, while *M. acutidens* appears more restricted to the main river channels and thus spawning requirements are less well-known. Spawning in shallow flooding habitats will be severely impacted by daily peaking of river levels should this occur below the dam during the breeding migrations, as eggs will be alternately left high and dry then flooded and potentially covered by silt.	
Fish catches [All seasons]	Fishing effort is low on alestids in this area, although breeding migrations of *B. imberi* into tributary streams may be targeted.	Low

6.9.7 Indicator 7: Barbus spp

Barbus spp		
Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will have a major deleterious impact on the shallow water Barbus habitat at EF Site 2, while maintaining a higher flow will give increased habitat in backwaters.	High
Flood volume [F season]	Flood volume has a direct impact on survival. High floods extend the period in which the small Barbus spp can find extensive cover from predation in flooded river margins and vegetation at EF Site 2. Low floods confine the river more within defined river banks thereby reducing available habitat.	High
Ephemeroptera [All seasons]	Small barbs feed primarily on small insects and other aquatic	Moderate

Barbus spp		
Linked indicator response curve	Explanation	Confidence
	organisms Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for barbs is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	
Chironomidae [All seasons]	Small barbs feed primarily on small insects and other aquatic organisms Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for barbs is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Ceratopogonidae [All seasons]	Small barbs feed primarily on small insects and other aquatic organisms Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for barbs is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Shrimps [All seasons]	Small barbs feed primarily on small insects and other aquatic organisms Opportunistic feeding behaviour means that changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for barbs is thus only likely to have significant	Moderate

Barbus spp		
Linked indicator response curve	Explanation	Confidence
	impacts if there are cumulative losses of food sources in the system.	
Marginal Graminoids [D season]	Submerged roots of reeds provide an important habitat for Barbus spp. Decrease in size of in-stream reedbeds, e.g. because of lower river levels, would negatively impact on fish habitat, while increased reed habitat appears unlikely in expected scenarios.	Moderate
Marginal Shrubs [All seasons]	Submerged roots of riparian vegetation provide cover for barbs. Increased river levels would create increased shrub-tree habitat diversity at EF Site 2 and thereby more protection from predation.	Moderate
Area of backwaters and secondary channels [D season]	Barbus unitaeniatus and B. fasciolatus are common throughout the extensive shallow areas at EF Site 2. Loss of these backwaters and small channels will have a major impact on the abundance of these species.	High
Vegetated midchannel bars [D season]	The Barbus spp are dependent on cover in shallow areas. The presence of vegetated midchannel bars increases the length of river bank area thus available habitat.	Moderate
Dry within day range [D season]	Fluctuations in daily flow will both greatly reduce available habitat for Barbus spp and force the fish to continually move with changing river levels and thus become more vulnerable to predation.	High
T1 within day range [T1 season]	Fluctuations in daily flow will both greatly reduce available habitat for Barbus spp and force the fish to continually move with changing river levels and thus become more vulnerable to	High

Barbus spp		
Linked indicator response curve	Explanation	Confidence
	predation. Barbus spp generally breed in the rains and can be oberved migrating out on to floodplains and into side streams to breed. Spawning in shallow flooding habitats will be severely impacted by daily peaking of river levels should this occur below the dam during the breeding migrations, as eggs will be alternately left high and dry then flooded and potentially covered by silt.	
Fish catches [All seasons]	Small barbs in the shallows are chased by women and children using small scraps of cloth or mosquito nets. Barbs are resilient to heavy mortality, being adapted to fluctuating environments such as floodplains. The scarcity of suitable environment in this stretch of river explains the very low diversity (Jackson 1961). Impact of fishing is therefore minimal.	Low

6.9.8 Indicator 8: Cornish jack, Mormyrops anguilloides

Cornish jack, Mormyrops anguilloides		
Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will greatly reduce the shallow rocky habitat of juvenile Cornish jack, and reduce the volume of pools inhabited by adults, increasing predation risk, whereas maintaining a higher flow will give increased habitat.	High
Flood volume [F season]	Flood volume has a direct impact on survival. High floods extend the period in which Cornish jack juveniles can find	High

Cornish jack, Mormyrops anguilloides		
Linked indicator response curve	Explanation	Confidence
	extensive cover from predation in rocky areas. Low floods confine the river more within defined river banks thereby reducing available habitat for the juveniles. Overall habitat for all sizes is also greater at high river volumes.	
Depth of pools [All seasons]	Although abundance and survival of large adult cornish jack depends on the area of deeper habitat available, the nature of the river at EF Site 1 with numerous deep rocky pools means that changes in river level will have minimal impact on the amount of habitat available. At EF Site 2, where the river is generally much broader and shallower than at Site 1, abundance and survival of large adult cornish jack will depend on the area of deeper habitat available.	High
Ephemeroptera [All seasons]	Insects in general are an important component of cornish jack diet (Marshall 2011). Larger fish take large prey such as odonate larvae, but juveniles among rocks will take smaller insects. Changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for cornish jack is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Oligoneuridae [All seasons]	Insects in general are an important component of cornish jack diet (Marshall 2011). Larger fish take large prey such as odonate larvae, but juveniles among rocks will take smaller insects. Changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food	Moderate

Cornish jack, Mormyrops anguilloides		
Linked indicator response curve	Explanation	Confidence
	availability for cornish jack is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	
Chironomidae [All seasons]	Insects in general are an important component of cornish jack diet (Marshall 2011). Larger fish take large prey such as odonate larvae, but juveniles among rocks will take smaller insects. Changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for cornish jack is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Ceratopogonidae [All seasons]	Insects in general are an important component of cornish jack diet (Marshall 2011). Larger fish take large prey such as odonate larvae, but juveniles among rocks will take smaller insects. Changes in abundance of one type of prey is likely to be compensated by switching to other prey items. Food availability for cornish jack is thus only likely to have significant impacts if there are cumulative losses of food sources in the system.	Moderate
Shrimps [All seasons]	Shrimps were reported by Marshall (2011) to occur in about half the stomachs of fish from open water. They are thus likely to be of greater importance in the overall diet than the various other macroinvertebrate families.	Moderate
Cichlids	Small cichlids up to 4-5 cm in length were reported by Marshall (2011) to be the main fish prey of Cornish Jack in Lake Kariba,	High

Cornish jack, Mormyrops anguilloides		
Linked indicator response curve	Explanation	Confidence
	with fish in general occurring in nearly 70% of stomachs of fish from open water. At EF Site 1, cornish jack juveniles and the small cichlid P. cf. acuticeps are the most common species in the shallow rocky pools. Small P. cf. acuticeps are therefore likely to be the main prey of the small cornish jack and therefore of importance to their survival.	
Area of backwaters and secondary channels [D season]	The presence of many juvenile cornish jack in the shallow rocky areas, both in and out of flow, at EF Site 1 means that loss of such shallow backwaters will have an important impact on juvenile habitat and thus survival.	High
Dry within day range [D season]	Daily peaking in the dry season will reduce the area of juvenile habitat availability in rocky areas where the juveniles hide beneath and between the rocks, as these areas will be alternately dry and covered. Some areas may remain as pools, but the amount of suitable habitat availability in this section of river is high and juveniles of this species are very common in this habitat, thus the negative impact of peaking will be high.	High
Fish catches [All seasons]	Cornish jack are caught in fairly low numbers by hook and line fishers.	Low

6.9.9 Indicator 9: Vundu, Heterobranchus longifilis

Vundu, Heterobranchus longifilis		
Linked indicator response curve	Explanation	Confidence

Vundu, Heterobranchus longifilis		
Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will impact on the volume of pools inhabited by the large vundu, while maintaining a higher flow will give increased pool volume, but effects at EF Site 1 will be less than at Site 2 because of the greater available deep pool habitat.	High
Flood volume [F season]	Flood volume is an important factor in maintaining deep pools that are the prime habitat for vundu. Low floods confine the river more within defined river banks with smaller, shallower pools.	High
Depth of pools [All seasons]	Vundu are restricted to deeper waters than other species in the Zambezi and thus the volume of water available, including pools, is an important factor, particularly at low flow periods. At EF Site 1, deep pools can be expected to persist, even at low river levels, and thus impacts of very low river flow on pool depth will be less than at EF Site 2.	High
Ephemeroptera [All seasons]	Invertebrates in general form part of the diet of juvenile vundu. Absence of one group will have no impact on vundu population size or survival as it will be compensated for by other food sources.	Moderate
Chironomidae [All seasons]	Invertebrates in general form part of the diet of juvenile vundu. Absence of one group will have no impact on vundu population size or survival as it will be compensated for by other food sources.	Moderate
Ceratopogonidae [All seasons]	Invertebrates in general form part of the diet of juvenile vundu. Absence of one group will have no impact on vundu	Moderate

Vundu, Heterobranchus longifilis		
Linked indicator response curve	Explanation	Confidence
	population size or survival as it will be compensated for by other food sources.	
Shrimps [All seasons]	Invertebrates in general form part of the diet of juvenile vundu. Absence of one group will have no impact on vundu population size or survival as it will be compensated for by other food sources.	Moderate
Cichlids	At EF Site 1, with its faster flow and rocky habitat compared to EF Site 2, cichlids will form a negligible part of the diet.	Moderate
Tigerfish, Hydrocynus vittatus [All seasons]	Tigerfish, because of their open water habits are unlikely to ever form more than an insignificant component of the diet of vundu and thus have no impact on vundu populations.	Moderate
Cornish jack, Mormyrops anguilloides [All seasons]	Cornish jack are likely to form a small part of the vundu diet in the pools at EF Site 1. As vundu feed on a wide variety of prey, effects of fish densities on vundu health will be cumulative, with no single fish species group being significant in isolation.	Moderate
Redeye labeo, Labeo cylindricus [All seasons]	Redeye labeo, as they graze on algae on the river bed and rocks, will form part of the vundu diet in pools with flowing water. As vundu feed on a wide variety of prey, effects of fish densities on vundu health will be cumulative, with no single fish species group being significant in isolation.	Moderate
Synodontis zambezensis [All seasons]	Squeakers are likely to form a significant part of the vundu diet in pools and may be of greater importance in the diet than the other species in this section of the river, but this is uncertain and thus squeakers are given the same weighting as the other fish species as part of the overall vundu diet.	Moderate

Vundu, Heterobranchus longifilis		
Linked indicator response curve	Explanation	Confidence
Alestids [All seasons]	Alestids are likely to form a small part of the vundu diet in the pools at EF Site 1. As vundu feed on a wide variety of prey, effects of fish densities on vundu health will be cumulative, with no single fish species group being significant in isolation.	Moderate
Chessa and Nkupe, Distichodus spp [All seasons]	Distichodus species will be preyed on by adult vundu in pools, but are likely to be fairly minor components of the vundu diet. As vundu feed on a wide variety of prey, effects of fish densities on vundu health will be cumulative, with no single fish species group being significant in isolation.	Moderate
Labeo altivelis [All seasons]	Labeo altivelis populations can fluctuate enormously dependent on breeding success in relation to flood regime and anthropogenic effects. Labeo will feature in the diet of vundu, but the extent of this, and thus the impact of population fluctuations on vundu populations is uncertain	Moderate
Barbus spp [All seasons]	Small Barbus species are not abundant in this part of the Zambezi and occur only in the shallows out of range of vundu predation. The larger barbine, Labeobarbus marequensis, does, however, occur in the open, fast-flowing water and may form part of the vundu diet, particularly at EF Site 1. As vundu feed on a wide variety of prey, effects of fish densities on vundu health will be cumulative, with no single fish species group being significant in isolation.	Low
Vundu, Heterobranchus longifilis [All seasons]	Cannibalism on vundu fry is possible but rare and thus with little or no effect on vundu populations.	Low
Fish catches [All seasons]	Vundu are caught in small numbers in deep pools on hook and	Low

Vundu, Heterobranchus longifilis		
Linked indicator response curve	Explanation	Confidence
	line.	

6.9.10 Indicator 10: Tigerfish, Hydrocynus vittatus

Tigerfish, Hydrocynus vittatus		
Linked indicator response curve	Explanation	Confidence
Dry season min 5d Q [D season]	Reducing the flow in the dry season will reduce extent of tigerfish pelagic habitat, while maintaining a higher flow will give increased habitat. Effects will be relatively low, however, because of the depth and scale of pelagic habitat available in the gorge.	High
Dry season duration [D season]	A short dry season contributes to maintaining high flows and thus improving habitat for the majority of the riverine species in the system, including tigerfish, whereas a long dry season results in a reduced flow over a longer period and thus restricting habitat and exposing fish to predation. Impacts of dry season length, dry season min 5d Q, and high flood volumes are cumulative.	High
Flood volume [F season]	Flood volume has a direct impact on survival. High floods extend the period in which newly spawned tigerfish fry can find extensive cover from predation in flooded river margins. Low floods confine the river more within defined river banks thereby reducing available habitat for fry. Overall habitat for all sizes is also greater at high river volumes. Tigerfish are	High

Tigerfish, Hydrocynus vittatus		
Linked indicator response curve	Explanation	Confidence
	migratory and thus abundance in the gorge may be related to abundance further downstream, where impact of flood volume changes is likely to be greater.	
Depth of pools [All seasons]	Tigerfish are roaming, open water predators, and thus the volume of water available, including pools, is an important fac`tor, particularly at low flow periods. At EF Site 1, many deep pools can be expected to persist, even at low river levels.	High
T1 within day range [T1 season]	Peaking at the time of the beginning of the rains and during the the naturally rising flood waters will have a deleterious effect on tigerfish spawning as eggs laid in the flooding river margins will be alternately drying out and being inundated and potentially smothered in silt. This may be mitigated to some extent by migration from downstream including Lake Kariba as tigerfish have been shown to range more widely in the Zambezi system than other fish species (Okland et al. 2005).	Moderate
Ephemeroptera [All seasons]	Emergent mayflies are an important but opportunistic food source for the majority of fish species, including juvenile tigerfish, but will not have any significant impact on fish health or survival.	Moderate
Oligoneuridae [All seasons]	Oligoneuridae form a very minor part of the diet of juvenile tigerfish but will not have any significant impact on fish health or survival.	Moderate
Chironomidae [All seasons]	The abundance of Chironomidae at low river levels is of larvae in the sediments. These are not available to juvenile tigerfish that feed only on the emerging adults, and thus have no	Moderate

Tigerfish, Hydrocynus vittatus		
Linked indicator response curve	Explanation	Confidence
	noticeable influence on tigerfish survival.	
Ceratopogonidae [All seasons]	Ceratopogonidae form a very minor part of the diet of juvenile tigerfish but will not have any significant impact on fish health or survival.	Moderate
Shrimps [All seasons]	Shrimps form a minor part of the diet of juvenile tigerfish, having little effect on tigerfish health or survival.	Moderate
Cichlids	Cichlids are likely to be slightly more important in the diet at EF Site 2 than at Site 1 as there is greater cichlid diversity and abundance as well as greater habitat diversity including areas of slower water habitat where juvenile cichlids may become vulnerable to predation.	Moderate
Tigerfish, Hydrocynus vittatus [All seasons]	Cannibalism is of some importance in tigerfish, reported at 4% of food items in Lake Kariba prior to the kapenta introduction (Kenmuir 1973), while Jackson (1961) and Bell-Cross (1972) reported on size structuring in tigerfish shoals based on potential prey size. Cannibalism will reduce recruitment slightly but have no impact on health of adult fish.	Moderate
Cornish jack, Mormyrops anguilloides [All seasons]	Chessa and nkupe juveniles will form part of the prey for tigerfish, but not to the extent where absence would will impact on tigerfish population size or health.	Moderate
Synodontis zambezensis [All seasons]	Squeakers are a component of the diet of large tigerfish but with no significance for tigerfish survival.	Moderate
Alestids [All seasons]	The three alestids are major prey items for tigerfish in the Zambezi River and thus abundance is likely to have an impact on health and survival.	Moderate

Tigerfish, Hydrocynus vittatus		
Linked indicator response curve	Explanation	Confidence
Chessa and Nkupe, Distichodus spp [All seasons]	Chessa and nkupe juveniles will form part of the prey for tigerfish, but not to the extent where absence would will impact on tigerfish population size or health.	Moderate
Redeye labeo, Labeo cylindricus [All seasons]	Labeo juveniles will form part of the prey for tigerfish, but not to the extent where absence would impact on tigerfish population size or health.	Moderate
Labeo altivelis [All seasons]	Labeo juveniles will form part of the prey for tigerfish, but not to the extent where absence would impact on tigerfish population size or health.	Moderate
Barbus spp [All seasons]	Barbus species, when present in abundance, such as in the Upper Zambezi floodplain systems (Tweddle et al. 2004), contribute to tigerfish diet, but only two small Barbus species were found in the Middle Zambezi sampling, and not in abundance, therefore Barbus spp absence would not impact on tigerfish population size or health.	Low
Vundu, Heterobranchus longifilis [All seasons]	Vundu are eaten by tigerfish but are an insignificant component of the diet and thus have no influence on survival.	Low
Fish catches [All seasons]	Tigerfish are a a major target for fishers in the area in nets and on hook and line, thus impacting on stock size. The migratory habits mitigate fishing effort as fish can migrate into the area from less heavily fished areas upstream and downstream in Lake Kariba.	Low

6.10 *THE POTENTIAL IMPACT OF THE BATOKA GORGE DAM ON THE FISHERIES OF LAKE KARIBA*

6.10.1 Historical changes in Lake Kariba fish diversity and fisheries

In the early days of Lake Kariba, there was much speculation on the potential impacts of lake level fluctuations caused by manipulation of the dam to optimise electricity production and to manage the level to accommodate the influx of annual floods. For example, Jackson (1966) recommended that "for the establishment of a fishery, the ideal man-made lake might best have its waters conserved as much as possible all the year round, so as to preserve at all times the maximum height of water". Jackson (1966) also suggested that an annual draw-down in most impoundments has a deleterious impact on fisheries due to inhibition of permanent growth of aquatic vegetation in littoral areas of dams. Harding (1966) and Coche (1974) agreed with Jackson (1966), drawing conclusions from a limited amount of data when the lake's hydrology and fisheries were still in very early stages of succession.

Since that time, a large amount of information has been gathered on productivity and fisheries in new, large man-made lakes, and also on fluctuations in productivity and fisheries in natural African lakes that vary enormously in size and volume over time, e.g. Lake Chilwa in Malawi (Furse et al. 1979) and Lake Liambezi in Namibia (van der Waal 1976; Peel 2012). It is now understood that new man-made lakes and ephemeral natural lakes that have refilled after drought periods benefit greatly, but only temporarily, from high productivity due to availability of nutrients from flooded terrestrial areas (refs). Even in lakes with relative stable levels, small annual changes in level can have measurable impact on fish stocks and yields (Tweddle and Magasa 1989 for the Lake Malawi tilapia fishery; and Kolding 1992 for Lake Turkana).

Karenge and Kolding (1995) noted that floodplain fisheries are among the most productive in the tropics (Welcomme, 1979; Junk *et al.*, 1989) and, as most Kariba species originate from the Zambezi, there is no reason why such a lake fishery requires stability whereas a floodplain fishery is dependent on the seasonal inundations. With the benefit of a much longer series of catch and hydrology data for Lake Kariba, Karenge and Kolding (1995a) examined the relationship between catch and lake level. They found no evidence for any relationship between annual mean lake level and any of the fisheries statistics and concluded that there is no evidence supporting the general notion that lower lake levels in Lake Kariba have adverse effects on the fisheries. In contrast, they noted a positive correlation between fish production and lake level fluctuations (defined as delta lake levels, i.e. the difference between the mean annual lake levels in one year and the preceding year). They stated that a suitably timed draw-down is a necessary pre-requisite for subsequent flooding and inundation, which appear to have highly beneficial effects on the productivity of the lake.

Karenge and Kolding (1995a) stated that this conclusion was of importance in relation to the proposed Batoka Gorge Dam, which they believed would increase the rates and amplitudes of lake fluctuations in Lake Kariba, based on a personal communication from Mr H.

Masundire. According to current information, however, the Batoka Gorge dam will be operated as run-of-the-river without peaking. Even with peaking, this will only cause short-term fluctuations in river level downstream, and thus changes in the level of Lake Kariba will be limited to the area of inflow of the Zambezi and, being short-lived, will quickly be buffered by the large volume of the lake.

Kenmuir (1984) documented the changes in the fish populations in Lake Kariba after impoundment and showed that the original riverine species, notably cyprinids, distichodontids and alestids, thrived in the early stages of the lake but then rapidly declined, replaced by more lacustrine species, particularly cichlids. The riverine species became increasingly restricted to areas near river inflows, particularly the Zambezi. *Labeo altivelis*, for example, disappeared from catches in at the Lakeside station and was restricted to the affluent rivers.

The two large *Distichodus* species were initially abundant in the lake but Kenmuir (1984) suggested that when they reached adult size they probably migrated from the marginal shorelines to riverine habitats. They became progressively more common in gillnet catches towards the more riverine western end of the lake.

For the alestids, particularly *Brycinus imberi*, Kenmuir (1984) noted that strength of year-classes may vary considerably from year to year and attributed such fluctuations to the breeding habits. *Brycinus imberi* breeds on newly flooded grassland (Balon 1971; Tweddle 1993) and thus spawning success may depend on whether lake level is rising or falling during their breeding season.

In contrast to the predominantly riverine species, cichlids increased in abundance and diversity in Lake Kariba as the lake provided relatively stable habitat for the cichlid species that are better suited to lacustrine conditions.

The major fishery in Lake Kariba is for the introduced clupeid *Limnothrissa miodon* (kapenta) from Lake Tanganyika, rather than for the indigenous Zambezi River species. There are inconsistencies in reported catch figures in different reports (World Commission on Dams, 2000; Magadza, 2006; FAO, 2006), with annual catches reportedly peaking at between 29,000 and 35,000 tonnes depending on data source (Tweddle 2010).

6.10.2 Expected effects of the construction, inundation and operation of the Batoka Gorge Dam on Lake Kariba fish and fisheries

6.10.2.1 Draw-down

At this stage in the design process for Batoka Gorge Dam, it is not possible to accurately predict the time taken to fill the reservoir but, allowing for environmental flows and in the absence of hydropower generation and significant droughts, it is anticipated that filling will take from 1-3 years. During the filling phase it is likely that there will be a noticeable draw-down in the level of Lake Kariba, the scale of which will depend on the magnitude of the annual floods in the basin.

6.10.2.2 Sediment loss

During the construction of the Batoka Gorge dam there will be a short-term increase in sediment loading in the river below the dam wall as a result of excavation, road construction, etc. (Cate, any comments on this increased sediment load, infilling of pools, etc. in the river between the dam and Kariba? I only comment here on Kariba) After completion of the dam, sediment loading will be reduced as silt settles out in the still water of the reservoir. Sediment loadings in this section of the river are, however, low because of the filtering effects of the extensive floodplain systems upstream from Victoria Falls. The accumulated sediment in the river bed from the construction phase will over time be flushed down into the western arm of Lake Kariba. In the medium to long-term, however, sediment inflow will be greatly reduced.

6.10.2.3 Nutrient levels

Nutrient levels in the inflowing water to Lake Kariba are unlikely to be measurably affected by Batoka Gorge Dam in the medium to long-term. In the short-term as the Batoka reservoir fills, an increase in nutrient levels can be expected from the newly flooded terrestrial environment (refs).

6.10.3 Combined potential impacts

The reduction in mean annual lake level of Lake Kariba during the filling of Batoka Gorge reservoir will have no measurable impact on the fish stocks of Lake Kariba, as Karenge and Kolding (1995) found no correlation between lake level and catch for any of the Kariba fisheries. The expected reduction in flood volume downstream as the Batoka reservoir fills will, however, have a negative impact. Karenge and Kolding (1995) stated that floods provide nutrients that ascend through the food chain. In rapidly absorbing ecotrophic systems such as most tropical reservoirs, plant nutrients are quickly exhausted. In draw-downs, nutrients are already utilised and effects on biological production therefore less. The reduction in flood volume due to the filling of the new dam will reduce the scale of the annual fluctuation of Kariba levels and thus negatively impact on fish abundance and catch rates.
The potential reduction in nutrients due to the reduced floods will, however, be compensated for in the short-term by increased nutrient levels as a result of the newly flooded terrestrial environments in the new Batoka reservoir. The environmental flows released from the dam will be enriched by these nutrients and the benefits will be transferred downstream to Lake Kariba.

Annual floods bring fresh sediments and associated nutrients to the western arm of Lake Kariba. After the short-term increase in sediment during and shortly after the construction phase, annual sediment and nutrient input to the western arm of Lake Kariba will be reduced. In the long-term, therefore, there may be a negative but slight impact on productivity in the western arm of Lake Kariba, unless flood releases from the dam can be designed to transport sediment from the reservoir bed.

6.10.3.1 Lacustrine species

The key species in this category are the kapenta, *L. miodon*, and a number of cichlid species, most notably the tilapias (*Oreochromis niloticus*, *O. mortimeri* (now approaching extinction in the lake), *O. macrochir* and *Coptodon rendalli*) and the serranochromines and sargochromines. The impact on these species of the construction and operation of Batoka Gorge hydroelectric scheme will be minimal and largely restricted to the period of filling when a reduction in flood volume and thus smaller annual changes in level may negatively impact on production if the hypothesis of Karenge and Kolding (1995) is valid.

6.10.3.2 Species adapted to riverine habitats but occurring in Lake Kariba adjacent to the Zambezi River inflow

The cyprinids, distichodontids and alestids in the western arm of Lake Kariba will be affected in the same way as these species in the river between the dam and Lake Kariba. The species are potamodromous and thus covered in this environmental flow analysis. Changes in stock size may be masked by recruitment from the other rivers and streams flowing into Kariba.

6.11 CONCLUSIONS

The overall impact of Batoka Gorge dam on the Lake Kariba fish and fisheries will be limited and, with the possible exception of lower annual flood lake level rise, restricted largely to the western arm of the lake near the Zambezi inflow.

In mitigation, it is recommended that during the filling phase, released flows should closely follow the natural flood cycle, with greater flow release at the beginning of the local rains, which act as spawning cues for many of the important fish species.

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Appendix A. FULL LIST OF MACROINVERTEBRATE TAXA RECORDED IN SEPTEMBER 2014

		EF Site 1: Batoka Gorge					EF Site 2: Upstream of Kariba Dam						
		S1_S1	S1_S2	S1_S3	S1_S4	S1_S5	S2_S1	S2_S2	S2_S3	S2_S4	S2_S5	S2_S6	S2_S7
Flow		fast broken flow	no/slow flow	SBT/BSF	no/slow flow	flickering flow	BPT	BSF	no flow	SBT	BPT	fast broken flow	no flow
Substratum		Boulder & Cobble	Bedrock	Bedrock	Sand over Bedrock	Sand & Gravel	Cobble	Cobble	Vegetation	Vegetation	Sand	Boulder & Cobble	Cobble
Biotope		SIC-cascade/riffle	SOOC-BW	SIC-Run	SOOC/Sand-BW	Sand-SW	SIC-slow Run	SIC-fast Run	Veg-OOC	Veg-IC	Sand-SW	SIC-riffle	SOOC-BW
Order (group)	Taxon												
Atyidae	Shrimps								100				
Annelida	Oligochaeta				4	5	1		2		1	4	1
Coleoptera	Coleoptera sp2				1								
	Coleoptera sp3								1				
	Coleoptera sp4								1				
	Dytiscidae				1								
	Elmidae	6		4			2	10		1			1
Diptera	Ceratopogonidae				23			7					
	Chironomidae	1	70	30	6	1	4	2	1	6	5	5	
	Diptera pupa		11		8					100			
	Empididae			1									
	Simuliidae									60			1
	Tabanidae							5					
Ephemeroptera	Baetidae sp1		4		4								
	Baetidae sp2	4		18						33		2	1
	Baetidae sp3			1			1			1			
	Baetidae sp4	5		145			1	11		37		28	2
	Baetidae sp5		29						22	55			3
	Baetidae sp6	35					0	1	1	7		64	
	Baetidae sp7		3	12								8	4
	Caenidae		5	1	5		1						73
	Heptageniidae	5					25	150	3	9		33	2
	Leptophlebiidae	4					18	75		9		10	33
	Oligoneuriidae	6					1	62				7	
	Polymitarcyidae											5	
	Prosopistomatidae											1	
	Tricorythidae	42		1			4	160	2	1		57	
Gastropoda	Thiaridae								3		3		1
	Viviparidae		1										
Hemiptera	Corixidae		11		1	1			6	1	1		1
	Hydrometridae								1	1			
	Notonectidae								3				
	Pleidae								3				
	Naucoridae					1							
	Veliidae								5	1			
Odonata	Coenagrionidae								22				
	Corduliidae		6		1							1	
	Gomphidae		5		1	1	1	3			7	10	2
	Libellulidae	1	1					33		1		4	
Ostracoda	Ostracod								1				
Pelecypoda	Corbiculidae				1						3	1	
	Mutelidae										18		
	Sphaeriidae										20		
Plecoptera	Perlidae						1	80	1			15	
Trichoptera	Leptoceridae sp1								10				
	Hydroptilidae									1			
	Hydropsychidae	3						10				9	
	Philopotamidae						2	12	7			17	
	Polycentropodidae	1											
Total Number of Individuals		111	155	212	48	11	68	659	202	284	56	370	114