water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA

WP 10544

RIVER INTERMEDIATE EWR
VOLUME 3: SPECIALIST REPORTS

FINAL

SEPTEMBER 2014

Report No. RDM/WMA6/CON/COMP/0813

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF WATER & SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS

CONTRACT NO. WP 10544

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SEPTEMBER 2014

This report should be cited as:

Department of Water & Sanitation (DWS). 2014. Chief Directorate – Water Ecosystems: Reserve determination study of selected surface water and groundwater resources in the Usutu/Mhlathuze Water Management Area. River Intermediate EWR – Volume 3: Specialist Reports. Prepared by Tlou Consulting (Pty) Ltd and Southern Waters Ecological Research and Consulting. Report no: RDM/WMA6/CON/COMP/0813.

Contract Title:	Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Usutu - Mhlathuze Water Management Area
Report Title:	River Intermediate EWR – Volume 3: Specialist Reports
Compilers:	K Reinecke and C Brown
Editor:	A Singh

Revision	**Date**	**Report Status**
Draft	29 September 2014	For external comment
Final	30 September 2014	Final

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ACKNOWLEDGEMENTS

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ABBREVIATIONS AND ACRONYMS

AI	Alien Invasive
amsl	Above mean sea level
AMD	Acid mine drainage
ASPT	Average Score Per Taxon
BM	Benchmark
CPUE	Catch Per Unit Effort
DD	IUCN Conservation Status: Data Deficient
DL	Detection limit
DRIFT	Downstream Response to Imposed Flow Transformation
d/s	Downstream
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
E	Species Evenness Index
EC	Ecological Category
En	IUCN Conservation Status: Endangered
EIS	Ecological Importance and Sensitivity
EWR	Environmental Water Requirement
FCS	Fast coarse sediment
FD	Fast deep
FEOW	Freshwater Ecoregions of the World
FCS	Fast coarse sediment
FD	Fast deep
FFS	Fast fine sediment
FI	Fast intermediate
FL	Fork Length
FRAI	Fish Response Assessment Index
FROC	Frequency of Occurrence
FS	Fast shallow
FVS	Fast very shallow
GPS	Global Positioning System
H’	Shannon-Weiner Diversity Index
HABFLO	Habitat-Flow Simulation Model
HEC-RAS	United States Army Corps of Engineers’ open channel hydraulics modelling program: Hydrologic Engineering Centre – River Analysis System
HSC	Habitat Suitability Criteria
IBT	Inter-basin transfer

LC	IUCN Conservation Status: Lease Concern
MoR	Mark on rock
MVEG	Marginal vegetation
NA	IUCN Conservation Status: Not Assessed
Na	Sodium
NCMP	National Chemical Monitoring Programme
NEMP	National Eutrophication Monitoring Programme
NH4	Ammonium
NMMP	National Microbiological Monitoring Programme
NO3+NO2	Nitrate plus nitrite
NT	IUCN Conservation Status: Near Threatened
PAI	Physico-chemical Driver Assessment Index
PD	Present day
PES	Present Ecological Status
PBMT	Potential Bed Material Transport
Peg	Iron peg
PMC	Project Management Committee
PO4	Phosphate
Q	Discharge
Q-C	Flow-Concentration (relationship/curve)
RC	Reference Condition
REC	Recommended Ecological Category
RHP	River Health Programme
S	Species Richness
SAIAB	South African Institute for Aquatic Biodiversity
SCS	Slow coarse sediment
SD	Slow deep
SFS	Slow fine sediment
SO4	Sulphate
SRP	Soluble Reactive Phosphorus
SS	Slow shallow
SVS	Slow very shallow
TIN	Total inorganic nitrogen
TOR	Terms of Reference
TPC	Threshold of Probable Concern
TFHR	Transparent Velocity Head Rod
TL	Total Length
u/s	Upstream
VFCS	Very fast coarse sediment
VFFS	Very fast fine sediment
VSCS	Very slow coarse sediment

VSFS	Very slow fine sediment
WMA	Water Management Area
WWF	World Wildlife Fund
WMS	Water Management System
WQ	Water quality
WQSU	Water quality sub-unit
WWTW	Waste Water Treatment Works
y	Depth of water above channel bottom

GLOSSARY OF TERMS

Acid/Alkaline Mine Drainage	Acid Mine Drainage is acidic water (pH <5.0), laden with iron, sulphate and other metals, that forms under natural conditions when geological strata containing pyrite are exposed to the atmosphere or oxidizing environments. AMD can form from coal mining, both in surface and in underground mines. Alkaline mine drainage is water that has a pH of 6.0 or above, contains alkalinity, but may still have dissolved metals that can create acid by oxidation and hydrolysis. http://www.aciddrainage.com/.
Aestivation	Ability to hibernate or remain dominant during unfavourable environmental conditions
Amphidromous	Fish are born in freshwater/estuaries, then drift into the ocean as larvae before migrating back into freshwater to grow into adults and spawn
Anthropogenic	Of human creation
Benchmark	Fixed marked point, either a peg or a mark on a solid surface which will not move, used to set up a coordinate system for a site and which allows repeat surveys on the same coordinate system every time.
Bioregion	A complex of ecoregions that share a similar biogeographic history and whose species have taxonomic affinities at higher levels
Biota	Living things, e.g., plants, animals, bacteria
Boundary/benchmark values	Numerical or descriptive cues or trigger values that indicate a change in environmental condition (Jooste and Rossouw 2002, Palmer *et al*. 2005) and therefore represent values of physical variables and chemical concentrations that should not be exceeded in aquatic resource in order to maintain the present environmental condition
Catadromous	Fish are born in saltwater, then migrate into freshwater as juveniles where they grow into adults before migrating back into the ocean to spawn.
Discharge	A volumetric flow rate of water, usually measured in m^3/s.
EcoClassification	A procedure to determine and categorise the Present Ecological State (PES) of various biological and physical attributes compared to the Reference State/condition (RC). The procedure of EcoClassification describes the health of a water resource and derives and formulates management targets / objectives / specifications for the resource. The classification ranges from A

	(natural) to F (highly impacted). (Rountree and Malan 2011).
Ecohydraulics	The study and prediction of hydraulics specifically for ecological applications
Ecoregion	An area of land or water with a distinct assemblage of species or communities, sharing taxonomic affinities and environmental conditions and which serve as a conservation unit. Nested within a biogregion
EcoStatus:	The overall PES or current state of the resource. It represents the totality of the features and characteristics of a river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services. The EcoStatus value is an integrated ecological state made up of a combination of various PES findings from component Ecostatus assessments (such as for invertebrates, fish, riparian vegetation, geomorphology, hydrology and water quality; Rountree and Malan 2011).
Eupotamon	Main channel
Euryhaline	Ability to adapt to a wide range of salinities
Eurytopic	Generalist species occupying a wide range of habitats
Facultative	Optional or discretionary use of an environmental resource or life history strategy by a species
Generalist	Species with a tolerance for wide spectrum of environmental conditions
Limnophilic	No requirement for flowing water, selects standing water
Lithophilic	Affinity for rock substrata
Manning's n	A coefficient used in Manning's equation to describe resistance to flow due to boulders, vegetation and other physical obstacles to flow.
Obligate	Compelled use of an environmental resource or life history strategy by a species
Paleopotamon	Permanently disconnected from main channel
Parapotamon	Backwaters and slack waters connected to the main channel
Phosphate (PO4)	a salt or compound that has phosphorus in it. Essentially equivalent in the sense used in this report to SRP (Soluble Reactive Phosphorus) and to ortho-phosphate. (Malan and Day 2005). Expressed as milligrams of phosphorus (P) per litre.
Photoperiod	Day length during the year
Phytophilic	Affinity for plant substrata
Plesiopotamon	Pools seasonally connected to the main channel
Rating curve	A function that relates discharge to stage at a cross-section.

Potamonic	Lower reaches of rivers, low gradient, slower velocities, deeper
Reference Condition	An unimpacted, or natural, state.
Rheophilic	Requirement for flowing water for all stages of the life history
Rhithronic	Upper reaches of rivers, fast flowing, turbulent, rheophilic main channel residents, longitudinal pool-riffle-pool sequence
Semi-rheophilic	Requirement for flowing water for some stages of the life history
Stage	Depth of water above a fixed datum.
Strandline	A debris line of dead vegetation left on the river bank at approximately the maximum water level during a flood
Total Inorganic Nitrogen	The combined dissolved concentration of nitrate, nitrite, ammonia and ammonium expressed as milligrams of nitrogen (N) per litre. (Malan and Day 2005).
Water Quality Sub-unit	A length of river exhibiting homogenous water quality. Derived from an examination of existing water quality data, land-use, topography and Ecoregion.

1 INTRODUCTION

1.1 Background to the study

The Chief Directorate: Resource Directed Measures issued an open tender invitation for the "Appointment of a Professional Service Provider to undertake Reserve Determinations for selected Surface water, Groundwater, Estuaries and Wetlands in the Usutu to Mhlatuze Basins". The focus on this area was a result of the high conservation status and importance of various water resources in the basin and the significant development pressures in the area affecting the availability of water.

Preliminary Reserve determinations are required to assist the DWS (previously DWA) in making informed decisions regarding the authorisations of future water use and the magnitude of the impacts of the proposed developments on the water resources in the WMA, and to provide the input data for Classification of the area's water resources, and eventual gazetting of the Reserve (DWA 1998).

On 19th November 2012, DWS appointed Tlou Consulting to undertake the project.

1.1.1 Study objectives

The objectives of the study are to:

- determine the Ecological Reserve (DWAF 1998), at various levels of detail, for the Nyoni, Matigulu, Mlalazi, Mhlatuze, Mfolozi, Nyalazi, Hluhluwe, Mzinene, Mkuze, Assegaai and Pongola Rivers;
- determine the Ecological Reserve, at an Intermediate level for the Pongola floodplain;
- determine the Ecological Reserve, at an Intermediate level for the St Lucia/Mfolozi, Estuary System;
- determine the Ecological Reserve, at an Rapid level for the Mlalazi Estuary;
- determine the Ecological Reserve, at a Rapid level for the Amatikulu Estuary;
- determine the Ecological Reserve, at an Intermediate level for Lake Sibaya;
- determine the Ecological Reserve, at a Rapid level for Kozi Lake and Estuary;
- classify the causal links between water supply and condition of key wetlands
- incorporate existing EWR assessments on the Mhlatuze (river and estuary) and Nhlabane (lake and estuary) into study outputs;
- determine the groundwater contribution to the Ecological Reserve, with particular reference to the wetlands;
- determine the Basic Human Needs Reserve for the Usutu/Mhlatuze WMA;
- outline the socio-economic water use in the Usutu/Mhlatuze WMA;

- build the capacity of team members and stakeholders with respect to EWR determinations and the ecological Reserve.

1.2 This report

This report is Volume 3 of four volumes of the River Intermediate EWR Report:
Volume 1: EcoClassification
Volume 2: EWR Assessment – Results
Volume 3: Specialist reports
Volume 4: EcoSpecs and Monitoring Programme.

This report provides the individual specialist reports required for an Intermediate Reserve determination as prescribed by the CD: RDM of DWS (DWAF 1999; DWAF 2002; Kleynhans *et al.* 2005; Kleynhans and Louw 2007).

1.3 Study area

The extent of the study area is shown in (

Figure 1-1). It comprises the following catchment areas, and main rivers (rivers in bold denote locations of Intermediate EWR determinations):

- Mhlatuze (W1), including:
    - Mhlatuze River;
    - **Matigulu River;**
    - Mfule River;
    - **Nseleni River;**
    - Mlalazi River.
- Mfolozi (W2), including:
    - Mfolozi River;
    - **White Mfolozi River;**
    - **Black Mfolozi River;**
    - Mvunyane River;
    - Nondweni River;
    - Hlonyane River;
    - SikweBezi River;
    - Mona River;
    - Msunduzi River.
- Mkuze (W3), including:
    - **Mkuze River;**
    - Nkongolwana River;
    - Msunduzi River;
    - Mzinene River;

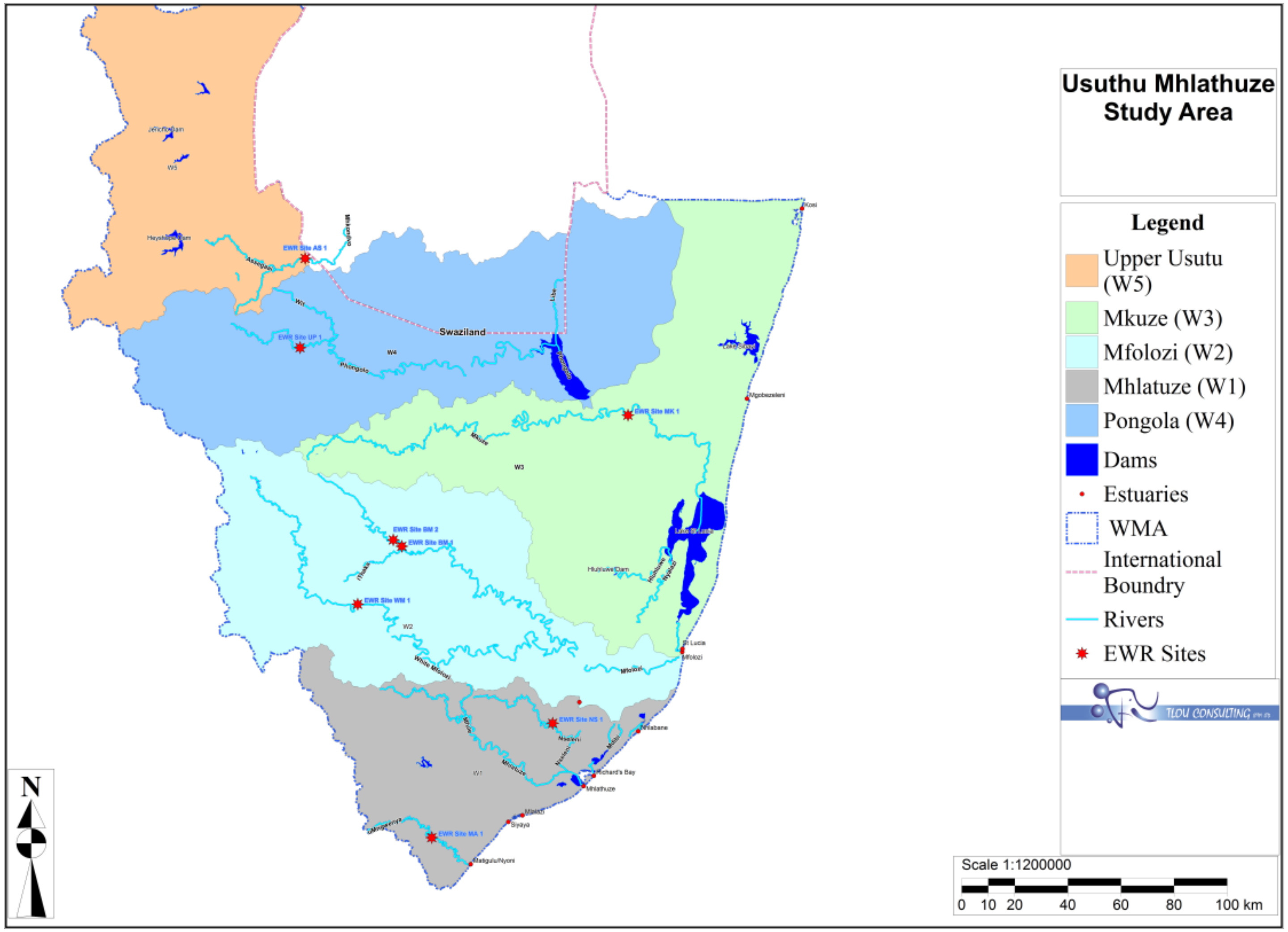

Figure 1-1 Map of the study area

  - Nzimane River;
  - Hluhluwe River;
  - Nylalazi River.
- Pongola (W4), including:
  - **Pongola River;**
  - Bivane River;
  - Manzana River;
  - Mozana River;
  - Ngwavuma River.
- Upper Usutu (W5), including:
  - **Assegaai River;**
  - Ohlelo River;
  - Ngwempisi River;
  - Usuthu River;
  - Bonnie Brook River.
- Lake Sibaya / Kosi (W7).

1.3.1 EWR sites

The NWRCS node delineation process identified 49 river nodes for which EWR data will be required for Classification. In accordance with the Terms of Reference for the study, these data will be informed by intermediate assessments at eight sites that will be used to extrapolate results across the remainder of the area.

The locations of the eight EWR sites for which Intermediate assessments have been done are provided in Table 1-1.

1.4 Specialist team

The specialist team responsible for the contents of this report are listed in Table 1-2.

Table 1-1 Locations of the eight EWR sites in the Intermediate EWR assessment

Quaternary	River name	Site Name	Location description	Latitude	Longitude
W51D	Assegaai	EWR Site AS1	Downstream of Heyshope Dam, near the Swaziland border.	27º3’44.28”S	30º59’19.68”E
W42E	Upper Pongola	EWR Site UP1	Near Frischgewaagd and Bilayoni Townships	27º21’50.88”S	30º58’10.62”E
W31J	Mkuze	EWR Site MK1	Adjacent to Mkuze National Park, almost opposite Mantuma Camp	27º35’31.56”S	32º13’4.80”E
W22C	Black Mfolozi	EWR Site BM1	Downstream of W2H028.	27º56’20.04”S	31º12’37.08”E
W22C	Black Mfolozi	EWR Site BM2	Near Basonhoek	28º0’50.04”S	31º19’27.48”E
W21H	White Mfolozi	EWR Site WM1		28º13’53.24”S	31º11’17.97”E
W12H	Nseleni	EWR Site NS1		28º38’2.76”S	31º55’51.24”E
W11B	Matigulu	EWR Site MA1	Downstream of old DWA gauging station.	29º1’12.36”S	31º28’13.44”E

Table 1-2 Specialist team responsible for the contents of this report

Person	Organisation	Discipline
Mr M Kleynhans	Aurecon	Hydraulics
Dr H Malan	Independent	Water Quality
Mr M Rountree	Fluvius Environmental Consultants	Geomorphology
Mr J MacKenzie	MacKenzie Ecological and Development Services CC	Riparian vegetation
Ms C Todd	Independent	Macroinvertebrates
Dr B Paxton	Independent	Fish

2 ECOHYDRAULICS: SPECIALIST REPORT

2.1 Introduction

2.1.1 Objectives of the ecohydraulics study

For the ecohydraulics component of the EWR assessment, 34 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 hydraulic variables (lookup tables) and report writing.

This report follows the ToR provided by Tlou Consulting *viz.*:

- Familiarise yourself to the extent possible with the study area, including:
    - The character of the rivers in the study area.
    - The character of the reaches encompassing the proposed sites.
- Organize the procurement of the necessary equipment required for the field work.
- Provide hydraulic relationships at eight EWR sites.
- Attend the data collection field visits (two trips one in wet and one in dry season) with the rest of the team to:
    - survey the stages and water surface slopes at each site in highflow conditions,
    - choose cross-sections, if possible, that describe rare and flow-sensitive habitats, as well as ones that facilitate accurate hydraulic modelling. Liaise with fish, vegetation and invertebrate specialists before making the final choice
    - survey cross-sectional profile/s at the EF sites during a low-flow condition (including the survey of geomorphological and ecologically-relevant points of interest);
    - record discharge at each site;
- Liaise and plan beforehand your techniques, *modus operandi* and equipment requirements. You will be responsible for providing all the equipment you require.
- Take responsibility for the adequacy of the data collected for modelling purposes.
- Collate and store data for use in the EWR assessment;
- Provide copies of data, as and when it becomes available, to Tlou Consulting for archiving;
- Develop, for each surveyed cross-section at the EWR sites, information on the relationships between discharge and
    - stage; maximum depth; average depth; wetted-width; wetted-perimeter and average velocity;
    - and other relevant data as experience suggests;
- Provide look-up tables in format required for input to the DRIFT-DSS.
- Provide integrated velocity/depth information for fish habitat in format required for input to the DRIFT-DSS.

- Attend PMC meetings if and as required (additional time will be made available).
- Assist with capacity building of an allocated DWA staff member, if and when required.
- Provide data files for use in the DRIFT DSS, and assess the accuracy of modelled results;

2.1.2 Layout of this Section

This Section comprises the report for ecohydraulics, and describes the methodology employed for data collection and ecohydraulic modelling and the outputs that were supplied to the other specialists. Tables describing the survey benchmark positions, the hydraulic data collected, cross-sections at each site, photographs, the adopted rating curves, hydraulic modelling outputs and estimates of the certainty of the modelling outputs are given.

2.2 Methodology

2.2.1 Data collection

Prior to the field trips the preselected sites were investigated using satellite photographs, and the locations and availability of data at nearby flow gauging stations were noted.

Sites should preferably have the following characteristics (in descending order of importance) to maximise the confidence in the outputs (James and King 2010):

- Contain suitable habitat for the biota of interest
- Have horizontal cross-channel stages at all discharges
- Similar average velocities in cross-river channels
- Be located on a reach with constant gradient and channel cross-section shape that results in an approximately uniform flow profile for all discharges
- Have no major hydraulic control downstream other than the local channel resistance unless this can be modelled easily and accurately
- Consist of a single channel for all discharges of interest
- Low and uniform flow resistance

In most EWR studies in South Africa, one or more cross-sections are surveyed at each site through geomorphic units of interest (a riffle, pool or run) relative to local benchmarks. The cross-section, water surface slope and macro channel slope are surveyed. A discharge is measured which corresponds to the water level measured on the cross-section. Various random spot velocities may also be collected in the geomorphic unit and across the cross-section. On repeat site visits water levels on the cross-sections, water surface slopes, the discharges and velocities are collected. These data are then used to determine a rating curve for each cross-section. The accuracy of the rating curve depends on the number of observed stage and discharge measurements and also on the hydraulic suitability of the site to model high flows, which generally are not possible to measure.

In this study two stage and discharge pairs were measured at all the sites except at BM 1 where three pairs were measured and at BM2 where one pair was measured.

For measurement of discharge, the velocity-area measurement method was used, based on the velocity at 60% of the depth when no nearby gauge data was available, and where good gauge data were available nearby then the gauge data were used.

The survey was undertaken using a total station and all points were recorded onboard together with notes, and downloaded later. The survey data were converted to coordinates and processed to determine the cross-sections that were surveyed together with gradients of the river bed and elevations of the water surface and any other points of interest. Many photos were also taken of each site.

2.2.2 Hydraulic modelling at EF sites

A rating curve was fitted to the following data:

- The stage at cessation of flow (which can be surveyed on site and is zero for a riffle, and non-zero for a pool)
- The measured stage and discharge pairs on the site visits
- Any strand lines (if present at the site) together with an associated flood which can be determined by asking local inhabitants and matching with gauged floods at a nearby gauging station (a nearby gauge record is required for the use of strand lines)
- One or two modelled high flows (that were modelled using the survey data and Manning’s equation).

The rating curve is fitted using Equation 1 below (Birkhead and James 1998), which is widely used and accepted in Southern Africa for this purpose and is essentially the standard equation recommended by the World Meteorological Organisation (WMO 2010) for flow gauging stations on river cross-sections, but with stage being the dependent variable in this case.

$$y = aQ^b + c \tag{1}$$

Where:

- y is the stage above the lowest point on the cross-section (m)
- Q is the discharge (m^3/s)
- a, b, and c are coefficients in the power equation, with c having physical meaning – being the stage at cessation of flow (m)

Sometimes it may be necessary to fit more than one equation to represent the rating curve and this has been done where necessary.

Modelling of a river cross-section in this way can only provide cross-section averaged data, for example only cross-section averaged velocities can be output. However, work has been done to overcome this issue with one-dimensional models and various empirical models have been derived to estimate the distributions of velocities in a cross-section based on a surveyed cross-section, a rating curve for the cross-section and a few other inputs. The program HABFLO has been developed based on two of these empirical models for riffles and has been shown to model the distributions of velocities and depths accurately (Hirschowitz et al. 2007). Once the distributions of depths and velocities have been estimated, HABFLO is then able to model the occurrence of any pre-defined velocity-depth classes for fish and velocity-substrate classes for invertebrates in a riffle.

The hydraulic habitat predictions for fish and invertebrates were used in this study and are based on certain combinations of depth and velocity (for fish) and velocity and substrate (for invertebrates). The habitat definitions are shown in the Figure 2-1.

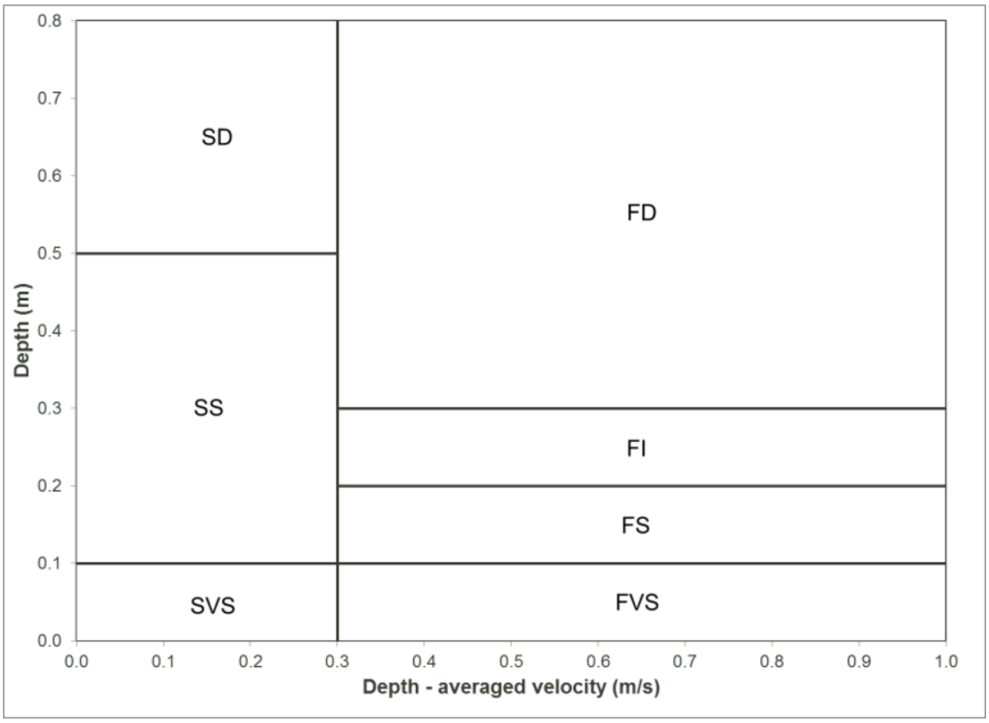

Figure 2-1 Habitat classes for fish used in this study

The fish habitats used in this study are as follows:

SVS	Slow / very shallow
SS	Slow / shallow
SD	Slow / deep

FVS	Fast / very shallow
FS	Fast / shallow
FI	Fast / intermediate
FD	Fast / deep

The invertebrate habitats used in this study are as follows:

VSFS	Very Slow Fine Sediment
VSCS	Very Slow Coarse Sediment
SFS	Slow Fine Sediment
SCS	Slow Coarse Sediment
FFS	Fast Fine Sediment
FCS	Fast Coarse Sediment
VFFS	Very Fast Fine Sediment
VFCS	Very Fast Coarse Sediment
MVEG	Marginal Vegetation

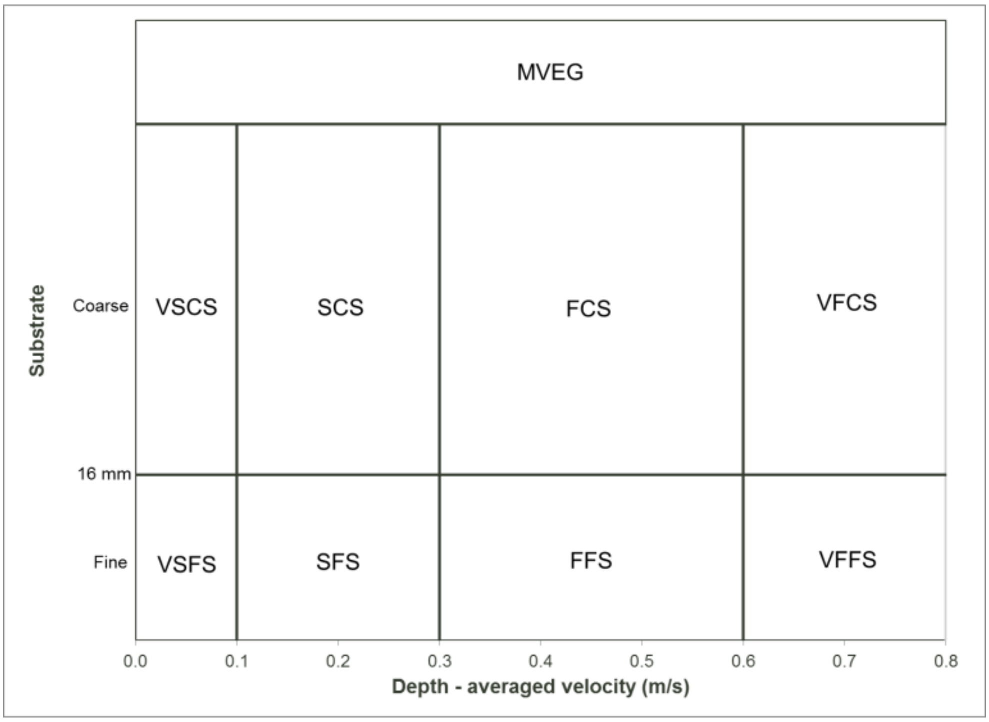

Figure 2-2 Habitat classes used for invertebrates in this study.

HABFLO is based on work that was done in France in riffle habitats, while some of the cross-sections in this study were in sand bed rivers (Mkuze Site MK1) or rivers dominated by bedrock (Black Mfolozi Site BM1). The predictions of velocity and habitat distributions are broad estimates only at these sites and should be treated with judgement.

The accuracy of the predictions can to some extent be validated by comparing the distributions of depth and velocity to those that were observed. An indication of the accuracy of the predictions can then be gained at least at the discharge at which the observations took place.

2.3 Data collection and modelling

2.3.1 Surveys at existing EWR sites

Two of the sites in this study have been surveyed before, these are AS1 (Birkhead 2008) and NS1 (Birkhead 2002).

AS1 was the only site where an existing cross-section (Birkhead 2008) was resurveyed and additional hydraulic data collected. At AS1, benchmarks 2.1 and 2.3 could not be found during the site visits. Benchmark 2.1 was an iron peg placed during the original Joint Maputo River Basin Study EWR determination (Birkhead 2008) and was probably buried by sediment. Benchmark 2.3 was a painted mark on a rock and could not be found. Benchmark 2.2 was located however and the original line of the cross-section was estimated based on photographs and survey data provided by Birkhead (pers. comm.). It appears that the resurveyed cross-section from December 2013 was very close to the line of the original cross-section, see Figure 2-3.

NS1 is also an existing rapid EWR site, originally called Nseleni Site 6 (Birkhead 2002). The benchmarks could not be found for the original cross-section, although the approximate position of the cross-section was determined based on the cross-section profile published in the report. It appears that the original cross-section crosses through an active channel with what appears to be a small riffle along the left bank, while it also crosses over a 2 m high and densely vegetated island and through a pool which appears to be controlled from downstream at low flows, on the right bank. The area around the cross-section was densely vegetated and survey would have been very difficult. It was decided to survey a new cross-section through an easily accessible riffle located not far upstream. The reasons for moving the cross-section include:

- The new cross-section contains a larger and better riffle section
- Significantly better access exists at the new cross-section location
- There should be greater confidence in the hydraulics at the new cross-section location due to the prismatic shape of the cross-section and the length and constant cross-sectional shape of the riffle
- The new cross-section location is easier to survey due to less vegetation growth
- The vegetation is slightly better as there is less invasion by Chromolaena, among other things at the new cross-section

- The benchmarks of the original cross-section could not be found and attempts to track down photographs of the benchmarks failed, additionally a search for them on site failed due to a dense infestation of Chromolaena
- Crocodiles occur in this river according to the owner of the adjacent property and the pool on the previous cross-section is dangerous being deep and murky. The new cross-section is far safer being located on a riffle with good visibility.

2.3.2 Survey data

The GPS coordinates of the various site benchmarks are given in Table 2-1.

Table 2-1 GPS coordinates of the various site benchmarks located on cross-sections

River	Site No.	Benchmark	Description	S (decimal degrees)	E (decimal degrees)
Assegai	AS1	2.1	Cross-section A: Riffle (low flows): right bank	27.06155	30.98834
		2.10	Cross-section B: Pool (high flows): right bank	27.06229	30.98838
Pongola	UP1	6.1	Cross-section: right bank	27.36401	30.96945
Mkuze	MK1	1	Cross-section: right bank	27.59228	32.21863
Black Mfolozi	BM1	1.1	Cross-section: right bank	27.93981	31.21142
Black Mfolozi	BM2	1.1	Cross-section A: Riffle (low flows) : left bank	28.01432	31.32372
		2.1	Cross-section B: Bedrock (high flows): left bank	28.01402	31.32412
White Mfolozi	WM1	1	Cross-section: right bank	28.23240	31.18724
Nseleni	NS1	1	Cross-section: right bank	28.63395	31.93100
Matigulu	MA1	1	Cross-section: left bank	29.02006	31.47033

The relationships between the various benchmarks placed at the sites and the cross-sections are given in Table 2-2, relative to a local datum at each site.

Table 2-2 Benchmarks at the EWR sites

River	Site No.	Benchmark	Hz (decimal degrees) relative to cross-section (0˚)	Distance (m)	Elevation above local datum (m)
Assegai	AS1 – A: Riffle	BM2.6 (Peg)	Setup	Setup	100.00
		BM2.2 (MoR)	261.83	10.76	100.09
		BM2.4 (MoR)	20.00	4.87	99.18
		BM2.5 (MoR)	213.10	4.18	100.53
	AS1 – B: Pool	BM2.10 (MoR)	Setup	Setup	100.00
		BM2.11 (MoR)	0.00	52.70	98.32
		BM 2.12 (MoR)	296.71	10.28	99.77
Pongola	UP1	BM6.1 (Peg)	Setup	Setup	100.00
		BM6.2 (MoR)	0.00	29.62	97.46
		BM6.3 (MoR)	36.53	41.27	99.02
		BM6.4 (MoR)	48.64	9.35	99.30
		BM6.5 (MoR)	265.10	25.07	100.99
Mkuze	MK1	BM1 (Peg)	Setup	Setup	100.00
		BM2 (Peg)	95.36	6.28	99.82
		BM3 (Peg)	202.81	14.02	99.73
Black Mfolozi	BM1	BM1.1 (Peg)	Setup	Setup	100.00
		BM1.2 (Peg)	180.00	8.77	102.12
		BM1.3 (MoR)	105.67	17.49	100.65
		BM1.4 (MoR)	251.82	16.56	100.88
		BM1.5 (MoR)	10.97	28.61	100.92

River	Site No.	Benchmark	Hz (decimal degrees) relative to cross-section (0˚)	Distance (m)	Elevation above local datum (m)
		BM1.6 (MoR)	349.77	31.90	102.23
		BM1.7 (MoR)	357.91	32.55	102.16
Black Mfolozi	BM2 – A: Riffle for low flows	BM1.2 (MoR)	Setup	Setup	100.00
		BM1.1 (MoR)	0.00	21.08	99.28
		BM1.3 (MoR)	321.22	24.04	99.99
		BM2.2 (MoR)	302.22	59.22	101.87
		BM2.1 (MoR)	315.76	59.22	100.58
		BM2.3 (MoR)	310.05	78.07	101.16
	BM2 – B: Bedrock for high flows	BM2.1 (MoR)	Setup	Setup	100.58
		BM2.2 (MoR)	180.00	14.01	101.87
		BM2.3 (MoR)	253.78	20.11	101.16
		BM1.1 (MoR)	78.33	46.53	99.28
		BM1.2 (MoR)	96.71	59.23	100.00
		BM1.3 (MoR)	93.06	35.36	99.99
White Mfolozi	WM1	BM1 (MoR)	Setup	Setup	100.00
		BM2 (MoR)	134.11	6.97	101.96
		BM3 (MoR)	100.90	19.98	100.47
		BM4 (MoR)	258.07	16.96	101.64
		BM5 (MoR)	290.54	71.37	100.19
Nseleni	NS1	BM1 (Peg)	Setup	Setup	100.00
		BM2 (Peg)	0.00	17.13	101.86

River	Site No.	Benchmark	Hz (decimal degrees) relative to cross-section (0˚)	Distance (m)	Elevation above local datum (m)
		BM3 (Peg)	267.85	7.42	100.70
Matigulu	MA1	BM1 (Peg)	Setup	Setup	100.00
		BM2 (MoR)	338.73	17.85	96.06
		BM3 (MoR)	321.78	26.46	95.38

Peg = Iron peg, placed in concrete
MoR = Mark on rock, usually a painted benchmark on a large stable rock.

The cross-section at AS1 was resurveyed based on best estimates of its position using photographs and BM 2.2 which was relocated. The cross-section comparison (Figure 2-3) shows that the two surveys resulted in very similar cross-sectional shapes, based on the same datum, using the level of BM 2.2, indicating that the cross-section surveyed in this study is probably very close to the original one surveyed in 2006 by Birkhead (2008).

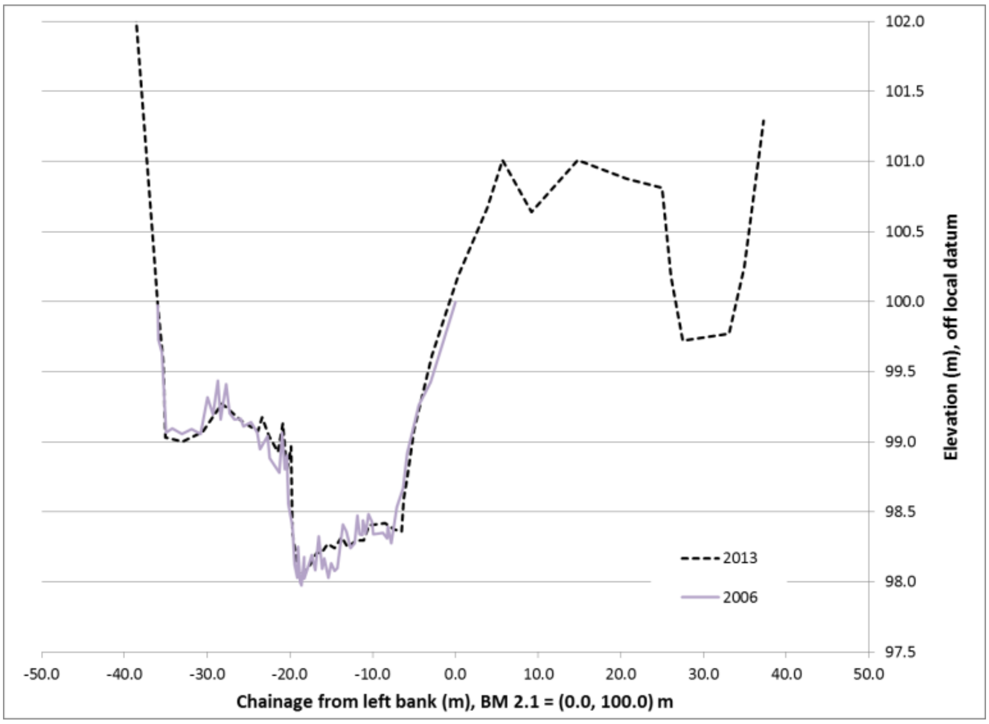

Figure 2-3 Comparison of surveys from 2006 (Birkhead 2008) and this study (2013)

2.3.3 Discharge and stage measurements

Modelled and measured stages, discharges and slopes for derivation of rating curves for each cross-section are given in Table 2-3. These include stage-discharge pairs from Birkhead (2008) for AS1 and where they were available, strandline stages and gauged floods.

Table 2-3 Measured and modelled stages, discharges and energy slopes. Modelled points are in *italics*.

River	Site No.	Date	Max depth (m)	Stage (mald)	Mannings resistance, n	Energy slope, S	Discharge, Q (m3/s)	Average velocity (m/s)	Comment
Assegai	AS1 – A: Riffle	10 July 2014	0.48	98.54	0.086	0.00668	1.303	0.377	Observed
		09 August 2006	0.49	98.55	0.078	0.00620	1.450	0.409	Observed - JMRBS
		26 November 2013	0.54	98.60	0.069	0.00606	2.201	0.514	Observed
		08 September 2007	0.58	98.64	0.090	0.00620	2.060	0.429	Observed - JMRBS
		01 December 2006	0.64	98.70	0.070	0.00620	3.410	0.605	Observed - JMRBS
		15 November 2013	4.43	102.48	0.102	0.00476	259.939	1.245	Strand line and flood peak at gauge
	AS1 – B: Pool	10 July 2014	0.91	96.94	0.052	0.00004	1.303	0.096	Observed
		Flood	*2.55*	*98.58*	*0.052*	*0.00156*	*61*	*1.091*	*Modelled*
		15 November 2013	4.19	100.23	0.052	0.00307	259.939	1.858	Strand line and flood peak at gauge
Pongola	UP1	10 July 2014	0.63	96.06	0.087	0.00704	3.410	0.447	Observed
		27 November 2013	0.85	96.27	0.093	0.00636	6.749	0.515	Observed
		Flood	*4.58*	*100.00*	*0.038*	*0.00500*	*843*	*3.627*	*Modelled*
Mkuze	MK1	09 July 2014	0.31	97.06	0.112	0.00169	0.715	0.105	Observed

River	Site No.	Date	Max depth (m)	Stage (mald)	Mannings resistance, n	Energy slope, S	Discharge, Q (m3/s)	Average velocity (m/s)	Comment
		30 November 2013	0.39	97.14	0.099	0.00118	1.360	0.132	Observed
		Flood	*4.70*	*101.46*	*0.070*	*0.00097*	*451*	*0.702*	*Modelled*
Black Mfolozi	BM1	12 July 2014	0.35	99.02	0.087	0.00382	0.258	0.205	Observed
		28 November 2013	0.36	99.03	0.076	0.00363	0.312	0.234	Observed
		29 November 2013	0.61	99.28	0.044	0.00532	2.756	0.681	Observed
		26 December 2013 ? (Strandline)	3.40	102.07	0.159	0.00625	72.854	0.805	Strandline surveyed in July 2014 – has very high Manning resistance
		4 February 2013 ? (Strandline)	4.29	102.96	0.454	0.00625	42.726	0.326	Strandline surveyed in December 2013 – has very high Manning resistance
		Flood	*6.01*	*104.68*	*0.045*	*0.00625*	*918*	*4.162*	*Modelled using roughness that was calculated for a Slope Area site done here after Cyclone Domoina (Kovàcs et al. 1985)*
Black Mfolozi	BM2 – A: Riffle for low flows	12 July 2014	0.26	98.92	0.168	0.03984	0.269	0.335	Observed
		Flood	*1.12*	*99.78*	*0.035*	*0.00089*	*7.2*	*0.643*	*Modelled*
	BM2 –	12 July 2014	0.31	98.61	0.144	0.01613	0.269	0.289	Observed

River	**Site No.**	**Date**	**Max depth (m)**	**Stage (mald)**	**Mannings resistance, n**	**Energy slope, S**	**Discharge, Q (m3/s)**	**Average velocity (m/s)**	**Comment**
	B: Bedrock for high flows	26 December 2013	4.61	102.91	0.317	0.00690	72.854	0.428	Strandline with Dec 2013 flood – very high Manning resistance
		Flood	*6.39*	*104.69*	*0.045*	*0.00690*	*1364*	*4.265*	*Modelled*
White Mfolozi	WM1	12 July 2014	0.54	97.55	0.158	0.00230	0.650	0.109	Observed
		29 November 2013	0.79	97.81	0.077	0.00426	6.438	0.474	Observed
		Flood	*4.52*	*101.53*	*0.035*	*0.00426*	*1328*	*3.962*	*Modelled*
Nseleni	NS1	08 July 2014	0.17	98.50	0.471	0.02869	0.036	0.081	Observed
		01 December 2013	0.22	98.54	0.274	0.02032	0.082	0.121	Observed
		Flood	*4.80*	*103.13*	*0.080*	*0.00233*	*94*	*0.981*	*Modelled*
Matigulu	MA1	07 July 2014	0.42	92.23	0.336	0.00457	0.149	0.071	Observed
		02 December 2013	0.72	92.53	0.183	0.01713	1.781	0.294	Observed
		Flood	*4.45*	*96.26*	*0.050*	*0.00769*	*939*	*3.420*	*Modelled*

JMRBS = Joint Maputo River Basin Study (Birkhead 2008)

2.3.4 EWR Site AS1

Two cross-sections were surveyed at this site because of the low confidence in the hydraulics at high flows on cross-section A. Cross-section A contains a pool on the right bank which acts independently to the main channel at higher flows and this cannot be quantified with only one cross-section. Cross-section B was surveyed for high flows only, for the geomorphology.

Figure 2-4 Approximate locations of the upstream (A) and downstream (B) surveyed cross-sections at EWR Site AS1.

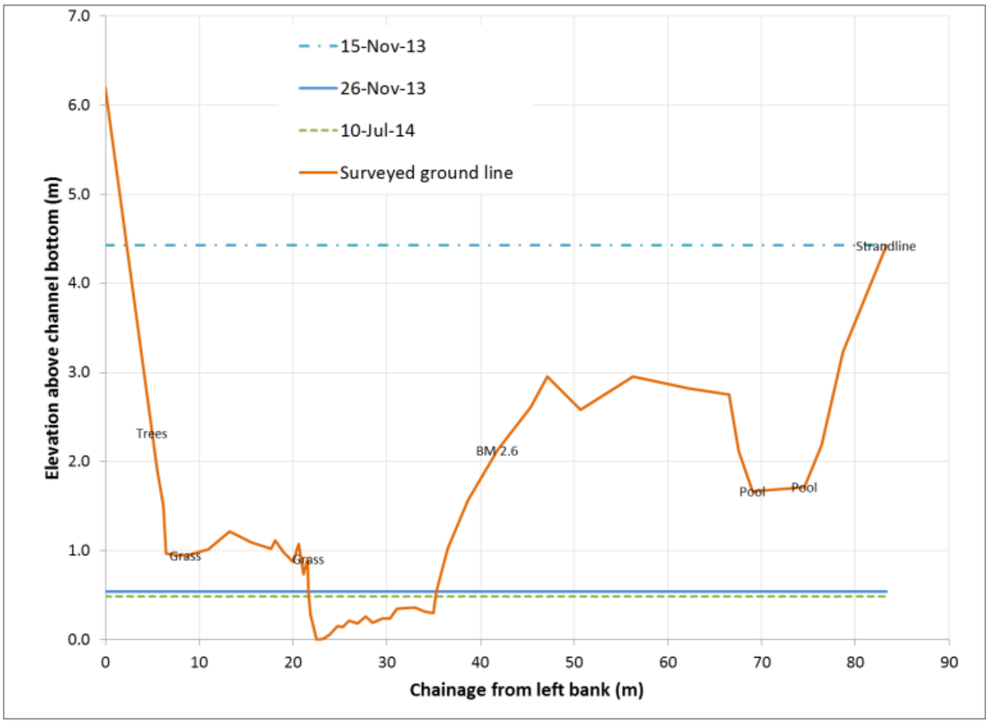

Figure 2-5 Cross-sectional Profile A through the riffle unit at EWR Site AS1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.

Figure 2-6 EWR Site AS1. Photograph of the riffle through which cross-section A was surveyed, taken from the right bank on 26 November 2013 (discharge of *2.20* m^3/s).

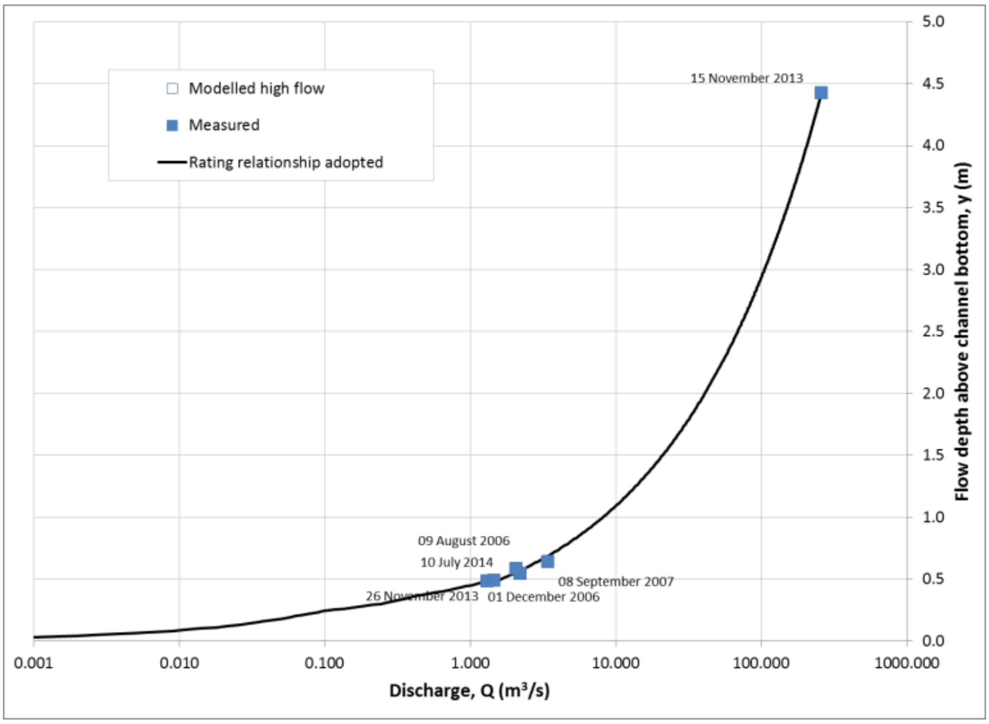

Figure 2-7 **Rating curve for profile AS1 A, riffle**

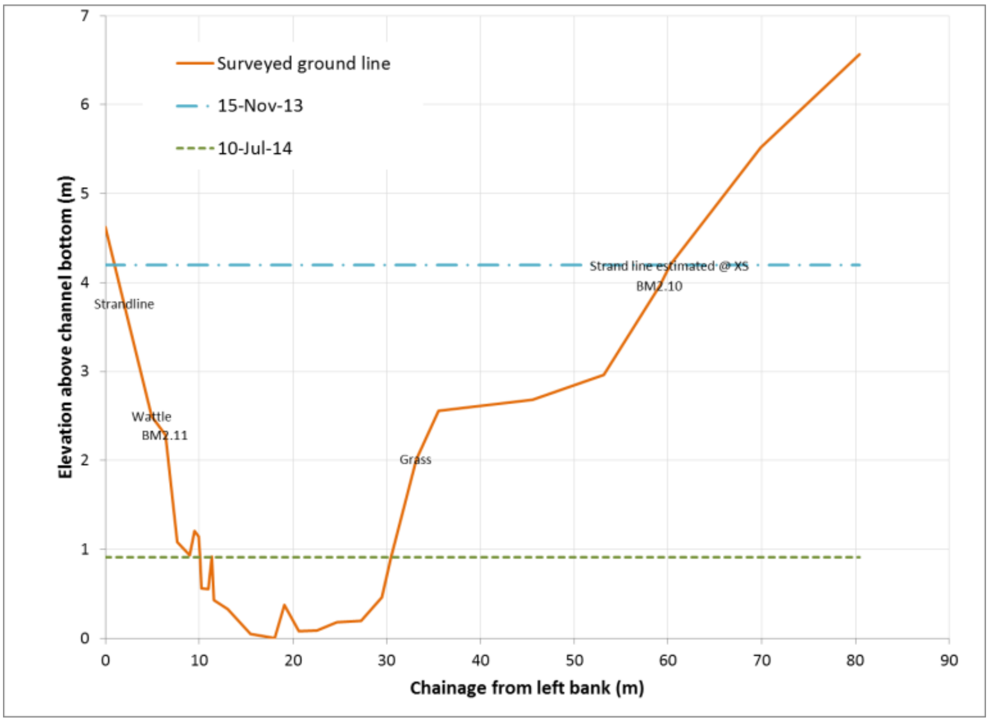

Figure 2-8 **Cross-sectional Profile B through the pool unit at EWR Site AS1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.**

Figure 2-9 **EWR Site AS1. Photograph of the pool through which cross-section B was surveyed, taken from the right bank on 10 July 2014 (discharge of *1.30* m³/s).**

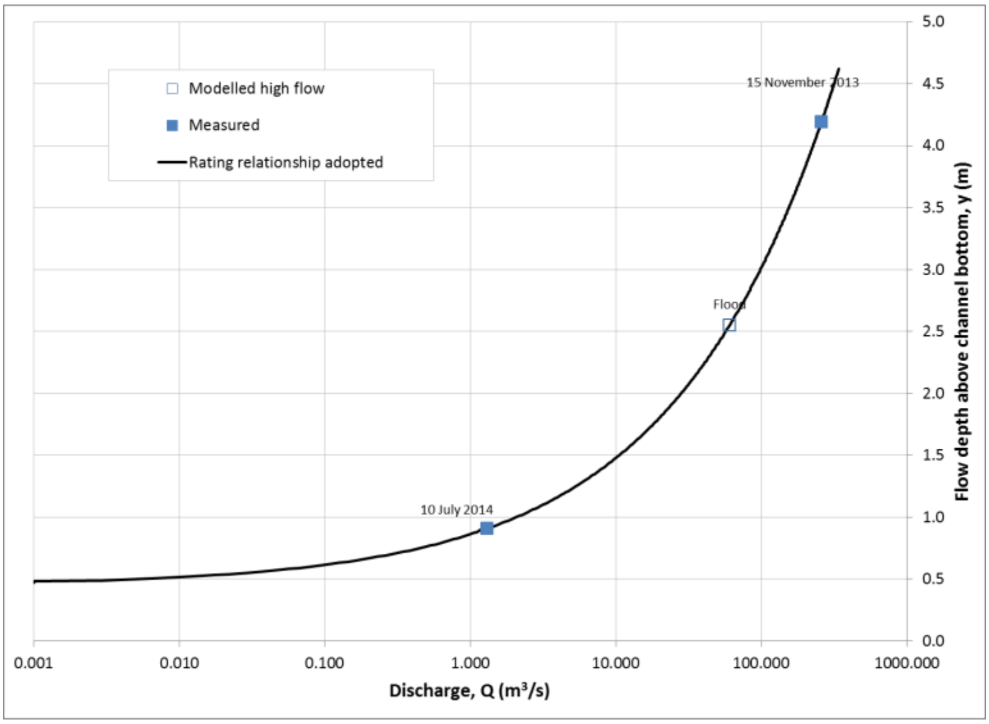

Figure 2-10 **Rating curve for profile AS1 B, pool**

2.3.5 EWR Site UP1

Figure 2-11 Approximate location of the cross-section at EWR Site UP1.

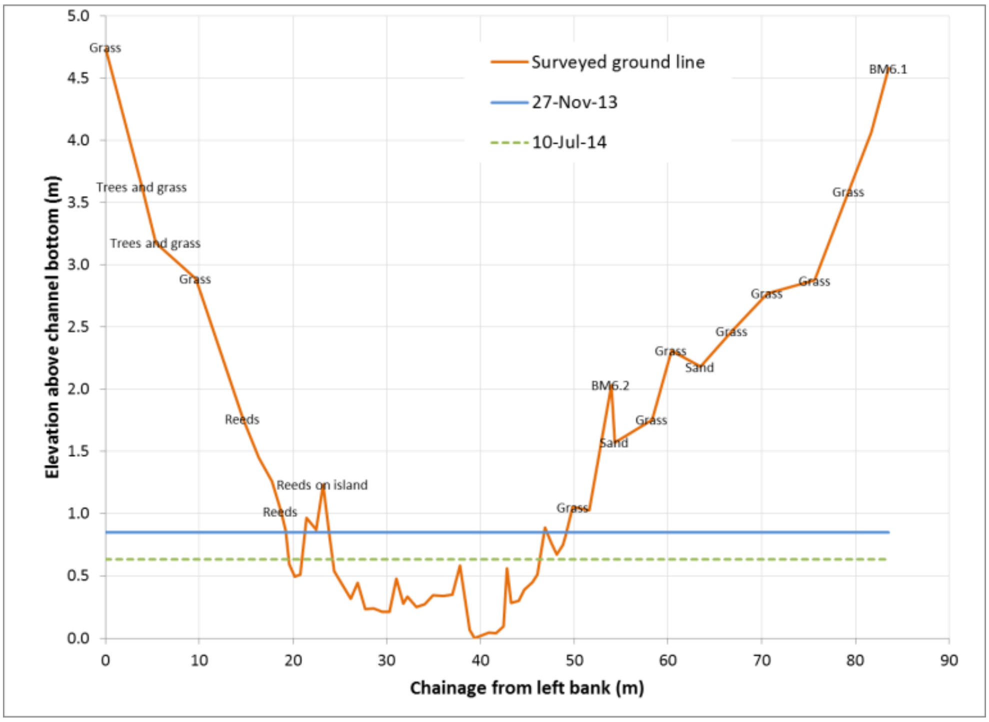

Figure 2-12 Cross-sectional profile through the riffle unit at EWR Site UP1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.

Figure 2-13 EWR Site UP1. Photograph of the riffle through which the cross-section was surveyed, taken from the right bank on 26 November 2013 (discharge of *2.20* m^3/s).

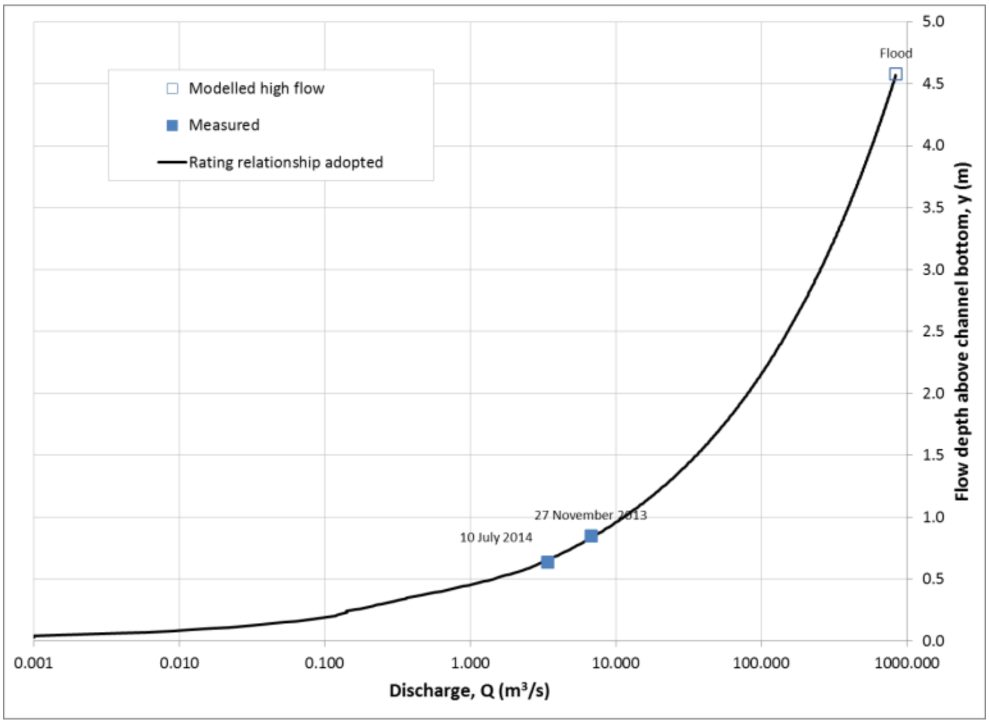

Figure 2-14 Rating curve for profile UP1

2.3.6 EWR Site MK1

Figure 2-15 Approximate location of the cross-section at EWR Site MK1.

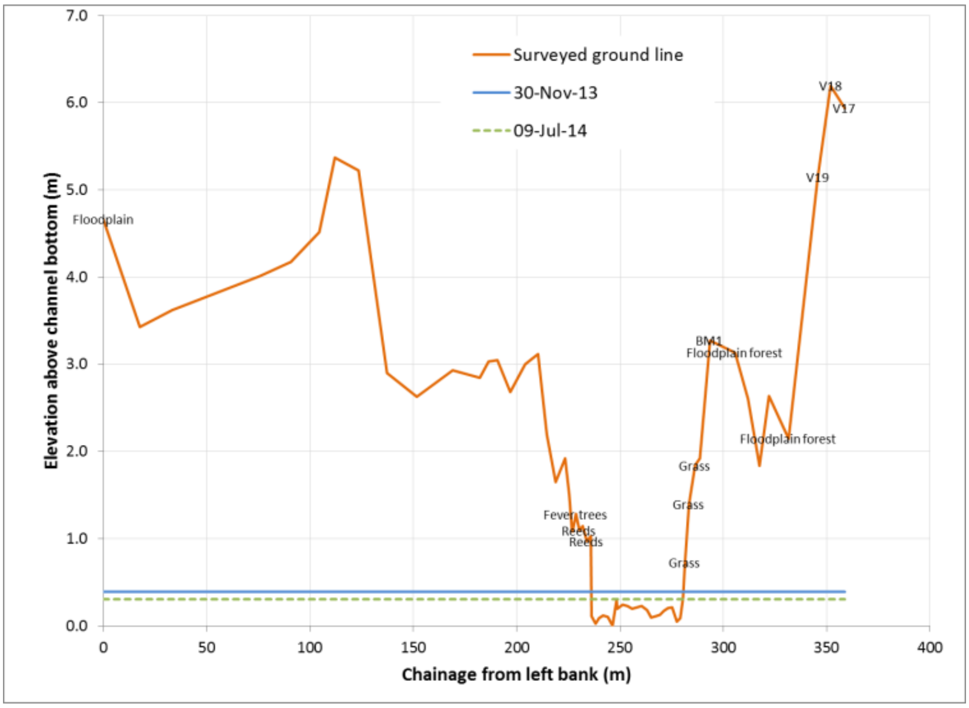

Figure 2-16 **Cross-sectional profile through the sand run unit at EWR Site MK1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.**

Figure 2-17 **EWR Site MK1. Photograph of the sand run through which the cross-section was surveyed, taken from the right bank on 30 November 2013 (discharge of *1.36* m^3/s).**

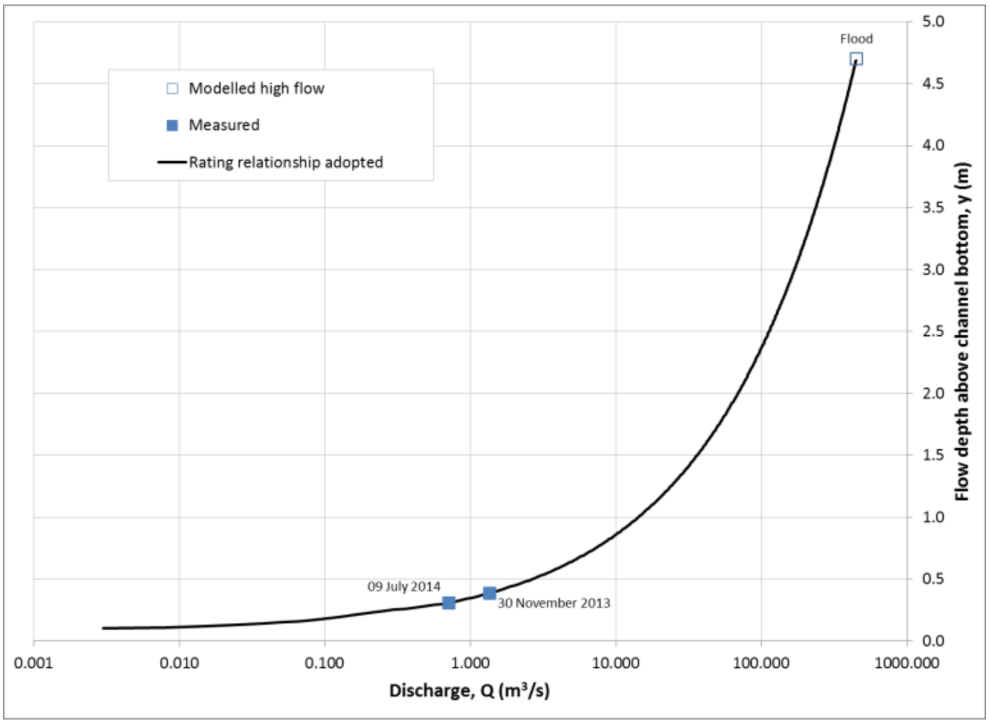

Figure 2-18 Rating curve for profile MK1

2.3.7 EWR Site BM1

The surveyed strandlines at BM1 do not tie in well with any of the recorded floods from the nearby gauging station as the back calculated hydraulics is not plausible. These strandlines were eventually ignored and a modelled high flow point was used based on a resistance value calculated from a Slope-Area survey done over this site after Cyclone Domoina in 1984 (Kovacs *et al.* 1984).

Figure 2-19 **Approximate location of the cross-section at EWR Site BM1.**

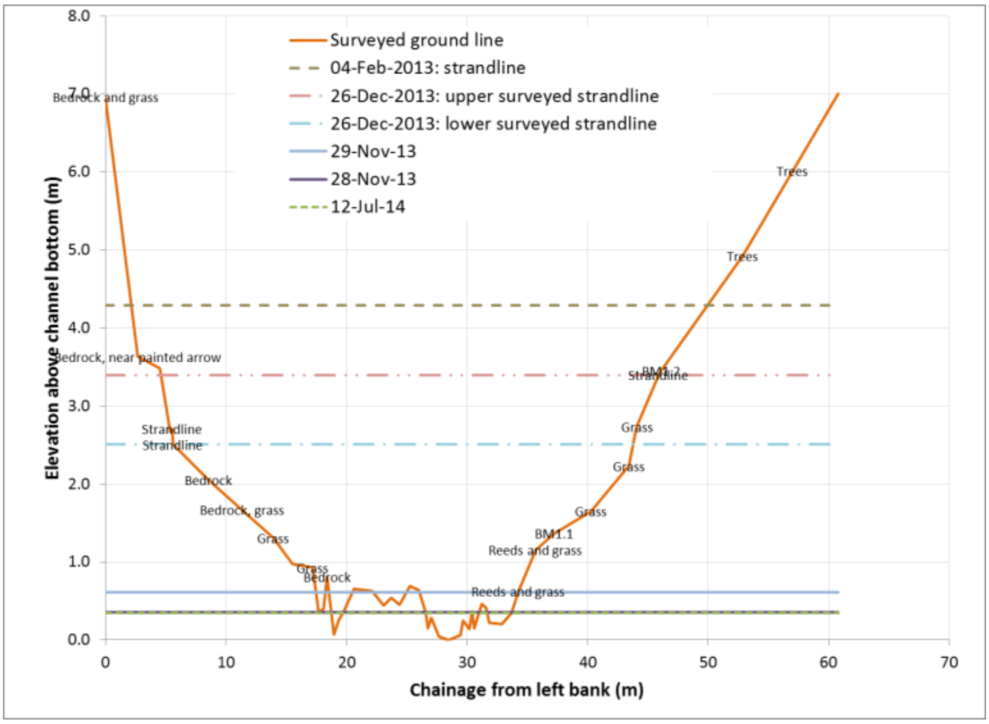

Figure 2-20 **Cross-sectional profile through the riffle unit at EWR Site BM1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates. Note the varying levels of the strandlines with estimated flood dates.**

Figure 2-21 EWR Site BM1. Photograph of the bedrock controlled 'riffle' through which the cross-section was surveyed, taken from the right bank on 28 November 2013 (discharge of *0.31* m^3/s).

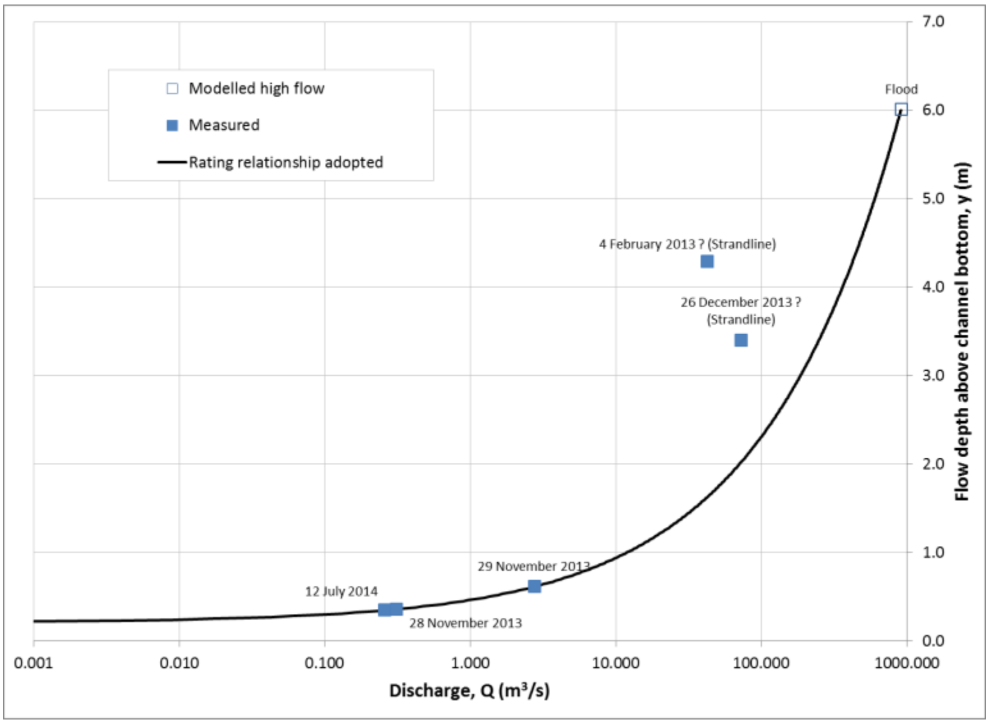

Figure 2-22 Rating curve for profile BM1

2.3.8 EWR Site BM2

Two cross-sections were surveyed at BM2 as the suitable habitat for invertebrates on the riffle at cross-section A was contained on a complex cross-section which could not be accurately modelled at high flows because of a second channel on the left bank and the skew angle of the cross-section at low flows compared to high flows (Figure 2-23). Cross-section B was consequently surveyed for high flows for the geomorphology. Because the constriction in the channel at cross-section B is likely to be the location of a control for cross-section A at medium flows, a model of the site was set up in HEC-RAS using the two surveyed cross-sections and a third synthesised cross-section, in an attempt to improve confidence in the hydraulics at these flows.

The surveyed strandline on cross-section BM2 B did not tie in well with the floods recorded at the gauging station upstream at BM1, as the back calculated hydraulics were not plausible. The strandline was ignored and a high flow point was modelled.

Figure 2-23 Approximate locations of cross-sections A and B at EWR Site BM2.

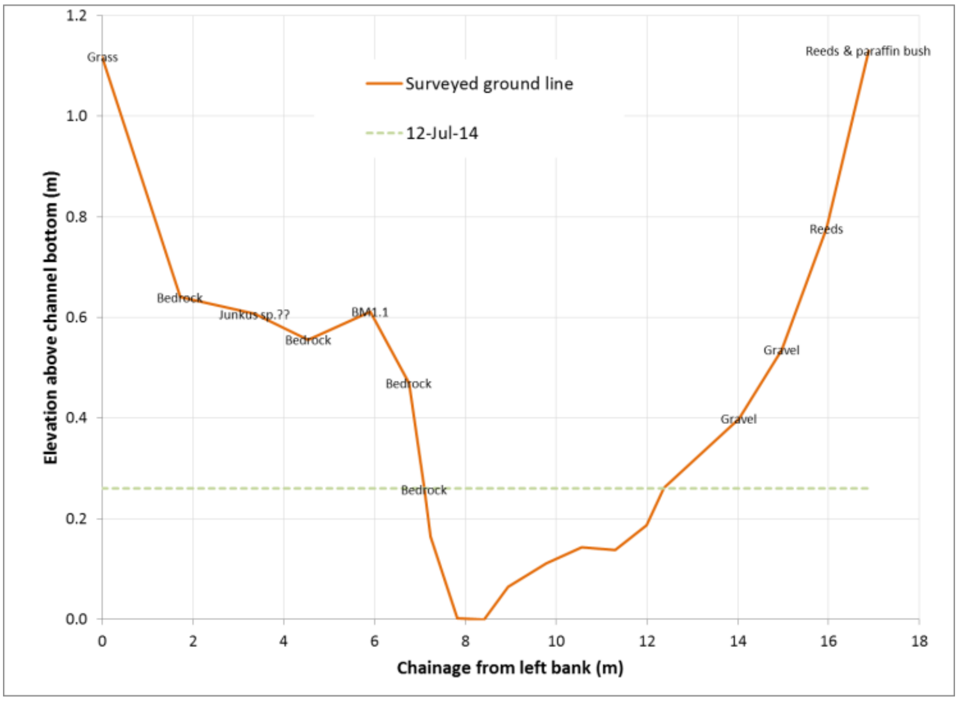

Figure 2-24 **Cross-sectional profile through cross-section A, the riffle unit for low flows, at EWR Site BM2. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.**

Figure 2-25 **EWR Site BM2. Photograph of cross-section A, the riffle for low flows, through which the cross-section was surveyed, taken from the right bank on 12 July 2014 (discharge of *0.27* m^3/s).**

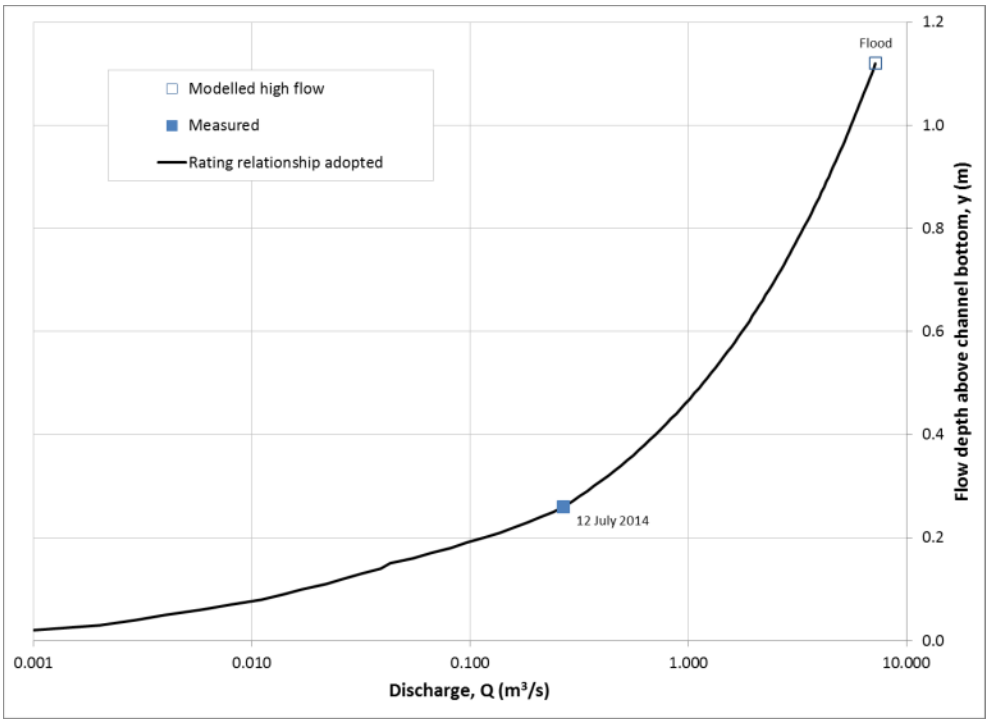

Figure 2-26 Rating curve for profile BM2 A, riffle

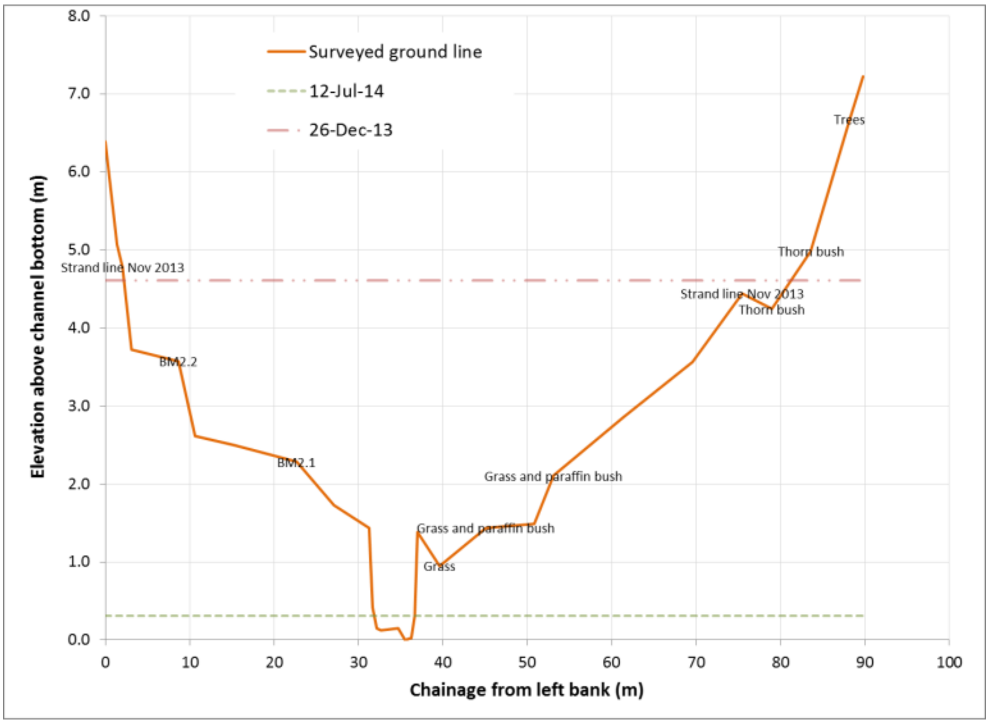

Figure 2-27 Cross-sectional profile through cross-section B, the bedrock unit for high flows, at EWR Site BM2. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.

Figure 2-28 **EWR Site BM2. Photograph of cross-section B, the bedrock chute for high flows, through which the cross-section was surveyed, taken from the right bank on 12 July 2014 (discharge of *0.27* m^3/s).**

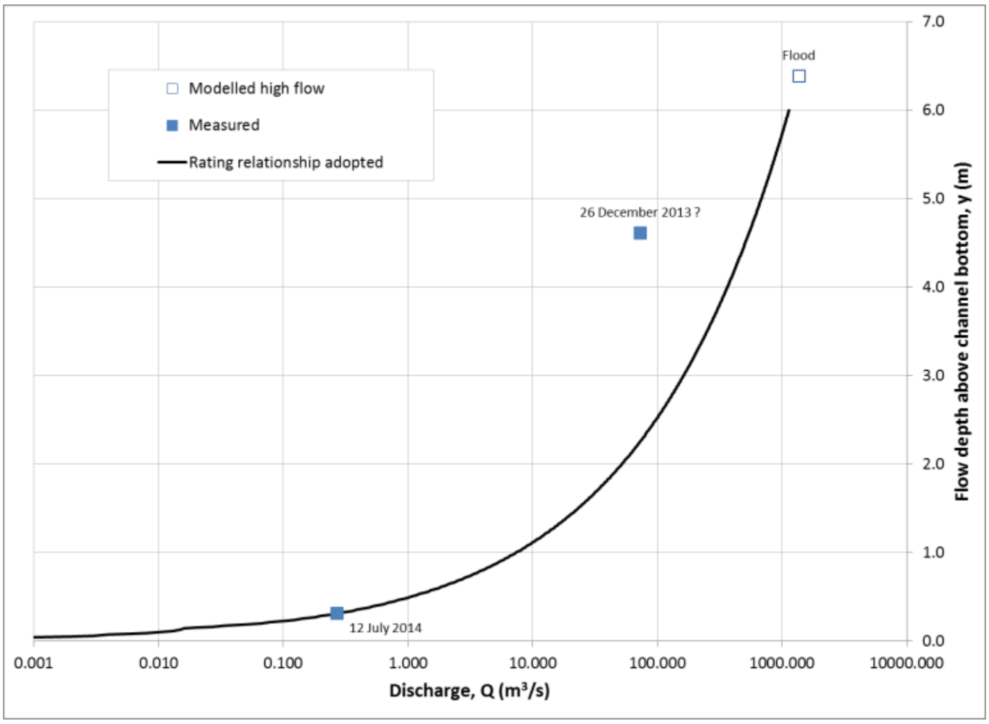

Figure 2-29 **Rating curve for profile BM2 B, bedrock**

2.3.9 EWR Site WM1

Figure 2-30 Location of the cross-section at EWR Site WM1.

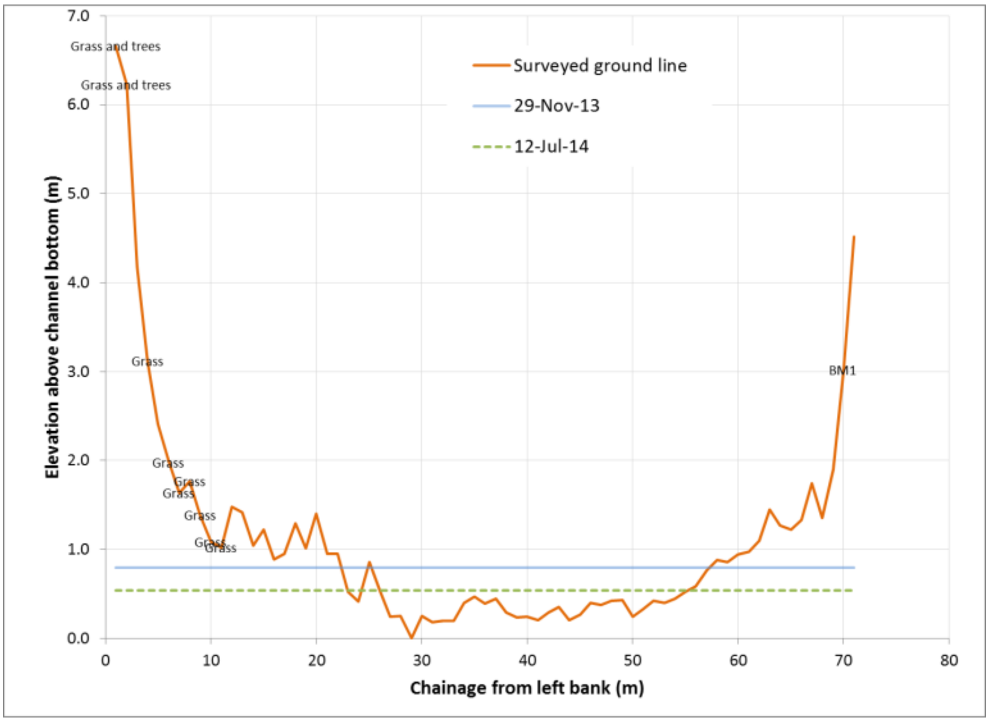

Figure 2-31 Cross-sectional profile through the riffle unit at EWR Site WM1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.

Figure 2-32 EWR Site WM1. Photograph of the riffle through which the cross-section was surveyed, taken from the right bank on 29 November 2013 (discharge of *6.44* m^3/s).

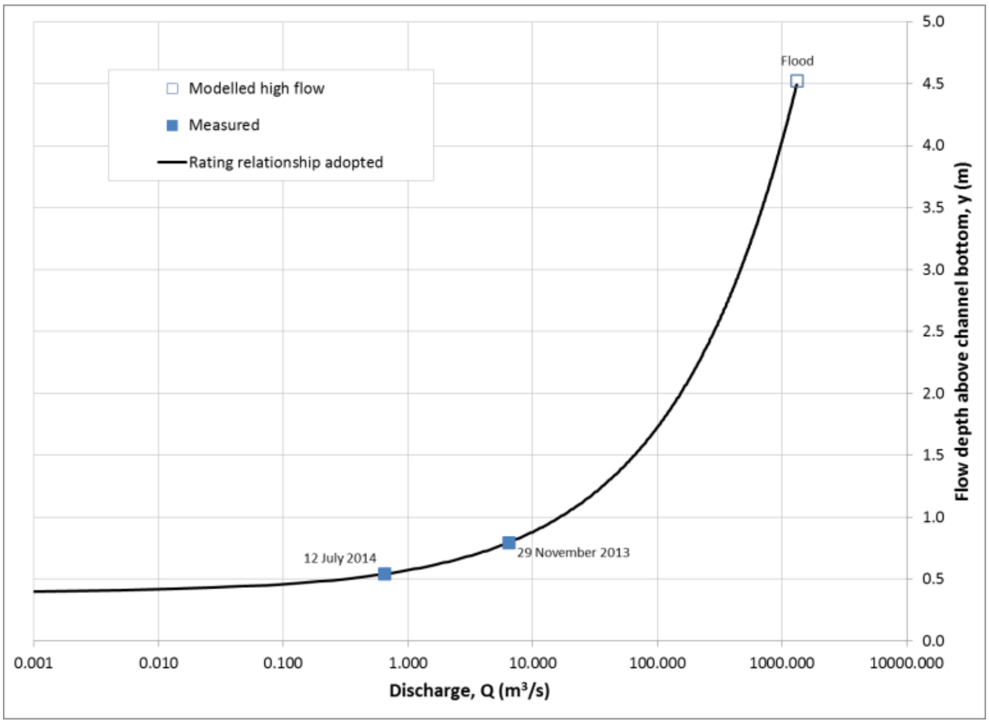

Figure 2-33 Rating curve for profile WM1

2.3.10 EWR Site NS1

Figure 2-34 Location of the cross-section at EWR Site NS1.

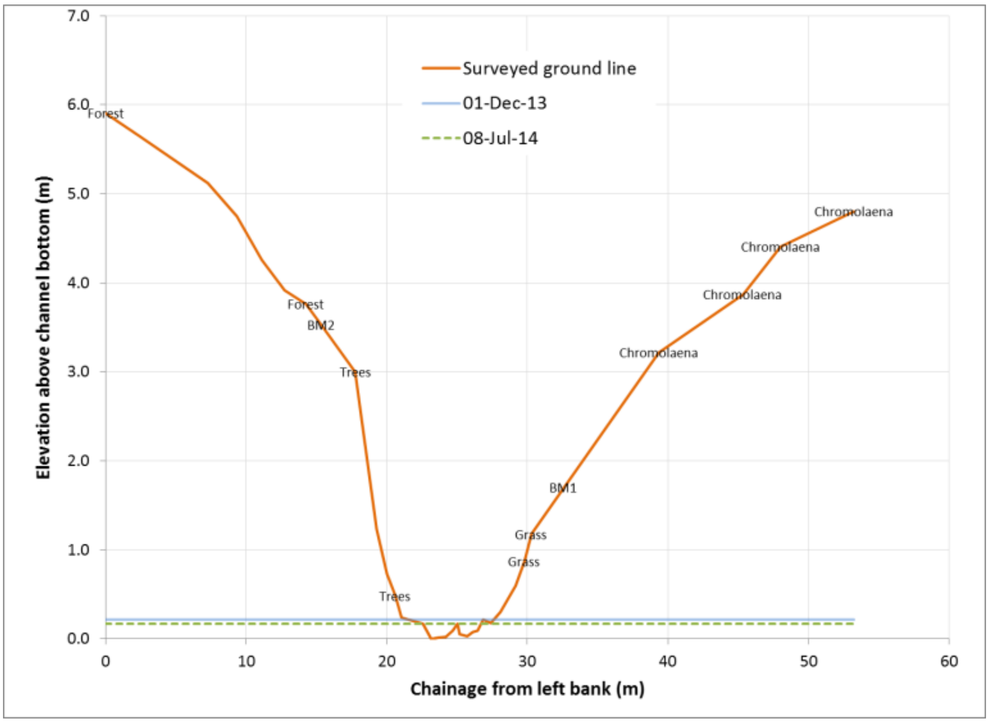

Figure 2-35 Cross-sectional profile through the riffle unit at EWR Site NS1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.

Figure 2-36 EWR Site NS1. Photograph of the riffle through which the cross-section was surveyed, taken from the right bank on 1 December 2013 (discharge of *0.08* m^3/s).

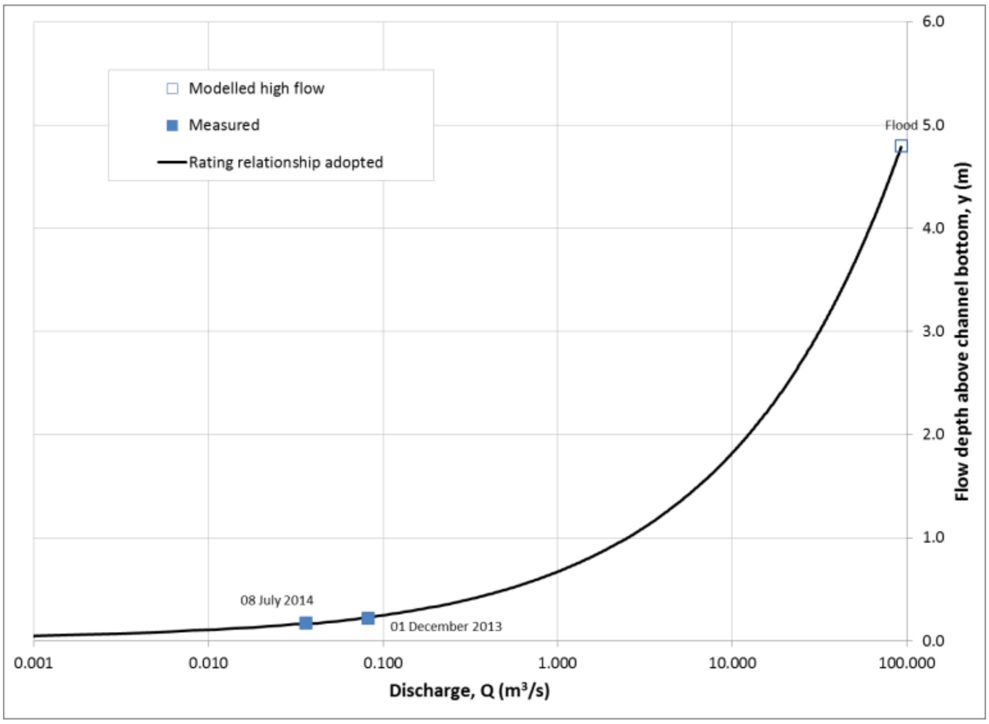

Figure 2-37 Rating curve for profile NS1

2.3.11 EWR Site MA1

Figure 2-38 Location of the cross-section at EWR Site MA1.

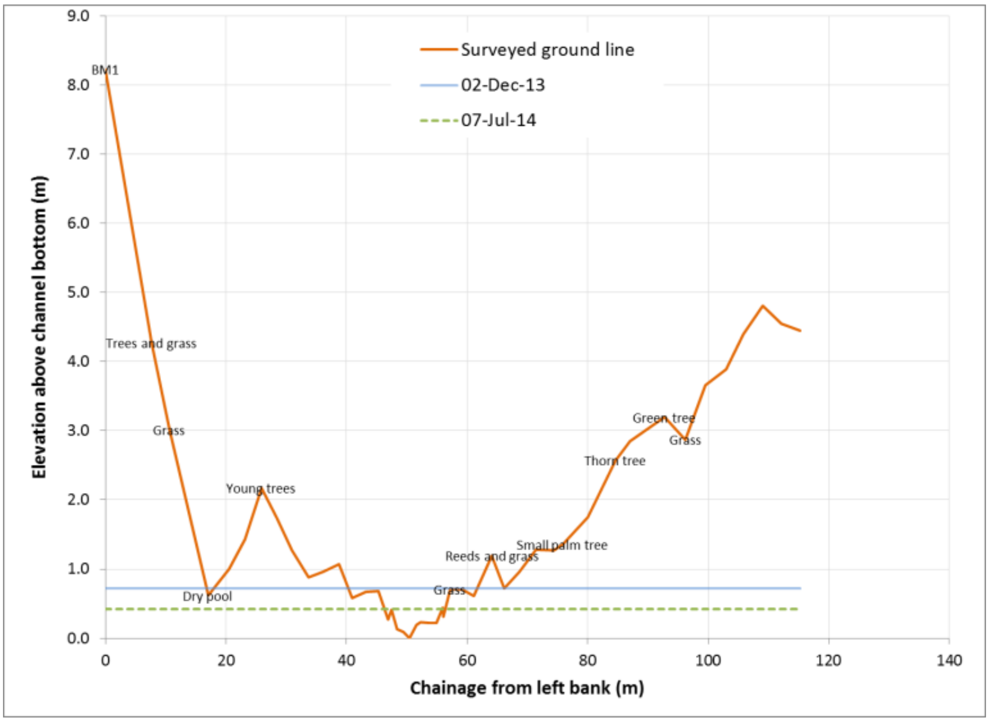

Figure 2-39 Cross-sectional profile through the riffle unit at EWR Site MA1. Refer to Table 2-3 for the discharges corresponding to the water levels (WL) survey dates.

Figure 2-40 EWR Site MA1. Photograph of the riffle through which the cross-section was surveyed, taken from the left bank on 2 December 2013 (discharge of *1.78* m^3/s).

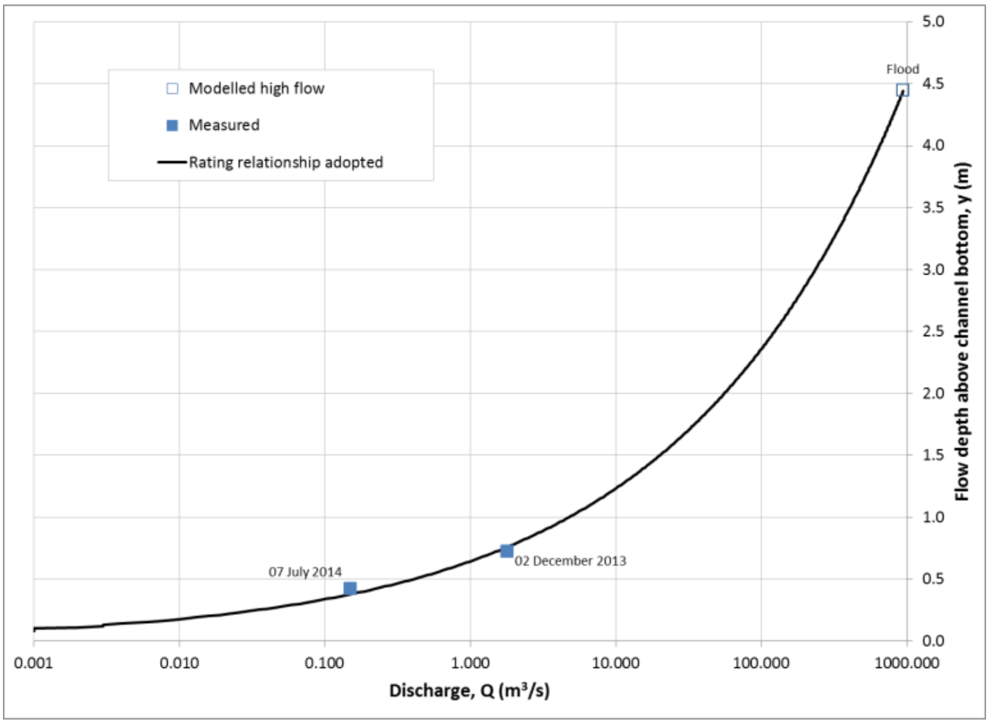

Figure 2-41 Rating curve for profile MA1

2.4 Environmental Flow site hydraulics

Hydraulic lookup tables for each cross-section along with habitat hydraulics for fish and invertebrates are given below.

Table 2-4 Hydraulic habitat look-up table for fish and invertebrates at EWR Site AS1 A (riffle) for the discharge range 0.00 to 257 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.01	0.00	0.00	0.70	0.70	0.02	0.07	100	0	0	0	0	0	0	15	0	0	0	85	0	0	0	0	0	0	0
0.05	0.03	0.00	1.30	1.40	0.07	0.24	100	0	0	0	0	0	0	11	4	0	0	65	20	0	0	0	0	0	0
0.10	0.07	0.01	2.00	2.00	0.11	0.38	91	3	0	6	0	0	0	8	6	1	0	46	34	5	0	0	0	0	0
0.15	0.09	0.04	2.60	2.60	0.15	0.48	42	47	0	5	6	0	0	7	7	2	0	37	39	9	1	0	0	0	0
0.20	0.09	0.06	4.70	4.70	0.15	0.49	51	38	0	6	4	0	0	6	7	2	0	37	39	9	1	0	0	0	0
0.25	0.09	0.12	8.10	8.20	0.15	0.53	60	28	0	9	2	2	0	6	7	2	0	35	39	10	1	0	0	0	0
0.30	0.13	0.24	9.00	9.00	0.21	0.69	36	41	0	11	7	5	0	5	7	3	1	28	37	16	4	0	0	0	0
0.35	0.14	0.38	11.70	11.90	0.23	0.75	23	48	0	9	12	4	3	5	6	3	1	26	35	19	5	0	0	0	0
0.40	0.18	0.64	13.30	13.50	0.27	0.90	19	43	0	12	13	8	6	4	5	4	1	22	30	25	7	1	1	0	0
0.45	0.22	1.01	13.40	13.70	0.34	1.08	4	47	0	4	17	18	10	3	4	5	2	17	25	29	11	3	1	0	0
0.50	0.27	1.63	13.50	13.80	0.44	1.40	1	37	0	1	19	19	22	2	3	5	4	12	19	28	21	5	1	0	0
0.55	0.32	2.04	13.70	14.00	0.47	1.46	1	32	3	1	6	19	38	2	3	5	4	11	18	27	24	6	1	0	0
0.60	0.37	2.49	13.80	14.10	0.49	1.50	1	28	5	1	1	19	45	2	3	5	5	10	17	26	26	8	1	0	0
0.65	0.41	3.01	13.90	14.30	0.52	1.55	0	24	7	1	0	10	57	2	3	4	5	9	16	25	28	9	1	0	0
0.70	0.46	3.57	14.00	14.50	0.55	1.59	0	19	10	1	1	1	69	1	3	4	5	8	14	23	31	11	1	0	0
0.75	0.50	4.19	14.20	14.80	0.59	1.67	1	11	15	1	2	1	69	1	2	4	6	7	13	22	33	12	1	0	0
0.80	0.54	4.87	14.60	15.20	0.62	1.69	1	8	16	2	1	1	71	1	2	4	6	6	12	21	35	14	1	0	0
0.85	0.58	5.61	14.90	15.60	0.65	1.76	1	5	17	3	2	2	71	1	2	3	7	6	11	19	37	15	1	0	0
0.90	0.60	6.40	15.60	16.40	0.68	1.81	1	2	18	5	3	1	69	1	2	3	7	5	10	18	39	15	1	0	0
0.95	0.58	7.26	17.50	18.30	0.71	1.80	3	2	16	10	3	2	64	1	2	3	7	5	10	17	40	15	1	0	0
1.00	0.52	8.18	21.40	22.30	0.73	1.89	5	2	12	21	4	2	52	1	2	3	8	5	10	17	43	13	1	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)										Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
1.05	0.51	9.17	23.90	24.90	0.75	1.90	4	4	11	18	12	3	48	1	2	3	8	5	9	17	44	13	2	0	0
1.10	0.51	10.21	26.70	27.70	0.75	1.90	4	5	10	18	14	5	44	1	2	3	8	5	10	17	45	11	2	0	0
1.15	0.52	11.33	28.60	29.60	0.76	1.92	3	6	9	13	16	10	42	1	2	3	8	5	9	17	45	10	2	0	0
1.20	0.54	12.50	30.30	31.40	0.76	1.90	2	8	9	10	15	13	45	1	2	3	8	5	9	17	46	10	2	0	0
1.25	0.58	13.75	31.10	32.20	0.77	1.90	1	8	8	7	11	15	49	1	2	3	8	5	9	17	46	10	2	0	0
1.30	0.62	15.06	31.30	32.50	0.77	1.93	1	9	8	3	11	15	54	1	2	3	8	4	9	16	47	10	2	0	0
1.35	0.67	16.44	31.60	32.70	0.78	1.90	0	9	8	2	6	11	64	1	2	3	8	4	9	16	47	10	2	0	0
1.40	0.71	17.90	31.80	33.00	0.79	1.92	0	8	8	2	2	9	70	1	2	3	8	4	9	16	48	9	2	0	0
1.45	0.76	19.42	32.00	33.30	0.80	1.91	0	7	10	1	1	6	75	1	2	3	9	4	9	16	48	9	2	0	0
1.50	0.80	21.01	32.30	33.50	0.81	1.95	0	5	11	2	1	2	79	1	1	3	9	4	8	15	49	9	2	0	0
1.55	0.85	22.67	32.50	33.80	0.82	1.96	0	4	12	1	1	1	81	1	1	3	9	4	8	15	50	9	2	0	0
1.60	0.89	24.41	32.90	34.20	0.84	2.00	0	3	13	2	1	1	81	1	1	3	9	4	8	15	50	9	2	0	0
1.65	0.93	26.22	33.30	34.60	0.85	2.01	0	2	13	1	1	1	82	1	1	3	9	4	8	15	51	9	2	0	0
1.70	0.85	28.11	38.20	39.60	0.86	2.01	2	1	12	10	3	1	71	1	1	3	9	4	8	14	52	8	2	0	0
1.75	0.86	30.07	40.10	41.50	0.87	2.04	2	1	11	12	3	1	68	1	1	2	9	4	8	14	53	7	2	0	0
1.80	0.90	32.10	40.80	42.20	0.88	2.03	1	2	11	8	6	3	68	1	1	2	9	4	8	14	53	7	2	0	0
1.85	0.93	34.22	41.50	43.00	0.89	2.00	0	3	11	2	9	7	68	1	1	3	9	4	8	14	53	7	2	0	0
1.90	0.96	36.41	42.30	43.80	0.89	2.04	0	3	11	3	9	7	68	1	1	2	10	4	7	14	54	7	2	0	0
1.95	1.00	38.67	43.00	44.60	0.90	2.06	0	3	10	3	5	6	72	1	1	2	10	4	7	14	54	7	2	0	0
2.00	1.03	41.02	43.80	45.30	0.91	2.10	0	3	10	3	3	5	76	1	1	2	10	4	7	14	55	7	2	0	0
2.05	1.06	43.44	44.50	46.10	0.92	2.11	0	3	10	3	3	5	77	1	1	2	10	4	7	13	55	7	2	0	0
2.10	1.09	45.95	45.20	46.90	0.93	2.13	0	3	10	2	2	4	78	1	1	2	10	3	7	13	56	7	2	0	0
2.15	1.13	48.53	45.90	47.60	0.94	2.13	0	2	10	2	2	3	80	1	1	2	10	3	7	13	56	7	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
2.20	1.16	51.20	46.60	48.30	0.95	2.16	0	2	10	3	3	2	79	1	1	2	10	3	7	13	57	6	2	0	0
2.25	1.20	53.94	47.10	48.90	0.96	2.16	0	2	11	2	2	2	81	1	1	2	10	3	7	13	57	6	2	0	0
2.30	1.23	56.77	47.70	49.50	0.97	2.19	0	2	11	2	2	3	81	1	1	2	10	3	7	12	57	6	2	0	0
2.35	1.27	59.68	48.30	50.20	0.98	2.21	0	1	11	2	2	2	81	1	1	2	10	3	7	12	58	6	2	0	0
2.40	1.30	62.68	48.90	50.80	0.99	2.27	0	1	10	2	2	2	81	1	1	2	10	3	6	12	58	6	2	0	0
2.45	1.34	65.76	49.50	51.40	1.00	2.25	0	1	11	2	2	2	83	1	1	2	10	3	6	12	58	6	2	0	0
2.50	1.37	68.92	50.00	52.00	1.01	2.27	0	1	10	2	2	2	83	1	1	2	10	3	6	12	59	6	2	0	0
2.55	1.40	72.17	50.60	52.70	1.02	2.30	0	1	10	2	2	2	83	1	1	2	10	3	6	12	59	6	2	0	0
2.60	1.42	75.50	51.70	53.80	1.03	2.29	0	1	10	2	2	2	82	1	1	2	10	3	6	12	59	6	2	0	0
2.65	1.43	78.92	53.50	55.60	1.04	2.32	0	1	10	3	3	2	80	1	1	2	11	3	6	11	60	6	2	0	0
2.70	1.43	82.43	55.20	57.40	1.04	2.31	0	1	9	4	4	2	79	1	1	2	11	3	6	11	60	5	2	0	0
2.75	1.43	86.02	57.00	59.20	1.05	2.35	1	1	9	5	5	1	78	1	1	2	11	3	6	11	61	5	2	0	0
2.80	1.37	89.70	61.80	64.00	1.06	2.31	1	2	8	7	6	2	74	1	1	2	11	3	6	11	61	5	2	0	0
2.85	1.33	93.47	66.00	68.30	1.06	2.32	1	2	8	9	8	2	70	1	1	2	11	3	6	11	61	5	2	0	0
2.90	1.31	97.33	70.00	72.30	1.07	2.32	1	2	7	10	9	3	67	1	1	2	11	3	6	11	62	4	2	0	0
2.95	1.28	101.28	73.90	76.30	1.07	2.32	1	2	7	10	10	4	65	1	1	2	11	3	6	11	62	4	2	0	0
3.00	1.33	105.31	74.10	76.50	1.07	2.32	1	3	7	7	7	6	69	1	1	2	11	3	6	11	62	4	2	0	0
3.05	1.38	109.44	74.30	76.70	1.07	2.37	1	3	7	5	5	8	72	1	1	2	11	3	6	11	62	4	2	0	0
3.10	1.42	113.66	74.40	76.90	1.07	2.38	0	3	8	3	3	8	76	1	1	2	11	3	6	11	62	4	2	0	0
3.15	1.47	117.97	74.60	77.10	1.07	2.38	0	3	8	1	1	8	80	1	1	2	11	3	6	11	62	4	2	0	0
3.20	1.52	122.37	74.80	77.30	1.08	2.41	0	3	8	0	0	7	81	1	1	2	11	3	6	11	62	4	2	0	0
3.25	1.56	126.86	75.00	77.50	1.08	2.41	0	2	9	0	0	5	83	1	1	2	11	3	6	11	62	4	2	0	0
3.30	1.61	131.44	75.30	77.80	1.09	2.41	0	2	9	0	0	3	86	1	1	2	11	3	6	11	62	4	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
3.35	1.65	136.12	75.50	78.10	1.09	2.41	0	1	10	0	0	2	87	1	1	2	11	3	6	11	62	4	2	0	0
3.40	1.70	140.89	75.80	78.40	1.10	2.45	0	1	10	1	1	1	87	1	1	2	11	3	6	11	62	4	2	0	0
3.45	1.74	145.76	76.00	78.70	1.10	2.46	0	0	10	1	1	0	88	1	1	2	11	3	6	11	62	4	2	0	1
3.50	1.79	150.72	76.30	79.00	1.11	2.46	0	0	10	0	0	0	88	1	1	2	11	3	6	11	62	4	2	0	1
3.55	1.83	155.77	76.50	79.20	1.11	2.50	0	0	10	1	1	1	87	1	1	2	11	3	6	10	63	4	2	0	1
3.60	1.87	160.92	76.80	79.50	1.12	2.51	0	0	10	1	1	1	88	1	1	2	11	3	6	10	63	4	2	0	1
3.65	1.92	166.17	77.10	79.80	1.13	2.54	0	0	10	1	1	1	88	1	1	2	11	3	6	11	63	4	2	0	1
3.70	1.96	171.51	77.30	80.10	1.13	2.52	0	0	10	0	0	0	88	1	1	2	11	3	6	11	63	4	2	0	1
3.75	2.00	176.95	77.60	80.40	1.14	2.54	0	0	10	0	0	0	89	1	1	2	11	3	6	11	63	4	2	0	1
3.80	2.05	182.49	77.80	80.60	1.15	2.58	0	0	10	1	1	1	88	0	1	2	11	3	6	10	63	4	2	0	1
3.85	2.09	188.12	78.10	80.90	1.15	2.60	0	0	10	1	1	1	88	0	1	2	11	3	6	10	63	4	2	0	1
3.90	2.13	193.85	78.30	81.20	1.16	2.59	0	0	10	0	0	0	89	0	1	2	11	3	6	10	63	4	2	0	1
3.95	2.18	199.68	78.60	81.50	1.17	2.61	0	0	10	0	0	0	89	0	1	2	11	3	6	10	63	4	2	0	1
4.00	2.22	205.61	78.80	81.80	1.18	2.61	0	0	10	0	0	0	89	0	1	2	11	3	6	10	64	4	2	0	1
4.05	2.26	211.63	79.10	82.00	1.18	2.62	0	0	10	0	0	0	89	0	1	2	11	3	5	10	64	4	2	0	1
4.10	2.30	217.76	79.40	82.30	1.19	2.66	0	0	10	1	1	1	88	0	1	2	11	3	5	10	64	4	2	0	1
4.15	2.35	223.98	79.60	82.60	1.20	2.70	0	0	10	0	0	0	89	0	1	2	11	3	5	10	64	4	2	0	1
4.20	2.39	230.31	79.90	82.90	1.21	2.72	0	0	10	0	0	0	89	0	1	2	11	3	5	10	64	4	2	0	1
4.25	2.43	236.74	80.10	83.20	1.22	2.75	0	0	9	1	1	1	88	0	1	2	11	3	5	10	64	4	2	0	1
4.30	2.47	243.26	80.40	83.40	1.22	2.75	0	0	9	1	1	1	89	0	1	2	11	3	5	9	64	4	2	0	1
4.35	2.52	249.89	80.60	83.70	1.23	2.73	0	0	9	0	0	0	89	0	1	2	11	3	5	9	64	4	2	0	1
4.40	2.56	256.63	80.90	84.00	1.24	2.78	0	0	9	1	1	1	89	0	1	2	11	3	5	9	65	4	2	0	1

Table 2-5 Hydraulic look-up table for geomorphology only, at EWR Site AS1 B (pool) for the discharge range 0.00 to 337 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)
0.45	0.27	0.00	17.80	17.90	0.00	0.00
0.50	0.32	0.01	18.00	18.20	0.00	0.00
0.55	0.36	0.03	18.10	18.30	0.00	0.02
0.60	0.39	0.08	19.10	19.40	0.01	0.04
0.65	0.44	0.16	19.30	19.70	0.02	0.07
0.70	0.49	0.29	19.50	20.00	0.03	0.11
0.75	0.53	0.45	19.70	20.30	0.04	0.16
0.80	0.57	0.67	19.90	20.60	0.06	0.21
0.85	0.62	0.93	20.10	20.90	0.08	0.27
0.90	0.66	1.19	20.30	21.20	0.09	0.32
0.95	0.70	1.64	20.60	21.50	0.11	0.40
1.00	0.73	2.08	21.30	22.30	0.13	0.47
1.05	0.75	2.59	22.00	23.10	0.16	0.54
1.10	0.78	3.17	22.60	23.70	0.18	0.61
1.15	0.82	3.81	22.90	24.10	0.20	0.68
1.20	0.85	4.54	23.50	24.80	0.23	0.77
1.25	0.89	5.34	23.80	25.10	0.25	0.84
1.30	0.93	6.22	24.00	25.30	0.28	0.91
1.35	0.98	7.18	24.20	25.50	0.30	0.98
1.40	1.02	8.22	24.30	25.70	0.33	1.07
1.45	1.06	9.36	24.50	25.90	0.36	1.13
1.50	1.10	10.58	24.70	26.10	0.39	1.21
1.55	1.15	11.89	24.90	26.30	0.42	1.30
1.60	1.19	13.30	25.00	26.50	0.45	1.36
1.65	1.23	14.80	25.20	26.70	0.48	1.45
1.70	1.27	16.41	25.40	26.90	0.51	1.51
1.75	1.31	18.11	25.60	27.10	0.54	1.58
1.80	1.35	19.91	25.70	27.30	0.57	1.66
1.85	1.39	21.82	25.90	27.50	0.60	1.72
1.90	1.43	23.84	26.10	27.70	0.64	1.78
1.95	1.47	25.96	26.30	27.90	0.67	1.86
2.00	1.51	28.19	26.40	28.20	0.70	1.92
2.05	1.55	30.54	26.70	28.40	0.74	1.97
2.10	1.58	33.00	26.90	28.70	0.77	2.04

Maxdepth (m)	Avdepth (m)	Discharge (m3/s)	Width (m)	Perim (m)	AvVel (m/s)	Vel98% (m/s)
2.15	1.62	35.58	27.20	29.00	0.81	2.10
2.20	1.65	38.27	27.50	29.30	0.84	2.12
2.25	1.68	41.08	27.80	29.60	0.88	2.18
2.30	1.71	44.02	28.10	30.00	0.91	2.21
2.35	1.73	47.07	28.70	30.50	0.95	2.26
2.40	1.75	50.25	29.20	31.10	0.98	2.31
2.45	1.76	53.56	29.80	31.70	1.02	2.37
2.50	1.78	57.00	30.40	32.30	1.06	2.41
2.55	1.81	60.56	30.70	32.60	1.09	2.48
2.60	1.65	64.26	34.70	36.60	1.12	2.49
2.65	1.53	68.09	38.70	40.60	1.15	2.47
2.70	1.47	72.05	41.60	43.60	1.18	2.49
2.75	1.46	76.15	43.10	45.10	1.21	2.54
2.80	1.47	80.39	44.60	46.60	1.23	2.61
2.85	1.47	84.76	46.10	48.00	1.25	2.63
2.90	1.47	89.28	47.50	49.50	1.28	2.67
2.95	1.48	93.94	49.00	51.00	1.30	2.70
3.00	1.51	98.74	49.60	51.60	1.32	2.68
3.05	1.55	103.69	50.00	52.10	1.34	2.75
3.10	1.58	108.78	50.40	52.50	1.36	2.80
3.15	1.62	114.02	50.90	52.90	1.38	2.85
3.20	1.66	119.42	51.30	53.40	1.41	2.89
3.25	1.69	124.96	51.70	53.80	1.43	2.92
3.30	1.73	130.65	52.10	54.20	1.45	2.94
3.35	1.77	136.50	52.50	54.60	1.47	2.98
3.40	1.80	142.51	52.90	55.10	1.49	3.00
3.45	1.84	148.67	53.30	55.50	1.52	3.09
3.50	1.87	154.99	53.70	55.90	1.54	3.13
3.55	1.91	161.46	54.10	56.30	1.56	3.16
3.60	1.94	168.10	54.60	56.80	1.58	3.22
3.65	1.98	174.90	55.00	57.20	1.61	3.23
3.70	2.01	181.86	55.40	57.60	1.63	3.26
3.75	2.05	188.99	55.80	58.00	1.65	3.32
3.80	2.08	196.29	56.20	58.50	1.68	3.41
3.85	2.12	203.75	56.60	58.90	1.70	3.45
3.90	2.15	211.38	57.00	59.30	1.72	3.52
3.95	2.19	219.18	57.40	59.70	1.74	3.49

Maxdepth (m)	Avdepth (m)	Discharge (m3/s)	Width (m)	Perim (m)	AvVel (m/s)	Vel98% (m/s)
4.00	2.22	227.15	57.80	60.10	1.77	3.59
4.05	2.26	235.29	58.20	60.50	1.79	3.63
4.10	2.30	243.61	58.50	60.90	1.81	3.66
4.15	2.33	252.10	58.90	61.30	1.84	3.72
4.20	2.37	260.76	59.30	61.70	1.86	3.78
4.25	2.40	269.61	59.80	62.20	1.88	3.80
4.30	2.43	278.63	60.20	62.60	1.91	3.90
4.35	2.46	287.83	60.70	63.10	1.93	3.94
4.40	2.49	297.22	61.20	63.60	1.95	3.94
4.45	2.52	306.78	61.70	64.10	1.97	3.97
4.50	2.55	316.53	62.20	64.60	2.00	4.03
4.55	2.58	326.47	62.60	65.10	2.02	4.10
4.60	2.61	336.59	63.10	65.60	2.04	4.13

Table 2-6 Hydraulic habitat look-up table for fish and invertebrates at EWR Site UP1 (riffle) for the discharge range 0.00 to 831 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)								Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.01	0.00	0.00	0.40	0.40	0.01	0.05	100	0	0	0	0	0	0	21	0	0	0	79	0	0	0	0	0	0	0
0.05	0.02	0.00	2.80	2.80	0.04	0.16	100	0	0	0	0	0	0	19	2	0	0	70	9	0	0	0	0	0	0
0.10	0.06	0.02	3.70	3.70	0.08	0.26	98	1	0	1	0	0	0	15	6	0	0	56	22	1	0	0	0	0	0
0.15	0.11	0.05	3.80	3.90	0.13	0.44	25	66	0	3	7	0	0	10	9	2	0	39	33	7	0	0	0	0	0
0.20	0.15	0.12	4.00	4.10	0.20	0.66	5	73	0	1	20	0	0	7	9	4	1	28	34	14	3	0	0	0	0
0.25	0.13	0.16	6.90	7.00	0.18	0.62	36	46	0	8	3	7	0	8	9	3	1	29	36	12	2	0	0	0	0
0.30	0.13	0.25	10.10	10.30	0.19	0.63	48	32	0	12	1	7	0	7	9	3	1	28	35	13	3	0	0	0	0
0.35	0.13	0.37	15.00	15.30	0.20	0.64	43	37	0	11	4	2	3	7	9	4	1	27	36	13	3	0	0	0	0
0.40	0.16	0.63	17.00	17.40	0.23	0.76	28	43	0	11	10	1	6	6	9	5	1	24	32	18	5	0	0	0	0
0.45	0.19	0.97	19.20	19.70	0.27	0.89	16	47	0	10	15	6	8	6	8	6	2	21	28	23	6	0	0	0	0
0.50	0.22	1.44	20.70	21.20	0.31	1.02	9	45	0	8	15	13	9	5	7	7	2	18	25	27	9	0	0	0	0
0.55	0.25	2.02	22.60	23.20	0.35	1.14	8	36	5	8	11	16	15	4	6	7	3	15	23	28	12	0	0	0	0
0.60	0.29	2.67	23.30	24.00	0.39	1.24	4	34	7	5	9	18	24	4	6	7	4	14	21	28	16	0	0	0	0
0.65	0.34	3.36	23.70	24.40	0.42	1.35	2	33	7	3	8	13	34	3	5	7	5	13	20	27	19	0	0	0	0
0.70	0.38	4.14	24.40	25.20	0.45	1.44	1	31	7	2	5	10	43	2	4	5	4	13	20	28	23	0	0	0	0
0.75	0.41	5.03	25.50	26.30	0.48	1.52	2	25	11	3	3	9	48	1	2	3	3	13	21	29	28	0	0	0	0
0.80	0.45	6.04	26.30	27.20	0.51	1.66	3	19	13	5	2	6	52	1	1	1	2	13	20	28	34	0	0	0	0
0.85	0.48	7.17	27.00	28.00	0.55	1.73	2	14	16	4	3	3	58	0	0	0	0	12	20	26	42	0	0	0	0
0.90	0.51	8.43	28.20	29.30	0.58	1.84	2	10	19	5	5	3	57	0	0	0	0	11	20	27	42	0	0	0	0
0.95	0.54	9.83	29.30	30.40	0.62	1.93	2	8	20	5	4	5	57	0	0	0	0	11	19	25	45	0	0	0	0
1.00	0.58	11.37	30.10	31.20	0.65	2.04	1	7	20	4	5	4	59	0	0	0	0	10	18	24	48	0	0	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
1.05	0.58	13.05	32.40	33.60	0.69	2.15	2	5	19	7	5	4	57	0	0	0	0	9	17	22	51	1	1	0	0
1.10	0.62	14.89	32.90	34.10	0.72	2.22	2	5	18	6	5	3	61	0	0	0	0	9	16	21	53	1	1	0	0
1.15	0.67	16.89	33.40	34.70	0.76	2.33	1	6	18	2	7	5	62	0	0	0	0	8	16	20	54	2	1	0	0
1.20	0.71	19.05	33.90	35.20	0.80	2.46	1	5	17	2	5	6	64	0	0	0	0	8	15	18	57	3	1	0	0
1.25	0.75	21.39	34.30	35.70	0.84	2.57	1	5	16	2	4	6	67	0	0	0	0	7	14	17	58	4	1	0	0
1.30	0.79	23.90	34.80	36.20	0.87	2.69	1	5	16	2	4	4	69	0	0	0	0	7	13	16	60	4	1	0	0
1.35	0.82	26.60	35.30	36.70	0.91	2.77	0	4	15	2	2	3	73	0	0	0	0	6	13	16	61	5	1	0	0
1.40	0.86	29.48	35.80	37.20	0.96	2.91	0	3	15	2	3	2	74	0	0	0	0	6	12	15	62	6	1	0	0
1.45	0.90	32.57	36.20	37.70	1.00	3.01	0	3	14	2	2	2	76	0	0	0	0	6	11	14	63	6	1	0	0
1.50	0.94	35.85	36.60	38.10	1.04	3.10	0	3	14	1	2	2	78	0	0	0	0	5	11	14	63	7	1	0	0
1.55	0.98	39.34	37.00	38.50	1.08	3.21	0	2	14	1	2	2	79	0	0	0	0	5	10	13	64	8	1	0	0
1.60	1.00	43.04	38.10	39.60	1.13	3.33	1	1	13	3	2	2	77	0	0	0	0	5	9	13	65	8	1	0	0
1.65	1.01	46.96	39.60	41.10	1.17	3.44	1	1	12	5	2	2	76	0	0	0	0	4	9	12	66	9	1	0	0
1.70	1.03	51.10	41.00	42.60	1.21	3.52	1	1	11	6	3	2	75	0	0	0	0	4	8	12	67	9	1	0	0
1.75	1.04	55.48	42.50	44.10	1.25	3.58	1	2	10	6	5	3	74	0	0	0	0	4	8	11	68	9	1	0	0
1.80	1.07	60.09	43.30	44.90	1.30	3.58	1	2	10	4	5	3	75	0	0	0	0	4	7	11	69	9	2	0	0
1.85	1.11	64.94	43.80	45.50	1.34	3.67	1	2	9	4	5	4	76	0	0	0	0	3	7	10	70	9	2	0	0
1.90	1.14	70.03	44.40	46.20	1.38	3.70	0	2	9	2	4	5	78	0	0	0	0	3	7	10	71	9	2	0	1
1.95	1.18	75.38	45.00	46.80	1.42	3.74	0	2	8	1	3	5	80	0	0	0	0	3	6	10	72	9	2	0	1
2.00	1.21	80.98	45.50	47.40	1.47	3.79	0	2	8	2	3	4	81	0	0	0	0	3	6	9	73	9	2	0	1
2.05	1.25	86.85	46.00	47.90	1.51	3.81	0	1	8	3	2	3	83	0	0	0	0	3	6	9	74	9	2	0	1
2.10	1.29	92.99	46.40	48.30	1.55	3.82	0	1	7	1	2	3	85	0	0	0	0	3	5	8	75	9	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
2.15	1.33	99.40	46.80	48.80	1.60	3.89	0	1	7	2	2	2	86	0	0	0	0	2	5	8	76	9	2	0	1
2.20	1.35	106.09	48.00	49.90	1.64	3.91	0	1	7	2	2	2	86	0	0	0	0	2	5	7	77	8	2	0	1
2.25	1.34	113.06	50.20	52.10	1.69	3.96	0	1	6	5	3	1	83	0	0	0	0	2	5	7	78	8	2	0	1
2.30	1.33	120.32	52.30	54.30	1.73	3.98	0	1	6	6	4	1	82	0	0	0	0	2	4	7	79	8	2	0	1
2.35	1.35	127.88	53.40	55.40	1.77	4.07	0	1	6	6	5	2	80	0	0	0	0	2	4	6	80	7	2	0	1
2.40	1.38	135.74	54.20	56.20	1.81	4.06	0	1	6	4	4	4	81	0	0	0	0	2	4	6	80	7	2	0	1
2.45	1.41	143.90	55.10	57.00	1.85	4.13	0	1	5	3	4	5	81	0	0	0	0	2	4	6	81	7	2	0	1
2.50	1.44	152.38	55.90	57.90	1.89	4.18	0	1	5	3	4	6	81	0	0	0	0	2	4	6	82	7	2	0	1
2.55	1.47	161.17	56.70	58.70	1.94	4.24	0	1	5	2	3	6	83	0	0	0	0	2	4	5	82	7	2	0	1
2.60	1.49	170.29	57.60	59.60	1.98	4.27	0	1	5	2	3	4	85	0	0	0	0	2	3	5	83	7	2	0	1
2.65	1.52	179.73	58.40	60.40	2.02	4.31	0	1	4	2	2	3	87	0	0	0	0	2	3	5	83	7	2	0	1
2.70	1.55	189.50	59.30	61.30	2.06	4.35	0	1	4	2	2	3	88	0	0	0	0	2	3	5	84	7	2	0	1
2.75	1.58	199.61	60.10	62.20	2.10	4.43	0	1	4	3	3	3	87	0	0	0	0	1	3	4	84	7	2	0	1
2.80	1.58	210.07	62.10	64.10	2.14	4.40	0	1	4	3	3	3	87	0	0	0	0	1	3	4	85	6	2	0	1
2.85	1.56	220.87	64.90	66.90	2.18	4.53	0	1	4	5	5	2	83	0	0	0	0	1	3	4	85	6	2	0	1
2.90	1.57	232.02	66.30	68.40	2.22	4.62	0	1	3	5	5	2	83	0	0	0	0	1	3	4	86	6	2	0	1
2.95	1.60	243.54	67.30	69.40	2.26	4.65	0	0	3	5	5	2	84	0	0	0	0	1	3	4	86	6	2	0	1
3.00	1.63	255.41	68.30	70.40	2.30	4.75	0	1	3	4	4	3	84	0	0	0	0	1	2	4	87	6	2	0	1
3.05	1.65	267.65	69.30	71.40	2.34	4.72	0	1	3	3	3	4	86	0	0	0	0	1	2	4	87	6	2	0	1
3.10	1.68	280.27	70.30	72.40	2.37	4.86	0	1	3	3	3	4	86	0	0	0	0	1	2	3	87	6	2	0	1
3.15	1.71	293.27	71.30	73.40	2.41	4.86	0	0	3	2	2	4	88	0	0	0	0	1	2	4	88	6	2	0	1
3.20	1.74	306.65	72.00	74.10	2.45	5.03	0	0	3	3	3	4	87	0	0	0	0	1	2	3	88	6	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
3.25	1.78	320.42	72.50	74.60	2.49	5.02	0	0	3	2	2	3	90	0	0	0	0	1	2	3	88	6	2	0	1
3.30	1.82	334.58	72.90	75.00	2.53	5.08	0	0	3	1	1	2	92	0	0	0	0	1	2	3	89	5	2	0	1
3.35	1.86	349.14	73.30	75.40	2.57	5.25	0	0	2	1	1	3	92	0	0	0	0	1	2	3	89	5	2	0	1
3.40	1.90	364.10	73.70	75.80	2.60	5.32	0	0	2	1	1	2	93	0	0	0	0	1	2	3	89	5	2	0	1
3.45	1.94	379.48	74.10	76.30	2.64	5.42	0	0	2	1	1	2	93	0	0	0	0	1	2	3	89	5	2	0	1
3.50	1.97	395.27	74.50	76.70	2.69	5.38	0	0	2	1	1	2	94	0	0	0	0	1	2	3	89	5	2	0	1
3.55	2.01	411.47	74.90	77.10	2.73	5.50	0	0	2	1	1	1	94	0	0	0	0	1	2	3	89	5	2	0	1
3.60	2.05	428.10	75.40	77.50	2.77	5.64	0	0	2	1	1	1	94	0	0	0	0	1	2	3	89	5	2	0	1
3.65	2.09	445.16	75.80	78.00	2.81	5.75	0	0	2	1	1	1	94	0	0	0	0	1	2	3	90	5	2	0	1
3.70	2.13	462.65	76.20	78.40	2.85	5.83	0	0	2	1	1	1	94	0	0	0	0	1	2	3	90	5	2	0	1
3.75	2.17	480.59	76.60	78.90	2.89	5.83	0	0	2	1	1	1	95	0	0	0	0	1	2	3	90	5	2	0	1
3.80	2.21	498.96	77.10	79.30	2.94	5.99	0	0	2	1	1	1	94	0	0	0	0	1	2	2	90	5	2	0	1
3.85	2.24	517.78	77.50	79.70	2.98	6.07	0	0	2	1	1	1	94	0	0	0	0	1	2	2	90	5	2	0	1
3.90	2.28	537.06	77.90	80.20	3.02	6.17	0	0	2	1	1	1	94	0	0	0	0	1	1	2	90	5	2	0	1
3.95	2.32	556.80	78.30	80.60	3.07	6.21	0	0	2	1	1	1	94	0	0	0	0	1	1	2	90	5	2	0	1
4.00	2.36	577.00	78.80	81.00	3.11	6.35	0	0	2	1	1	1	94	0	0	0	0	1	1	2	91	5	2	0	1
4.05	2.39	597.66	79.20	81.50	3.15	6.38	0	0	2	1	1	1	95	0	0	0	0	1	1	2	91	5	2	0	1
4.10	2.43	618.80	79.60	81.90	3.20	6.55	0	0	2	1	1	1	95	0	0	0	0	1	1	2	91	5	2	0	1
4.15	2.47	640.42	79.90	82.20	3.24	6.57	0	0	2	1	1	1	96	0	0	0	0	1	1	2	91	5	2	0	1
4.20	2.51	662.52	80.30	82.60	3.29	6.68	0	0	2	1	1	1	95	0	0	0	0	1	1	2	91	5	2	0	1
4.25	2.55	685.11	80.60	83.00	3.33	6.73	0	0	2	1	1	1	96	0	0	0	0	1	1	2	91	5	2	0	1
4.30	2.59	708.19	81.00	83.30	3.38	6.81	0	0	2	1	1	1	96	0	0	0	0	1	1	2	91	5	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
4.35	2.63	731.77	81.30	83.70	3.43	6.90	0	0	2	1	1	1	96	0	0	0	0	1	1	2	91	5	2	0	1
4.40	2.66	755.85	81.70	84.10	3.47	7.01	0	0	2	1	1	1	95	0	0	0	0	1	1	2	91	5	2	0	1
4.45	2.70	780.44	82.10	84.50	3.52	7.15	0	0	2	1	1	1	95	0	0	0	0	1	1	2	91	5	2	0	1
4.50	2.74	805.53	82.40	84.80	3.57	7.21	0	0	2	1	1	1	96	0	0	0	0	1	1	2	91	5	2	0	1
4.55	2.78	831.15	82.80	85.20	3.61	7.38	0	0	2	1	1	1	95	0	0	0	0	1	1	2	91	5	2	0	1

Table 2-7 Hydraulic habitat look-up table for fish and invertebrates at EWR Site MK1 (sand run) for the discharge range 0.00 to 440 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.09	0.03	0.00	8.90	8.90	0.00	0.01	100	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0
0.10	0.04	0.00	10.30	10.30	0.01	0.03	100	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0
0.15	0.06	0.05	20.90	20.90	0.04	0.14	87	13	0	0	0	0	0	91	8	0	0	0	0	0	0	1	1	0	0
0.20	0.09	0.14	26.90	27.00	0.06	0.20	57	43	0	0	0	0	0	81	17	0	0	0	0	0	0	2	1	0	0
0.25	0.10	0.30	43.40	43.50	0.07	0.23	52	47	0	0	0	0	0	75	23	0	0	0	0	0	0	2	1	0	0
0.30	0.15	0.65	44.10	44.30	0.10	0.32	37	60	0	1	1	1	0	55	39	3	0	0	0	0	0	3	1	0	0
0.35	0.20	1.03	44.30	44.50	0.12	0.38	3	92	0	0	3	2	0	46	46	5	0	0	0	0	0	3	1	0	0
0.40	0.25	1.49	44.50	44.70	0.14	0.43	1	92	0	0	2	3	2	40	49	7	0	0	0	0	0	4	1	0	0
0.45	0.29	2.04	44.60	44.90	0.15	0.48	0	90	0	0	0	5	5	35	50	9	1	0	0	0	0	5	1	0	0
0.50	0.34	2.67	44.80	45.10	0.17	0.54	1	85	0	0	0	5	9	31	50	12	2	0	0	0	0	5	1	0	0
0.55	0.39	3.40	44.90	45.30	0.19	0.60	1	74	6	0	0	1	18	28	48	16	2	0	0	0	0	6	1	0	0
0.60	0.44	4.23	45.10	45.50	0.21	0.65	0	54	22	0	0	0	24	26	46	19	3	0	0	0	0	7	1	0	0
0.65	0.49	5.15	45.20	45.70	0.23	0.70	0	39	33	0	0	0	29	23	43	23	4	0	0	0	0	7	1	0	0
0.70	0.54	6.16	45.40	45.90	0.25	0.76	1	21	43	0	0	0	34	21	39	28	4	0	0	0	0	8	1	0	0
0.75	0.59	7.27	45.50	46.10	0.27	0.81	0	3	57	0	0	0	39	19	36	30	6	0	0	0	0	9	1	0	0
0.80	0.63	8.49	45.70	46.30	0.29	0.87	1	1	54	0	0	0	43	18	33	33	7	0	0	0	0	9	1	0	0
0.85	0.68	9.80	45.90	46.50	0.31	0.92	1	1	51	0	0	0	47	16	31	35	8	0	0	0	0	10	1	0	0
0.90	0.73	11.21	46.10	46.70	0.33	0.96	0	1	48	0	1	0	50	15	29	36	10	0	0	0	0	10	1	0	0
0.95	0.78	12.72	46.20	46.90	0.36	1.02	0	1	44	1	1	0	54	14	27	37	12	0	0	0	0	11	1	0	0
1.00	0.80	14.34	47.90	48.60	0.38	1.06	1	1	39	2	0	1	55	13	25	37	15	0	0	0	0	11	1	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
1.05	0.82	16.06	49.40	50.10	0.40	1.10	2	1	37	3	1	0	56	12	24	36	17	0	0	0	0	12	1	0	0
1.10	0.85	17.88	50.50	51.30	0.41	1.14	2	2	33	3	2	0	57	11	22	36	20	0	0	0	0	12	1	0	0
1.15	0.85	19.81	53.80	54.50	0.43	1.16	3	3	30	5	3	1	55	10	21	36	21	0	0	0	0	11	2	0	0
1.20	0.88	21.84	54.90	55.70	0.45	1.19	2	4	28	4	4	2	56	10	20	35	24	0	0	0	0	11	2	0	0
1.25	0.91	23.98	56.10	56.90	0.47	1.24	1	4	26	3	5	2	58	9	19	35	26	0	0	0	0	11	2	0	0
1.30	0.95	26.22	57.00	57.80	0.49	1.27	1	5	25	2	4	4	59	9	19	33	28	0	0	0	0	11	2	0	0
1.35	0.99	28.57	57.30	58.10	0.50	1.32	1	5	23	2	3	5	61	9	18	32	31	0	0	0	0	10	2	0	0
1.40	1.04	31.03	57.60	58.50	0.52	1.34	0	5	23	0	3	4	64	8	17	31	33	0	0	0	0	10	2	0	0
1.45	1.08	33.59	58.10	59.00	0.54	1.40	0	5	22	1	2	3	67	8	16	30	35	0	0	0	0	10	2	0	0
1.50	1.12	36.27	58.70	59.60	0.55	1.42	0	4	22	1	1	2	70	8	16	29	37	0	0	0	0	10	2	0	0
1.55	1.16	39.05	59.20	60.10	0.57	1.45	0	4	22	1	1	1	72	7	15	28	39	0	0	0	0	10	2	0	0
1.60	1.20	41.94	59.80	60.70	0.59	1.49	0	3	21	1	1	1	73	7	15	27	41	0	0	0	0	10	2	0	0
1.65	1.23	44.95	60.40	61.30	0.60	1.51	0	2	21	1	1	1	73	7	15	27	42	0	0	0	0	10	2	0	0
1.70	1.25	48.06	62.30	63.20	0.62	1.55	1	2	20	3	2	1	72	7	14	26	44	0	0	0	0	10	2	0	0
1.75	1.26	51.28	64.10	65.00	0.64	1.55	1	2	20	3	2	2	71	6	14	25	45	0	0	0	0	9	2	0	0
1.80	1.27	54.62	65.90	66.90	0.65	1.56	1	2	19	4	2	2	71	6	13	25	47	0	0	0	0	9	2	0	0
1.85	1.28	58.07	68.10	69.10	0.66	1.60	1	2	17	4	3	3	69	6	13	24	48	0	0	0	0	9	2	0	0
1.90	1.27	61.63	71.80	72.70	0.68	1.59	1	2	16	6	4	3	67	6	13	24	49	0	0	0	0	8	2	0	0
1.95	1.27	65.30	74.30	75.30	0.69	1.62	1	3	15	6	4	3	67	6	12	23	51	0	0	0	0	8	2	0	0
2.00	1.29	69.08	76.00	77.00	0.70	1.63	1	3	15	5	4	3	68	6	12	23	51	0	0	0	0	8	2	0	0
2.05	1.31	72.98	77.80	78.80	0.71	1.65	1	3	14	4	5	4	68	5	12	23	53	0	0	0	0	8	2	0	0
2.10	1.33	77.00	79.50	80.60	0.73	1.66	1	4	14	3	4	5	69	5	12	22	53	0	0	0	0	8	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
2.15	1.35	81.12	81.30	82.30	0.74	1.70	1	4	13	3	5	5	69	5	11	21	55	0	0	0	0	7	2	0	0
2.20	1.36	85.36	84.20	85.30	0.75	1.68	1	4	13	3	3	3	72	5	11	22	55	0	0	0	0	7	2	0	0
2.25	1.36	89.72	87.00	88.10	0.76	1.74	1	3	13	5	4	3	72	5	11	21	56	0	0	0	0	7	2	0	0
2.30	1.37	94.19	89.80	90.90	0.77	1.76	1	3	12	5	4	4	70	5	11	21	57	0	0	0	0	7	2	0	0
2.35	1.38	98.78	92.60	93.70	0.77	1.75	1	3	12	4	4	4	71	5	10	21	58	0	0	0	0	6	2	0	0
2.40	1.39	103.48	95.40	96.50	0.78	1.77	1	3	12	5	4	4	71	5	10	20	59	0	0	0	0	6	2	0	0
2.45	1.40	108.30	98.20	99.40	0.79	1.77	1	3	12	4	4	6	70	5	10	20	59	0	0	0	0	6	2	0	0
2.50	1.41	113.24	101.00	102.20	0.80	1.79	1	3	12	4	4	6	70	5	10	20	60	0	0	0	0	6	2	0	0
2.55	1.42	118.29	103.80	105.00	0.80	1.81	1	3	11	5	5	4	70	5	10	19	60	0	0	0	0	6	2	0	0
2.60	1.43	123.46	106.60	107.80	0.81	1.82	1	3	12	4	4	4	72	5	10	19	61	0	0	0	0	6	2	0	0
2.65	1.42	128.75	111.30	112.60	0.82	1.83	1	3	11	5	5	5	71	5	10	19	61	0	0	0	0	5	2	0	0
2.70	1.37	134.16	119.40	120.70	0.82	1.86	1	3	10	7	7	5	67	4	9	19	62	0	0	0	0	5	2	0	0
2.75	1.32	139.68	128.70	130.00	0.82	1.82	1	3	10	8	8	4	65	4	9	19	62	0	0	0	0	5	2	0	0
2.80	1.28	145.32	138.00	139.30	0.82	1.80	2	3	10	10	9	4	63	4	9	19	63	0	0	0	0	4	2	0	0
2.85	1.23	151.08	149.00	150.30	0.82	1.75	2	3	9	10	10	4	61	4	9	20	62	0	0	0	0	4	2	0	0
2.90	1.15	156.96	166.70	168.10	0.82	1.74	2	4	8	12	11	6	57	4	9	20	63	0	0	0	0	4	2	0	0
2.95	1.12	162.96	178.10	179.40	0.81	1.75	2	4	8	12	12	6	56	4	9	20	63	0	0	0	0	3	2	0	0
3.00	1.14	169.08	183.30	184.70	0.81	1.74	2	5	8	10	10	7	59	4	10	20	63	0	0	0	0	3	2	0	0
3.05	1.13	175.32	193.50	194.90	0.80	1.75	2	5	8	10	10	8	58	4	10	20	63	0	0	0	0	3	2	0	0
3.10	1.15	181.68	198.10	199.60	0.80	1.73	1	5	8	7	7	10	62	4	10	20	62	0	0	0	0	3	2	0	0
3.15	1.19	188.16	200.60	202.00	0.79	1.73	1	6	9	4	4	11	66	5	10	21	62	0	0	0	0	3	2	0	0
3.20	1.24	194.77	201.10	202.60	0.78	1.76	1	5	9	4	4	9	68	5	10	21	62	0	0	0	0	3	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
3.25	1.28	201.49	201.60	203.10	0.78	1.76	1	5	10	3	3	7	71	5	10	21	61	0	0	0	0	3	2	0	0
3.30	1.33	208.33	202.20	203.60	0.78	1.78	0	5	11	1	1	8	75	5	11	21	61	0	0	0	0	3	2	0	0
3.35	1.37	215.30	202.70	204.20	0.77	1.76	0	4	13	0	0	4	79	5	11	21	60	0	0	0	0	3	2	0	0
3.40	1.42	222.38	203.20	204.70	0.77	1.78	0	3	14	0	0	3	80	5	11	21	60	0	0	0	0	3	2	0	0
3.45	1.45	229.59	205.70	207.20	0.77	1.77	0	2	14	0	0	3	80	5	11	21	60	0	0	0	0	3	2	0	0
3.50	1.47	236.92	211.10	212.60	0.77	1.78	0	2	15	2	2	2	78	5	11	21	60	0	0	0	0	3	2	0	0
3.55	1.48	244.37	216.50	218.10	0.76	1.75	0	2	15	2	2	2	78	5	11	22	59	0	0	0	0	3	2	0	0
3.60	1.49	251.95	221.90	223.50	0.76	1.76	1	1	15	2	2	1	77	5	11	22	59	0	0	0	0	3	2	0	0
3.65	1.50	259.65	228.10	229.70	0.76	1.77	1	1	15	4	4	2	73	5	11	22	59	0	0	0	0	3	2	0	0
3.70	1.51	267.47	234.80	236.30	0.76	1.77	1	2	15	4	4	2	72	5	12	22	59	0	0	0	0	3	2	0	0
3.75	1.52	275.42	241.40	243.00	0.75	1.77	1	2	15	4	4	3	71	6	12	22	58	0	0	0	0	2	2	0	0
3.80	1.52	283.49	248.10	249.60	0.75	1.76	1	2	15	4	4	3	71	6	12	22	58	0	0	0	0	2	2	0	0
3.85	1.53	291.68	254.70	256.30	0.75	1.76	1	3	14	4	4	3	71	6	12	22	58	0	0	0	0	2	2	0	0
3.90	1.54	299.99	261.40	263.00	0.74	1.76	1	3	14	4	4	4	71	6	12	22	58	0	0	0	0	2	2	0	0
3.95	1.55	308.44	268.00	269.60	0.74	1.75	1	3	14	4	4	4	71	6	12	23	57	0	0	0	0	2	2	0	0
4.00	1.57	317.00	274.70	276.30	0.74	1.74	1	3	14	3	3	4	71	6	12	23	57	0	0	0	0	2	2	0	0
4.05	1.58	325.69	280.60	282.20	0.73	1.77	1	3	14	4	4	4	70	6	12	23	57	0	0	0	0	2	2	0	0
4.10	1.60	334.51	286.20	287.90	0.73	1.77	1	3	15	4	4	4	70	6	12	23	57	0	0	0	0	2	2	0	0
4.15	1.62	343.45	291.90	293.60	0.73	1.77	1	3	15	3	3	3	71	6	12	23	57	0	0	0	0	2	2	0	0
4.20	1.64	352.51	296.70	298.30	0.72	1.76	1	3	15	3	3	3	71	6	13	23	56	0	0	0	0	2	2	0	0
4.25	1.68	361.70	299.90	301.60	0.72	1.76	1	3	16	3	3	3	73	6	13	23	56	0	0	0	0	2	2	0	0
4.30	1.71	371.02	303.20	304.90	0.72	1.79	1	3	16	3	3	3	73	6	13	23	56	0	0	0	0	2	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
4.35	1.74	380.46	306.50	308.20	0.71	1.79	1	3	16	2	2	3	73	6	13	23	55	0	0	0	0	2	2	0	0
4.40	1.77	390.03	309.80	311.50	0.71	1.78	0	2	17	2	2	2	74	6	13	24	55	0	0	0	0	2	2	0	0
4.45	1.80	399.73	313.10	314.80	0.71	1.81	0	3	17	2	2	2	74	7	13	23	55	0	0	0	0	2	2	0	0
4.50	1.83	409.55	316.40	318.10	0.71	1.80	0	2	18	2	2	2	75	7	13	23	55	0	0	0	0	2	2	0	0
4.55	1.87	419.50	318.70	320.50	0.70	1.83	0	2	18	2	2	2	74	7	13	23	55	0	0	0	0	2	2	0	0
4.60	1.91	429.58	320.40	322.20	0.70	1.81	0	2	19	1	1	1	75	7	14	24	54	0	0	0	0	2	2	0	0
4.65	1.95	439.78	322.10	323.80	0.70	1.83	0	2	19	1	1	1	77	7	14	24	54	0	0	0	0	2	2	0	0

Table 2-8 Hydraulic habitat look-up table for fish and invertebrates at EWR Site BM1 (riffle) for the discharge range 0.00 to 910 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.22	0.10	0.00	4.80	5.10	0.00	0.01	55	45	0	0	0	0	0	15	0	0	0	85	0	0	0	0	0	0	0
0.25	0.11	0.02	5.60	6.00	0.03	0.10	57	43	0	0	0	0	0	15	0	0	0	82	3	0	0	0	0	0	0
0.30	0.14	0.10	6.50	7.10	0.11	0.39	46	47	0	4	1	2	0	8	6	1	0	47	32	6	0	0	0	0	0
0.35	0.17	0.26	7.40	8.10	0.21	0.70	17	56	0	6	12	3	6	5	6	3	1	28	34	19	4	0	0	0	0
0.40	0.20	0.54	8.40	9.20	0.32	1.04	12	42	0	10	17	7	12	3	5	5	2	18	27	29	10	0	0	0	0
0.45	0.22	0.89	9.40	10.40	0.42	1.31	8	32	0	12	12	20	16	2	4	5	3	13	21	31	20	0	0	0	0
0.50	0.24	1.35	11.10	12.20	0.51	1.54	8	24	0	17	10	19	21	2	3	5	5	10	18	27	30	0	0	0	0
0.55	0.26	1.91	12.60	13.80	0.59	1.74	7	18	3	18	12	12	31	1	3	4	7	8	15	24	38	0	0	0	0
0.60	0.29	2.57	13.50	14.80	0.66	1.91	4	17	4	12	17	10	36	1	2	4	8	7	14	21	43	0	0	0	0
0.65	0.30	3.34	15.40	16.90	0.73	2.01	4	15	3	13	16	11	38	1	2	3	8	6	12	19	47	1	1	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.70	0.32	4.23	16.90	18.50	0.78	2.14	4	12	5	15	12	12	41	1	2	3	9	6	11	17	50	1	1	0	0
0.75	0.36	5.22	17.20	18.80	0.83	2.30	2	11	6	7	14	15	45	1	2	3	9	5	10	16	52	2	1	0	0
0.80	0.41	6.33	17.40	19.10	0.89	2.48	0	10	7	2	17	11	53	1	2	2	10	5	10	14	54	3	1	0	0
0.85	0.45	7.56	17.60	19.40	0.94	2.59	0	9	7	1	9	14	59	1	2	2	10	4	9	13	55	3	1	0	0
0.90	0.50	8.90	17.80	19.60	1.00	2.73	0	8	7	1	4	15	65	1	1	2	10	4	8	12	57	4	1	0	0
0.95	0.53	10.37	18.60	20.40	1.06	2.79	1	6	7	4	3	10	69	1	1	2	10	4	8	11	58	5	1	0	0
1.00	0.54	11.96	19.90	21.60	1.11	2.85	1	4	7	9	2	3	73	1	1	2	11	3	7	11	60	5	1	0	0
1.05	0.58	13.66	20.20	22.00	1.16	2.84	1	4	7	4	6	2	76	1	1	2	11	3	6	10	61	6	1	0	0
1.10	0.62	15.50	20.60	22.40	1.21	2.83	0	3	7	3	7	2	77	0	1	2	11	3	6	10	62	6	1	0	0
1.15	0.66	17.45	21.00	22.80	1.26	2.86	0	2	7	3	7	5	76	0	1	2	11	3	5	9	63	7	1	0	0
1.20	0.69	19.54	21.60	23.50	1.31	2.94	0	2	7	3	5	6	77	0	1	1	11	2	5	8	64	6	2	0	0
1.25	0.72	21.75	22.20	24.10	1.36	3.00	0	2	6	4	4	6	77	0	1	1	12	2	4	8	65	6	2	0	0
1.30	0.75	24.09	22.90	24.70	1.41	3.04	0	1	6	4	5	5	79	0	1	1	12	2	4	7	66	6	2	0	0
1.35	0.78	26.56	23.60	25.40	1.45	3.07	0	1	5	4	5	4	80	0	1	1	12	2	4	7	67	6	2	0	0
1.40	0.80	29.16	24.40	26.30	1.50	3.12	0	1	5	5	5	4	80	0	1	1	12	2	4	7	68	6	2	0	0
1.45	0.82	31.89	25.30	27.20	1.54	3.18	0	1	5	5	6	4	79	0	1	1	12	2	3	6	69	6	2	0	0
1.50	0.84	34.75	26.20	28.10	1.58	3.30	0	1	4	7	6	5	77	0	1	1	12	2	3	6	70	5	2	0	0
1.55	0.86	37.75	27.10	28.90	1.62	3.35	0	1	4	6	5	5	78	0	1	1	12	1	3	6	70	5	2	0	0
1.60	0.88	40.88	27.90	29.80	1.65	3.42	0	1	4	6	6	5	78	0	0	1	13	1	3	6	71	5	2	0	0
1.65	0.91	44.15	28.80	30.70	1.69	3.42	0	1	3	5	6	5	79	0	0	1	13	1	3	5	72	5	2	0	0
1.70	0.94	47.55	29.40	31.40	1.72	3.49	0	1	3	5	6	6	79	0	0	1	13	1	2	5	72	5	2	0	0
1.75	0.97	51.09	30.10	32.00	1.76	3.54	0	1	3	3	5	6	82	0	0	1	13	1	2	5	73	5	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
1.80	1.00	54.77	30.70	32.60	1.79	3.61	0	1	3	3	4	5	83	0	0	1	13	1	2	5	73	5	2	0	0
1.85	1.03	58.58	31.40	33.30	1.82	3.67	0	1	3	3	4	5	84	0	0	1	13	1	2	5	73	4	2	0	0
1.90	1.05	62.54	32.00	33.90	1.85	3.71	0	1	3	3	4	4	85	0	0	1	13	1	2	5	73	4	2	0	0
1.95	1.08	66.63	32.60	34.60	1.89	3.82	0	1	3	3	3	4	86	0	0	1	13	1	2	5	74	4	2	0	0
2.00	1.11	70.87	33.30	35.20	1.92	3.86	0	1	3	3	3	4	86	0	0	1	13	1	2	4	74	4	2	0	0
2.05	1.14	75.25	33.90	35.90	1.95	3.94	0	1	3	3	3	3	86	0	0	1	13	1	2	4	74	4	2	0	0
2.10	1.17	79.76	34.50	36.50	1.98	3.94	0	1	3	3	3	3	87	0	0	1	13	1	2	4	74	4	2	0	0
2.15	1.20	84.43	35.10	37.10	2.00	4.07	0	1	3	3	3	3	86	0	0	1	13	1	2	4	75	4	2	0	0
2.20	1.23	89.23	35.70	37.70	2.03	4.08	0	0	3	3	3	3	88	0	0	1	13	1	2	4	75	4	2	0	0
2.25	1.26	94.18	36.20	38.20	2.06	4.16	0	0	3	3	3	3	88	0	0	1	13	1	2	4	75	4	2	0	0
2.30	1.30	99.27	36.60	38.60	2.09	4.27	0	0	3	2	3	3	88	0	0	1	13	1	2	4	75	4	2	0	0
2.35	1.33	104.51	37.00	39.00	2.12	4.30	0	0	3	2	3	4	89	0	0	1	13	1	2	4	75	4	2	0	0
2.40	1.37	109.89	37.40	39.40	2.15	4.33	0	0	3	1	2	3	90	0	0	1	13	1	2	4	75	4	2	0	0
2.45	1.41	115.42	37.70	39.80	2.17	4.44	0	0	3	2	2	3	90	0	0	1	13	1	2	4	75	4	2	0	0
2.50	1.44	121.10	38.10	40.20	2.20	4.49	0	0	3	2	2	2	91	0	0	1	13	1	2	4	76	4	2	0	0
2.55	1.49	126.92	38.30	40.40	2.23	4.54	0	0	3	2	2	2	91	0	0	1	13	1	2	4	76	4	2	0	0
2.60	1.53	132.90	38.30	40.60	2.26	4.58	0	0	3	1	1	2	92	0	0	1	13	1	2	3	76	4	2	0	0
2.65	1.58	139.02	38.40	40.70	2.29	4.65	0	0	3	1	1	2	93	0	0	1	13	1	2	3	76	4	2	0	0
2.70	1.62	145.29	38.70	41.10	2.32	4.67	0	0	3	0	0	2	94	0	0	1	13	1	2	3	76	4	2	0	1
2.75	1.66	151.71	38.90	41.20	2.35	4.73	0	0	3	0	0	2	95	0	0	1	13	1	2	3	76	4	2	0	1
2.80	1.70	158.28	39.10	41.50	2.38	4.79	0	0	3	0	0	2	95	0	0	1	13	1	2	3	76	4	2	0	1
2.85	1.75	165.00	39.20	41.70	2.41	4.86	0	0	3	1	1	1	95	0	0	1	13	1	2	3	76	4	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
2.90	1.79	171.87	39.40	41.90	2.44	4.93	0	0	3	1	1	1	96	0	0	1	14	1	2	3	77	4	2	0	1
2.95	1.83	178.89	39.60	42.10	2.47	5.00	0	0	3	0	1	1	95	0	0	1	14	1	2	3	77	4	2	0	1
3.00	1.87	186.07	39.80	42.30	2.50	5.06	0	0	3	0	0	1	95	0	0	1	14	1	2	3	77	4	2	0	1
3.05	1.91	193.40	40.00	42.50	2.53	5.10	0	0	3	0	0	1	95	0	0	1	14	1	2	3	77	4	2	0	1
3.10	1.95	200.88	40.20	42.80	2.56	5.14	0	0	3	0	0	1	95	0	0	0	14	1	2	3	77	3	2	0	1
3.15	1.99	208.51	40.40	43.00	2.59	5.24	0	0	3	0	0	1	95	0	0	0	14	1	2	3	77	3	2	0	1
3.20	2.03	216.30	40.50	43.20	2.62	5.31	0	0	3	0	0	1	95	0	0	0	14	1	2	3	77	3	2	0	1
3.25	2.07	224.24	40.70	43.40	2.65	5.38	0	0	3	0	0	1	96	0	0	0	14	1	1	3	77	3	2	0	1
3.30	2.11	232.34	40.90	43.60	2.69	5.44	0	0	3	0	0	1	96	0	0	0	14	1	1	3	77	3	2	0	1
3.35	2.16	240.59	41.10	43.80	2.72	5.47	0	0	3	0	0	1	96	0	0	0	14	1	1	2	77	3	2	0	1
3.40	2.20	249.00	41.30	44.00	2.75	5.54	0	0	3	0	0	1	96	0	0	0	14	1	1	2	78	3	2	0	1
3.45	2.23	257.57	41.60	44.30	2.78	5.66	0	0	2	1	1	1	95	0	0	0	14	1	1	2	78	3	2	0	1
3.50	2.25	266.29	42.10	44.90	2.81	5.73	0	0	2	1	1	1	94	0	0	0	14	1	1	2	78	3	2	0	1
3.55	2.26	275.17	42.90	45.70	2.84	5.73	0	0	2	2	2	1	93	0	0	0	14	1	1	2	78	3	2	0	1
3.60	2.27	284.21	43.70	46.60	2.87	5.81	0	0	2	2	2	1	92	0	0	0	14	1	1	2	78	3	2	0	1
3.65	2.28	293.40	44.30	47.20	2.90	5.85	0	0	2	3	3	2	90	0	0	0	14	1	1	2	78	3	2	0	1
3.70	2.32	302.75	44.60	47.50	2.92	5.87	0	0	2	2	2	2	91	0	0	0	14	1	1	2	78	3	2	0	1
3.75	2.36	312.26	44.90	47.80	2.95	6.01	0	0	2	2	2	2	91	0	0	0	14	1	1	2	78	3	2	0	1
3.80	2.39	321.93	45.20	48.10	2.98	6.02	0	0	2	2	2	2	93	0	0	0	14	1	1	2	78	3	2	0	1
3.85	2.43	331.76	45.40	48.40	3.01	6.06	0	0	2	1	1	1	94	0	0	0	14	1	1	2	78	3	2	0	1
3.90	2.46	341.75	45.70	48.70	3.04	6.20	0	0	2	1	1	2	94	0	0	0	14	1	1	2	78	3	2	0	1
3.95	2.50	351.90	46.00	49.00	3.06	6.16	0	0	2	1	1	1	95	0	0	0	14	1	1	2	78	3	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)										Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
4.00	2.53	362.21	46.20	49.30	3.09	6.23	0	0	2	1	1	2	94	0	0	0	14	1	1	2	79	3	2	0	1
4.05	2.57	372.69	46.50	49.60	3.12	6.32	0	0	2	1	1	1	94	0	0	0	14	1	1	2	79	3	2	0	1
4.10	2.60	383.32	46.80	49.90	3.15	6.35	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.15	2.64	394.11	47.00	50.20	3.17	6.43	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.20	2.67	405.07	47.30	50.50	3.20	6.51	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.25	2.71	416.19	47.60	50.80	3.23	6.50	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.30	2.74	427.47	47.90	51.10	3.26	6.64	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.35	2.78	438.92	48.10	51.40	3.28	6.70	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.40	2.81	450.52	48.40	51.70	3.31	6.64	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.45	2.85	462.30	48.70	52.00	3.34	6.78	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.50	2.88	474.23	48.90	52.30	3.36	6.79	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.55	2.91	486.33	49.20	52.60	3.39	6.84	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.60	2.95	498.60	49.50	52.90	3.42	6.96	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.65	2.98	511.03	49.80	53.20	3.44	6.97	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.70	3.02	523.63	50.00	53.50	3.47	7.01	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.75	3.05	536.39	50.30	53.80	3.50	7.13	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.80	3.08	549.32	50.60	54.10	3.52	7.07	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.85	3.12	562.41	50.80	54.40	3.55	7.16	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
4.90	3.15	575.67	51.10	54.70	3.58	7.27	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
4.95	3.18	589.10	51.40	54.90	3.60	7.25	0	0	2	1	1	1	96	0	0	0	14	1	1	2	79	3	2	0	1
5.00	3.22	602.70	51.60	55.20	3.63	7.39	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
5.05	3.26	616.46	51.80	55.50	3.65	7.44	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)										Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
5.10	3.29	630.39	52.00	55.70	3.68	7.49	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
5.15	3.33	644.49	52.30	56.00	3.71	7.51	0	0	2	1	1	1	95	0	0	0	14	1	1	2	80	3	2	0	1
5.20	3.36	658.76	52.50	56.30	3.73	7.56	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.25	3.40	673.20	52.70	56.50	3.76	7.58	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
5.30	3.43	687.81	53.00	56.80	3.78	7.66	0	0	2	1	1	1	95	0	0	0	14	1	1	2	79	3	2	0	1
5.35	3.47	702.58	53.20	57.00	3.81	7.64	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.40	3.50	717.53	53.40	57.30	3.84	7.71	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.45	3.54	732.64	53.70	57.60	3.86	7.77	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.50	3.57	747.93	53.90	57.80	3.89	7.82	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.55	3.61	763.38	54.10	58.10	3.91	7.87	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.60	3.64	779.01	54.40	58.30	3.94	7.91	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.65	3.68	794.81	54.60	58.60	3.96	7.97	0	0	2	1	1	1	96	0	0	0	14	1	1	2	80	3	2	0	1
5.70	3.71	810.78	54.80	58.90	3.99	8.10	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
5.75	3.74	826.92	55.00	59.10	4.01	8.13	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
5.80	3.78	843.24	55.30	59.40	4.04	8.18	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
5.85	3.81	859.72	55.50	59.60	4.06	8.26	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
5.90	3.85	876.38	55.70	59.90	4.09	8.31	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
5.95	3.88	893.21	56.00	60.20	4.11	8.38	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
6.00	3.91	910.21	56.20	60.40	4.14	8.41	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	2	2	0	1
5.80	3.78	843.24	55.30	59.40	4.04	8.18	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
5.85	3.81	859.72	55.50	59.60	4.06	8.26	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
5.90	3.85	876.38	55.70	59.90	4.09	8.31	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
5.95	3.88	893.21	56.00	60.20	4.11	8.38	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	3	2	0	1
6.00	3.91	910.21	56.20	60.40	4.14	8.41	0	0	2	1	1	1	96	0	0	0	14	0	1	1	80	2	2	0	1

Table 2-9 Hydraulic habitat look-up table for fish and invertebrates at EWR Site BM2 A (riffle) for the discharge range 0.00 to 6.92 m³/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.01	0.01	0.00	0.70	0.70	0.03	0.10	100	0	0	0	0	0	0	32	1	0	0	65	2	0	0	0	0	0	0
0.05	0.04	0.00	1.20	1.20	0.09	0.32	97	0	0	3	0	0	0	20	12	1	0	41	24	2	0	0	0	0	0
0.10	0.06	0.02	2.10	2.20	0.14	0.46	87	4	0	9	0	0	0	14	15	3	0	29	31	6	0	0	0	0	0
0.15	0.07	0.04	4.10	4.20	0.16	0.53	61	26	0	9	4	0	0	13	16	4	0	26	33	8	1	0	0	0	0
0.20	0.10	0.12	4.90	4.90	0.23	0.74	39	31	0	16	12	1	0	9	14	8	2	19	29	16	3	0	0	0	0
0.25	0.14	0.24	5.20	5.30	0.32	1.01	11	42	0	10	26	11	0	7	11	12	4	14	22	24	8	0	0	0	0
0.30	0.18	0.37	5.80	5.90	0.36	1.15	7	39	0	9	25	19	1	6	9	12	5	12	19	25	11	0	0	0	0
0.35	0.21	0.53	6.50	6.60	0.39	1.23	8	35	0	11	13	23	11	5	9	12	7	11	18	25	14	0	0	0	0
0.40	0.23	0.71	7.20	7.30	0.42	1.29	7	31	0	11	8	23	18	5	8	12	8	9	16	25	16	0	0	0	0
0.45	0.27	0.92	7.60	7.70	0.45	1.33	5	30	0	9	11	9	35	4	7	12	9	8	15	25	18	0	0	0	0
0.50	0.30	1.17	8.10	8.30	0.48	1.38	4	28	1	8	11	7	41	4	7	12	11	7	14	24	22	0	0	0	0
0.55	0.33	1.45	8.70	8.90	0.51	1.41	4	22	4	10	8	10	42	3	7	11	12	7	13	23	24	0	0	0	0
0.60	0.30	1.77	11.30	11.50	0.53	1.44	8	15	6	19	6	8	37	3	6	11	12	7	13	22	25	0	0	0	0
0.65	0.29	2.12	13.70	13.90	0.53	1.45	10	11	8	25	7	6	34	3	6	11	13	7	13	22	26	0	0	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.70	0.33	2.50	14.10	14.30	0.53	1.46	5	13	10	14	16	5	36	3	6	11	13	6	13	22	26	0	0	0	0
0.75	0.37	2.92	14.50	14.70	0.54	1.43	1	16	10	3	25	6	38	3	6	11	13	6	12	22	26	0	0	0	0
0.80	0.41	3.38	14.90	15.10	0.55	1.46	1	15	10	3	14	16	40	3	6	11	13	6	12	21	27	0	1	0	0
0.85	0.45	3.87	15.20	15.40	0.56	1.48	1	14	11	3	6	21	43	3	6	10	14	6	12	21	28	1	1	0	0
0.90	0.49	4.40	15.50	15.70	0.58	1.48	1	13	12	2	3	14	55	3	6	10	14	5	11	20	29	2	1	0	0
0.95	0.53	4.97	15.80	16.00	0.59	1.50	1	12	12	2	3	5	65	3	5	10	14	5	11	20	29	3	1	0	0
1.00	0.57	5.58	16.10	16.40	0.61	1.53	1	11	12	2	3	3	68	2	5	9	15	5	10	19	30	4	1	0	0
1.05	0.61	6.23	16.40	16.70	0.62	1.57	1	10	12	3	3	3	68	2	5	9	15	5	10	18	31	5	1	0	0
1.10	0.65	6.92	16.70	17.00	0.64	1.59	1	6	15	3	3	3	69	2	5	9	16	5	9	17	32	5	1	0	0

Table 2-10 Hydraulic habitat look-up table for the geomorphology at EWR Site BM2 B (bedrock chute) for the discharge range 0.00 to 1334 m^3/s

Maxdepth (m)	Avdepth (m)	Discharge (m3/s)	Width (m)	Perim (m)	AvVel (m/s)	Vel98% (m/s)
0.01	0.00	0.00	0.40	0.40	0.01	0.03
0.05	0.03	0.00	1.00	1.00	0.05	0.16
0.10	0.07	0.01	1.40	1.40	0.11	0.37
0.15	0.05	0.02	4.30	4.30	0.09	0.32
0.20	0.10	0.07	4.50	4.50	0.16	0.53
0.25	0.14	0.14	4.60	4.70	0.22	0.71
0.30	0.19	0.25	4.80	4.90	0.28	0.90
0.35	0.23	0.39	4.90	5.10	0.34	1.10
0.40	0.28	0.57	5.00	5.20	0.41	1.29
0.45	0.32	0.79	5.10	5.40	0.48	1.50
0.50	0.37	1.06	5.10	5.50	0.56	1.66
0.55	0.42	1.38	5.10	5.60	0.65	1.80
0.60	0.46	1.77	5.20	5.70	0.74	1.91
0.65	0.51	2.21	5.20	5.80	0.83	2.01
0.70	0.56	2.72	5.20	5.90	0.93	2.10
0.75	0.60	3.31	5.30	6.00	1.04	2.22
0.80	0.65	3.96	5.30	6.10	1.15	2.37
0.85	0.69	4.70	5.30	6.20	1.27	2.60
0.90	0.74	5.52	5.40	6.30	1.39	2.85
0.95	0.78	6.42	5.40	6.40	1.51	3.11
1.00	0.72	7.42	6.30	7.40	1.63	3.31
1.05	0.68	8.51	7.20	8.40	1.74	3.52
1.10	0.65	9.69	8.10	9.40	1.84	3.69
1.15	0.63	10.98	9.00	10.30	1.93	3.90
1.20	0.62	12.38	9.90	11.30	2.01	4.04
1.25	0.62	13.88	10.80	12.30	2.08	4.16
1.30	0.62	15.50	11.80	13.30	2.14	4.34
1.35	0.62	17.23	12.70	14.30	2.19	4.46
1.40	0.63	19.09	13.40	15.10	2.24	4.50
1.45	0.58	21.06	15.90	17.60	2.28	4.56
1.50	0.50	23.17	20.50	22.20	2.28	4.58
1.55	0.52	25.40	21.40	23.10	2.27	4.66

Maxdepth (m)	Avdepth (m)	Discharge (m3/s)	Width (m)	Perim (m)	AvVel (m/s)	Vel98% (m/s)
1.60	0.55	27.77	22.30	24.00	2.26	4.50
1.65	0.58	30.28	23.20	24.90	2.26	4.66
1.70	0.61	32.93	24.10	25.80	2.25	4.52
1.75	0.64	35.72	24.90	26.60	2.26	4.59
1.80	0.67	38.66	25.50	27.20	2.26	4.65
1.85	0.71	41.76	26.00	27.80	2.27	4.57
1.90	0.74	45.00	26.60	28.40	2.28	4.61
1.95	0.77	48.41	27.20	29.00	2.30	4.71
2.00	0.81	51.98	27.80	29.60	2.32	4.69
2.05	0.84	55.71	28.40	30.20	2.34	4.76
2.10	0.87	59.61	29.00	30.80	2.36	4.84
2.15	0.90	63.69	29.90	31.70	2.38	4.87
2.20	0.92	67.94	30.80	32.60	2.41	4.84
2.25	0.94	72.36	31.80	33.60	2.43	4.92
2.30	0.94	76.97	33.30	35.10	2.45	4.97
2.35	0.93	81.76	35.50	37.40	2.47	5.03
2.40	0.93	86.75	37.80	39.60	2.48	5.03
2.45	0.92	91.92	40.00	41.90	2.49	5.08
2.50	0.92	97.29	42.30	44.20	2.50	4.97
2.55	0.92	102.85	44.70	46.60	2.50	5.01
2.60	0.92	108.62	47.20	49.00	2.50	5.01
2.65	0.94	114.59	48.60	50.40	2.50	5.05
2.70	0.98	120.76	49.20	51.10	2.50	5.11
2.75	1.02	127.15	49.90	51.80	2.50	5.03
2.80	1.05	133.75	50.60	52.50	2.51	5.03
2.85	1.09	140.57	51.20	53.10	2.52	5.10
2.90	1.13	147.61	51.90	53.80	2.53	5.08
2.95	1.16	154.87	52.60	54.50	2.54	5.13
3.00	1.20	162.35	53.30	55.20	2.55	5.16
3.05	1.23	170.07	53.90	55.90	2.56	5.14
3.10	1.26	178.02	54.60	56.60	2.58	5.22
3.15	1.30	186.20	55.30	57.30	2.59	5.28
3.20	1.33	194.62	56.00	58.00	2.61	5.28
3.25	1.37	203.29	56.70	58.70	2.63	5.25
3.30	1.40	212.20	57.30	59.40	2.64	5.27

Maxdepth (m)	Avdepth (m)	Discharge (m3/s)	Width (m)	Perim (m)	AvVel (m/s)	Vel98% (m/s)
3.35	1.43	221.35	58.00	60.10	2.66	5.40
3.40	1.47	230.76	58.70	60.80	2.68	5.45
3.45	1.50	240.42	59.40	61.50	2.70	5.48
3.50	1.53	250.33	60.10	62.20	2.72	5.47
3.55	1.56	260.51	60.70	62.90	2.74	5.51
3.60	1.57	270.95	62.30	64.40	2.76	5.59
3.65	1.57	281.65	64.50	66.60	2.78	5.60
3.70	1.57	292.62	66.70	68.80	2.80	5.71
3.75	1.59	303.87	67.80	69.90	2.82	5.66
3.80	1.63	315.38	68.20	70.30	2.83	5.77
3.85	1.67	327.18	68.60	70.80	2.85	5.80
3.90	1.71	339.26	69.00	71.20	2.87	5.82
3.95	1.75	351.62	69.30	71.60	2.89	5.77
4.00	1.79	364.26	69.70	72.00	2.91	5.83
4.05	1.83	377.20	70.10	72.40	2.93	5.95
4.10	1.87	390.43	70.50	72.80	2.96	5.96
4.15	1.91	403.95	70.90	73.20	2.98	6.08
4.20	1.95	417.77	71.30	73.60	3.00	6.06
4.25	1.99	431.89	71.90	74.30	3.02	6.12
4.30	1.99	446.32	73.50	75.90	3.05	6.22
4.35	2.00	461.05	75.00	77.50	3.07	6.21
4.40	2.01	476.09	76.60	79.10	3.09	6.28
4.45	2.03	491.44	77.90	80.40	3.11	6.26
4.50	2.07	507.11	78.30	80.80	3.14	6.33
4.55	2.11	523.10	78.60	81.20	3.16	6.36
4.60	2.15	539.41	79.00	81.60	3.18	6.48
4.65	2.19	556.04	79.40	82.00	3.20	6.46
4.70	2.23	573.00	79.70	82.40	3.23	6.56
4.75	2.27	590.29	80.10	82.80	3.25	6.54
4.80	2.31	607.91	80.50	83.20	3.28	6.68
4.85	2.34	625.87	80.90	83.60	3.30	6.71
4.90	2.38	644.16	81.30	84.10	3.33	6.73
4.95	2.42	662.79	81.80	84.50	3.35	6.83
5.00	2.46	681.77	82.10	84.90	3.38	6.87
5.05	2.50	701.10	82.40	85.10	3.41	6.93

Maxdepth (m)	**Avdepth (m)**	**Discharge (m3/s)**	**Width (m)**	**Perim (m)**	**AvVel (m/s)**	**Vel98% (m/s)**
5.10	2.54	720.77	82.60	85.40	3.43	7.00
5.15	2.59	740.80	82.80	85.60	3.46	6.98
5.20	2.63	761.18	83.00	85.80	3.49	7.06
5.25	2.67	781.92	83.20	86.00	3.52	7.14
5.30	2.72	803.02	83.30	86.30	3.54	7.26
5.35	2.76	824.48	83.50	86.50	3.57	7.25
5.40	2.81	846.31	83.70	86.70	3.60	7.30
5.45	2.85	868.50	83.90	86.90	3.63	7.44
5.50	2.89	891.07	84.10	87.10	3.66	7.50
5.55	2.94	914.02	84.30	87.30	3.69	7.54
5.60	2.98	937.34	84.50	87.60	3.72	7.55
5.65	3.02	961.03	84.70	87.80	3.75	7.57
5.70	3.07	985.12	84.90	88.00	3.79	7.61
5.75	3.11	1009.58	85.10	88.20	3.82	7.68
5.80	3.15	1034.44	85.20	88.40	3.85	7.83
5.85	3.20	1059.68	85.40	88.70	3.88	7.91
5.90	3.24	1085.32	85.60	88.90	3.91	7.90
5.95	3.28	1111.36	85.80	89.10	3.95	7.98
6.00	3.32	1137.79	86.00	89.30	3.98	8.10
6.05	3.37	1164.63	86.20	89.50	4.01	8.03
6.10	3.41	1191.87	86.40	89.70	4.05	8.14
6.15	3.45	1219.51	86.60	90.00	4.08	8.29
6.20	3.49	1247.57	86.80	90.20	4.12	8.38
6.25	3.54	1276.04	86.90	90.40	4.15	8.34
6.30	3.58	1304.92	87.10	90.60	4.18	8.43
6.35	3.62	1334.22	87.30	90.80	4.22	8.61

Table 2-11 Hydraulic habitat look-up table for fish and invertebrates at EWR Site WM1 (riffle) for the discharge range 0.00 to 1280 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.40	0.15	0.00	16.60	17.10	0.00	0.00	19	54	0	0	0	0	0	15	0	0	0	85	0	0	0	0	0	0	0
0.45	0.15	0.07	24.90	25.40	0.02	0.07	41	59	0	0	0	0	0	15	0	0	0	85	0	0	0	0	0	0	0
0.50	0.19	0.31	27.10	27.60	0.06	0.23	36	64	0	0	0	0	0	11	4	0	0	65	20	0	0	0	0	0	0
0.55	0.23	0.75	28.10	28.70	0.12	0.40	9	81	1	1	3	2	3	8	5	1	0	47	31	7	0	0	0	0	0
0.60	0.27	1.41	29.20	29.90	0.18	0.64	7	71	3	2	7	3	8	6	6	2	1	34	34	14	3	0	0	0	0
0.65	0.31	2.32	29.70	30.40	0.25	0.85	4	60	3	2	3	11	17	5	5	4	1	27	30	21	7	0	0	0	0
0.70	0.36	3.48	30.10	30.90	0.32	1.08	2	45	7	2	3	10	31	4	4	5	2	21	25	27	12	0	0	0	0
0.75	0.40	4.92	30.60	31.40	0.40	1.33	1	29	14	2	3	6	45	3	4	5	3	15	22	29	19	0	0	0	0
0.80	0.45	6.64	31.00	31.90	0.48	1.54	1	21	15	2	1	5	54	2	3	5	5	13	19	27	26	0	0	0	0
0.85	0.48	8.65	32.20	33.20	0.56	1.79	2	16	15	4	1	4	59	2	3	4	6	10	17	24	34	0	0	0	0
0.90	0.51	10.97	33.50	34.50	0.64	1.98	2	8	18	5	2	2	63	1	3	4	7	8	15	21	40	0	0	0	0
0.95	0.46	13.61	41.00	42.10	0.71	2.18	5	4	15	17	3	2	54	1	2	3	8	7	13	18	46	0	0	0	0
1.00	0.48	16.56	44.30	45.40	0.78	2.33	4	5	13	14	9	2	53	1	2	3	9	6	12	17	50	0	0	0	0
1.05	0.50	19.85	47.20	48.50	0.85	2.39	2	6	12	9	14	5	53	1	2	3	9	6	11	16	52	1	1	0	0
1.10	0.52	23.48	50.20	51.60	0.91	2.53	2	5	11	9	14	8	51	1	2	3	10	5	10	14	55	2	1	0	0
1.15	0.55	27.46	52.20	53.70	0.96	2.60	1	6	9	7	10	14	53	1	2	2	10	4	9	13	57	3	1	0	0
1.20	0.58	31.78	54.10	55.80	1.02	2.71	1	5	8	7	9	14	56	1	1	2	10	4	8	12	58	3	1	0	0
1.25	0.59	36.47	58.00	59.80	1.07	2.70	1	5	7	7	8	9	62	1	1	2	10	4	7	12	59	4	1	0	0
1.30	0.60	41.52	61.80	63.70	1.12	2.79	1	5	6	10	7	8	63	1	1	2	11	3	7	11	60	5	1	0	0
1.35	0.62	46.95	65.20	67.20	1.17	2.82	1	5	6	9	8	7	65	1	1	2	11	3	6	10	61	5	1	0	0
1.40	0.63	52.75	68.60	70.70	1.21	2.82	1	4	6	8	10	6	66	0	1	2	11	3	6	10	62	6	1	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
1.45	0.66	58.94	70.90	73.10	1.26	2.87	1	3	6	7	7	8	67	0	1	2	11	3	5	9	63	6	1	0	0
1.50	0.69	65.51	73.10	75.40	1.30	2.98	0	3	5	5	10	8	68	0	1	1	11	2	5	8	64	7	1	0	0
1.55	0.73	72.48	74.10	76.40	1.34	2.94	0	3	5	4	8	8	72	0	1	1	11	2	4	8	64	7	1	0	0
1.60	0.77	79.85	75.10	77.40	1.38	2.95	0	2	5	2	6	8	76	0	1	1	11	2	4	8	64	8	1	0	0
1.65	0.80	87.62	77.10	79.40	1.42	2.99	0	2	5	3	5	7	78	0	1	1	11	2	4	7	65	9	1	0	0
1.70	0.83	95.80	79.00	81.40	1.46	3.06	0	2	5	3	4	5	80	0	1	1	12	2	4	7	65	9	1	0	0
1.75	0.86	104.39	80.70	83.10	1.50	3.12	0	2	5	4	3	4	82	0	1	1	12	2	3	6	65	9	1	0	0
1.80	0.89	113.41	82.40	84.90	1.54	3.18	0	1	5	3	4	3	84	0	1	1	12	2	3	6	66	10	1	0	0
1.85	0.93	122.84	83.40	85.80	1.58	3.24	0	1	4	2	4	4	84	0	1	1	12	1	3	6	66	10	1	0	0
1.90	0.97	132.70	84.30	86.70	1.62	3.30	0	1	4	2	3	3	86	0	0	1	12	1	3	6	66	11	1	0	0
1.95	1.02	142.99	85.00	87.40	1.66	3.39	0	1	4	1	3	4	87	0	0	1	12	1	2	5	66	11	1	0	0
2.00	1.06	153.72	85.70	88.20	1.70	3.46	0	1	4	1	3	4	89	0	0	1	12	1	2	5	67	12	2	0	0
2.05	1.10	164.88	86.40	88.80	1.74	3.51	0	1	4	1	2	3	91	0	0	1	12	1	2	5	67	12	2	0	0
2.10	1.14	176.49	87.10	89.50	1.78	3.60	0	0	4	1	2	2	91	0	0	1	12	1	2	5	68	11	2	0	0
2.15	1.18	188.54	87.80	90.20	1.82	3.66	0	0	3	1	2	2	91	0	0	1	12	1	2	4	68	11	2	0	0
2.20	1.22	201.04	88.40	90.90	1.86	3.78	0	0	3	1	2	2	91	0	0	1	12	1	2	4	68	11	2	0	0
2.25	1.26	214.00	89.10	91.60	1.90	3.85	0	0	3	1	1	2	92	0	0	1	12	1	2	4	68	11	2	0	0
2.30	1.30	227.42	89.80	92.30	1.95	3.89	0	0	3	1	1	2	93	0	0	1	12	1	2	4	69	11	2	0	0
2.35	1.34	241.29	90.50	93.00	1.99	3.98	0	0	3	1	1	2	93	0	0	1	12	1	2	4	69	11	2	0	0
2.40	1.38	255.63	91.20	93.70	2.03	4.12	0	0	3	1	1	2	92	0	0	1	12	1	2	4	69	11	2	0	0
2.45	1.43	270.44	91.60	94.10	2.07	4.18	0	0	3	1	1	2	92	0	0	1	12	1	2	4	69	11	2	0	0
2.50	1.47	285.72	92.00	94.50	2.11	4.26	0	0	3	1	1	1	94	0	0	1	12	1	2	4	70	11	2	0	0
2.55	1.51	301.47	92.40	94.90	2.16	4.40	0	0	3	1	1	2	94	0	0	1	12	1	2	3	70	11	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
2.60	1.56	317.70	92.80	95.30	2.20	4.43	0	0	3	0	0	2	95	0	0	1	12	1	2	3	70	11	2	0	0
2.65	1.60	334.41	93.10	95.70	2.24	4.55	0	0	3	0	0	2	95	0	0	1	12	1	2	3	70	11	2	0	0
2.70	1.64	351.61	93.50	96.10	2.29	4.70	0	0	3	1	1	1	95	0	0	1	12	1	2	3	70	11	2	0	0
2.75	1.69	369.29	93.90	96.50	2.33	4.73	0	0	3	0	0	1	96	0	0	1	12	1	2	3	71	11	2	0	0
2.80	1.73	387.46	94.30	96.90	2.38	4.80	0	0	3	0	0	1	96	0	0	1	12	1	2	3	71	11	2	0	0
2.85	1.77	406.13	94.70	97.30	2.42	4.94	0	0	3	1	1	1	95	0	0	1	13	1	2	3	71	11	2	0	0
2.90	1.81	425.29	95.10	97.70	2.47	4.98	0	0	3	0	0	1	96	0	0	0	13	1	1	3	71	11	2	0	0
2.95	1.86	444.95	95.50	98.20	2.51	5.05	0	0	3	0	0	1	96	0	0	0	13	1	1	3	71	10	2	0	0
3.00	1.90	465.11	95.90	98.60	2.55	5.23	0	0	3	0	0	1	95	0	0	0	13	1	1	3	71	10	2	0	0
3.05	1.94	485.77	96.30	99.00	2.60	5.27	0	0	3	0	0	1	96	0	0	0	13	1	1	3	72	10	2	0	0
3.10	1.98	506.95	96.70	99.40	2.64	5.43	0	0	3	0	0	1	95	0	0	0	13	1	1	2	72	10	2	0	0
3.15	2.03	528.63	97.00	99.70	2.69	5.44	0	0	3	0	0	1	96	0	0	0	13	1	1	2	72	10	2	0	0
3.20	2.07	550.82	97.30	100.00	2.73	5.55	0	0	3	0	0	1	97	0	0	0	13	1	1	2	72	10	2	0	1
3.25	2.11	573.53	97.60	100.40	2.78	5.67	0	0	2	0	0	1	96	0	0	0	13	1	1	2	72	10	2	0	1
3.30	2.16	596.76	98.00	100.70	2.83	5.76	0	0	2	0	0	1	96	0	0	0	13	1	1	2	72	10	2	0	1
3.35	2.20	620.51	98.30	101.00	2.87	5.79	0	0	2	0	0	1	97	0	0	0	13	1	1	2	72	10	2	0	1
3.40	2.24	644.78	98.60	101.40	2.92	5.88	0	0	2	0	0	1	97	0	0	0	13	1	1	2	72	10	2	0	1
3.45	2.28	669.58	98.90	101.70	2.96	6.00	0	0	2	0	0	1	97	0	0	0	13	1	1	2	73	10	2	0	1
3.50	2.33	694.90	99.20	102.00	3.01	6.12	0	0	2	0	0	1	96	0	0	0	13	1	1	2	73	10	2	0	1
3.55	2.37	720.76	99.50	102.40	3.06	6.15	0	0	2	0	0	1	96	0	0	0	13	1	1	2	73	10	2	0	1
3.60	2.41	747.15	99.90	102.70	3.10	6.23	0	0	2	0	0	1	96	0	0	0	13	1	1	2	73	10	2	0	1
3.65	2.45	774.07	100.20	103.00	3.15	6.34	0	0	2	0	0	1	96	0	0	0	13	1	1	2	73	10	2	0	1
3.70	2.50	801.53	100.50	103.40	3.20	6.51	0	0	2	1	1	1	95	0	0	0	13	1	1	2	73	10	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
3.75	2.54	829.54	100.80	103.70	3.24	6.53	0	0	2	1	1	1	95	0	0	0	13	1	1	2	73	10	2	0	1
3.80	2.58	858.08	101.10	104.00	3.29	6.65	0	0	2	1	1	1	96	0	0	0	13	1	1	2	73	10	2	0	1
3.85	2.62	887.17	101.40	104.40	3.34	6.71	0	0	2	0	0	1	97	0	0	0	13	1	1	2	73	10	2	0	1
3.90	2.66	916.81	101.80	104.70	3.38	6.82	0	0	2	0	0	1	97	0	0	0	13	1	1	2	73	10	2	0	1
3.95	2.71	946.99	102.10	105.00	3.43	6.96	0	0	2	1	1	1	96	0	0	0	13	1	1	2	73	10	2	0	1
4.00	2.75	977.73	102.40	105.40	3.48	7.01	0	0	2	1	1	1	96	0	0	0	13	1	1	2	74	10	2	0	1
4.05	2.79	1009.02	102.70	105.70	3.52	7.07	0	0	2	0	0	0	97	0	0	0	13	1	1	2	74	10	2	0	1
4.10	2.83	1040.87	103.00	106.00	3.57	7.21	0	0	2	0	0	0	97	0	0	0	13	1	1	2	74	10	2	0	1
4.15	2.87	1073.28	103.30	106.40	3.62	7.30	0	0	2	0	0	0	97	0	0	0	13	1	1	2	74	10	2	0	1
4.20	2.91	1106.25	103.70	106.70	3.66	7.45	0	0	2	1	1	1	96	0	0	0	13	0	1	1	74	10	2	0	1
4.25	2.96	1139.78	103.90	107.00	3.71	7.51	0	0	2	1	1	1	96	0	0	0	13	0	1	1	74	10	2	0	1
4.30	3.00	1173.87	104.20	107.30	3.76	7.65	0	0	2	1	1	1	96	0	0	0	13	0	1	1	74	10	2	0	1
4.35	3.04	1208.53	104.40	107.50	3.81	7.69	0	0	2	0	0	0	97	0	0	0	13	0	1	1	74	10	2	0	1
4.40	3.08	1243.76	104.70	107.80	3.85	7.79	0	0	2	0	0	0	97	0	0	0	13	0	1	1	74	10	2	0	1
4.45	3.13	1279.56	104.90	108.10	3.90	7.90	0	0	2	0	0	0	97	0	0	0	13	0	1	1	74	10	2	0	1

Table 2-12 Hydraulic habitat look-up table for fish and invertebrates at EWR Site NS1 (riffle) for the discharge range 0.00 to 91 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.01	0.00	0.00	0.50	0.50	0.01	0.03	100	0	0	0	0	0	0	40	0	0	0	60	0	0	0	0	0	0	0
0.05	0.03	0.00	2.00	2.00	0.02	0.09	100	0	0	0	0	0	0	40	0	0	0	59	1	0	0	0	0	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.10	0.06	0.01	3.30	3.30	0.04	0.16	99	1	0	0	0	0	0	35	5	0	0	52	8	0	0	0	0	0	0
0.15	0.10	0.03	3.90	4.00	0.07	0.25	48	51	0	0	0	0	0	30	10	0	0	45	15	0	0	0	0	0	0
0.20	0.11	0.06	5.40	5.50	0.10	0.36	37	57	0	2	4	0	0	23	15	2	0	35	22	4	0	0	0	0	0
0.25	0.13	0.10	6.80	6.90	0.11	0.40	40	53	0	3	2	2	0	22	15	3	0	33	23	5	0	0	0	0	0
0.30	0.17	0.16	7.20	7.30	0.13	0.44	23	67	0	2	3	4	0	21	15	4	0	31	23	6	0	0	0	0	0
0.35	0.22	0.22	7.40	7.60	0.14	0.48	7	81	0	1	5	3	3	20	16	4	0	29	24	7	0	0	0	0	0
0.40	0.26	0.31	7.70	7.90	0.15	0.54	6	79	0	1	3	4	6	18	16	5	1	27	24	8	1	0	0	0	0
0.45	0.30	0.40	8.00	8.10	0.17	0.58	5	78	0	1	1	6	8	17	16	6	1	26	24	9	1	0	0	0	0
0.50	0.34	0.51	8.20	8.40	0.18	0.64	6	73	2	1	1	4	13	16	16	6	1	24	24	10	2	0	1	1	0
0.55	0.38	0.64	8.50	8.70	0.20	0.68	5	55	17	1	2	2	18	15	16	7	2	22	24	11	3	1	1	1	0
0.60	0.41	0.78	8.80	9.10	0.21	0.73	5	43	27	2	2	2	20	13	16	8	2	20	24	12	3	2	1	1	0
0.65	0.45	0.93	9.00	9.30	0.23	0.77	4	37	31	1	2	2	23	12	15	9	2	19	23	13	4	3	1	1	0
0.70	0.49	1.11	9.30	9.60	0.24	0.82	4	27	37	2	2	2	27	12	14	10	3	17	22	15	4	4	1	1	0
0.75	0.53	1.30	9.50	9.80	0.26	0.86	3	15	46	2	2	2	30	11	14	11	3	16	21	16	4	5	1	1	0
0.80	0.57	1.51	9.70	10.00	0.27	0.89	2	13	46	1	2	3	32	10	13	11	3	15	20	17	5	6	1	1	0
0.85	0.61	1.73	9.90	10.20	0.29	0.95	2	13	44	1	2	2	36	9	13	12	4	14	19	18	5	6	1	1	0
0.90	0.64	1.97	10.10	10.40	0.30	0.98	1	12	43	1	2	2	39	8	12	12	4	13	19	19	6	7	1	1	0
0.95	0.68	2.24	10.20	10.60	0.32	1.03	2	10	42	1	2	2	42	8	12	13	4	12	17	19	7	8	1	1	0
1.00	0.72	2.52	10.40	10.80	0.34	1.07	2	9	40	1	1	2	44	7	11	13	5	11	17	20	7	9	1	1	1
1.05	0.76	2.82	10.50	11.00	0.35	1.11	1	8	40	1	1	2	47	7	11	13	5	10	16	20	8	9	1	1	1
1.10	0.80	3.13	10.70	11.20	0.37	1.16	2	6	38	2	1	2	48	6	10	13	6	10	15	20	9	10	1	1	1
1.15	0.84	3.47	10.90	11.40	0.38	1.19	1	6	38	1	1	1	51	6	10	13	7	9	15	20	10	11	1	1	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
1.20	0.87	3.83	11.10	11.60	0.40	1.23	1	5	36	1	2	2	53	6	9	13	7	9	14	20	11	11	1	1	1
1.25	0.90	4.21	11.40	11.90	0.41	1.28	2	5	34	3	2	1	54	5	9	13	8	8	13	20	12	11	2	1	1
1.30	0.93	4.61	11.60	12.20	0.43	1.30	1	5	33	2	2	2	55	5	9	13	9	8	13	20	13	11	2	1	1
1.35	0.96	5.02	11.90	12.50	0.44	1.36	2	5	31	3	3	2	56	5	8	13	9	7	13	20	14	11	2	1	1
1.40	0.99	5.46	12.10	12.80	0.46	1.39	2	5	30	3	3	2	57	5	8	13	10	7	12	19	15	11	2	1	1
1.45	1.01	5.92	12.40	13.10	0.47	1.41	1	5	29	2	3	3	58	5	8	13	11	7	12	19	16	10	2	1	1
1.50	1.04	6.41	12.70	13.40	0.48	1.45	1	5	28	2	3	3	58	4	8	12	11	7	12	19	17	10	2	1	1
1.55	1.07	6.91	12.90	13.70	0.50	1.49	1	5	27	3	3	3	59	4	8	12	12	6	11	18	18	10	2	1	1
1.60	1.10	7.43	13.20	14.00	0.51	1.51	1	5	26	2	3	3	61	4	7	12	13	6	11	18	19	10	2	1	1
1.65	1.13	7.98	13.40	14.20	0.53	1.54	1	5	25	2	3	3	62	4	7	12	13	6	11	17	20	10	2	1	1
1.70	1.16	8.55	13.70	14.50	0.54	1.58	1	5	24	2	3	3	62	4	7	11	14	6	11	17	21	9	2	1	1
1.75	1.18	9.14	14.00	14.80	0.55	1.59	1	4	24	2	3	3	63	4	7	11	15	6	10	17	22	9	2	1	1
1.80	1.21	9.75	14.20	15.10	0.57	1.62	1	4	24	2	3	3	64	4	7	11	15	5	10	17	23	9	2	1	1
1.85	1.24	10.38	14.50	15.40	0.58	1.66	1	4	23	2	3	3	64	3	7	11	16	5	10	16	24	9	2	1	1
1.90	1.27	11.04	14.80	15.70	0.59	1.68	1	4	22	2	3	3	65	3	6	10	16	5	10	16	24	9	2	1	1
1.95	1.29	11.72	15.00	16.00	0.60	1.70	1	4	22	2	2	3	67	3	6	10	17	5	9	15	25	9	2	1	1
2.00	1.32	12.43	15.30	16.30	0.62	1.72	1	4	22	2	2	3	67	3	6	10	17	5	9	15	26	9	2	1	1
2.05	1.35	13.16	15.60	16.60	0.63	1.76	1	3	21	2	3	3	68	3	6	10	18	5	9	15	26	8	2	1	1
2.10	1.37	13.91	15.80	16.90	0.64	1.79	1	3	20	3	3	3	68	3	6	10	18	5	9	14	27	8	2	1	1
2.15	1.40	14.68	16.10	17.20	0.65	1.81	1	3	20	2	2	3	69	3	6	10	18	4	9	14	28	8	2	1	1
2.20	1.43	15.48	16.40	17.50	0.66	1.83	1	3	20	2	2	3	70	3	6	9	19	4	9	14	28	8	2	1	1
2.25	1.45	16.30	16.60	17.80	0.67	1.85	1	3	19	2	2	3	70	3	6	9	19	4	8	14	29	8	2	1	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
2.30	1.48	17.15	16.90	18.10	0.69	1.89	1	3	19	3	3	3	70	3	5	9	20	4	8	13	30	8	2	1	1
2.35	1.51	18.02	17.20	18.40	0.70	1.91	1	3	18	2	2	2	71	3	5	9	20	4	8	13	30	8	2	1	1
2.40	1.53	18.92	17.40	18.70	0.71	1.94	1	3	18	2	2	2	71	3	5	9	21	4	8	13	31	7	2	1	1
2.45	1.56	19.84	17.70	19.00	0.72	1.94	1	2	18	2	2	2	72	3	5	9	21	4	8	13	31	7	2	1	1
2.50	1.59	20.78	17.90	19.20	0.73	1.98	1	2	18	2	2	2	72	3	5	8	21	4	8	12	32	7	2	1	1
2.55	1.61	21.75	18.20	19.50	0.74	1.98	0	2	18	2	2	2	73	3	5	8	21	4	8	12	32	7	2	1	1
2.60	1.64	22.75	18.50	19.80	0.75	2.01	0	2	17	2	2	2	74	2	5	8	22	4	7	12	33	7	2	1	1
2.65	1.67	23.77	18.70	20.10	0.76	2.03	0	2	17	2	2	2	74	2	5	8	22	4	7	12	33	7	2	1	1
2.70	1.69	24.81	19.00	20.40	0.77	2.07	1	2	16	2	2	2	74	2	5	8	22	4	7	12	34	7	2	1	1
2.75	1.72	25.88	19.30	20.70	0.78	2.08	1	2	16	2	2	2	75	2	5	8	23	4	7	11	34	7	2	1	1
2.80	1.75	26.98	19.50	21.00	0.79	2.10	0	2	16	2	2	2	75	2	5	7	23	3	7	11	34	7	2	1	1
2.85	1.77	28.11	19.80	21.30	0.80	2.10	0	2	16	2	2	2	76	2	5	7	23	3	7	11	35	7	2	1	1
2.90	1.80	29.25	20.10	21.60	0.81	2.14	0	2	15	2	2	2	76	2	4	7	23	3	7	11	35	6	2	1	1
2.95	1.82	30.43	20.30	21.90	0.82	2.14	0	2	15	2	2	2	77	2	4	7	24	3	7	11	35	6	2	1	1
3.00	1.85	31.63	20.60	22.20	0.83	2.15	0	2	15	2	2	2	77	2	4	7	24	3	7	11	36	6	2	1	1
3.05	1.86	32.86	21.10	22.70	0.84	2.17	0	2	15	2	2	2	77	2	4	7	24	3	6	11	36	6	2	1	1
3.10	1.87	34.11	21.50	23.10	0.85	2.19	0	2	15	2	2	2	76	2	4	7	24	3	6	10	36	6	2	1	1
3.15	1.88	35.39	22.00	23.60	0.86	2.21	1	2	14	3	3	2	75	2	4	7	25	3	6	10	37	6	2	1	1
3.20	1.89	36.70	22.40	24.00	0.86	2.22	1	2	14	4	4	2	75	2	4	7	25	3	6	10	37	6	2	1	1
3.25	1.89	38.04	23.00	24.60	0.87	2.23	1	2	13	3	3	3	75	2	4	7	25	3	6	10	38	6	2	1	1
3.30	1.89	39.40	23.70	25.30	0.88	2.24	1	2	13	4	4	3	74	2	4	7	25	3	6	10	38	5	2	1	1
3.35	1.88	40.79	24.40	26.00	0.89	2.25	1	2	13	4	4	3	74	2	4	7	25	3	6	10	38	5	2	1	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
3.40	1.88	42.20	25.10	26.70	0.89	2.23	1	2	12	4	4	3	73	2	4	7	25	3	6	10	38	5	2	1	1
3.45	1.88	43.65	25.80	27.40	0.90	2.25	1	2	12	4	4	3	73	2	4	6	26	3	6	10	39	5	2	1	1
3.50	1.88	45.12	26.40	28.10	0.91	2.24	1	2	12	4	4	3	73	2	4	7	26	3	6	10	39	5	2	1	1
3.55	1.88	46.62	27.10	28.80	0.91	2.28	1	3	12	5	5	4	72	2	4	6	26	3	6	9	39	5	2	1	1
3.60	1.89	48.15	27.80	29.50	0.92	2.26	1	2	12	4	4	4	73	2	4	6	26	3	6	10	39	5	2	1	1
3.65	1.89	49.70	28.50	30.20	0.92	2.29	1	3	11	4	4	4	73	2	4	6	26	3	6	9	39	5	2	1	1
3.70	1.89	51.28	29.20	31.00	0.93	2.30	1	3	11	4	4	4	73	2	4	6	26	3	6	9	40	4	2	1	1
3.75	1.90	52.89	29.90	31.70	0.93	2.28	1	3	11	4	4	4	74	2	4	6	26	3	6	9	40	4	2	1	1
3.80	1.89	54.53	30.90	32.60	0.94	2.27	1	3	11	4	4	4	74	2	4	6	27	3	5	9	40	4	2	1	1
3.85	1.88	56.20	31.80	33.60	0.94	2.26	1	3	11	4	4	4	74	2	4	6	27	3	5	9	40	4	2	0	1
3.90	1.88	57.90	32.70	34.40	0.94	2.27	1	2	11	4	4	4	73	2	4	6	27	3	5	9	40	4	2	0	1
3.95	1.90	59.62	33.20	35.00	0.94	2.31	1	2	11	4	4	4	74	2	4	6	27	3	5	9	40	4	2	0	1
4.00	1.92	61.37	33.70	35.40	0.95	2.29	1	2	11	4	4	4	75	2	4	6	27	3	5	9	40	4	2	0	1
4.05	1.95	63.16	34.20	35.90	0.95	2.29	1	2	11	3	3	3	76	2	4	6	27	3	5	9	40	4	2	0	1
4.10	1.97	64.97	34.60	36.40	0.95	2.33	1	2	11	3	3	3	77	2	4	6	27	3	5	9	41	4	2	0	1
4.15	1.99	66.81	35.10	36.90	0.95	2.31	0	2	12	2	2	3	79	2	4	6	27	3	5	9	40	4	2	0	1
4.20	2.02	68.68	35.60	37.40	0.96	2.33	0	2	12	2	2	2	79	2	4	6	27	3	5	9	41	4	2	0	1
4.25	2.04	70.58	36.10	37.90	0.96	2.35	0	2	12	2	2	2	80	2	4	6	27	3	5	9	41	4	2	0	1
4.30	2.06	72.50	36.50	38.40	0.96	2.35	0	2	12	2	2	2	80	2	4	6	27	3	5	9	41	4	2	0	1
4.35	2.09	74.46	37.00	38.80	0.96	2.37	0	2	12	2	2	2	80	2	4	6	27	3	5	9	41	4	2	0	1
4.40	2.11	76.45	37.40	39.20	0.97	2.35	0	2	12	2	2	2	81	2	4	6	27	3	5	9	41	3	2	0	1
4.45	2.12	78.46	38.20	40.00	0.97	2.37	0	1	12	2	2	2	80	2	4	6	27	3	5	9	41	3	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
4.50	2.12	80.51	39.00	40.90	0.97	2.38	0	1	12	2	2	2	79	2	4	6	27	3	5	9	41	3	2	0	1
4.55	2.13	82.59	39.90	41.70	0.97	2.39	0	2	12	3	3	3	79	2	4	6	27	3	5	9	41	3	2	0	1
4.60	2.13	84.69	40.70	42.60	0.98	2.37	0	2	12	3	3	3	79	2	4	6	27	3	5	9	41	3	2	0	1
4.65	2.14	86.83	41.50	43.40	0.98	2.38	0	2	12	3	3	3	78	2	4	6	27	3	5	9	41	3	2	0	1
4.70	2.15	89.00	42.40	44.30	0.98	2.38	0	2	12	3	3	3	77	2	4	6	27	3	5	9	41	3	2	0	1
4.75	2.15	91.19	43.20	45.20	0.98	2.40	1	2	12	3	3	3	77	2	4	6	28	3	5	9	41	3	2	0	1

Table 2-13 Hydraulic habitat look-up table for fish and invertebrates at EWR Site MA1 (riffle) for the discharge range 0.00 to 916 m^3/s

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.01	0.00	0.00	0.20	0.20	0.00	0.00	100	0	0	0	0	0	0	5	0	0	0	95	0	0	0	0	0	0	0
0.05	0.02	0.00	0.90	0.90	0.01	0.02	100	0	0	0	0	0	0	5	0	0	0	95	0	0	0	0	0	0	0
0.10	0.05	0.00	1.90	1.90	0.02	0.06	99	1	0	0	0	0	0	5	0	0	0	95	0	0	0	0	0	0	0
0.15	0.07	0.01	3.10	3.10	0.03	0.09	71	29	0	0	0	0	0	5	0	0	0	93	2	0	0	0	0	0	0
0.20	0.11	0.02	3.60	3.70	0.04	0.15	47	53	0	0	0	0	0	4	1	0	0	83	12	0	0	0	0	0	0
0.25	0.09	0.04	7.10	7.10	0.05	0.19	57	43	0	0	0	0	0	4	1	0	0	78	17	0	0	0	0	0	0
0.30	0.13	0.07	7.70	7.80	0.07	0.24	53	47	0	0	0	0	0	4	1	0	0	72	23	0	0	0	0	0	0
0.35	0.16	0.12	8.60	8.80	0.08	0.29	17	81	0	0	1	1	0	3	1	0	0	62	27	2	0	4	1	0	0
0.40	0.20	0.19	9.60	9.80	0.10	0.35	18	77	0	1	2	1	1	3	2	0	0	53	29	5	0	9	1	0	0
0.45	0.23	0.28	10.30	10.50	0.12	0.41	13	78	0	1	1	4	3	2	2	0	0	46	30	7	0	12	1	0	0
0.50	0.27	0.41	10.60	10.80	0.14	0.49	9	78	1	1	2	5	5	2	2	0	0	39	31	9	1	16	1	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
0.55	0.32	0.58	10.90	11.10	0.17	0.58	4	72	8	1	3	3	10	2	2	1	0	33	30	11	2	20	1	0	0
0.60	0.34	0.78	11.80	12.10	0.20	0.67	7	58	13	2	2	4	14	2	2	1	0	29	29	13	3	22	1	0	0
0.65	0.31	1.04	15.10	15.40	0.22	0.77	20	37	15	8	1	3	16	1	2	1	0	26	29	16	5	20	1	0	0
0.70	0.28	1.35	20.10	20.40	0.24	0.82	27	27	14	13	2	2	15	1	2	1	0	25	29	19	6	18	1	0	0
0.75	0.28	1.73	23.70	24.10	0.26	0.87	24	21	20	13	6	1	15	1	1	1	0	24	28	21	7	17	1	0	0
0.80	0.31	2.17	25.50	25.90	0.27	0.92	12	31	19	8	12	2	16	1	1	1	0	23	26	22	7	17	1	0	0
0.85	0.34	2.69	27.40	27.80	0.29	0.99	8	32	19	6	12	8	16	1	1	1	0	21	25	23	9	18	1	0	0
0.90	0.36	3.30	29.90	30.30	0.31	1.04	8	30	18	7	7	13	17	1	1	1	1	20	24	24	10	18	1	0	0
0.95	0.37	3.99	33.50	34.00	0.33	1.07	9	28	17	8	5	12	21	1	1	1	1	19	24	25	10	17	1	0	0
1.00	0.38	4.79	36.90	37.40	0.34	1.15	9	27	15	9	6	8	26	1	1	1	1	18	23	26	12	17	1	0	0
1.05	0.40	5.69	40.00	40.50	0.36	1.18	8	28	14	8	7	5	30	1	1	1	1	17	23	27	13	17	1	0	0
1.10	0.43	6.71	42.30	42.80	0.37	1.24	6	27	14	7	8	5	32	1	1	1	1	16	22	26	15	17	1	0	0
1.15	0.46	7.86	44.00	44.60	0.39	1.29	4	25	17	5	8	7	34	1	1	1	1	15	21	26	16	17	1	0	0
1.20	0.49	9.14	45.60	46.20	0.41	1.33	3	21	21	4	6	8	37	1	1	1	1	15	20	26	17	18	2	0	0
1.25	0.53	10.56	46.80	47.40	0.43	1.40	2	19	22	3	5	7	42	1	1	1	1	14	20	26	19	17	2	0	0
1.30	0.53	12.14	51.30	52.00	0.45	1.46	5	16	21	7	4	6	42	1	1	1	1	13	20	26	22	16	2	0	0
1.35	0.56	13.88	52.80	53.50	0.47	1.52	4	15	21	6	3	5	46	1	1	1	1	13	19	25	24	15	2	0	0
1.40	0.60	15.79	54.20	54.90	0.49	1.58	2	14	22	3	6	4	48	1	1	1	1	12	19	24	26	15	2	0	0
1.45	0.63	17.88	55.40	56.10	0.51	1.68	2	13	22	3	7	3	50	1	1	1	1	11	18	23	28	14	2	0	0
1.50	0.67	20.16	56.50	57.20	0.53	1.74	1	11	23	3	3	6	52	1	1	1	2	11	18	23	30	14	2	0	0
1.55	0.71	22.65	57.60	58.40	0.56	1.80	1	10	24	2	2	7	54	1	1	1	2	11	17	22	32	14	2	0	0
1.60	0.74	25.35	58.70	59.50	0.58	1.89	1	8	24	2	2	5	57	1	1	1	2	10	17	21	34	14	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)									Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
1.65	0.78	28.27	59.80	60.60	0.61	1.97	1	7	23	2	2	3	60	1	1	1	2	10	16	20	36	13	2	0	0
1.70	0.82	31.43	60.90	61.80	0.63	2.06	1	7	22	2	2	2	62	0	1	1	2	9	16	19	38	13	2	0	0
1.75	0.85	34.83	62.10	62.90	0.66	2.11	1	6	22	2	3	3	64	0	1	1	2	9	15	19	40	13	2	0	0
1.80	0.89	38.49	62.90	63.80	0.69	2.17	1	4	22	2	3	3	65	0	1	1	2	8	15	18	42	13	2	0	0
1.85	0.93	42.42	63.80	64.80	0.72	2.23	1	4	22	2	3	2	67	0	1	1	2	7	14	18	44	13	2	0	0
1.90	0.96	46.62	64.70	65.70	0.75	2.32	1	3	21	2	2	2	69	0	1	1	2	7	13	17	46	12	2	0	0
1.95	1.00	51.12	65.60	66.60	0.78	2.38	1	3	19	2	2	2	70	0	1	1	3	7	13	16	48	12	2	0	0
2.00	1.04	55.92	66.50	67.50	0.81	2.45	0	3	19	1	2	3	72	0	1	1	3	6	12	16	50	12	2	0	0
2.05	1.07	61.04	67.40	68.40	0.85	2.53	1	2	18	2	2	2	72	0	1	1	3	6	11	15	52	12	2	0	0
2.10	1.11	66.49	68.30	69.30	0.88	2.58	0	2	17	2	2	2	74	0	1	1	3	5	11	14	53	12	2	0	0
2.15	1.14	72.27	69.10	70.20	0.91	2.66	1	2	16	2	2	2	75	0	1	1	3	5	10	14	55	12	2	0	0
2.20	1.18	78.41	69.70	70.80	0.95	2.71	0	2	15	2	2	3	76	0	1	1	3	5	10	13	56	11	2	0	0
2.25	1.23	84.91	70.20	71.30	0.99	2.75	0	1	14	1	2	2	79	0	0	1	3	5	9	13	58	11	2	0	0
2.30	1.27	91.80	70.60	71.70	1.03	2.81	0	1	14	1	1	2	81	0	0	1	3	4	9	12	59	11	2	0	0
2.35	1.31	99.07	71.00	72.10	1.06	2.90	0	1	13	1	2	2	81	0	0	1	3	4	8	12	60	11	2	0	0
2.40	1.35	106.75	71.40	72.50	1.11	2.97	0	1	12	1	1	2	83	0	0	1	3	4	8	11	62	11	2	0	0
2.45	1.40	114.85	71.80	72.90	1.15	3.01	0	1	12	1	1	2	84	0	0	1	3	4	7	11	63	11	2	0	0
2.50	1.44	123.38	72.20	73.40	1.19	3.06	0	1	11	1	1	1	85	0	0	1	3	3	7	10	64	11	2	0	0
2.55	1.48	132.35	72.60	73.80	1.23	3.12	0	1	10	1	1	1	86	0	0	1	3	3	6	10	65	11	2	0	0
2.60	1.52	141.79	73.10	74.30	1.28	3.12	0	1	10	1	1	1	87	0	0	1	3	3	6	10	66	11	2	0	0
2.65	1.56	151.70	73.70	74.90	1.32	3.19	0	0	9	1	1	2	86	0	0	0	4	3	6	9	67	11	2	0	0
2.70	1.59	162.09	74.20	75.50	1.37	3.23	0	0	9	1	1	1	87	0	0	0	4	3	5	9	68	11	2	0	0

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)										Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
2.75	1.63	172.99	74.80	76.00	1.42	3.29	0	0	8	1	1	1	88	0	0	0	4	2	5	8	69	11	2	0	0
2.80	1.67	184.40	75.40	76.60	1.46	3.33	0	0	8	1	1	1	88	0	0	0	4	2	5	8	70	11	2	0	0
2.85	1.71	196.35	76.00	77.20	1.51	3.35	0	0	7	1	1	1	89	0	0	0	4	2	4	7	71	11	2	0	0
2.90	1.72	208.84	77.40	78.70	1.56	3.50	0	0	7	2	2	1	87	0	0	0	4	2	4	7	72	10	2	0	0
2.95	1.74	221.89	79.10	80.40	1.61	3.55	0	0	6	2	2	1	87	0	0	0	4	2	4	7	73	10	2	0	0
3.00	1.75	235.52	80.80	82.20	1.67	3.56	0	0	6	3	3	1	86	0	0	0	4	2	4	6	74	10	2	0	0
3.05	1.76	249.73	82.60	83.90	1.72	3.63	0	0	6	3	3	1	86	0	0	0	4	2	4	6	74	10	2	0	0
3.10	1.78	264.56	84.30	85.60	1.77	3.74	0	0	5	4	4	2	85	0	0	0	4	2	3	6	75	9	2	0	0
3.15	1.79	280.00	86.00	87.40	1.82	3.86	0	1	5	4	4	2	84	0	0	0	4	2	3	5	76	9	2	0	0
3.20	1.81	296.08	87.40	88.80	1.87	3.86	0	1	4	4	4	2	85	0	0	0	4	1	3	5	77	9	2	0	0
3.25	1.85	312.82	87.80	89.20	1.92	3.96	0	1	4	3	3	3	87	0	0	0	4	1	3	5	77	9	2	0	0
3.30	1.90	330.22	88.10	89.50	1.98	4.10	0	1	4	3	3	3	87	0	0	0	4	1	3	4	78	9	2	0	0
3.35	1.94	348.31	88.40	89.80	2.03	4.15	0	0	4	1	1	3	90	0	0	0	4	1	2	4	78	9	2	0	0
3.40	1.98	367.10	88.70	90.20	2.09	4.30	0	0	3	1	1	3	91	0	0	0	4	1	2	4	79	9	2	0	1
3.45	2.02	386.60	89.10	90.50	2.14	4.36	0	0	3	0	0	2	93	0	0	0	4	1	2	4	79	9	2	0	1
3.50	2.07	406.84	89.40	90.90	2.20	4.47	0	0	3	1	1	2	93	0	0	0	4	1	2	4	80	9	2	0	1
3.55	2.11	427.83	89.70	91.20	2.26	4.60	0	0	3	1	1	2	93	0	0	0	4	1	2	4	80	9	2	0	1
3.60	2.15	449.58	90.10	91.60	2.32	4.68	0	0	3	0	0	1	95	0	0	0	4	1	2	4	80	9	2	0	1
3.65	2.19	472.12	90.40	91.90	2.38	4.85	0	0	3	1	1	1	94	0	0	0	4	1	2	3	81	9	2	0	1
3.70	2.22	495.45	91.20	92.80	2.44	4.94	0	0	3	1	1	1	95	0	0	0	4	1	2	3	81	9	2	0	1
3.75	2.25	519.61	92.00	93.60	2.51	5.04	0	0	3	1	1	1	95	0	0	0	4	1	2	3	81	9	2	0	1
3.80	2.28	544.59	92.90	94.40	2.57	5.19	0	0	3	1	1	1	95	0	0	0	4	1	2	3	81	9	2	0	1

Maxdepth	Avdepth	Discharge	Width	Perim	AvVel	Vel98%	Distribution of fish habitat types (%)							Distribution of invertebrate habitat types (%)										Veg hydraulics		
(m)	(m)	(m3/s)	(m)	(m)	(m/s)	(m/s)	SVS	SS	SD	FVS	FS	FI	FD	VSFS	SFS	FFS	VFFS	VSCS	SCS	FCS	VFCS	VEG	#Int	Vveg	Vint
3.85	2.31	570.43	93.70	95.30	2.63	5.32	0	0	3	1	1	1	94	0	0	0	4	1	2	3	82	9	2	0	1
3.90	2.34	597.14	94.50	96.10	2.70	5.43	0	0	3	1	1	1	94	0	0	0	4	1	2	3	82	8	2	0	1
3.95	2.38	624.73	94.90	96.50	2.76	5.61	0	0	2	1	1	1	93	0	0	0	4	1	2	3	82	8	2	0	1
4.00	2.42	653.23	95.30	96.90	2.83	5.65	0	0	2	1	1	1	94	0	0	0	4	1	1	2	82	8	2	0	1
4.05	2.46	682.65	95.70	97.30	2.90	5.82	0	0	2	1	1	1	95	0	0	0	4	1	1	2	83	8	2	0	1
4.10	2.50	713.01	96.10	97.80	2.97	6.03	0	0	2	1	1	1	94	0	0	0	4	1	1	2	83	8	2	0	1
4.15	2.54	744.33	96.50	98.20	3.03	6.07	0	0	2	0	0	1	96	0	0	0	4	1	1	2	83	8	2	0	1
4.20	2.58	776.62	96.90	98.60	3.11	6.32	0	0	2	1	1	1	95	0	0	0	4	1	1	2	83	8	2	0	1
4.25	2.62	809.90	97.30	99.00	3.18	6.48	0	0	2	1	1	1	96	0	0	0	4	1	1	2	83	8	2	0	1
4.30	2.66	844.20	97.70	99.40	3.25	6.53	0	0	2	0	0	0	97	0	0	0	4	1	1	2	83	8	2	0	1
4.35	2.70	879.53	98.10	99.80	3.32	6.70	0	0	2	0	0	0	97	0	0	0	4	1	1	2	83	8	2	0	1
4.40	2.74	915.91	98.50	100.30	3.40	6.91	0	0	2	1	1	1	96	0	0	0	4	1	1	2	84	8	2	0	1

2.5 Assumptions, uncertainty and limitations

An indication of the confidence including notes on any assumptions and limitations in the hydraulics is given in the table below.

Table 2-14 Confidence in the hydraulic characterisations

<table>
<tr><th colspan="5">Confidence ratings and explanations (Confidence rating total out of 5, where 0=none and 5=high)</th></tr>
<tr><th>Site</th><th>Character</th><th>Data</th><th>Low flows</th><th>High flows</th></tr>
<tr><td>AS1 A</td><td>3</td><td>3</td><td>3</td><td>2</td></tr>
<tr><td colspan="5">

Site character rating = 3:

Advantages:

Good gauging station located close to the site.
Uniform flow conditions along the riffle.

Disadvantages:

Influence of vegetation at higher flows makes modelling of high flows difficult
Second channel linked to pool upstream, becomes active at high flows but it acts independently of the main channel and makes prediction at high flows difficult. Due to this the shape of the rating curve is relatively uncertain at higher stages below the strandline stage. Also complicates the prediction of habitat distributions at higher flows.
Large roughness elements at low flows make resistance coefficient hard to predict at very low flows

Data rating = 3:

Good flow data available at gauging station close by.
Five observed stage-discharge pairs now available from this study and previous studies (Birkhead 2008), although unfortunately all plot in a narrow range of stages.
Strandline with gauged flood for high flows.

Low flow confidence = 3:

For discharges in the range of those measured the confidence is high, for lower discharges confidence is slightly reduced due to large roughness elements.

High flow confidence = 2:

Confidence is reduced at high flows because although there is good certainty in the stage and discharge pair for the strandline flood, the shape of the rating curve at stages lower than this has reduced confidence, because of the influence of the high flow channel which acts independently, at least at first, from the main channel.

</td></tr>
<tr><td>AS1 B</td><td>3</td><td>2</td><td>2</td><td>3</td></tr>
<tr><td colspan="5">

Site character rating = 3:

Advantages:

Good gauging station located close to the site.

Disadvantages:

</td></tr>
</table>

<table>
<tr><th colspan="5">Confidence ratings and explanations (Confidence rating total out of 5, where 0=none and 5=high)</th></tr>
<tr><th>Site</th><th>Character</th><th>Data</th><th>Low flows</th><th>High flows</th></tr>
<tr><td colspan="5">
    - Slopes difficult to estimate for intermediate flows.
- Data rating = 2:
  - Good flow data available at gauging station close by.
  - Stage at which flow ceases was extrapolated using the fitted rating curve equation.
  - Strandline with gauged flood for high flows.
- Low flow confidence = 2:
  - Stage at which flow ceases is uncertain as it was extrapolated.
- High flow confidence = 3:
  - Good certainty for the surveyed strandline, but an additional high flow point was modelled at a lower flow in order to fit a rating curve and the slope for this point is of lower certainty.
</td></tr>
<tr><td>UP1</td><td>2</td><td>2</td><td>3</td><td>2</td></tr>
<tr><td colspan="5">
- Site character rating = 2:
  - Advantages:
    - Uniform flow conditions on riffle except at very high flows when backwater effect from pool downstream will come into effect.
  - Disadvantages:
    - Slopes difficult to estimate for intermediate flows due to long pool downstream.
    - Large scale roughness reduces confidence in rating curve at flows below the observed points.
    - Difficult to gauge flows accurately because of lack of highly suitable locations that are also safe from crocodiles.
- Data rating = 2:
  - Only two observed points
  - Confidence in the measured discharges is reduced because of less suitable gauging location.
- Low flow confidence = 3:
  - Large scale roughness elements increase uncertainty at discharges lower than measured.
- High flow confidence = 2:
  - Some uncertainty with the high flow slope due to the very long flat pool downstream of the site.
</td></tr>
<tr><td>MK1</td><td>3</td><td>2</td><td>3</td><td>2</td></tr>
<tr><td colspan="5">
- Site character rating = 3:
  - Advantages:
    - Uniform flow conditions likely at all discharges.
    - Smooth sand bed for which roughness is easy to predict at low to medium flows.
    - Discharges can be measured with relatively high confidence at low to medium flows due to good gauging locations available at the site.
  - Disadvantages:
    - Influence of vegetation on resistance is difficult to predict at higher flows.
    - Will be very challenging to gauge high flows at this site because of the wide floodplain.
</td></tr>
</table>

<table>
<tr><th colspan="5">Confidence ratings and explanations (Confidence rating total out of 5, where 0=none and 5=high)</th></tr>
<tr><th>Site</th><th>Character</th><th>Data</th><th>Low flows</th><th>High flows</th></tr>
<tr><td colspan="5">• Data rating = 2:
o Only two observed points.
• Low flow confidence = 3:
o Smooth sand bed at low flows leads to reasonable confidence in hydraulics at low flows.
• High flow confidence = 2:
o Confidence at high flows is less because of the probably significant influence of vegetation on resistance which is hard to predict.</td></tr>
<tr><td>**BM1**</td><td>**3**</td><td>**2**</td><td>**2**</td><td>**2**</td></tr>
<tr><td colspan="5">• Site character rating = 3:
o Advantages:
▪ Relatively uniform flow conditions likely at all discharges.
▪ Gauging station located close by with what appears like reasonable data for low to medium flows.
o Disadvantages:
▪ Influence of bank vegetation on resistance is difficult to predict at higher flows.
▪ Gauge data for floods does not make sense hydraulically and suggests there are issues with measurement at high flows.
▪ Cross-section is through a very shallow pool and the depth at which flow ceases is difficult to predict since it seems to be governed by a sand bar.
• Data rating = 2:
o Three observed points.
o But depth at which flow ceases is not clear due to sand bar just downstream in a pool that may control this depth.
• Low flow confidence = 2:
o Although three points were collected at the site, two of them are at very similar discharges and the depth at which flow ceases is not clear.
• High flow confidence = 2:
o A point was collected during a freshet event which increases confidence for medium flows.
o However the strandlines surveyed did not make any sense hydraulically when paired with the observed floods at the gauging station. It appears the station does not record high flows properly and is missing floods.
o Estimation of resistance at high flows is difficult due to bank vegetation. However a slope-area survey after Cyclone Domoina was conducted over this reach (Kovacs *et al.* 1985) and resistance from this survey was used for the modelled flood at this site in this study – the resistance is therefore a little more certain than it would otherwise be.</td></tr>
<tr><td>**BM2 A**</td><td>**2**</td><td>**1**</td><td>**2**</td><td>**2**</td></tr>
<tr><td colspan="5">• Site character rating = 2:
o Advantages:
▪ Smaller scale roughness elements mean that prediction at low flows is at reasonable confidence.</td></tr>
</table>

Confidence ratings and explanations (Confidence rating total out of 5, where 0=none and 5=high)

Site	Character	Data	Low flows	High flows

  - Disadvantages:
    - Was forced to survey two cross-sections, one for high and one for low flows due to lack of suitable sites for all flows.
    - Slope very difficult to estimate for the modelled high flow point due to the low maximum stage on the cross-section.
    - Control potentially moves downstream to bedrock constriction or to the outflow of the large downstream pool at high flows. This was modelled in HEC-RAS by including the downstream surveyed cross-section BM2 B and a third synthesised cross-section.
- Data rating = 1:
  - One observed point.
- Low flow confidence = 2:
  - Only one point was collected but due to smaller roughness elements low flow hydraulics can be characterised with greater confidence than at many other sites.
- High flow confidence = 2:
  - Confidence in the modelled high flow point was increased by modelling the two cross-sections at the site using HEC-RAS, as the downstream high flow cross-section BM2 B lies across the potential control for BM2 A.

BM2 B	**2**	**1**	**2**	**2**

- Site character rating = 2:
  - Advantages:
    - Cross-section was surveyed for high flows at the likely control section in this area.
  - Disadvantages:
    - Was forced to survey two cross-sections, one for high and one for low flows due to lack of suitable sites for all flows.
    - Massive boulders on the right bank at high flows, while the left bank is smooth bedrock, making for estimation of a resistance coefficient for the entire cross-section difficult.
- Data rating = 1:
  - One observed point.
- Low flow confidence = 2:
  - Only one observed point.
- High flow confidence = 2:
  - Strandline and floods recorded at gauging station at BM1 do not produce plausible hydraulics. It is likely that the gauging station is not recording high flows accurately.
  - Resistance difficult to quantify due to large boulders on right bank and bedrock on left bank.

WM1	**2**	**2**	**2**	**3**

- Site character rating = 2:
  - Advantages:
    - Uniform flow likely for all discharges.
    - Possible to gauge flow off the low level bridge at medium discharges.

<table>
<tr><th colspan="5">Confidence ratings and explanations (Confidence rating total out of 5, where 0=none and 5=high)</th></tr>
<tr><th>Site</th><th>Character</th><th>Data</th><th>Low flows</th><th>High flows</th></tr>
<tr><td colspan="5">▪ A rated section exists at the low level bridge with gauge plates, but was unable to obtain data.
▪ Good sites available for flow gauging at low flows.
o Disadvantages:
▪ Appears channel silts up with sand at low flows.
▪ Large scale roughness at low flows.
• Data rating = 2:
o Two observed points approximately an order of magnitude in discharge from each other.
• Low flow confidence = 2:
o Depth of flow cessation may not be zero, the rating curve was extrapolated.
o Good confidence in the range of the observed flows.
• High flow confidence = 3:
o Reasonable confidence due to likely uniform flow during floods.</td></tr>
<tr><td>NS1</td><td>2</td><td>2</td><td>2</td><td>1</td></tr>
<tr><td colspan="5">• Site character rating = 2:
o Advantages:
▪ Uniform flow likely for low to medium flows on riffle.
o Disadvantages:
▪ Not clear at what discharge control moves downstream to pool.
▪ Large scale roughness at low flows.
▪ Influence of vegetation on resistance at high flows will be significant but is hard to quantify.
• Data rating = 2:
o Two observed points.
• Low flow confidence = 2:
o Good confidence in the range of the observed flows.
• High flow confidence = 1:
o Dense vegetation on banks makes accurate modelling at high flows difficult.</td></tr>
<tr><td>MA1</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td colspan="5">• Site character rating = 2:
o Advantages:
▪ Uniform flow likely for all discharges.
o Disadvantages:
▪ Large scale roughness makes prediction at low flows difficult.
▪ Influence of vegetation on banks on flow resistance difficult to predict.
▪ Presence of channel on left bank and its relationship with flow in the main channel is difficult to quantify with only one cross-section at the site.
• Data rating = 2:</td></tr>
</table>

Confidence ratings and explanations (Confidence rating total out of 5, where 0=none and 5=high)				
Site	Character	Data	Low flows	High flows
o Two observed points an order of magnitude apart in discharge. • Low flow confidence = 2: o Confidence good in range of observed flows. o Hydraulics at low flows complicated by large scale roughness in the channel. • High flow confidence = 2: o Impact of vegetation on hydraulics at higher flows difficult to quantify. o Difficult to quantify the hydraulics with the second channel on left bank at high flows.				

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3 WATER QUALITY: SPECIALIST REPORT

Grateful acknowledgements to Dr Patsy Scherman who, as always, gave generously of her time and expertise towards this project.

3.1 Introduction

3.1.1 Objectives of the water quality study

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

For the water quality component of the EWR assessment, 34 days were allocated to undertaking a literature review of existing information and analysis of data, data analysis of the site information collected in the field, prediction of impacts and report writing.

This report follows the ToR provided by Tlou Consulting *viz*.:

- Familiarise yourself to the extent possible with the study area, including:
    - The water quality of the rivers in the study area.
    - Delineation of homogenous areas
    - The water quality of the reaches encompassing the proposed sites.
- Collate existing water quality data for the study area.
- Provide detailed information for eight EWR sites.
- If necessary attend the field visit with the rest of the team to:
    - Collect water quality data from relevant authorities in the area.
- Determine the WQ EWR at the Intermediate level for the allotted eight EWR sites.
- Select key aspects as indicators for the DRIFT assessment, and provide/develop information on:
    - anticipated sensitivity to change in the flow regime;
    - any additional relevant information on the water quality characteristic of each site, from the scientific literature or from data collections;
    - 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.
- Prepare data files for use at the DRIFT Workshop.
- Attend PMC meetings if and as required (additional time will be made available).
- Assist with capacity building of an allocated DWA staff member, if and when required.
- Attend the DRIFT Workshop(s), prepared to provide in and to populate the DRIFT response curves for water quality.

- Prepare response curve motivation tables, and make statements about the confidence level of your outputs.

3.1.2 Layout of this Section

This Section comprises the summary report for water quality, and provides:

- Overview of the study area, with focus on delineation of homogenous areas;
- EcoClassification assessments for water quality at the eight EWR sites, with supporting evidence
- The WQ EWR at the Intermediate level for the EWR sites:
    - the DRIFT indicators chosen, and reasons therefore;
    - the relationships between the chosen indicators and flow or other, with referenced, supporting motivations.
- Data and the details of any analyses performed (Appendix A - C).
- EcoSpecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to water quality.

3.2 General description of the study area, with the focus on water quality

The Usutu-Mhlatuze Water Management Area (WMA) is located on the north-eastern seaboard of South Africa. It is comprised of six main catchments that rise in the high-altitude western side of the WMA and flow eastwards to the sea. The catchments, listed from south to north are:

- Catchment W1: Mhlatuze
- Catchment W2: Umfolozi
- Catchment W3: Mkuze
- Catchment W4: Phongolo
- Catchment W5: Usutu
- (Catchment W6: Located in Swaziland – not included in this study)
- Catchment W7: Lake Sibaya/ Kosi Bay

Surface water quality (WQ) in each major catchment is discussed in the Section 1.3 but first, general observations that are applicable to the entire WMA are presented. The WMA can be considered to be predominantly rural with only a few developed areas, noticeably Richards Bay, Vryheid, and Empangeni (DWAF 2002a). There is coal mining in the upper catchments, forestry in the upper, middle and lower catchments and commercial agriculture (predominantly sugarcane - both irrigated and dry-land) in the middle and lower catchments (DWAF 2002a). Coal mining and its associated activities results in acid/alkaline mine drainage (AMD), characterised by high electrical conductivity (EC), and high sulphate levels (Dallas and Day 2004), which impacts some localised areas (DWAF 2002a). There are also extensive tribal and communal lands. An important feature of the WMA is that the poverty index is very high and the most impoverished areas tend to be situated in rural regions (Mosai 2004). This has implications for WQ in that there is often a high level of subsistence agriculture in such areas and sometimes overgrazing. In areas of steep topography, especially, this can lead to erosion and high sediment loads in rivers (a parameter that is not regularly monitored by DWA). Typically, poor rural settlements in the area are not supplied with sanitation (ZDM 2004) sometimes leading to localised problems of faecal and nutrient pollution (Mosai 2004). Cholera epidemics have occurred in the WMA in the past (DWAF 2002a; DWAF 2002b). According to Kotzé *et al*. (2006), conservation and ecotourism also form key economic sectors within this region, with several nature reserves including Hluhluwe-Umfolozi, Mkuze, St Lucia, Sodwana and Itala. iSimangaliso Wetland Park (Lake St Lucia) is a proclaimed World Heritage Site.

3.3 Delineation into homogeneous WQ sub-units

Existing data and expert judgement were used to delineate river units (termed "water quality sub-units" (WQSU)) that are likely to be homogenous in terms of WQ. This was a necessary step because of the large number of rivers in the WMA and the wide geographical area that is covered. The following information sources were used:

- Level 1 ecoregions generated by the project team.
- Literature on water quality issues in the catchments.
- Examination of Google Earth imagery of the area including location of DWA monitoring sites.
- Analysis of available DWA-Water Management System (WMS) data from suitable WQ monitoring stations in the area.
- Land-use and topography maps generated by the project team.
- 1:50 000 topographical maps for the relevant area.
- Biomonitoring data from the River Health Programme (RHP).

Delineation into homogenous WQ sub-units was done by first considering the topography in relation to the ecoregional boundaries. Ecoregions represent areas within which ecological characteristics are similar and are based on topography, vegetation, altitude and climate (Kleynhans *et al*. 2004). Topography and ecoregion, under *natural conditions*, i.e. in the absence of anthropogenic (i.e. caused by mankind) disturbances, would be expected to influence WQ and a change in these would be likely to cause a concomitant subtle change in WQ. An example of this is the level of dissolved oxygen (DO). In a mountain stream DO would be expected to be high because of high turbulence, but in a slow-flowing river on a flat coastal plain, DO values would tend to be lower (Davies and Day 1998).

In the *present day situation*, WQ impacts resulting from various land-use activities are superimposed on the above pattern and frequently dominate the underlying natural WQ signature. Thus, land-use in the catchment was examined with particular emphasis on the location of major point-sources of pollutants such as towns, major industries or mines. The likelihood of diffuse (nonpoint-sources) of pollution was also deduced from land-use in the area. The presence of a within-channel impoundment on a river can potentially have a marked effect on WQ, since sediments and associated pollutants tend to settle to the bottom of such structures. The effect on WQ will depend on the specifics of the dam itself (e.g. depth, residence time of water) and especially on the depth from which water is released (Malan and Day 2002). Confluence with a significant tributary, especially if the topography, ecoregion or land-use in the tributary sub-catchment differs from the main-stem river, can change WQ and such features were frequently used to delineate sub-units.

A literature search of WQ issues in the WMA was carried out using the internet and interviews were conducted with DWA personnel to identify sources of WQ data and insight into issues in particular areas. The location of DWA WQ monitoring stations in each catchment, the length of the dataset, frequency of sampling and the parameters measured were investigated. Water quality data for key parameters namely; electrical conductivity (EC), pH, phosphate, Total Phosphorus (TP) if available, nitrate plus nitrite, and ammonium – the latter combined to give Total Inorganic Nitrogen, TIN) in the form of median values were taken from the DWA-WMS database in order to give an indication of differences in WQ in different river reaches. Median sulphate and sodium concentrations were also reported for some sites where these values were high, since they indicate potential impacts from coal mining. **Note that such summaries give a *general impression* of the WQ at a site. They are NOT necessarily reflective of the PES** since medians in the summary have been calculated from the entire dataset rather than the just the last few (3-5) years as required for a more exact analysis (and as carried out for each EWR site – see Section 1.4.1) and there are no statistical comparisons with data from reference (un-impacted) sites. Nevertheless, these statistical summaries provide a useful “snap-shot” of WQ in a catchment. The boundary values given in DWA (2008 *in prep*.) were used to assess the deviation of the medians obtained from the WMS database. In other words the quality of the water was assessed and assigned a “rating” taken from the above document, which indicated to what extent a given parameter had deviated from reference conditions (RC). See Section 1.4.1 for further discussion of these rating values.

As noted above, sulphate has been included in the WQ assessments since high concentrations of this anion indicate impacts from mining and thus the risk of toxic metals having leached into surface waters. Guidelines for sulphate are not given in the DWAF Water Quality Guidelines for Aquatic Ecosystems (DWAF 1996a) nor are boundary values for the anion given in DWAF (2008 *in prep*.). The South African Water Quality Guidelines for *domestic use* give a Target Water Quality Range for sulphate of 200 mg/L or lower (DWAF 1996b). The guidelines caution that values of 200-400 mg/L can cause diarrhea in sensitive or non-adapted individuals. Since 2000, the Province of British Columbia has used a guideline of 100 mg/L to protect aquatic life, but these have recently been updated (MOE BC 2013). The revised guidelines vary from 128 mg/L for soft waters to 429 mg/L for very hard waters.

The key rivers in each catchment were delineated into homogeneous WQ sub-units and the major impacts and issues in each summarized in a table. In the interests of simplicity, adjacent sub-units in which it was considered WQ would be fairly similar were combined.

3.3.1 Catchment W1: Mhalatuze

The Mhalatuze River and its upper tributaries (e.g. Gologodo, Mavungwini Rivers) arise in the highlands of the Nkandla area and flow eastwards into the Goedetrouw Dam. Land-use in this area is subsistence farming and forestry, with some conservation areas, but no major towns. Land degradation around Nkandla has been reported (DWAF 2002a) and high sediment loads and high nutrient levels are likely since algal blooms in the dam have been recorded (DWAF 2002a). Cholera has been reported in the W1 catchment (DWAF 2002b). Downstream of the Goedetrouw Dam (constructed c. 1980) there is extensive commercial farming along the banks of the Mhlatuze River. The Mfule River joins from the north and drains a large area of subsistence farming and is likely to carry high sediment loads. The DWA WQ monitoring site W1H009Q01 Mhlatuze River @ Riverview (Dec 1967 – Nov 2013 n = 942 for EC) shows a median EC of 44 mS/m, median values of phosphate = 0.02 mg P/L and TIN = 0.27 mg N/L indicating that WQ in the mid-Mhlatuze is good, but that EC and nutrients are somewhat elevated. Unfortunately there are no turbidity or sediment data.

The Mhlatuze River flows through more areas of subsistence agriculture and then commercial agriculture before entering the extensively-developed areas draining Empangeni and Richards Bay. Industries in this area include those based on timber, metal (iron, steel, aluminum), sugar refineries, fertilizer manufacturers and a large coal terminal for exporting coal (DWAF 2002a; DWAF 2004). There have been concerns that the groundwater is being polluted by the extensive industrialization of the area. There are water transfers from the Thukela and Umfolozi Rivers into the Mhlatuze River (DWAF 2004).

To the south, the Matigulu River (EWR MA1) is predominantly rural along its entire length with mixed forestry, conservation, subsistence agriculture and some cultivation in the upper catchment. Amatikulu is the only settlement of size, but there are numerous homesteads in the area. There is natural vegetation around the EWR site itself with subsistence farming downstream, interspersed with commercial farming. The Matigulu River flows through a conservation area at the coast. A new titanium dioxide mine has been licensed on tributary to the Matigulu River and joins the river near the coast (C. Moonsamy, DWA. *pers. com*. Aug. 2014). There is no current DWA WQ monitoring site on this river.

To the north of the Mhlatuze River, the Nseleni River drains an extensive rural sub-catchment where subsistence agriculture is the major land-use. The EWR site (NS1) is situated in the mid-reaches of the Nseleni River in such an area. Downstream it joins the Okula River (draining largely commercial agriculture), and the Mposa River (whose catchment is dominated by forestry), flows through Enseleni Town and afforested areas before flowing into Lake Nsezi and then joining the Mhlatuze River a few kilometers above Richards Bay. There are no DWA WQ monitoring sites in the upper Nseleni R. where the EWR is located. There are several stations in the forested areas downstream of the town of

Enseleni, but most of these are no longer current, collect only pH (in addition to microbiological parameters), or have an incomplete data record. The results for the WQ sub-units of W1 are summarized in Table 3-1.

3.3.2 Catchment W2: Umfolozi

This catchment is dominated by the White Umfolozi River, which rises near the town of Vryheid, and the Black Umfolozi, which lies further to the north. The two rivers converge at the downstream border of the Hluhluwe-Umfolozi Game Reserve c. 50 km from the coast and drain to the Indian Ocean as the Umfolozi River. Since July 2012, the Umfolozi mouth has joined with the outflow from Lake St Lucia, replacing the management strategy of the previous 65 years which kept them separate (iSimangaliso Wetland Park 2014).

The Msunduzi River, a short river lying to the south of the lower Umfolozi River, also falls within W2. It enters the Indian Ocean roughly 5 km south of the Umfolozi mouth. Table 3-2 shows delineation of the catchment into WQ sub-units and presents the WQ impacts from the various land-uses in each area.

According to DWAF (2004), the Umfolozi catchment (10 000 km^2) consists mostly of communal land, which is used for stock farming, although there is also a significant amount of irrigation (72 km^2), forestry (435 km^2) and dryland sugarcane (65 km^2). There are also several game parks and conservation areas, the largest being the Hluhluwe-Umfolozi Game Reserve. The only towns are Vryheid, Ulundi, Babanango, Mondlo and Mtubatuba. In the upper reaches of the White Umfolozi River, the Klipfontein Dam experiences serious WQ issues as a result of return-flows from settlements in the Vryheid area and from a Waste Water Treatment Works (WWTW) causing eutrophication in the dam (DWAF 2004). Coal mining also takes place around the town of Vryheid, and pollutes surface waters in the area. As a consequence of the extensive subsistence agriculture and un-serviced rural settlements, monitoring data from the White Umfolozi River in 2000 (reported in DWAF 2002a) established this as the 6th most polluted river in the country in terms of microbiological impacts.

Coal mining is also prevalent in the upper reaches of the Black Umfolozi River causing problems with AMD. DWAF (2002a) is a study case of the upper Black Umfolozi River, plotting pH and sulphate levels along the length of the river and in various tributaries, using data from DWA WQ monitoring stations. They show serious impacts in some areas, indicated by low pH values and high concentrations of sulphate. Although DWAF (2002a) is now dated, there are no more recent monitoring data for those four sites from which to make a more up-to-date assessment. The monitoring station "Black Umfolozi River @ Ekuhlengeni (W2H28Q01/W22 102857)" which is situated in the upper reaches of the river, but below the mining area, is currently active, however. The data show that sulphate levels at this site have decreased since the late 1990's, although some impacts are still discernable (Table 3-2; WQ subunit 7), and sulphates are still elevated. This same monitoring station was used to describe the WQ for EWR site BM2 and so trends in various parameters are discussed in more detail in Section 2.4.6.

Table 3-1 Delineation of WQ sub-units and description of WQ in catchment W1 for the main-stem rivers[1]

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
1	Niii13	Mhlatuze	Mhlatuze and upper tributaries from source to Goedetrouw Dam.	Effectively similar WQ at both nodes because of topography (upland area). Impacts = u/s forestry and subsistence agriculture thus high sediment loads, but WQ improves d/s due to conservation areas (e.g. Nkandla Nature Reserve) and areas of natural veld.	No monitoring site, only W1H024Q01 (ended 1987).	
	Nvii5					
2	Ni19	Mhlatuze	From d/s of Goedetrouw Dam to confluence with Mhtatuzana. Could possibly divide into upper 2a reach (above Mfule) and below this tributary (2b).	Goedetrouw Dam would be expected to change WQ from the WQ subunit above. Commercial farming u/s of confluence with Mfule and thus likely impacts of salinization, nutrients, pesticides elevated. Mfule R. = subsistence farming so expected to carry sediments. Node at confluence with Mhtatuzana.	W1H009Q01 (W12 102809) Mhlatuze River @ Riverview = current monitoring station. W1H20Q01 (W12 102814) (no present data).	*W1H009Q01 1967 – 2013 (n = 942): Median EC = 44 mS/m (rating=1) pH = 8.0 TIN = 0.27 mg N/L (rating=1) PO4 =0.02 mg P/L (rating=2) WQ good but salinity and nutrients a little elevated.

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[1] Data taken from WMS data summary

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
4	Nvii6	Mhlatuze	D/s of confluence with Mhtatuzana to Richards Bay.	There are extensive areas of cultivated land in this reach, thus impacts due to fertilisers, pesticides and salinity. But fairly good quality water from Mhtatuzana (this inferred from land-use - no data) which should ameliorate WQ in main-stem river.	WIH032Q01 (W12 177769) Mhlatuze Valley Pump Station (Sugar factory) = current monitoring site.	*W1H032Q01 1999-2013 (n=141): Median EC = 49mS/m (rating =1) pH=7.9 TIN=0.27mgN/L(rating =1) PO4=0.02 mgP/L (rating = 2) WQ surprisingly good considering it is low down in catchment, but salinity and phosphates elevated as in u/s WQ subunit.
3	Niii14	Mfule	Entire Mfule River to confluence with Mhlatuze	Likely high sediment levels due to subsistence agriculture in addition to elevated nutrients. Likely to be similar to upper reaches of Nseleni (WQSU 5A)	W1H005Q01 Mfulazane @ Golden Reef WMS 189765: 2008 – present.	*W1H005Q01 1971-2013 (n=620): Median EC = 17 mS/m (rating=0) pH=7.7 TIN = 0.17 mg N/L (rating=0) PO4 = 0.014 mg P/L (rating=1) WQ is good.
5	Niv10	Nseleni	Entire catchment of Nseleni River, with possible delineation of WQ subunit 5a (upper Nseleni to confluence with Mposa (5b) and WQ subunit 52 = Nseleni R d/s of confluence with Mposa.	Upper Nseleni and EWR site = impacts due to subsistence farming. Below EWR sites also commercial farming, thus likely to be sediments and elevated nutrients. Small impacts from forestry lower down, but WQ probably improved by wetlands around node.	No monitoring in upper catchment. Several stations in lower catchment, but either no longer monitoring or only pH measured (e.g. W12 187078). Best = W12 188841 Maitlands u/s Nsezi Lake on Nseleni. But gap in data series.	Similar to upper reaches of Mfule, although in a different ecoregion. *W12 188841 2005-2014 (n=33): Median EC= 73 mS/m (rating =2) pH=8.2 TIN= 0.17 mg N/L (rating = 0) PO4= 0.02 mg P/L (rating = 2) Salinity is naturally high due to the geology of the area.

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
8	Ni20	Matigulu	Entire Matigulu river. Could subdivide to 8a (upper reaches to uMhgwenya) and d/s of this (8b).	U/S impacts = subsistence farming, some commercial farming. Small amount of forestry and conservation on the Ngoje R. WQ will improve from confluence of Ngoje. Immediately u/s of node is natural veld and thus improved WQ compared to upper reaches. D/s of node WQ deteriorates again due to subsistence agriculture.	W1H010Q01 (W11 102810) Matigulu River at Reserve no 21. But data only until 1992. NB. No present data for EWR site.	Similar in WQ to Mlalazi, but no urban impacts. There is no RHP data for the Matigulu, but the Nwaku, a small tributary which joins just above the EWR site has very good WQ (ASPT = 7; sampling date = 2012/05/11).
11	Ni21	Mlalazi	Entire Mlalazi River	U/S impacts = commercial farming, residential (Eshowe). At node there are likely to be impacts from subsistence agriculture.	A handful of WQ sample results for the estuary and u/s at Eshowe (W1H04Q01 Mlalazi R @ Eshowe), but nothing for at the node.	Similar WQ to Matigulu, but also impacts from Eshowe. *W1H04Q01 1977-2014 (n=414): Median EC= 20 mS/m (rating =0) pH=7.4 TIN= 0.2 mg N/L (rating = 0) PO4= 0.013 mg P/L (rating = 1) Very good quality water, but this is above Eshowe. Likely to be impacts below town.

Table 3-2 Delineation of WQ sub-units and description of WQ in catchment W2 for the main-stem rivers.

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
1	No node	White Umfolozi	Upper reaches of White Umfolozi to Klipfontein Dam.	Town of Vryheid, industry and coal mining. Likely elevated salts, nutrients and AMD.	No current monitoring site u/s of dam.	No data for river but some monitored pollution point sources (e.g. W21 188377 and 188378 show elevated EC and sulphate) i.e. impacts of mining.
2	No node	White Umfolozi	White Umfolozi below Klipfontein Dam to Mvuyane (this tributary drains subsistence farming area).	WQ fairly good. No impacts of mining (because ameliorated by Klipfontein dam). Results from W2H30Q01 and W2H09Q01 show TIN slightly elevated, and phosphates moderately elevated.	Current monitoring sites: W2H030Q01/W21 102858 just d/s of Klipfontein Dam and further d/s W2H009Q01/W21 102838 (Wit Umfolozi @ Doornhoek).	*W2H09Q01 (W21 102838)1971-2013 (n=536) Median: EC = 23 mS/m (rating = 0) pH = 7.7 SO4 = 10 mg/L TIN = 0.28 mg N/L (rating =1) PO4 = 0.03 mg P/L (rating =2) Sulphates and EC are low (i.e. no AMD), but phosphates and TIN elevated.
3	Niv12	Mvunyane	Western tributaries of White Umfolozi and White Umfolozi itself to confluence with Nsubeni.	Land-use mainly subsistence agriculture. Thus impacts = high sediment loads, possibly nutrients and microbiological impacts, especially d/s of settlements.	W2H22Q01 (W21 102851) - but monitoring stopped 1997. No present DWA monitoring site	Both nodes should have similar WQ because same ecoregion, topography, land-use.
	Niv11	Nondweni				
4	No node		White Umfolozi from confluence with Nsubeni to confluence with Mbilane.	EWR WM1 site in this reach. Fairly few impacts because largely undisturbed land, but polluted water probably brought in from settlements around Ulundi (Mbilane R) and WQ unit 3 (sediments).	Current monitoring site = W2H005Q01/W21 102834 (White Umfolozi @Overvloed/Ulundi)	W2H05Q01 (W21 102834) shows good WQ, but is u/s of Mbilane R. and therefore doesn't show impacts from Ulundi. *W2H05Q01: 1971-2013 (n=1213) Median: EC = 32 mS/m (rating = 1) pH = 8.2 SO4 = 17 mg/L TIN = 0.09 mg N/L (rating =0) PO4 = 0.02 mg P/L (rating =2) Sulphates and EC slightly elevated –

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
						due to mining in the upper catchment.
5	Niii11	White Umfolozi	From Mbilane to confluence with Black Umfolozi.	This is d/s of the flow from the town of Ulundi. The White Umfolozi then enters conservation areas/undisturbed land. WQ should gradually improve and be good in this WQSU.	No current DWA monitoring station.	Similar WQ to node Ui17 (i.e. WQ SU 8), but better because fewer impacts upstream
6	Ni18	Umfolozi	From confluence of White and Black Umfolozi to coast.	The WQ is likely to be fairly good as the river exits the game reserve. There are then impacts from subsistence agriculture, forestry and extensive commercial farming in addition to the small town of Mtubatuba (sugar refinery).	W2H032Q01/W23 102859 (Umfolozi @ State land/Monzi) is a current monitoring station. W2H10Q01 has a good data-set but effectively no recent data collected.	*W2H032Q01 (W23 102859) 1995-2013 (n=169) Median: EC = 52 mS/m (rating 1) pH = 8.3 SO4 = 18 mg/L TIN = 0.08 mg N/L (rating 0) PO4 = 0.025 mg P/L (rating 2) WQ is good in terms of nutrients. EC and sulphate slightly higher than expected.
7	Niv6	Black Umfolozi	This WQSU consists of the upper reaches of the Black Umfolozi and its tributaries to roughly the confluence with the iThaka (where there is a change in topography and land-use).	The terrain is undulating with land-use consisting of forestry, conservation, and limited areas of commercial farming and SA. There is mining in this catchment. EWR BM2 in this reach.	Current monitoring station W2H028Q01/W22 102857 (Black Umfolozi @Ekuhlengeni).	This node is very close to DWA station W2H028Q01. *W2H028Q01: 1988-2013 (n=224) Median: EC = 31 mS/m (rating = 1) pH = 7.7 SO4 = 81 mg/L TIN = 0.06 mg N/L (rating =0) PO4 = 0.01 mg P/L (rating =1) The data indicates* good WQ in terms of nutrients, but sulphate levels are high due to coal mining.
	Nv1	Black Umfolozi				
	Niii10	Hlonyane				

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
8	Niv7	Black Umfolozi	This WQSU consists of the middle reaches of the Black Mfolozi and its tributaries from the iThaka to the confluence with the White Ufolozi. It includes the Sikwabezi and Mona R.	This area is flatter than WQSU 7 (Lowveld). In the upper parts and tributaries there is extensive subsistence agriculture. Lower down is the Hluhluwe-Umfolozi Game Reserve which will lead to improved WQ.	Current DWA monitoring site W2H006Q01/W22 102835 (Black Mfolozi	Probably more impacted than WQSU 5 (Niii11) because more impacts upstream - mainly subsistence agriculture. From W2H06Q01 WQ is good but sediment loads are not measured. Sulphate levels lower than WQSU 7 *W2H06Q01: 1971-2013 (n=1210) Median: EC = 26 mS/m (rating = 0) pH = 8.0 SO4 = 20 mg/L TIN = 0.08 mg N/L (rating =0) PO4 = 0.017 mg P/L (rating =2)
	Ni17	Black Umfolozi				
	Ni16	SikweBezi				
	Niv8	Mona				
9	Niii12	Msunduzi	Entire Msunduzi R	In the upper reaches there is subsistence agriculture, with forestry d/s and commercial farming. There is fairly extensive land change in the catchment and only at the coast is there a small conservation area.	There is no current DWA monitoring station in this catchment.	WQ probably similar to WQSU 6
	Niv9	Msunduzi				

*Data taken from WMS data summary.

3.3.3 Catchment W3: Mkuze

The Mkuze River rises in the highlands to the west and flows eastwards passing 8km or so south of the Pongolapoort (Jozini) Dam. Further downstream it turns south flowing over the coastal plain and eventually enters the northern reaches of Lake St Lucia, which forms part of the iSimangaliso Wetland Park (DWA 2004). The catchment is largely rural with few towns but extensive areas of subsistence farming, and conservation areas in the lower areas. Forestry and commercial irrigated farming are also extensive (DWAF 2004) in the upper and middle reaches respectively. Other major rivers in this catchment are the Nylalazi, the Hluhluwe and Mzinene Rivers.

Salinisation arising from irrigation return-flows has been cited as problematic in the middle and lower reaches of the Mkuze River (DWAF 2002b). DWAF (2004) notes that high salinity in both the Mkuze and the Hluhluwe catchments is of concern, although there is uncertainty regarding the origin of salts in the system. Certainly, elevated EC (accompanied by high sulphates and sodium levels) occur due to mining activities, irrigation and rural subsistence activities, but the high salinity throughout the catchment suggests other, possibly natural causes, that are being exacerbated by anthropogenic activities. The authors of DWAF (2004) call for investigation into the geology of the area and the possible sources of salinity. The results from the present study (Table 3-3) support the above findings of elevated EC throughout the catchment.

As in the catchment of the Black and White Mfololozi Rivers, there is coal mining (both active and decommissioned mines) in the upper part of the Mkuze River i.e. WQ sub-unit 1 (see Table 3-3) which has seriously impacted on WQ in surface waters leading to elevated sulphate and sodium concentrations (and thus high EC) and somewhat lowered pH. This impact on WQ is apparent in WQ sub-unit 1, but also further downstream in WQ sub-unit 2. It appears that there are many WQ monitoring stations (approximately 10) located in WQ sub-units 1, 2 and 4 on the Mkuze River, which all seem to have ended in 2010. Only at W3H32Q01 (W31 102886, Mkuze River @ Overwin) are samples still being collected. This station is downstream of Mkuze town and thus located in the mid-reaches of the river (on the border between WQ subunit 4 and 5). The lack of data for the upper catchment is unfortunate since it is imperative to monitor WQ in the upper reaches considering the ongoing threat from coal mining. For example, the median sulphate levels at W3H26Q01 (W31 102880), in WQ subunit 1 if calculated for the time period 1995-2010 is very high (243 mg/L). Concerns have also been raised about the continued suitability of water from the upper Mkuze for the irrigation of sugarcane because of the high salinity and sodium contents (van der Laan, *et al.* 2011).

After the confluence of the Mkuze with the Manzimhlope River, the topography becomes much flatter. For this reason this reach was divided into WQ sub-units 1 and 2, but because of the over-arching effect of AMD, from the point of view of WQ management, these could probably be lumped together. There is expansion of cultivated land progressing downstream. The catchment of the Nkunzana (WQ sub-unit 3) which flows from the south into the Mkuze River drains an area of extensive subsistence agriculture. Data from

W3H029Q01/W31102883 (Nkunzana R @ Welverdiend; 1995 – 2009; n = 132 for EC) indicates that EC is fairly high (median = 55 mS/M) although sulphate levels are low (median = 12 mg/L). Nutrient levels are fairly good (median phosphate = 0.015 mg P/L; TIN = 0.18 mg N/L). It is unclear what, if anything, other than irrigation return-flows is causing the high EC in this region. Downstream of the Manzimhlope River, around the town of Mkuze there are large areas of irrigated agriculture. An inter-basin transfer (IBT) scheme supplies good quality water from the Pongolapoort Dam to the Mkuze for irrigation purposes. Water quality monitoring station W3H032Q01 (W31 102886 Mkuze River @ Overwin) is below this point (A. Singh, Tlou Consulting. *pers. com*. July 2014) and thus the data from that station represent the “improved” WQ after mixing with that from the Pongolapoort Dam.

The river then flows through fairly extensive conservation areas (WQSU 5 and 7), with some impacts from subsistence farming entering via the Mthambalala, Neshe and Msunduzi Rivers. The WQ would be expected to improve as it flows through areas of natural vegetation and thus gradually improve to Lake St Lucia. If the pollutant loads brought into the system by the above-mentioned tributaries are low, then WQ between sub-units 5 and 7 would be expected to be similar and thus from the point of view of WQ management the two could be lumped together. Although there are monitoring stations on the tributaries, the only environmental WQ parameter that is recorded in the WMS data-base is pH so it is difficult to establish the quality of water entering from these sources. WQ station W3H033Q01/W32 102887 Muzi R @ Yengweni u/s of Mkuzie confluence (1995 – 2009) shows elevated median EC (= 57 mS/m), high sulphate (61 mg/L) although nutrients are low (median phosphate = 0.18 mgP/L and TIN = 0.14 mg/L). This small river/lake drains from the north, an area in which land-use change is not intensive. The elevated EC values support the hypothesis that salinity is naturally high in the catchment (possibly because of old marine deposits). Consequently site W3H011Q01/W32 102867 (Mkuze River @ Morrisvale) downstream also has high levels of EC and sulphate. There appears to be no currently-maintained WQ station further downstream in order to monitor the quality of water entering into Lake St Lucia.

Because of the presence of the Hluhluwe Dam half-way down this system, the Hluhluwe catchment was divided into an upper section (WQ subunit 8a) and lower section, below the dam (WQ subunit 8b). There are areas of subsistence farming and conservation located in the upper section. Around the dam is a fairly extensive area of subsistence farming. W3H022Q01/W32 102876 (Hluhluwe Dam @ Hluhluwe River, d/s of weir) currently monitors the WQ of water from the dam – and indicates that EC is slightly elevated, and that TIN, but not phosphate, is high (Table 3-3). Further downstream is subsistence agriculture mixed with commercial farming and afforestation.

Table 3-3 Delineation of WQ sub-units and description of WQ in catchment W3 for the main-stem rivers

WQSU	NODE	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
1	Ni9	Nkongolwana	Upper undulating reaches of the Mkuze R. and its upper tributaries to around confluence with the Manzimhlope.	Impacts from coal mining. High EC and high sulphate at some sites.	No current monitoring site, but several ending in 2010 e.g. W3H026Q01/W31 102880 (Mkuze R @ Groeneweiding)	*W3H26Q01/W31 102880: 1995-2010 (n=106) Median: **EC = 76** mS/m (rating = 2) pH = 7.99 **SO4 = 243** mg/L Na = 61 mg/L TIN = 0.14 mg N/L (rating =0) PO4 = 0.012 mg P/L (rating =1) EC and sulphate levels are high due to coal mining.
	Niii9	Mkuze				
2		Mkuze	Mkuze R. d/s confluence with the Manzimhlope (i.e. low relief area) to confluence with Nkunzana	Cultivated land. Mining still impacting on WQ.	W3H028Q01/W31 102882 (monitoring from 1995 - 2010) Mkuze R. @Vergelegen	*W3H028Q01/W31 102882: 1995-2010 (n=131) Median: EC = 67 mS/m (rating = 2) pH = 8.06 Na = 57 mg/L SO4 = 160 mg/L TIN = 0.19 mg N/L (rating =0) PO4 = 0.014 mg P/L (rating =1) Although the impact of AMD is reduced compared to WQ subunit 1, sulphate, sodium and EC values are still high.
4	Nvii7	Mkuze	Mkuze R d/s confluence with Nkunzana to end of irrigated farming area (Lebombo Mountains)	Impacts from commercial irrigated agriculture - salinity, nutrients pesticides. Salinity is quite high in this region.	W3H030Q01 or W3H031Q01 (monitoring for both sites from 1995 - 2010). Most useful monitoring site = W3H032Q01/W31 102886 Mkuze R. @ Overwin.	*W3H032Q01/W31 102886: 1995-2009 (n=133) Median: EC = 94 mS/m (rating = 4) pH = 8.3 Na = 109 mg/L SO4 = 164 mg/L TIN = 0.271 mg N/L (rating=1) PO4 = 0.017 mg P/L (rating =2) Elevated salinity and sulphate. Probably from u/s mining and irrigation.

WQSU	NODE	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
5	Ni10	Mkuze	Downstream of IBT near Mkuze town to Mthambalala and Msunduzi Rivers.	EWR site in WQ subunit 5. Extensive areas of natural vegetation and wetland, some rural settlements on northern shore in WQSU 5, with potentially sediment and nutrient laden waters entering Mkuze via the Mthambalala and Msunduzi Rivers.	W3H011Q01/W32 102867 Mkuze R @ Morrisvale (1973-2010)	*W3H011Q01/W32 102867: 1973-2010 (n=268) Median: EC = 75 mS/m (rating =2) pH = 7.77 Na = 84 mg/L SO4 = 47 mg/L TIN = 0.144 mg N/L (rating=0) PO4 = 0.013 mg P/L (rating =1) This site is in WQ subunit 7, and shows high EC, sodium and sulphate. Nutrients fairly low.
7		Mkuze	Mkuze From Mthambalala and Msunduzi Rivers to Lake St Lucia			
Lake St Lucia	Nvii3	Mkuze				
3		Nkunzana	Entire Nkunzana catchment	Extensive subsistence agriculture in catchment	W3H29Q01 (monitoring from 1995 - 2010).	Nutrients fairly low. EC on the high side (median = 55 mS/m) but not sulphate. Cause of high EC uncertain.
6	Ni11	Msunduzi	Msunduzi catchment	Subsistence agriculture in upper reaches then undisturbed vegetation in lower reaches. WQ should be fairly good except for elevated sediments and nutrients.	No monitoring station	
8 upper	Nvii4	Nzimane	Upper Hluhluwe catchment to Hluhluwe Dam	Upper reaches of Hluhluwe and Nzimane impacts from subsistence agriculture. WQ improves as the rivers flow through the Hluhluwe-Umfolozi Game Reserve to the dam.	No current monitoring site	

WQSU	NODE	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
8 lower	Ni15	Hluhluwe	Hluhluwe catchment d/s of dam to Lake St Lucia	Subsistence farming around dam, further d/s forestry and irrigated farming.	Current monitoring sites are: W3H022Q01/W32 102876 Hluhluwe R d/s of dam. W3H015Q01/W32 102871 at outflow to Lake St Lucia (at Ni15).	*W3H022Q01/W32 102876: 1985-2013 (n=220) Median: EC = 51 mS/m (rating =1) pH = 7.94 SO4 = 10 mg/L TIN = 0.44 mg N/L (rating=1) PO4 = 0.011 mg P/L (rating =1) EC higher than natural, as is TIN.
9 +10	Ni14	Nylalazi	Entire Nylalazi catchment	Upper reaches extensive subsistence farming. Also most of western bank in lower reach to Lake St Lucia rural settlements. Eastern bank of lower reaches mostly afforested. Conservation area eastern bank near inflow to lake.	Node at W3H013Q01/W32 102869 (monitoring stopped in 1966)	Subsistence agriculture in lower reaches. Not on land-use map but visible on Google Earth and 1:50 000 map.
11	Ni12	Mzinene	Entire Mzinene catchment	Subsistence farming in upper reaches and commercial farming in lower reaches.	No current WQ station	

*Data taken from WMS data summary.

3.3.4 Catchment W4: Phongolo

As noted in DWAF (2002b), this is a complex catchment with topography and climate that change significantly from the mountainous reaches of northern Natal and southern Mpumalanga in the west, to the Mhakatini Flats in the east. Rainfall is high in the west (1 500 mm/yr) but low (600 mm/yr) in the rain-shadowed area east of the Lebombo Mountains (DWAF 2004). This is also an international catchment with the Ngwavuma flowing eastwards from Swaziland joining the Lower Phongolo, just before the confluence with the Usutu. The Usutu forms the border between South Africa and Moçambique for a short-distance and then after joining the Phongolo River, the combined system forms the Maputo River and flows through southern Moçambique. The Lower Phongolo River forms an extensive floodplain system with natural pans and levees and is an ecologically important and sensitive area (DWA 2009). There are few towns in the catchment, the largest being Paulpietersberg and Frischewaagd in the upper portion. The settlements of Pongola and Jozini are located in the middle and lower catchment, to the east and west of the Pongolapoort (Jozini) Dam respectively.

The major rivers in the South African part of the catchment are the Phongolo River which flows eastwards from the slopes of the Drakensberg Mountains and joins with the Bivane River from the south. Situated in the upper reaches of the Bivane is the Bivane/Paris Dam. There are extensive afforested areas in the upper reaches of the Bivane and Phongolo Rivers (DWAF 2004; ZDM 2004) with some cultivated agriculture. Although there are several on-going monitoring sites in the middle to lower half of the system there is very little in the upper portion in which the EWR site is located (in WQ subunit 1). Rossouw *et al*. (2008) highlighted the lack of monitoring sites in the upper Phongolo River as an issue, particularly because of the risk of impacts from coal mines (both working and closed) in the Paulpietersberg area. Rossouw *et al.* (2008) cite monitoring carried out by DWAF 1993-1995, and research by Vivier and Cyrus (1999) in the upper Phongolo and Bivane Rivers concerning the risk of pollution from mines. It was concluded that although localized leakage of AMD had occurred, this had not extended into the Phongolo or Bivane Rivers, although elevated EC in the Manzane River (which flows into the Bivane Dam) was apparent. There is a WQ monitoring station located in the upper Bivane River - W4H004Q01/W41 102897 (Bivane R @ Welgelegen Pivaansbad) in WQ sub-unit 5 which was investigated. The data for this site confirm that WQ of the Bivane River is very good. There is a danger in extrapolating this result to the Upper Phongolo River, however, in that land-use change in the Bivane is less intense than in the Phongolo (for example there are no towns in the Bivane). This is discussed further in Section 3.4.9.

Just downstream of the confluence of the Upper Phongolo and Bivane Rivers is the Ithala Nature Reserve. In the middle reaches of the Phongolo river (WQ subunit 3) around the town of Pongola is extensive irrigated commercial farming. Sugarcane is the major crop, but also citrus, mangoes and vegetables (DWA 2009). This is the largest irrigated area in the WMA and substantial impacts from polluted agricultural return-flows have been reported (DWAF 2004). This assertion is supported by data from the monitoring site W4H006Q01/ W44 102898 (Phongolo R @ Mhlati) which indicates elevated EC (i.e. salinity) and nitrogen (as indicated by TIN) concentrations (Table 3-4). According to Rossouw *et al*. (2008) irrigation return-flows are resulting in a trend of increasing salinity and nutrient levels within the Pongolapoort Dam and problems with eutrophication in the dam are emerging. Elevated concentrations of toxins arising from pesticide use in the irrigation area are also likely.

The Pongolapoort Dam and the gorge through the Lebombo Mountains are scenic areas in which several game lodges are located. The Pongolapoort Dam is one of the largest in South Africa (DWAF 2002b). From the dam, the Phongolo River flows northwards across the Mhakatini Flats area and is joined by numerous tributaries draining the slopes of the Lebombo Mountains to the west, including the Ngwavuma River from Swaziland. The area is characterized by extensive subsistence agriculture, although there is some commercial farming around Jozini (Makhathini Irrigation Scheme). According to DWAF (2004) the Mahkatini Flats region is situated on old marine deposits and groundwater is naturally saline in this region. Most likely as a consequence of this geological influence, the median EC value at W4H009Q01/W45 102901 (Phongolo R. @ Ndume Game Reserve), which is situated near the outflow to Moçambique, is unexpectedly high considering the land-use in the area. Rossouw *et al*. (2008) report that increasing salinity from irrigation is causing extremely high salinities to occur in the natural pans of the floodplain as water evaporates, a situation which is only remedied when floods occur and the pans are inundated. The sediment load in the Lower Phongolo is also likely to be high considering the intensive subsistence farming, the steep topography to the west, and the issue of poor land care in Swaziland. This parameter, however, is not currently monitored by DWA in this region.

Table 3-4 Delineation of WQ sub-units and description of WQ in catchment W4 for the main-stem rivers.

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
1	Ni2	Phongolo	Upper Phongolo R to confluence with Bivane R.	EWR UP1 in this reach. Forestry, commercial farming and in area u/s of confluence some subsistence farming. Towns of Paupietersberg and Frischewaagd. Possible mining impacts in this region.	No current WQ station	Many pollution monitoring sites – non on the Phongolo R. No current site from which WQ can be deduced. Possible impacts from towns and mines.
	Ni3	Phongolo				
	Niii6	Phongolo				
	Niv4	Phongolo				
2	Niv5	Phongolo	Phongolo R from confluence with Bivane to outflow from Ithala Game Reserve. Also lower reaches of Mozana.	Within Ithala Game Reserve	No current WQ station	WQ is probably good because just d/s of a conservation area and good WQ from Bivane R. Uncertain, but could be some pollution from upper Phongolo.
	Ni4	Mozana				
3	Niii8	Phongolo	Phongolo R from outflow from Ithala Game Reserve to Phongolapoort Dam	Town of Phongola on the river. Extensive irrigated commercial farming in the area.	Current monitoring site W4H006Q01/W44 102898 (Phongolo R @ Mhlati)	Node Niii8 is at W4H006Q01 *W4H006Q01/W44 102898: 1971-2013 (n=969) Median: EC = 47 mS/m (rating =1) pH = 8.3 SO4 = 16 mg/L TIN = 0.46mg N/L (rating=1) PO4 = 0.018mg P/L (rating =2) Salinity and nitrogen levels are elevated at this site.
4	Ni8	Phongolo	Lower Phongolo R on Makatini Flats area to border with Moçambique	Low-relief area. Extensive subsistence agriculture.	W4H009Q01/W45 102901 Phongolo R at Ndume Game Reserve. Situated at outflow to Moçambique	*W4H009Q01/W45 102901: 1980-2013 (n=366) Median: EC = 48 mS/m (rating =1) pH = 7.9 SO4 = 17 mg/L TIN = 0.20mg N/L (rating=0) PO4 = 0.019mg P/L (rating =2) Salinity (EC) is elevated at this site.

WQSU	Node	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
5	Ni5	Bivane	Bivane R to Bivane Dam and Manzana R.	Some forestry and commercial farming in this area. Possibly localised mining impacts in upper catchment, but not in the Bivane R.	W4H004Q01/ W41 102897 Bivane R @ Welgelegen Pivaansbad	Node Ni6 is at W4H04Q01. *W4H04Q01/W41 102897: 1977-2008 (n=523) Median: EC = 10 mS/m (rating =0) pH = 7.5 SO4 = 5.3 mg/L TIN = 0.17 mg N/L (rating=0) PO4 = 0.014 mg P/L (rating =1) WQ is very good at this site and confirmed by RHP (ASPT = 6.4 sampling date = 2012/05/08).
	Ni6	Bivane				
	Niv2	Manzana				
	Niv3	Bivane	In Bivane (Paris) Dam			
6	Niii7	Bivane	D/s of Bivane Dam to confluence with Phongolo R.	Very little land-use change in this area. Good WQ expected.	No current WQ station	Node just above inflow to Bivane Dam
7	Ni8	Ngwavuma	Eastward-draining tributaries of the lower Phongolo draining Lebombo Mountains.	Subsistence agriculture, especially on flatter areas, but also in mountains. Likely to be high sediment loads and nutrients.	No WQ monitoring station.	RHP (ASPT = 5; sampling date = 2012/05/09). Indicating impacted WQ.

*Data taken from WMS data summary.

3.3.5 Catchment W5: Usutu

The Usutu River and its major South African tributaries, the Assegaai (called the "Mhkondvo" in Swaziland), Ohlelo and Ngwempisi Rivers, rise in the mountainous eastern escarpment of the Drakensberg and flow eastwards through Swaziland. The Usutu River then exits Swaziland, forms the border between South Africa and Moçambique for roughly 20km and joins the lower Phongolo River before crossing the coastal plain of southern Moçambique. Dams are located in the headwaters of many Usutu tributaries, namely, the Heyshope (on the Assegaai River), Jerichoe and Morgenstond (Nwempsi River), and Westoe (Usutu River) dams, and supply water to the Vaal River via the Vaal Transfer Scheme (DWAF 2002b; Rossouw *et al.* 2008). Development in the upper Usutu catchment is generally limited with the only towns of significant size being Piet Retief and Amsterdam. The main land-use is forestry with some commercial and subsistence agriculture in the south-west.

WQ sub-unit 1 is comprised of the head-waters of the Assegaai River to the Heyshope Dam (Table 3-5). Commercial and subsistence agriculture takes place in the catchment around the Heyshope Dam with limited coal mining (DWAF 2004). Although there have been various historical *ad hoc* monitoring initiatives in this WQSU there is no current monitoring station. The town of Piet Retief is located close to the Assegaai River below the dam with forestry and some commercial farming being the major land-use in the surrounding environs. Rossouw *et al.* (2008) compared the WQ from W5H039Q01/W51 102924 (Assegaai R. @ Heyshope Dam) with that downstream, just above the border into Swaziland (W5H022Q01/ W51 102914; Assegaai R. @ Zandbank) and found that there was a slight increase in EC and nitrogen downstream, which they attributed to the WWTW in Piet Retief. But in general they considered the WQ of the Assegaai, and the rest of the upper W5 catchment to be very good (but note the WQ was assessed by these authors for "fitness of use" for power stations rather than based on environmental requirements). Monitoring of WQ at both of the above stations has been discontinued. The EWR site AS1 is located in this WQSU.

Because of the uniformity in topography (mountainous), ecoregion and land-use (mostly forestry), the Usutu, Ohlelo and Ngwempisi Rivers (i.e. the upper W5 catchment excluding the Assegaai River) were grouped into one WQ sub-unit (Table 1-5). There are several WQ monitoring stations in the region e.g. (W5H005Q01/W52 102911; W5H026Q01/W53 102918; W5H008Q01/ W54 102913) – not all of which are currently monitoring WQ. All these sites, however, show water of low EC (median EC < 10 mS/m) and low nutrient levels (although W5H026Q01/W53 102918 Ngwempisi R. @ Merriekloof and W5H024Q01/ W55 102916 Mpuluzi @ Dumbarton do show slightly higher TIN values due to the presence of small townships upstream).

The DWA's WQ monitoring station W5H023Q01/W57 102915 (Great Usutu R. @Ndumu Game Reserve) is situated in WQ subunit 4, just above the confluence with the Phongolo River. The data-set is disjointed with data for the 1980's a gap from 1989 to 2011, and a single sampling occasion in 2012. Thus it is difficult to detect a trend but EC and nutrient values from the 2012 sampling were fairly high (EC = 53 mS/m; TIN = 0.23 mg N/L; PO4 = 0.02 mg P/L) indicating impacts from the upstream catchment in Swaziland (Table 3-5).

Table 3-5 Delineation of WQ sub-units and description of WQ in catchment W5 for the main-stem rivers

WQSU	NODE	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
1	No node	Assegaai	Assegaai River from source to Heyshope Dam.	Some coal mining in upper catchment and commercial farming. Subsistence agriculture around dam.	No current WQ monitoring site.	
2	Ni1	Assegaai	Assegaai R d/s from Heyshope Dam to Swaziland border. EWR As1 site in this reach	Forestry and town of Piet Retief. Coal mining in tributary.	W5H039Q01/W51 102924 gives indication of WQ of water leaving Heyshope Dam - ended 2010). Also W5H022Q01/W51 102914 (ended 2009 and sampling frequency erratic). No current monitoring site.	WQ leaving the dam is very good and still good at Swaziland border as indicated below (but data not current). *W5H022Q01/W51 102914: 1977-2009 (n=348) Median: EC = 12 mS/m (rating=0) pH = 7.7 SO4 = 8 mg/L TIN = 0.21 mg N/L (rating=0) PO4 = 0.017mg P/L (rating=2) RHP: sampling date 2008/06/03. ASPT =6.1 (WQ very good). This RHP sampling site is above Piet Retief.
3A	Niii4	Ohlelo	Ohlelo R from source to Swaziland Border	A little commercial farming in upper reaches and extensive forestry.	Monitoring site W5H005Q01 effectively ended 2001 (1 sample since). Nothing else.	WQ expected to be very good. Some impacts from forestry. I.e. nutrients a little elevated.

WQSU	NODE	River name	Delineation of WQ sub-unit	WQ impacts	Availability of WQ monitoring data	Comment
3B	Nvii2	Ngwempisi	Ngwempisi R from source to Swaziland border	A little commercial farming in upper reaches, but extensive forestry. Small town of Amsterdam lower down.	No current WQ monitoring site - best is W5H026Q01/ W53 102918 Ngwempisi R. @ Merriekloof (ended in 2009).	Morgenstond and Jericho Dams in this catchment. WQ is good. *W5H026Q01/W53 102918: 1977-2009 Median EC = 9.4 mS/m (rating=0) pH =7.6 TIN = 0.19mg N/L (rating=0) PO4 = 0.015mg P/L (rating=2)
3C	Nvii1	Usutu	Usutu R from source to Swaziland Border. Upper 3C above Westoe Dam, lower 3C below dam.	Some commercial farming in upper reaches, but most of catchment is under extensive forestry.		Node at inflow to Westoe Dam
	Niv1	Bonnie Brook				Node below Westoe Dam
4	No node	Usutu	Usutu R d/s Swaziland	In conservation area but WQ indicates impacts from u/s.	W5H023Q01/W57 102915 Great Usutu R @ Ndumu Game Reserve.	Sampling only recently resumed. WQ good, but slightly elevated EC and high nitrates.

*Data taken from WMS data summary.

3.3.6 Catchment W7: Lake Sibaya/Kosi Bay

The Lake Sibaya catchment is a coastal system north of Sodwana Bay. The catchment is essentially endorheic (DWAF 2002b). According to Kotzé *et al.* (2006) this area has relatively high rainfall and limited surface runoff due to the flat terrain and supports a high groundwater recharge area. The Zululand Coastal Aquifer which underlays this catchment, is the largest primary aquifer in South Africa. There is no WQ monitoring of rivers in the area, but there is for some of the lakes. Land-use is predominantly conservation, tourism, with some forestry and subsistence farming.

3.4 Description of the EWR sites

3.4.1 Method used to derive the EcoClassification

In this section, for each EWR site, the present ecological state (PES) for WQ is described in relation to the WQ under least-impacted (reference) conditions (RC). As explained in the previous section, each of the main rivers was divided into reaches (WQSU) which would be expected to exhibit homogeneous water quality. The likely WQ for each WQSU was described based on land-use and impacts in the area and on available WMS WQ summary data (Table 3-6 to Table 3-11). The WQ for the river reaches in which each of the eight EWR sites is located is now discussed in more detail.

The method used to derive the RC, PES and the Recommended Ecological Category (REC), unless otherwise stated, were those described in DWAF (2008 *in prep*.). At the time of undertaking this project, there was uncertainty around the validity of the methods described in DWAF (2008 *in prep*.) but no alternative method was available (Joyce Machaba, DWA RDM/Adhishri Singh, Tlou Consulting, *pers. com*. May 2014). Thus in this project, especial attention has been directed to ensuring that the methods used here are as clear and as replicable as possible. For example, tables of results have been included to give the background reasoning for the choice of WQ monitoring stations (or lack thereof) used to derive a PES/RC for a given EWR site. In addition, median values are reported and the rating (i.e. deviation from RC) given in parenthesis. Consequently, if rating/boundary values are changed, the new ratings can be easily recalculated. The use of “ratings” on a scale from 0 -5 (where 0 = natural/no change and 5 = severely impacted) has been used in this report because this is what is used in DWAF (2008 *in prep*.). The PAI EcoStatus model uses categories A – F (where A = natural and F = severely impacted). DWAF (2008) notes, however, that “There is (therefore) a direct relationship between the ratings of 0 -5 and the A – F categories.” Essentially; Category A ≡ Rating= 0 (natural/no change from RC); Category B ≡ Rating =1 (small change) etc. to Category F ≡ Rating =5 (extreme change from RC).

The data sources listed in Section 3.10 were used to describe the PES and RC for WQ at each EWR site. In addition, *in situ* WQ data were collected during the site visit in July 2014 (Colleen Todd, *pers. com*. Aug. 2014).

The list of DWA WQ monitoring sites for the relevant catchments was downloaded from the DWA National Water Management System (extracted on 2014/06/13). Each station was evaluated in terms of its exact location (e.g. upstream/downstream of a town or tributary) in relation to the EWR site, the length of the dataset and time period e.g. pre-development or current monitoring site (the former useful to describe the RC, the latter for the PES). Although there are >460 WQ monitoring sites listed for the WMA, many are no longer operational, have few data points, form an interrupted data series, or only capture limited WQ parameters. Furthermore, many are pollution-source data i.e. they give measurements from a point-source of pollution rather than instream values and are of limited value in describing the WQ for a given river reach.

The confidence in the monitoring site used to represent the PES (and sometimes the RC) in terms of its location in relation to the EWR site, frequency of sampling and length of the dataset was recorded. The data used to derive the EcoStatus of each EWR site are summarised in the relevant sections.

The RC water quality was derived by:

- Using historic data, considered to be prior to major impacts in the catchment, for the site in question.
- Using data extrapolated from an un-impacted site on another (similar) river.
- Where no suitable data were available, using the default boundary values for the natural (“A”) category (from DWAF 2008 *in prep*.).

The PES water quality was derived using one or a combination of the following approaches:

- Using present-day data from a nearby WQ station.
- Using data extrapolated from a similar (in terms of surrounding land-use) river from an adjacent catchment.
- Using biological indicator data to infer water quality.
- Using the limited data from the once-off data sampling in July 2024.

The present state rating values given in Table 3-6 to Table 3-11 were used to rate the status of individual water quality variables for each WQSU and for each EWR. The overall site classification for water quality at each EWR site was obtained using the PAI EcoStatus model (Kleynhans *et al.* 2005) shown in Appendix A. No in-stream toxicity testing or chlorophyll *a* samples were undertaken since it was considered that once-off samples would not be particularly useful in assessing the trophic state (Ewart-Smith, *pers. com*. 2014).

Furthermore, none of the above variables are obligatory for Reserve Determinations (DWAF 2008 *in prep*.).

Table 3-6 Present state rating values for Electrical Conductivity (from DWAF 2008 *in prep*.).

Description of WQ	A – F category	Rating	Value (mS/m)
Natural	A	0	≤ 30
Good	B	1	30.1 - ≤ 55
Upper fair	C	2	55.1 - ≤ 85
Lower fair	D	3	>85
Poor	E/F	4	-

Table 3-7 Present state rating values for phosphate (PO_4-P) and Total Inorganic Nitrogen (TIN) used to describe water quality in terms of Category and Rating (adapted from DWAF 2008 *in prep*.).

Rating	Deviation from reference condition	Environmental clues about the periphyton and phytoplankton response to nutrient enrichment	PO_4-P (mg/L)	TIN-N (mg/L)
0	No change	Natural (Oligotrophic) - pristine river and catchment, no known man-made changes to the nutrient regime, oligotrophic conditions, no visible presence of phytoplankton, thin periphyton mats (<0.5 mm thick), water clear.	<0.005	<0.25
1	Small change	Oligo – mesotrophic – minor modifications to the catchment affecting the nutrient status, phytoplankton barely evident, thin periphyton mats (<0.5 mm thick), water is largely clear. Less than 10% cover with filamentous algae.	0.005 – 0.015	0.25-0.70
2	Moderate change	Mesotrophic moderate modifications to the catchment affecting the nutrient status, some evidence of phytoplankton, medium periphyton mats 0.5-3mm thick), short filamentous algae (< 2cm long). 10 - 20% cover with filamentous algae.	0.015-0.025	0.70-1.0
3	Large change	Eutrophic –visible evidence of phytoplankton and the water appears green, thick periphyton mats (> 3 mm thick), long filamentous algae (> 2cm long). 20 - 50% cover with filamentous algae.	0.025-0.125	1.0-4.0
4	Serious change	Eutrophic conditions, visible evidence of algal phytoplankton blooms, thick periphyton mats (> 3 mm thick), long filamentous algae	>0.125	>4.0

Rating	Deviation from reference condition	Environmental clues about the periphyton and phytoplankton response to nutrient enrichment	PO_4-P (mg/L)	TIN-N (mg/L)
		(> 5 cm long), periphyton rarely washed away. 50 - 80% cover with filamentous algae.		
5	Extreme change	Hyper-eutrophic conditions are present, low DO and noxious odours, visible evidence of algal scums accumulating in embayments, toxic blue-green algae present or suspected to be present, periphyton <80% cover present most of the time, or long strands of filamentous algae visible. 80 – 95% cover with filamentous algae.		

Table 3-8 Present state rating values for pH (from DWAF 2008 *in prep*.)

Rating	Deviation from reference condition	pH (5th percentile)	pH (95th percentile)
0	No change	6.5 to 8.0	6.5 to 8.0
1	Small change	5.9 – 6.5	8.0 – 8.8
2	Moderate change	5.6 – 5.9	8.8 – 9.2
3	Large change	5.0 – 5.6	9.2 – 10.0
4	Serious change	4.0 - 5.0	10.0 – 11.0
5	Extreme change	<4	>11.0

Table 3-9 Present state rating values for dissolved oxygen (from DWAF 2008 *in prep*.)

Rating	Deviation from reference condition	Environmental clues about the dissolved oxygen status	Dissolved oxygen concentration (mg/L)
0	No change	Known to be a pristine river, no known problems or concerns about dissolved oxygen; all oxygen sensitive species are present.	> 8
1	Small change	Some man-made modifications in the catchment but no known problems or concerns about DO, most oxygen sensitive species are present.	7 – 8
2	Moderate	Some concerns about dissolved oxygen,	6 – 7

Rating	Deviation from reference condition	Environmental clues about the dissolved oxygen status	Dissolved oxygen concentration (mg/L)
	change	some oxygen sensitive species are present but mostly oxygen tolerant species.	
3	Large change	Known problems with reduced dissolve oxygen, mostly low DO tolerant species are present.	4 – 6
4	Serious change	Major know problems with low dissolved oxygen, anoxic odours sometimes present, only very low DO tolerant species present.	2 – 4
5	Extreme change	Extreme concerns about low DO, anoxic odours present most of the time, colour of the water often dark with organic material, benthic algae replaced by grey/black bacterial films and sewage fungus, no biota present most of the time.	0 – 2

Table 3-10 Present state rating values for temperature (from DWAF 2008 *in prep*.)

Rating	Deviation from reference condition	Environmental clues about the temperature status	Deviation from the natural monthly temperature range (10th and 90th percentile values)
0	No change	Pristine river, catchment natural, no known problems with temperature. All temperature sensitive species present in abundances and frequencies of occurrence as expected for reference.	Natural temperature range, measured or estimated from air temperature
1	Small change	Some minor man-made changes to the river but no known changes to the natural temperature regime. Some highly temperature sensitive species in lower abundance and frequency of occurrence than expected for reference.	Natural temperature range, measured or estimated from air temperature
2	Moderate change	Moderate change to temperature, occurs infrequently. Most highly temperature sensitive species in lower abundances and frequency of occurrence than expected for reference.	Vary by no more than 2°C
3	Large change	Large change to temperature regime occurs often. Most moderately temperature sensitive species in lower abundances and frequency of	Vary by no more than 4°C

Rating	Deviation from reference condition	Environmental clues about the temperature status	Deviation from the natural monthly temperature range (10^{th} and 90^{th} percentile values)
		occurrence than expected for reference.	
4	Serious change	Serious changes to temperature regime, occurs most of the time, only biota highly tolerant to temp changes occur. All moderately temperature sensitive species in much lower abundances and frequency of occurrence than expected for reference. Temperature insensitive species may have high abundances and frequency of occurrence.	Vary by more than 4°C
5	Extreme change	Extreme changes to temperature regime, occurs all the time, only biota highly tolerant to temp changes occur. At best, only temperature insensitive species present, often with very low abundances and frequency of occurrence.	Vary by more than 5°C, up to a maximum 30°C for the upper boundary

Table 3-11 Present state rating descriptions for turbidity/clarity (from DWAF 2008 *in prep*.)

Rating	Deviation from reference condition	Environmental clues about the turbidity status
0	No change	Pristine river, no known man-made modifications of the catchment, no known concerns about turbidity, changes in turbidity appears to be natural and related to natural catchment processes such as rainfall runoff.
1	Small change	Some minor man-made modifications to the catchment, changes in turbidity appear to be largely natural and related to natural catchment processes such as rainfall runoff. Very minor effects of silting of habitats, large of a temporary nature and natural river processes clear newly deposited silt soon after the event.
2	Moderate change	Moderate changes to the catchment land-use have resulted in unnaturally high sediment loads and high turbidity during runoff events. The impacts are however temporary.
3	Large change	Erosion and/or urban runoff processes is a known cause of unnaturally large increases in sediment loads and turbidity, habitat often silted but it is cleared from time to time. Low amounts of periphyton algae or phytoplankton are present.

Rating	**Deviation from reference condition**	**Environmental clues about the turbidity status**
4	Serious change	The catchment is known to have serious erosion problems, increased turbidity levels are present most of the time, large silt loads are deposited leading to a serious reduction in habitat. Low amounts of periphyton algae or phytoplankton are present.
5	Extreme change	The catchment is known to have serious erosion problems, increased turbidity levels are present most of the time, large silt loads are deposited leading to an almost total loss of habitat, silt loads are so high that fish kills have been attributed to it.

3.4.2 EcoClassification of river reaches represented by the EWR sites

The WQ monitoring sites used to derive the WQ EcoClassification i.e. used to describe the Present Ecological State (PES) and the Reference Condition (RC) or natural state for WQ are summarised in Table 3-12. Also given is the location of each EWR site and its code. A detailed discussion of each site is given in the following sections.

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Table 3-12 Summary of the monitoring sites investigated to derive the PES and RC WQ for the EWR sites

Quaternary Catchment	River	Site Name	Description	Latitude	Longitude	RC	PES
W11B	Matigulu	EWR Site MA1	Riffle downstream of old DWA gauging station.	29º1’12.36”S	31º28’13.44”E	Default values	W1H009Q01 Mhlatuze R @ Riverview
						No current DWA monitoring station. WQ inferred from other catchments.	
W12H	Nseleni	EWR Site NS1	Small river, with good habitat and relatively un-impacted	28º38’2.76”S	31º55’51.24”E	Default values	W12 188841 Maitlands upstream of Nsezi Lake on Nseleni (NEMP)
						No current monitoring station in WQSU. WQ derived from d/s site.	
W21H	White Umfolozi	EWR Site WM1	Wide, flat river, with riffle area downstream of the old road drift/culvert	28º13’53.24”S	31º11’17.97”E	Default values)	W2H005Q01 @ Overvloed/Ulundi on Wit-Umfolozi (NCMP)
W22C	Black Umfolozi	EWR Site BM1	Bedrock and riffle section downstream of DWA gauging station W2H028. Distinct low flow channel and high flow zones	27º56’20.04”S	31º12’37.08”E	Default values	W2H028Q01 (W22 102857) @ Ekuhlengeni on Swart - Mfolozi (NCMP)
W22C	Black Umfolozi	EWR Site BM2	Distinct channel with bedrock and very large boulders	28º0’50.04”S	31º19’27.48”E	Default values	W2H006Q01 (W22 102835) @ Reserve no 12 on Swart - Umfolozi (NCMP)
W31J	Mkuze	EWR Site MK1	Wide, sandy bed, with subsurface flow.	27º35’31.56”S	32º13’4.80”E	W3H025Q01 Mtebeni River @ Fortuin	No recent site but W3H032Q01 (W31 102886) used to infer WQ
W42E	Upper Phongolo	EWR Site UP1	Bedrock and riffles, good flow.	27º21’51.99”S	30º58’10.18”E	Default values	W4H004Q01 (W41 102897) @ Welgelegen Pivaansbad on Bivane (NCMP)
W51D	Assegaai	EWR Site AS1	Downstream of Heyshope Dam, close to border with Swaziland. Good flow and habitat diversity	27º3’44.28”S	30º59’19.68”E	Default values	W5H022Q01 (W51 102914) @ Zandbank on Assegaai River (NCMP)

3.4.3 EWR Site MA 1: Matigulu River

As noted previously, the Matigulu River is predominantly rural along its entire length with subsistence agriculture interspersed with commercial farming, as the major activities. There is natural vegetation around the EWR site itself with subsistence farming downstream. Currently there is no active DWA WQ monitoring site on this river, since W1H010Q01 (W11 102810) was closed in 1978. This station was, however, considered for assessing the RC. To infer the PES with regard to WQ, two stations from other catchments to the north, were investigated. Firstly, W1H004Q01 (W13 102806 Mlalazi R @Eshowe), located in the adjacent northern catchment to the Matigulu River. This catchment has fairly similar land-use and thus would be expected to have comparable WQ to the EWR site. Unfortunately though, this monitoring site is just downstream of Eshowe Dam, which might alter WQ (possibly improving WQ due to settlement of sediment-associated nutrients). Thus the data for WIH009Q01 (W12 102809 Mhlatuze R @ Riverview) were also investigated, because land-use in the lower Mhlatuze River is also predominantly subsistence and commercial agriculture and thus the same WQ impacts could be expected. The results for these three sites are summarized in Table 3-13, which shows the time-period chosen, the number of samples for each variable and the summary statistics.

From Table 3-13 it can be seen that for the possible RC site (W1H010Q01/ W11 102810), although median EC falls within an “A” (natural) class being <30 mS/m, median TIN is higher than the boundary value for “A” category (being >0.25 mg N/L) as is phosphate (>0.005 mg P/L). Although this could possibly be because levels of nutrients are naturally high in this area, the most likely explanation is that in 1976 WQ was already impacted in the river and nutrient levels elevated. This is substantiated by the fact that the median TIN value for this site is higher than that from the “PES” site W1H009Q01/ W12 102809, and median phosphate is higher than for both potential “PES” sites. Thus W1H010Q01 is NOT a suitable reference site, and for this EWR site, the default values for the “A” (natural) class were used (i.e. those shown in Table 3-6 to Table 3-11). Furthermore the EcoClassification derived for the EWR site was not adjusted since natural background concentrations were considered to be normal.

With regard to the PES for the EWR site, because there is currently no monitoring site in the catchment WQ was inferred from WIH009Q01 (W12 102809 Mhlatuze R @ Riverview). Since this is in another catchment, the EcoClassification assessment carries a low confidence. From Table 3-13, the likely WQ of the EWR site is low nutrient levels (TIN in a natural category with phosphate only slightly impacted). The greatest impact is likely to be high turbidity arising from the extensive subsistence agriculture in the catchment (but there are no data for this WQ parameter). These results are supported by the once-off sampling data from July 2014 for EC, DO, temperature and pH and by the invertebrate results (ASPT = 6). An overall category = B is predicted for the river reach in which this EWR is situated.

The WQ EcoClassification results for EWR site MA 1 are summarised in Table 3-14.

Table 3-13 Summary of the WQ data for WQ monitoring stations of relevance to EWR MA 1

	Monitoring station	Time period used	Summary statistics	Water quality parameters										
				Ca (mg/L)	Cl (mg/L)	EC (mS/m)	Mg (mg/L)	Na (mg/L)	NH4_N (mg/L)	NO3_NO2_N (mg/L)	TIN (mg/L)	pH	PO4_P (mg/L)	SO4 (mg/L)
RC	W1H010Q10 Matigulu R.	1976/10/07 to 1978/12/18	Median	7.05	36.2	25	6.75	26.4	0.02	0.23	0.27	7.05	0.014	4.9
			5%									6.58		
			95%									7.58		
			n	78	78	103	78	78	78	78	78	78	78	78
PES	W1H004Q01 Mlalazi R.	2009/01/27 to 2014/03/04	Median	5.56	39.62	20	4.52	20.31	0.14	0.13	0.38	7.52	0.005	2.20
			5%									7.15		
			95%									7.88		
			n	37	37	37	30	34	36	31	37	30	30	37
PES	W1H009Q01 Mhlatuze R.	2009/02/03 to 2014/02/04	Median	11.29	46.71	35	9.32	42.88	0.025	0.197	0.222	7.93	0.006	8.753
			5%									7.25		
			95%									8.37		
			n	41	41	39	40	39	41	40	40	137	41	41

Table 3-14 PES categories and overall site assessment for EWR MA1 Matigulu River.

RIVER	Matigulu River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 8B	**RC**	Default boundary tables for "A" category river
EWR SITE	MA1	**PES**	W1H009Q01 (W12 102809) Mhlatuze R @ Riverview. 2009/02/03 – 2014/02/04; n= 40 for EC.
Confidence assessment		**Low confidence as no current monitoring station in catchment**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg/L)	0.006	Very slight impact (Rating = 1)
	TIN (mg/L)	0.222	No impact (Rating = 0)
Physical variables	pH (5th–95th %ile)	7.3-8.4 7.11*	Slight impact (Rating = 0.5)
	Temperature °C	No data 15.6*	Slight impact (Rating = 1)
	Dissolved oxygen (mg/L)	No data 7.8*	Slight impact (Rating = 1)
	Turbidity (NTU)	No data	Expected to be fairly high (Rating =2)
	Electrical conductivity (mS/m)	35 24*	Slight impact (Rating = 1)
Response variables	Chl a: periphyton	No data	
	Chl a: phytoplankton	No data	
	Macroinvertebrates (ASPT)	6	
	Fish community score	B	
Toxics	Sulphate (mg/L)	9	No data – expected to fairly low (no mining, limited pesticides). (Rating = 0)
OVERALL SITE CLASSIFICATION		**B** (from PAI)	

*Sampled at site July 2014.

3.4.4 EWR Site NS 1: Nseleni River

As noted previously, this EWR site is located in an extensive area of subsistence farming. There is no WQ monitoring station in the upper catchment where this EWR site is located, although there are several in the lower catchment which vary in the number of samples and the parameters measured (Table 3-15). None of the sites were, however, useful to describe either the RC or the PES of the EWR site.

With regard to a possible RC site, the data from W1H005Q01 (W12 102807) were examined, because monitoring at this site started in 1977 (and it is thus possibly pre-impact) and the site is fairly high up in the catchment, above the town of Melmouth and other impacts. Note though that this site is on the Mfulazane River and not in the same catchment. (The monitoring station W1H024Q01/ W12 102819 is also high in the catchment does not have any useful data). As can be seen from Table 3-16, the median phosphate concentrations at this site for the early time period are higher than the default “A” category value of 0.005 mg P/L and thus this site was not used.

Because of the lack of a suitable site to infer PES WQ, the data for W12 188841 (Nseleni R @ Maitlands u/s of Nsezi Lake), although situated in the lower half of the catchment, was analysed to give an indication of WQ further down in the river, near the coast. The results for this site are summarized in Table 3-16. Water quality monitoring site W12 188841 (Nseleni R @ Maitlands u/s of Nsezi Lake) shows surprisingly high EC values (median = 55 mS/m – compare with those for W1H005Q01/W12 102807 and the values in Table 3-6). Since monitoring started at this site in 2005, the EC has been consistently greater than 50 mS/m. The reason for this elevated salinity is unclear – although it might be due to naturally saline ground-water (C. Moonsamy, DWA. *pers. com*. July 2014). The once-off sample taken in July 2014 at the EWR site (and thus in the dry season, when salinity can be expected to be the highest) was = 123 mS/m and is thus also very high, supporting a hypothesis of naturally high salinity in the Nseleni River.

The WQ EcoClassification results for EWR site NS 1 are summarised in Table 3-17. The ASPT for the site was fairly low when sampled in July 2014 and was likely to be because flow was very low at the site (C. Todd, *pers. com*. Aug. 2014). On using the PAI model, the rating value entered for EC, and whether the naturally high levels were considered to be natural or not, did not affect the final EcoClassification for the site, which was rated as a “B” category for WQ.

Table 3-15 Summary of possibly useful monitoring sites in the Nseleni catchment.

Water quality Monitoring station	Name	n	First date	Last date	Latitude	Longitude	WQSU	COMMENTS
W12 102817 (W1H022Q01)	Mbabe River @ Nseleni/Earlswood	65	1985/10/24	2012/12/20	-28.6861	32.01806	5B	Effectively only 2 samples since early years. Also just d/s of town so impacted.
W12 183757	Mdibi River @ Bridge to Rbm (NMMP)	760	2001/01/23	2013/10/16	-28.7065	32.157	7	Near coast, d/s of forestry area. Not good indicator for EWR site.
W12 183761	Mposa River Under Bridge (NMMP)	882	2001/01/16	2013/10/16	-28.6789	32.0283	5B	Mposa R. flows into Nseleni. Only pH measured.
W12 187078	Between N2 Bridge and Mposa Confluence on Nseleni (NEMP NMMP)	656	2003/03/04	2013/10/15	-28.6934	32.015	5B	Only pH measured.
W12 187079	@ Road Bridge downstream of Lake Nsezi on Nseleni (NMMP)	531	2003/03/04	2013/10/15	-28.7761	31.9604	5C	Just u/s of confluence with Mhlatuze R. Only pH measured.
W12 188841	Maitlands upstream of Nsezi Lake on Nseleni (NEMP)	37	2005/11/30	2013/11/01	-28.7325	31.98389	5C	Low down in catchment so not very good indicator of EWR site. Limited data, but useful site. Gap in time series.
W12 189765	Nhlozane on Mfule (NMMP)	285	2008/11/05	2013/10/16	-28.60608	31.60203	3	On Mfule River, but similar land-use to EWR site on Nseleni. Only pH measured.

Table 3-16 Summary of the WQ data for WQ monitoring stations of relevance to EWR NS 1

	Monitoring station	**Time period used**	**Summary statistics**	**Water quality parameters**									
				EC (mS/m)	**KJEL_N** (mg/L)	**Na** (mg/L)	**NH4_N** (mg/L)	**NO3_NO2_N** (mg/L)	**TIN** (mg/L)	**TP** (mg/L)	**pH**	**PO4_P** (mg/L)	**SO4** (mg/L)
RC	W12 102807/ W1H005Q01 Mfulazane R.	1977/02/09 to 1979/12/19	Median	12	ND	13.3	0.020	0.100	0.150	ND	6.7	0.017	2
			5%								6.2		
			95%								7.6		
			n	117		63	63	63	63		63	63	63
PES	W12 188841 Nseleni R @ Maitlands u/s of Nsezi Lake	2012/08/28 to 2014/02/03	Median	55	0.777	69.4	0.025	0.052	0.077	0.042	8.3	0.005	14
			95%								8.6		
			5%								7.8		
			n	15	15	11	15	15	15	15	15	15	15

ND = No data

Table 3-17 PES categories and overall site assessment for EWR NS1 Nseleni River

RIVER	Nseleni River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 5	**RC**	Default boundary tables for “A” category river (adjusted for EC)
EWR SITE	NS1	**PES**	W12 188841 Nseleni R @ Maitlands u/s of Nsezi Lake; 2012/08/28 – 2014/02/03; n = 15 (EC)
Confidence assessment		**Low confidence as no current monitoring station in upper catchment**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg/L)	0.005	No impact (Rating = 0)
	TIN (mg/L)	0.077	No impact (Rating = 0)
Physical variables	pH (5th – 95th %ile)	7.8-8.6 7.5*	Low impact (Rating = 1)
	Temperature (°C)	No data 15.2*	Slight impact (Rating = 1)
	Dissolved oxygen (mg/L)	No data 7.6*	Expected to be good (Rating = 1)
	Turbidity (NTU)		Expected to be fairly high (Rating =2)
	Electrical conductivity (mS/m)	55 123*	Possibly naturally high. (Rating =1)
Response variables	Chl a: periphyton	No data	
	Chl a: phytoplankton	No data	
	Macroinvertebrates (ASPT)	5.4	Low score probably due to low flow
	Fish community score	C	
Toxics	Sulphate	14	No data – expected to fairly low (no mining, limited pesticides). Rating =0
OVERALL SITE CLASSIFICATION		**B** (from PAI model)	

*Sampled at the site July 2014

3.4.5 EWR Site WM 1: White Umfolozi River

This EWR site is situated in an area of largely natural vegetation. Upstream in the catchment, however, there is extensive subsistence farming and thus possibly high turbidity and can be expected.

There are two possibly useful WQ monitoring stations for this EWR site, namely W2H022Q01/W21 102851 (Klipstapel on the White Umfolozi) and W2H005Q01/W21 102834 (White Umfolozi @ Overvloed/Ulundi). The first site mentioned above is located upstream of the EWR site and unfortunately stopped monitoring in 1997. Approximately 30km downstream of the EWR site is the currently-active station W2H005Q01/W21 102834, which has a good dataset of the major WQ parameters since 1971 (n = 1215) until 2014, although most data are since 1977. From an examination of the trends for W2H005Q01/W21 102834, over the past 40 or so years, EC and phosphate have decreased slightly, and TIN has remained stable. Thus this site was not used as a RC site as it is unclear what the un-impacted state was. This WQ station was used, however, to describe the PES for the EWR site (Table 3-18). The summary statistics for this site show that the WQ is very good with low TIN (rating = 0), low phosphate (rating = 0). Electrical conductivity is slightly raised, being >30 mS/m, but only just in a rating category = 1. Sulphate, is perhaps also slightly increased if the value for W2H005Q01 is compared with the other two sites in Table 3-18. Although there are no data, because of the extensive subsistence use upstream turbidity is expected to be quite high. Because of this and because EC and sulphates are a little elevated, the overall site classification was given as B (Table 3-19).

A potential RC site was sought high up in the catchment of the White Mfolozi where land-use change has been less extensive. As with many catchments of the Usuthu-Mhlatuze WMA, however, it was difficult to find a suitable RC, because WQ has been impacted for a long time. Water quality usually progressively deteriorates down the length of a catchment with the cumulative impact of point and non-point pollutants. Often, however, tributaries especially if located high up in the catchment can be used to give an indication of the natural WQ. In the case of the Usuthu- Mhlatuze WMA, even tributaries near the source areas to the west have been impacted by mining. As mentioned above, the early data for W2H005Q01 (W21 102834) were examined but found to be impacted (Table 3-18). The earliest data for W2H012Q01 (W21 102841) White Umfolozi Tributary @ Vryheid/Bridge was also examined (Table 1-18) since this site is high up in the catchment and was possibly un-impacted. It was found that although the median values for EC, sulphate and phosphate were low, that for TIN was >0.25 mg/L and therefore impacted. Interestingly, although the median EC and sulphate were low, examination of the data showed sporadic pulses of high EC and sulphate on occasion. The monitoring at this site stopped effectively in 1988, however, and so it is unclear if this impact to WQ still occurs. For EWR WM1, the default values for an un-impacted river were used as the RC (Table 3-19).

Table 3-18 Summary of the WQ data for WQ monitoring stations of relevance to EWR WM1

	Monitoring station	**Time period used**	**Summary statistics**	**Water quality parameters**									
				EC (mS/m)	**Mg** (mg/L)	**Na** (mg/L)	**NH4_N** (mg/L)	**NO3_NO2_N** (mg/L)	**TIN** (mg/L)	**TP** (mg/L)	**pH**	**PO4_P** (mg/L)	**SO4** (mg/L)
RC?	W2H012Q01 (W21 102841) White Mfolozi	1983/08/04 to 1986/12/17	Median	11.25	4.1	6.8	0.06	0.23	0.29	0.035	7.20	0.006	4.80
			5%								6.16		
			95%								7.60		
			n	96	96	96	96	96	96	94	96	96	96
RC?	W2H005Q01 (W21 102834) White Mfolozi	1977/01/11 to 1979/06/106	Median	34	15.1	25.9	0.04	0.05	0.11	ND	7.46	0.014	10.4
			5%								8.08		
			95%								6.92		
			n	63	63	63	63	63	63		63	63	63
PES	W2H005Q01 (W21 102834) White Mfolozi	2009/03/03 to 2014/03/12	Median	30.4	13.5	23.7	0.025	0.088	0.113	ND	8.32	0.005	14.83
			5%								7.98		
			95%								8.49		
			n	33	33	29	33	29	29		33	33	31

ND = No data

Table 3-19 PES categories and overall site assessment for EWR WM 1 White Umfolozi River

RIVER	White Umfolozi River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 4	**RC**	Default boundary tables for A category river
EWR SITE	WM1	**PES**	W2H005Q01 (W21 102834) White Umfolozi @ Overvloed/Ulundi; 2009/03/03 to 2014/03/12 n = ± 33 (for EC)
Confidence assessment		**High confidence as WQ station in same WQSU and recent data, although n < 60 points**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg/L)	0.005	Natural (Rating = 0)
	TIN (mg/L)	0.113	Natural (Rating = 0)
Physical variables	pH (5th – 95th %ile)	7.98 - 8.49 7.6*	Slight impact (Rating =1)
	Temperature (°C)	No data 11.2*	Slight impact (Rating =1)
	Dissolved oxygen (mg/L)	No data 11.8*	Expected to be good (Rating = 0)
	Turbidity (NTU)	No data	Expected to **be fairly high (Rating = 2)**
	Electrical conductivity (mS/m)	30.4 37*	Slightly impacted (Rating = 1)
Response variables	Chl *a:* periphyton	No data	
	Chl *a:* phytoplankton	No data	
	Macroinvertebrates (ASPT)	6.3	
	Fish community score	C	
Toxics	Sulphate (mg/L)	15	No data – expected to fairly low, but potential from mining u/s.
OVERALL SITE CLASSIFICATION		**B** (from PAI)	

*Sampled at the site July 2014

3.4.6 EWR Site BM 1: Black Umfolozi River

This site is in the upper, hilly part of the Black Umfolozi River catchment, in WQSU 7. Above this site are forestry, conservation areas and some coal mining. The most suitable monitoring station for describing the PES WQ of this reach of the river is W2H028Q/W22 102857 (Black Umfolozi @Ekuhlengeni) which has a reasonably good data set from 1988 – 2014 (n= 224) although samples were taken less frequently than monthly. This monitoring station is also just a few kilometres upstream of the EWR site. Analysis of the change in key WQ parameters with time at W2H028Q01 shows that whilst median EC and sulphate have decreased over the past 25 years, phosphate has remained stable, and TIN has increased slightly. The PES WQ was derived using the most recent 5 years data (Table 3-20) i.e. from 2009 to 2014. It can be seen that although EC is low (<30 mS/m) and thus in an "A" or natural category, sulphate levels are fairly high (median of 56 mg/L) – see below.

Once again it proved to be difficult to find a suitable RC site to compare the PES data against. Monitoring station W2H020Q01/W22 102849 on the Hlonyana River, a nearby tributary has a few measurements from the mid-1980s, but unfortunately nitrogen levels were already high at that time period and thus it is not useful as a RC site. This is a similar situation to W2H011Q01 (W21102840) located just downstream of Klipfontein Dam, which also has elevated nitrogen levels. As a consequence, the data for W2H012Q01 (W21 102841) White Umfolozi Tributary @ Vryheid/Bridge is shown in Table 3-20 as a possible RC site. This was also considered for EWR WM1, but as mentioned previously, although the median values for EC, sulphate and phosphate were low, that for TIN was >0.25 mg/L and is therefore impacted. It is interesting to compare the median EC and sulphate values from the two sites in Table 3-20. Note how high the median sulphate concentration is for the PES site W2H028Q01, indicating that there is significant impact, probably from the mining activities upstream.

The WQ EcoClassification results for EWR site BM 1 are summarised in Table 3-21. Overall WQ is likely to be good at this site, with the main impact being elevated sulphate concentrations.

Table 3-20 Summary of the WQ data for WQ monitoring stations of relevance to EWR BM1

	Monitoring station	**Time period used**	**Summary statistics**	**Water quality parameters**							
				EC (mS/m)	**NH4_N** (mg/L)	**NO3_NO2_N** (mg/L)	**TIN** (mg/L)	**TP** (mg/L)	**pH**	**PO4_P** (mg/L)	**SO4** (mg/L)
RC?	W2H012Q01 (W21 102841) White Mfolozi	1983/08/04 to 1986/12/17	Median	11	0.06	0.23	0.29	0.035	7.2	0.006	5
			5%						6.2		
			95%						7.6		
			n	96	96	96	96	94	96	96	96
PES	W2H028Q01 (W22 102857) Black Mfolozi	2009/01/15 to 2014/03/06	Median	25	0.025	0.025	0.05	ND	7.8	0.005	56
			5%						7.3		
			95%						8.1		
			n	35	35	34	34		35	35	35

Table 3-21 PES categories and overall site assessment for EWR BM 1 Black Umfolozi River

RIVER	Black Umfolozi River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 7	**RC**	Default boundary tables for A category river
EWR SITE	BM1	**PES**	W2H028Q01 (W22 102857) Black Umfolozi @Ekuhlengeni; 2009/01/15 to 2014/03/06; n = 35 (for EC)
Confidence assessment		**High confidence as WQ station in same WQSU and recent data, although n < 60 points**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg/L)	0.005	No impact (Rating = 0)
	TIN (mg/L)	0.05	No impact (Rating = 0)
Physical variables	pH (5th – 95th %ile)	7.28 - 8.14 7.2*	Slight impact (Rating =1)
	Temperature (°C)	No data 12.1*	Expected slight impact (Rating =1)
	Dissolved oxygen (mg/L)	No data 11.13*	Expected to be slight impact (Rating = 1)
	Turbidity (NTU)	No data	Expected to be low (little subsistence ag u/s). Rating =1
	Electrical conductivity (mS/m)	25 31*	No/low impact (Rating = 0)
Response variables	Chl a: periphyton	No data	
	Chl a: phytoplankton	No data	
	Macroinvertebrates (ASPT)	6.8	
	Fish community score	C	
Toxics	Sulphate	56 mg/L	No data – expected to be some impacts (mining u/s). Sulphate high (Rating = 1).
OVERALL SITE CLASSIFICATION		**B** (from PAI)	

*Sampled at the site July 2014

3.4.7 EWR Site BM 2: Black Umfolozi River

This EWR site is approximately 30km downstream of EWR BM 1, but is in a different WQ sub-unit (WQSU 8), being in a flatter area, with different land-use (subsistence agriculture). This site is just upstream of the DWA WQ monitoring station W2H024Q01 (W22 102853), however, monitoring at that site was carried out from 1983-1986 only.

Approximately 20km downstream of EWR BM2 is the monitoring station W2H006Q01 (W22 102835) Black Umfolozi @ Reserve no 12, which has data for most parameters from effectively 1977 to the present (n = >1210 for EC). Trend analysis at this site shows that EC and sulphate have remained fairly stable over the past 35 years, as have the levels of nutrients (TIN and phosphate). Water quality at W2H006Q01 is very good with regard to nutrient levels (median TIN and phosphate being less than, or equal to, the maximum concentration for the natural category i.e. < 0.25 mg N/L and 0.005 mg P/L respectively). [The detection limit for orthophosphate is in any case = 0.01 mg P/L. Where measurements are less than the DL, DWA, as is common practice, report the value as half the DL, and thus 0.005 mg P/L. It would not be possible for median orthophosphate levels < 0.005 mg P/L to be obtained]. This monitoring station is downstream of an area of subsistence agriculture thus turbidity is expected to be fairly high. Electrical conductivity is un-impacted. Sulphate levels are lower (12 mg/L) than for the upstream EWR site (BM1) as illustrated by the data for W2H028Q01 which exhibited a median sulphate concentration of 56 mg/L (Table 3-21) . This shows that due to dilution, the impacts of mining in the upper catchment are being ameliorated down the length of the river.

The WQ EcoClassification results for EWR site BM 2 are summarised in Table 3-22. From observations at the time of sampling it would appear that turbidity is fairly high at the site. A rating =2 was assigned for this parameter and an overall EcoClassification of “B”. This value is based on expert judgement and consideration of land-use as no sediment/turbidity data are available for this site.

Table 3-22 PES categories and overall site assessment for EWR BM 2 Black Umfolozi River

RIVER	Black Umfolozi River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 8	**RC**	Default boundary tables for "A" category river
EWR SITE	BM2	**PES**	W2H006Q01 (W22 102835) Black Umfolozi @ Reserve no 12; 2009/03/03 - 2014/03/12; n = 37 (for EC)
Confidence assessment		**High confidence as WQ station in same WQSU and recent data, although n < 60 points**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg/L)	0.005	No impact (Rating = 0)
	TIN (mg/L)	0.089	No impact (Rating = 0)
Physical variables	pH (5th – 95th %ile)	7.44 - 8.32 7.2*	Slight impact (Rating =1)
	Temperature	No data 10.2*	Slight impact expected (Rating =1)
	Dissolved oxygen (mg/L)	No data 11.3*	Expected to be good (Rating =0)
	Turbidity (NTU)	No data	Expected to be fairly high (Rating =3)
	Electrical conductivity (mS/m)	21 32*	No impact (Rating = 0)
Response variables	Chl *a*: periphyton	No data	
	Chl *a*: phytoplankton	No data	
	Macroinvertebrates (ASPT)	6.1	Slightly impacted due to sedimentation
	Fish community score	C	
Toxics	Sulphate (mg/L)	12	No data – expected to low (no mining, limited pesticides from commercial farming)
OVERALL SITE CLASSIFICATION		**B** (from PAI)	

*Sampled at the site July 2014

3.4.8 EWR Site MK 1: Mkuze River

This EWR site is downstream of the IBT from Pongolapoort Dam and is located in WQU 5 in the lower reaches of the river. It is within a conservation area to the south, with subsistence agriculture on the northern bank. Upstream of the EWR site is extensive commercial agriculture with some subsistence use. As noted in Table 3-3, there is mining in the upper catchment of the Mkuze River.

Although there appears to be several monitoring stations in the lower part of the Mkuze River that could potentially be used to describe the PES WQ of this EWR site (Table 3-23), none of them are particularly suitable, since they either closed in 2009 or are part of the NMMP and the only useful ecological WQ parameter recorded is pH.

Table 3-23 Summary of potentially useful sites to describe the PES WQ of EWR MK1 (taken from the WMS database June 2014).

Water quality	Description	n	First date	Last date	WQ-SU	Comment
W3H008Q01 **W31 102866**	Mkuze R. @ Doornhoek	868	1969/10/06	2001/02/13	4	Data too old
W3H011Q01	Mkuze R. @ Morrisvale/Lower Mkuze (NCMP)	355	1973/08/05	2010/03/25	7	Effectively ended 2009
W3H030Q01 **W31 102884**	Mkuze R. @ Zeekoeivlei d/s Nkunzana Confl	272	1995/12/12	2010/01/26	2/4	Monitoring ended 2009
W3H031Q01 **W31 102885**	Mkuze R. @ Welcome/Betw Mkuze Falls.	217	1995/12/12	2010/01/26	4	Monitoring ended 2009
W3H032Q01 **W31 102886**	Mkuze R. @ Overwin d/s Mondi Irr + Vorster (NCMP)	273	1995/12/12	2009/05/30	4/5	Monitoring ended 2009
W3H018Q01 **W32 102872**	Mkuze Swamp @ State Land/Airboat Section	8	1987/02/17	1989/03/01	7	Date too old and far d/s
W3H033Q01 **W32 102887**	Muzi R. @ Yengweni u/s Mkuze Confluence	171	1995/12/13	2009/03/25	-	Not on Mkuze. Different land-use. Monitoring ended 2009
W31 187937	State Land on Mthambalala (NMMP)	729	2004/02/10	2013/10/08	5	Not on Mkuze. Only pH measured
W32 187934	Near Yengweni on Neshe u/s of Muzi and Mkuze (NMMP)	745	2004/02/10	2013/10/08	5	Not on Mkuze. Only pH measured

The data for W3H032Q01 (W31 102886 Mkuze River @ Overwin) were examined in more detail because this station is just a few kilometres upstream of the EWR site. Note though from Table 3-23 that the monitoring at this site ended in 2009 and the data are therefore no longer indicative of the current WQ situation. The median values for the most recent 3 years data (2006-2009) were EC = 245 mS/m; TIN = 0.54 mg N/L; phosphate = 0.02 mg P/L and sulphate = 167 mg/L. Over the time period of monitoring (1995 – 2009) there was a trend of increasing EC at this site (although sulphate concentrations increased only very slightly). Nutrients also increased slightly. Thus, although only a low confidence can be placed in the results because the data are old, it is expected that the WQ at the EWR site will have a high EC with concomitant high sulphate levels. The high sulphate levels are likely to arise from mining in the upper catchment. High salinity is most likely a consequence of the mining activities exacerbated by saline irrigation return-flows. Fairly high levels of TIN and phosphate are also to be expected due to the intense cultivation around the town of Mkuze. Due to this land-use, fairly high levels of pesticides would also be expected.

The EWR site is further downstream from W3H032Q01/ W31 102886 with some areas of conservation in between. Thus WQ would be expected to be slightly better than at the monitoring site. There is a RHP monitoring site at the EWR site (W3MKZE-DNYDR) from where an ASPT = 4.8 was recorded when last visited in May 2012, indicating that WQ was then fairly severely impacted. Some of the upstream farms have closed down recently, however, and according to the manager at Mkuze game reserve “water quality has improved in the past few years.”

The data from various stations in the catchment were examined as potential RC sites e.g. W3H024Q01 and W3H025Q01, however, none were un-impacted, usually having high EC or sulphate levels. W3H025Q01 (W31 102879 Mtebeni River @ Fortuin – upstream of Mkuze confluence) which is high up in the catchment on a tributary of the Mkuze River, was examined because the median EC for this site was low. This site is unusual in that the earliest data (1995-2001) were impacted, with somewhat elevated levels of EC, sulphate and nutrients. After 2002 the levels of all these variables decreased to below the threshold values for an un-impacted river and thus this site was used to describe the RC (Table 3-24). Comparison of the two sites in Table 3-24 illustrates, particularly for EC and sulphate, how impacted the WQ at EWR MK1 is. The WQ EcoClassification results for EWR site MK 1 are summarised in Table 3-25 and shows that the overall WQ category = C/D. This was revised from the “D” category predicted by the PAI model based on the anecdotal information mentioned previously and to agree with the results obtained for invertebrates.

Table 3-24 Summary of the WQ data for WQ monitoring stations of relevance to EWR MK1

	Monitoring station	**Time period used**	**Summary statistics**	**Water quality parameters**							
				EC (mS/m)	**Na** (mg/L)	**NH4_N** (mg/L)	**NO3_NO2_N** (mg/L)	**TIN** (mg/L)	**pH**	**PO4_P** (mg/L)	**SO4** (mg/L)
RC	W3H025Q01 (W31 102879) Mtebeni R.	2005/03/30 to 2009/07/28	Median	8	5.53	0.025	0.119	0.151	7.65	0.006	6
			5%						7.188		
			95%						8.092		
			n	40	38	39	35	35	41	39	39
PES	W3H032Q01 (W31 102886) Mkuze R.	2007/01/29 to 2009/11/25	Median	245	327.53	0.081	0.411	0.536	8.38	0.016	167
			5%						8.16		
			95%						8.65		
			n	25	21	23	16	16	25	23	24

Table 3-25 PES categories and overall site assessment for EWR MK1 Mkuze River

RIVER	Mkuze River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 5	**RC**	W3H025Q01 (W31 102879) Mtebeni River @ Fortuin 2005/03/30 to 2009/07/28 n=40
EWR SITE	MK1	**PES**	W3H032Q01 (W31 102886) Mkuze River @ Overwin; 2007/01/29-2009/11/25; n=25 (for EC)
Confidence assessment		**Low confidence as no recent data**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg/L)	0.016	Moderate change (Rating = 2)
	TIN (mg/L)	0.534	Small impact (Rating =1)
Physical variables	pH (5th – 95th %ile)	8.16 – 8.65 8.12*	Small impact (Rating =1)
	Temperature (°C)	No data 19.0*	Small impact (Rating =1)
	Dissolved oxygen (mg/L)	No data 7.0	Small impact (Rating =1)
	Turbidity (NTU)	No data	Small impact expected (Rating =1)
	Electrical conductivity (mS/m)	245 147*	WQ = poor (Rating =4)
Response variables	Chl *a*: periphyton	No data	
	Chl *a*: phytoplankton	No data	
	Macroinvertebrates (ASPT)	5.4	Low score due to poor WQ
	Fish community score	B/C	
Toxics	Sulphate (mg/L)	167	Pesticides expected to be high due to intensive cultivation u/s. Sulphates from u/s mining.
OVERALL SITE CLASSIFICATION		**C/D** (from PAI model and expert judgement)	

*Sampled at the site July 2014

3.4.9 EWR Site UP 1: Upper Phongolo River

This site is located in the upper portion of the Phongolo River close to the town of Frischgewaagd. The major land-use in the upper part of the catchment is forestry with commercial agriculture. There is also mining upstream of the EWR site. The site is just downstream of the station W42 189409 (Silverton 21 u/s Paul Pietersburg-Piet Retief Road Bridge on Phongolo River) for which there are a few data (excluding nutrients) from 2008 – 2009, which are captured in Table 3-26. The only current WQ monitoring station for which there is an extensive data-series is W4H004Q01 (W41 102897 Bivane River @ Welgelegen Pivaansbad). Although this is not on the Phongolo River, it is close-by, upstream of the Bivane Dam, and there is similar land-use in the two areas.

The results of the analysis in Table 3-26 show that W4H004Q01/W41 102897 is probably useful as a RC since the median values of EC, sulphate, and TIN are all low. Phosphate however is higher than the 0.005 mg P/L boundary value for an un-impacted (“A” category) river. It is likely that this site was already impacted during 1977 – 1979 by phosphate. This particularly in the light of the fact that the most recent data for the same site (2009-2014) show low phosphate levels – i.e. natural levels. Thus, the default values were used for the RC.

Compared to the RC data, the present-day values for TIN (deduced from W4H004Q01) have increased slightly (although still “A” category), although EC and sulphate are virtually the same. The limited data for W42 189409 which is close to the EWR site, show low EC and sulphate levels and circum-neutral pH and agree with the results from W4H004Q01/ W41 102897 on the Bivane River. Observations whilst sampling at the site in July 2014, however, suggested localised impacts from nutrients (high biomass of algae) and the overall EcoClassification (Table 3-27) was revised from an “A” to a “B” category.

Table 3-26 Summary of the WQ data for WQ monitoring stations of relevance to EWR UP1.

	Monitoring station	**Time period used**	**Summary statistics**	**Water quality parameters**								
				EC (mS/m)	**Mg** (mg/L)	**Na** (mg/L)	**NH4_N** (mg/L)	**NO3_NO2_N** (mg/L)	**TIN** (mg/L)	**pH**	**PO4_P** (mg/L)	**SO4** (mg/L)
RC?	W4H004Q01 (W41 102897) Bivane R.	1977/07/20 to 1979/07/10	Median	10	3.4	5.2	0.05	0.05	0.11	7.01	0.014	2
			5%							6.373		
			95%							7.564		
			n	**77**	**75**	**75**	**75**	**75**	**75**	**75**	**75**	75
PES	W4H004Q01 (W41 102897) Bivane R.	2009/02/11 to 2014/02/25	Median	11	3.53	5.944	0.025	0.137	0.171	7.76	0.005	4
			5%							7.12		
			95%							8.19		
			n	36	37	35	37	37	37	37	37	37
PES?	W42 189409 Phongolo R.	2008/12/08 to 2009/04/14	Median	5	3	8.6	ND	ND	ND	7.1	ND	13
			n	5	2	2				5		2

ND = No data

Table 3-27 PES categories and overall site assessment for EWR UP1 Upper Phongolo River

RIVER	Phongolo River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 1	**RC**	Default boundary tables for "A" category river
EWR SITE	UP 1	**PES**	W4H004Q01 (W41 102897) Bivane River @ Welgelegen 2009/02/11 to 2014/02/25 n = 36 (for EC)
Confidence assessment		**Low-medium confidence as WQ station from different river and n < 60 points.**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg P/L)	0.005	No impact (Rating = 0)
	TIN (mg N/L)	0.167	No impact (Rating = 0)
Physical variables	pH (5th – 95th %ile)	7.12 - 8.19 7.4*	Small impact (Rating =1)
	Temperature (°C)	No data 10.3*	Expected to be very good (Rating =0)
	Dissolved oxygen (mg/L)	No data 12.2*	Expected to be very good (Rating =0)
	Turbidity (NTU)	No data	Expected to be no impact (Rating = 0)
	Electrical conductivity (mS/m)	11 11.5*	No impact (Rating = 0)
Response variables	Chl a: periphyton	No data	
	Chl a: phytoplankton	No data	
	Macroinvertebrates (ASPT)	7.0	Possibly slightly impacted by elevated nutrients at site?
	Fish community score	C	
Toxics	Sulphate (mg/L)	4 - 13	Possibly slightly elevated sulphates from mining and pesticides from farming.
OVERALL SITE CLASSIFICATION		**B** (from PAI model and expert judgement)	

Sampled at the site July 2014

3.4.10 EWR Site AS 1: Assegaai River

EWR A1 is situated downstream both of the Heyshope Dam and of the town of Piet Retief. It is upstream of DWA monitoring site W5H022Q01 (W51 102914 @ Zandbank on Assegaai River) which is close to the Swaziland border. There is a station monitoring the water downstream of the dam (W5H039Q01/W51 102924 Heyshope Dam on Assegaai River: Down Stream of weir), but monitoring for this site ended in 2010. Similarly, W5H022Q01 only has data until 2009, and the number of samples taken since 2000 is limited. Thus current WQ can only be inferred with a low level of confidence. Table 3-28 summarizes the available data for relevant monitoring sites.

With regard to the RC, the earliest data (1982 -1985) from W5H039Q01/W51 102924 (downstream of Heyshope Dam) were examined. The data in Table 3-28 show that while EC, sulphate and TIN were low (“A” category indicating natural WQ), phosphate was elevated and greater than the boundary value between natural and slightly impacted (i.e. > 0.005 mg P/L). Data from another catchment (Bonnie Brook – W5H008Q01/ W54 102913) were also examined. Water quality was very similar to that of the early data from Heyshope Dam, including slightly impacted phosphate levels. Thus the default RC values were used and PES values were not adjusted.

To describe the PES, two sites were considered. Sulphate levels increased at W5H022Q01 from 1977 – 1978 when monitoring started until 2009 when the station closed. The median sulphate concentration in the late 70’s was around 4mg/L and was approximately 13 mg/L in 2009. Electrical conductivity (EC) also increased slightly, whereas nutrients have remained fairly stable. Although the data are out of date for this site, WQ at the time of closing was good, with only slightly impacted EC and sulphate but high phosphate levels. Unfortunately nitrates and nitrites were not measured. Ammonium was measured, however, and was quite high (median = 0.21 mg/L), especially if compared with the putative RC sites in Table 3-28. The high levels of nitrogen possibly arise from the town of Piet Retief (from the WWTW). This is supported by the limited data from other monitoring stations:

- W51 189547 (Assegaai R. d/s of Dorpspruit confluence); 2006-2009; n=34 (median NH4 = 1.02 mg/L; EC = 16 mS/m; pH = 7.5).
- W51 189548 (Assegaai R. u/s Dorpspruit confluence); 2006-2009; (median NH4 = 0.2 mg/L; EC = 12 mS/m; pH = 7.4).
- W51 189598 (Assegaai R. Potgietershoop); 2007-2009; n =12 (median NH4 = 0.26 mg/L; EC = 13 mS/m; pH = 7.35; PO4 = 0.05 mg/L).

In the case of W5H039Q01 (W5 102924) downstream of Heyshope Dam, WQ for the PES is very similar to that of W5H022Q01 in that EC is low, sulphates only very slightly elevated and phosphate concentrations high. Total inorganic nitrogen is measured at this site, however, and is elevated, possibly as a result of the agriculture in the area.

The WQ EcoClassification results for EWR site AS 1 are summarised in Table 3-29.

Table 3-28 Summary of the WQ data for WQ monitoring stations of relevance to EWR AS 1

	Monitoring station	**Time period used**	**Summary statistics**	**Water quality parameters**								
				EC (mS/m)	**KJEL_N** (mg/L)	**Na** (mg/L)	**NH4_N** (mg/L)	**NO3_NO2** (mg/L)	**TIN** (mg/L)	**pH**	**PO4_P** (mg/L)	**SO4** (mg/L)
RC?	W5H039Q01 (W51 102924) Assegaai R. d/s Heyshope Dam	1982/07/28 to 1985/05/06	Median	11		5.7	0.020	0.030	0.070	7.2	0.015	2
			5%							6.4		
			95%							7.8		
			n	38		31	31	38	31	38	31	31
RC?	W5H008Q01 (W54 102913) Bonnie Brook	1977/05/10 to 1979/04/19	Median	5		4.2	0.050	0.020	0.070	6.7	0.013	2
PES	W5H022Q01 (W51 102914) Assegaai R. @ Swazi border	2007/02/21 to 2009/04/20	Median	14	ND	12	0.24	ND	ND	7.6	0.05	12.85
			5%							7.2		
			95%							8.0		
			n	12		12	12	0	0	12	12	12
PES?	W5H039Q01 (W51 102924) Assegaai R. d/s Heyshope Dam	2006/04/20 to 2010/12/22	Median	13	2.80	9.50	0.120	0.620	0.700	7.6	0.050	18.40
			5%							6.6		
			95%							8.0		
			n	17	1	17	17	17	17	17	17	17

ND = No data

Table 3-29 PES categories and overall site assessment for EWR AS 1 Assegaai River

RIVER	Assegaai River	**WATER QUALITY MONITORING POINTS**	
WQSU	WQSU 2	**RC**	Default boundary tables for "A" category river
EWR SITE	AS1	**PES**	W5H022Q01 (W51 102914) @ Zandbank on Assegaai R; 2007/02/21 to 2009/04/20 n = 12 (for EC)
Confidence assessment		**Medium confidence as WQ data no current and <60 points.**	
Water Quality Constituents		**Median Value**	**Category/Comment**
Nutrients	Phosphate (mg/L)	0.05	Large change (Rating = 3)
	TIN (mg/L)	No data (NH4 = 0.24)	Likely to be high (Rating = 2)
Physical variables	pH (5th – 95th %ile)	7.21 - 7.95 7.1*	No impact (Rating =0)
	Temperature (°C)	No data 9.4*	Expected small impact (Rating =1)
	Dissolved oxygen	No data 11.6*	Expected small impact (Rating =1)
	Turbidity (NTU)	No data	Expected small impact (Rating =1)
	Electrical conductivity (mS/m)	14 16.4*	No impact (Rating = 0)
Response variables	Chl a: periphyton	No data	
	Chl a: phytoplankton	No data	
	Macroinvertebrates (ASPT)	6.7	Small impact
	Fish community score	B/C	
Toxics	Sulphate (mg/L)	13	No data – expected to fairly low but some toxic substances from mining and pesticides from commercial farming. Rating =0
OVERALL SITE CLASSIFICATION		**B** (from PAI model and expert judgement)	

*Sampled at the site July 2014

3.5 Identification of indicators

3.5.1 Indicator list for water quality

This project made use of the DRIFT (Downstream Response to Imposed Flow Transformations) approach in order to determine the likely impact of different flow scenarios on the ecological condition at a given EWR site. In order to predict the effect of flow changes on WQ, a selection of water quality variables (“indicators”) were chosen based on their importance in overall ecosystem health, on sensitivity to flow changes and on the availability of data. A list of the WQ indicators and the reason for their selection is given in Table 3-30.

Table 3-30 WQ indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Electrical conductivity (EC)	An important “system variable” which indicates the salinity or concentration of dissolved salts, potentially indicating impacts from mining, irrigation return-flows and urban/industrial development.
Sulphate	An indicator of Acid/Alkaline Mine Drainage (AMD). Useful since coal mining is prevalent in parts of the catchment.
Nitrogen (Total Inorganic Nitrogen)	An important indicator of eutrophication (nutrient enrichment), arising from, amongst other activities, farming, WWTW and manufacturing.
Phosphate	An important indicator of eutrophication (nutrient enrichment). Phosphorus exists both in the dissolved form and bound to sediments. Elevated phosphates originate, amongst other activities, from mining, farming, WWTW and manufacturing.
Temperature	An important environmental variable for fish and invertebrates. Has knock-on effect on DO and toxic substances.

In addition to the five indicators listed in Table 3-30, several others were considered. According to Pegram and Görgens (2001) the most serious nonpoint-source contaminants in South Africa are salts, nutrients, sediments and pathogens. Salts and nutrients are listed above and pathogens are more relevant to an assessment of risk to humans rather than to aquatic ecosystems. The amount of suspended sediment in a river, on the other hand, (and hence the turbidity of the water) is an important indicator of the “environmental health” of a system. Furthermore, sediments are an important important medium for the transport of phosphates, metals, toxic substances and pathogens (Rossouw and Gorgens 2005). Sediment loads are likely to be un-naturally high in some catchments of the Usutu-Mhlatuze WMA where there is extensive land-degradation and erosion. This variable was not modelled directly as part of WQ component because “Total Suspended Sediments” are not routinely measured at DWA WQ monitoring stations. Sediments were modelled in DRIFT, however, under “geomorphology”.

Toxic substances are another group of variables that could have been considered in this modelling activity. There are no quantitative data, however, for toxic substances and thus sulphate was modelled as a surrogate, since it is indicative of impacts from mining.

Water temperature is also an important variable affecting ecosystem health (Dallas and Day 2004) and because of this, it was included in the DRIFT modelling. Dissolved oxygen is also critical to the health of fish and invertebrates and DO concentrations are dependent to a large extent on water temperature - the higher the ambient water temperature, the lower the concentration of dissolved oxygen in that water will be (DWAF 1996a). Temperature, dissolved oxygen and organic pollutants are not routinely measured by DWA. Therefore, DO could not be modelled in this project and predictions for temperature are of low confidence.

The expected responses of each of the selected WQ variables (indicators) to flow changes are outlined in Table 3-31.

Table 3-31 List of water quality indicators and their predicted direction of response to flow changes.

Indicator	Definition	Predicted change	References
Electrical conductivity (EC)	The electrical charge carried by water expressed as mS/m	General dilution effect – will increase with decreased flow	Malan and Day (2002)
Sulphate	Concentration of the anion dissolved in water. Expressed as mg sulphate/L	A conservative pollutant it will mirror that of EC	Malan and Day (2002)
Total Inorganic Nitrogen (TIN)	Concentration of dissolved nitrate, nitrite, ammonia and ammonium as mg N/L.	Non-conservative pollutants. Complex relationship with flow. Nutrient concentrations likely to increase with decreased flow, but not easy to predict.	Malan and Day (2002)
Phosphate	Concentration of dissolved phosphorus as mg P/L.		
Temperature	Expressed as °C.	As flow decreases the buffering capacity of a water body is diminished. Higher and lower instream temperatures are expected. Risk of low DO under high temperatures.	Malan and Day (2002)

3.5.2 Linked indicators

The key WQ variables (indicators) listed in Table 1-39 were linked with specific aspects of the various proposed flow scenarios (e.g. Wet season average daily volume) in order to predict how a changed flow regime would affect WQ. The linked indicators are shown in Table 3-32.

The response curves for each key WQ variable in relation to the selected indicators are recorded in Section 3.8. In addition, an explanation is given for the predicted response together with the degree of confidence in the accuracy of the prediction. For some of the EWR sites, suitable flow and WQ data were available and Q-C plots (e.g. a graph of the concentration of sulphate recorded for a given flow at a particular DWA WQ monitoring station/flow gauge) were generated to aid the predictions. The Q-C plots are given in Section 3.9.

Table 3-32 Linked indicators and motivations

Indicator	Linked indicator	Motivation
Electrical conductivity (EC)	Dry season average daily volume (Mm^3/day) or Mean Annual Runoff + Dry season duration	The smaller the volume of water the smaller the dilution capacity.
	Wet season average daily volume (Mm^3/day)	
	Annual mean zero flow (%days/year)	As the days of zero flow increases, the concentration of chemical constituents in the water will increase due to evaporation.
Sulphate	Dry season average daily volume (Mm^3/day)	As for EC
	Wet season average daily volume (Mm^3/day)	
	Annual mean zero flow (%days/year)	As for EC
TIN	Dry season average daily volume (Mm^3/day)	As for EC
	Wet season average daily volume (Mm^3/day)	
	Annual mean zero flow (%days/year)	As for EC
	Bed sediment conditions	Nitrogen can bind to sediments (although to a lesser extent than phosphates)
Phosphate	Dry season average daily volume (Mm^3/day)	As for EC
	Wet season average daily volume (Mm^3/day)	
	Annual mean zero flow (%days/year)	As for EC
	Bed sediment conditions	A large proportion of phosphates binds to sediments. This proportion is site-specific and varies temporally.

Indicator	Linked indicator	Motivation
Summer water temperature	Wet season average daily volume (Mm^3/day)	*See explanation below
	T1: Daily average volume - baseflow	

* Water temperature was considered to be a possible issue both in summer and in winter months. As flow decreases the buffering capacity of the river will decrease and the daily fluctuation in temperature will expand. Increased water temperature in particular is the most critical for the biota because the higher the water temperature, the lower the concentration of dissolved oxygen. The hottest air temperatures are to be expected in summer, which is fortunately when high flows are to be expected. Low ambient air temperatures occur in winter and this coincides with the time of lowest flows, when the buffering effect of water is at a minimum. Thus for this project it was decided to model summer water temperature when ambient air temperature is the highest. In addition, flows in spring were examined, and were considered to be problematic if this time of the year coincided with the delayed onset of the high flow season.

3.6 Assumptions and limitations

The following considerations, assumptions and limitations govern the outcomes of this project:

- There is currently no officially-sanctioned method for determining the water quality component of the Ecological Reserve. Furthermore, historically there have been several changes in policy around certain aspects which has resulted in confusion. For example Ecological Categories have been previously defined as 5 categories A-F; redefined as 4 categories Natural, Good, Fair, Poor; and then changed to five ratings (Ratings 0 – 5). There is an urgent need to streamline the WQ method. Despite the current failings and lack of clarity around details, the overall approach to WQ is well-established, is reported in DWAF (2008 *in prep*.) and was followed in this project.
- Benchmark values for individual ions (e.g. sulphate) are not given in DWAF (2008 *in prep*.), but rather are given for salts (e.g. magnesium sulphate, sodium sulphate). Salt concentrations are calculated using the DWA computer software “TEACHA” which at the time of the project was no longer in use (Scherman, Patsy. *pers. com*. 2014). Consequently EcoSpecs for sulphate were not reported and relevance of median values calculated for this anion were a little difficult to interpret (although see Section 1.3).
- The assessments of EcoStatus are based largely on the data lodged in the WMS database. Values at some WQ monitoring stations particularly for phosphate were suspect (e.g. those for W5H022Q01/W51 102914 from 2007-2009 when monitoring

ended are a constant value of 0.05 mg/L – not 0.005 or half the DL) and need to be checked.

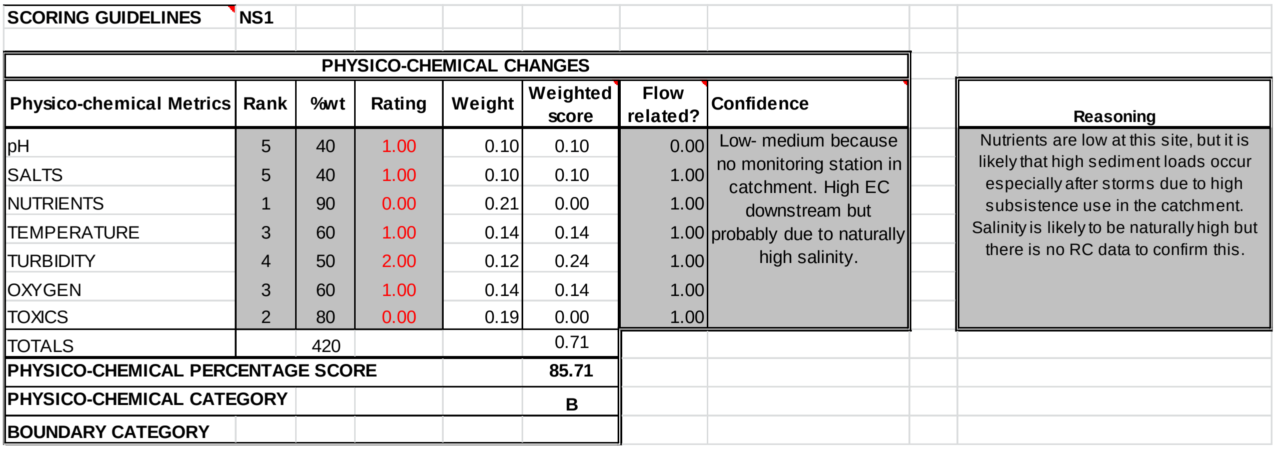
- Temperature was modelled in this exercise because it influences the dissolved oxygen (DO) concentration (as well as affecting other processes in aquatic environments). There are limited data for temperature and thus quantitative predictions are tentative. In future, consideration should be given to installing low-cost temperature loggers at the EWR sites for the duration of the project. Alternatively (and less accurately) estimates of instream water temperature could be made by modelling air temperature. Due to restrictions in time and budget, this was not done in the present project.
- The response curves shown in Section 1.7 are based on the understanding that the loading of pollutants to the catchment, both in terms of the total amount and the relative sources, is the same as at present.
- Q-C plots are useful for predicting how the concentration of a chemical parameter will alter with flow, particularly for conservative constituents such as EC or sulphate. These effectively do not alter in chemical nature downstream and concentration is largely determined only by the dilution capacity (Q). Nutrients on the other hand are considered to be non-conservative, they can be taken up by living organisms, change in chemical composition from one for to another (e.g. nitrogen can under certain circumstances be released back to the atmosphere). Such inter-conversion of chemical forms is affected by many factors e.g. temperature, activity of bacteria. This complexity makes predictions of concentrations difficult without the help of sophisticated (and data-intensive) WQ models (Dortch and Martin 1989).

3.7 PAI tables

3.7.1 Matigulu River: EWR site MA1

SCORING GUIDELINES	**MA1**							
PHYSICO-CHEMICAL CHANGES								
Physico-chemical Metrics	**Rank**	**%wt**	**Rating**	**Weight**	**Weighted score**	**Flow related?**	**Confidence in assessment**	**Reasoning**
pH	5	40	0.50	0.10	0.05	0.00	Low because no monitoring station in catchment. Extrapolated from Mhlatuze. Similar land-use. Once-off data for temp, DO, pH, EC July 2014.	Nutrients are low at this site, but it is likely that high sediment loads occur especially after storms due to high subsistence use in the catchment
SALTS	5	40	1.00	0.10	0.10	1.00		
NUTRIENTS	1	90	1.00	0.21	0.21	1.00		
TEMPERATURE	3	60	1.00	0.14	0.14	1.00		
TURBIDITY	4	50	2.00	0.12	0.24	2.00		
OXYGEN	3	60	1.00	0.14	0.14	1.00		
TOXICS	2	80	0.00	0.19	0.00	1.00		
TOTALS		420			0.88			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**82.38**			
PHYSICO-CHEMICAL CATEGORY					**B**			
BOUNDARY CATEGORY								

3.7.2 Nseleni River: EWR site NS1

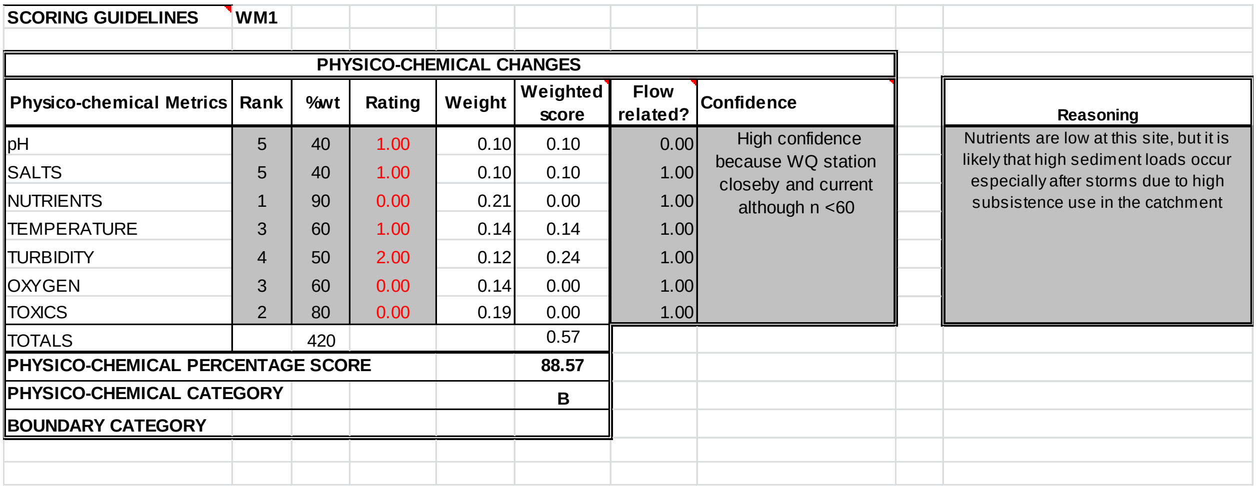


SCORING GUIDELINES **NS1**

PHYSICO-CHEMICAL CHANGES

Physico-chemical Metrics	Rank	%wt	Rating	Weight	Weighted score	Flow related?	Confidence	Reasoning
pH	5	40	1.00	0.10	0.10	0.00	Low- medium because no monitoring station in catchment. High EC downstream but probably due to naturally high salinity.	Nutrients are low at this site, but it is likely that high sediment loads occur especially after storms due to high subsistence use in the catchment. Salinity is likely to be naturally high but there is no RC data to confirm this.
SALTS	5	40	1.00	0.10	0.10	1.00		
NUTRIENTS	1	90	0.00	0.21	0.00	1.00		
TEMPERATURE	3	60	1.00	0.14	0.14	1.00		
TURBIDITY	4	50	2.00	0.12	0.24	1.00		
OXYGEN	3	60	1.00	0.14	0.14	1.00		
TOXICS	2	80	0.00	0.19	0.00	1.00		
TOTALS		420			0.71			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**85.71**			
PHYSICO-CHEMICAL CATEGORY					**B**			
BOUNDARY CATEGORY								

3.7.3 White Mfolozi River: EWR site WM1

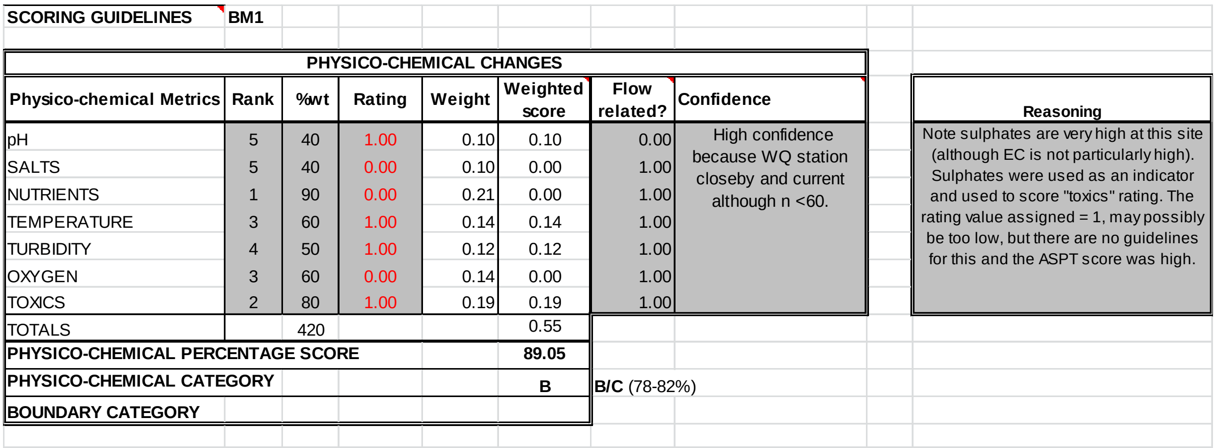


SCORING GUIDELINES **WM1**

PHYSICO-CHEMICAL CHANGES

Physico-chemical Metrics	Rank	%wt	Rating	Weight	Weighted score	Flow related?	Confidence	Reasoning
pH	5	40	1.00	0.10	0.10	0.00	High confidence because WQ station closeby and current although n <60	Nutrients are low at this site, but it is likely that high sediment loads occur especially after storms due to high subsistence use in the catchment
SALTS	5	40	1.00	0.10	0.10	1.00		
NUTRIENTS	1	90	0.00	0.21	0.00	1.00		
TEMPERATURE	3	60	1.00	0.14	0.14	1.00		
TURBIDITY	4	50	2.00	0.12	0.24	1.00		
OXYGEN	3	60	0.00	0.14	0.00	1.00		
TOXICS	2	80	0.00	0.19	0.00	1.00		
TOTALS		420			0.57			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**88.57**			
PHYSICO-CHEMICAL CATEGORY					**B**			
BOUNDARY CATEGORY								

3.7.4 Black Mfolozi River: EWR site BM1



SCORING GUIDELINES **BM1**

PHYSICO-CHEMICAL CHANGES

Physico-chemical Metrics	Rank	%wt	Rating	Weight	Weighted score	Flow related?	Confidence	Reasoning
pH	5	40	1.00	0.10	0.10	0.00	High confidence because WQ station closeby and current although n <60.	Note sulphates are very high at this site (although EC is not particularly high). Sulphates were used as an indicator and used to score "toxics" rating. The rating value assigned = 1, may possibly be too low, but there are no guidelines for this and the ASPT score was high.
SALTS	5	40	0.00	0.10	0.00	1.00		
NUTRIENTS	1	90	0.00	0.21	0.00	1.00		
TEMPERATURE	3	60	1.00	0.14	0.14	1.00		
TURBIDITY	4	50	1.00	0.12	0.12	1.00		
OXYGEN	3	60	0.00	0.14	0.00	1.00		
TOXICS	2	80	1.00	0.19	0.19	1.00		
TOTALS		420			0.55			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**89.05**			
PHYSICO-CHEMICAL CATEGORY					**B**	**B/C** (78-82%)		
BOUNDARY CATEGORY								

3.7.5 Black Mfolozi River: EWR site BM2

SCORING GUIDELINES **BM2**

PHYSICO-CHEMICAL CHANGES

Physico-chemical Metrics	Rank	%wt	Rating	Weight	Weighted score	Flow related?	Confidence	Reasoning
pH	5	40	1.00	0.10	0.10	0.00	High confidence because WQ station fairly close-by and current although n <60.	Sulphates are low at this site as is EC. Nutrients also low, but sediment loads probably very high.
SALTS	5	40	0.00	0.10	0.00	1.00		
NUTRIENTS	1	90	0.00	0.21	0.00	1.00		
TEMPERATURE	3	60	1.00	0.14	0.14	1.00		
TURBIDITY	4	50	3.00	0.12	0.36	1.00		
OXYGEN	3	60	0.00	0.14	0.00	1.00		
TOXICS	2	80	0.00	0.19	0.00	1.00		
TOTALS		420			0.60			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**88.10**			
PHYSICO-CHEMICAL CATEGORY					**B**			
BOUNDARY CATEGORY								

3.7.6 Mkuze River: EWR site MK1

SCORING GUIDELINES **MK1**

PHYSICO-CHEMICAL CHANGES

Physico-chemical Metrics	Rank	%wt	Rating	Weight	Weighted score	Flow related?	Confidence	Reasoning
pH	5	40	1.00	0.10	0.10	0.00	Medium confidence as monitoring ended in 2009	Note sulphates and EC very high at this site. Nutrients are also elevated, particularly phosphate. Adjusted to "C/D" to agree with biotic results.
SALTS	5	40	4.00	0.10	0.38	1.00		
NUTRIENTS	1	90	2.00	0.21	0.43	1.00		
TEMPERATURE	3	60	1.00	0.14	0.14	1.00		
TURBIDITY	4	50	1.00	0.12	0.12	1.00		
OXYGEN	3	60	1.00	0.14	0.14	1.00		
TOXICS	2	80	3.00	0.19	0.57	1.00		
TOTALS		420			1.88			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**62.38**			
PHYSICO-CHEMICAL CATEGORY					**C**			
BOUNDARY CATEGORY								

3.7.7 Upper Phongolo River: EWR site UP1

SCORING GUIDELINES **UP1**

PHYSICO-CHEMICAL CHANGES

Physico-chemical Metrics	Rank	%wt	Rating	Weight	Weighted score	Flow related?	Confidence	Reasoning
pH	5	40	1.00	0.10	0.10	0.00	Low-medium confidence as data taken from different river. Some limited supporting data from Phongola R.	Localised impacts from nearby residential area at site. Overall PES adjusted to B using expert judgement
SALTS	5	40	0.00	0.10	0.00	1.00		
NUTRIENTS	1	90	0.00	0.21	0.00	1.00		
TEMPERATURE	3	60	0.00	0.14	0.00	1.00		
TURBIDITY	4	50	0.00	0.12	0.00	1.00		
OXYGEN	3	60	0.00	0.14	0.00	1.00		
TOXICS	2	80	0.00	0.19	0.00	1.00		
TOTALS		420			0.10			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**98.10**			
PHYSICO-CHEMICAL CATEGORY					**A**			
BOUNDARY CATEGORY								

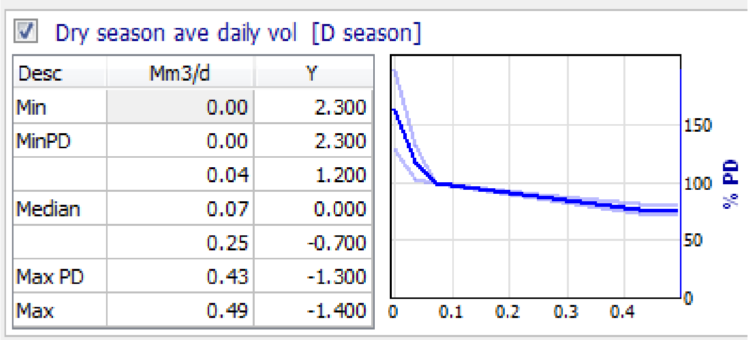
3.7.8 Assegaai River: EWR site AS1

SCORING GUIDELINES	**AS1**							
PHYSICO-CHEMICAL CHANGES								
Physico-chemical Metrics	**Rank**	**%wt**	**Rating**	**Weight**	**Weighted score**	**Flow related?**	**Confidence**	**Reasoning**
pH	5	40	0.00	0.10	0.00	0.00	Decreased flow likely to cause increased nutrient levels and lead to increased temperature and decreased oxygen. pH and turbidity unlikely to be affected by flow.	Medium confidence because no current WQ monitoring data. Nutrients a concern at this site.
SALTS	5	40	0.00	0.10	0.00	1.00		
NUTRIENTS	1	90	3.00	0.21	0.64	3.00		
TEMPERATURE	3	60	1.00	0.14	0.14	1.00		
TURBIDITY	4	50	1.00	0.12	0.12	1.00		
OXYGEN	3	60	0.00	0.14	0.00	1.00		
TOXICS	2	80	0.00	0.19	0.00	1.00		
TOTALS		420			0.90			
PHYSICO-CHEMICAL PERCENTAGE SCORE					**81.90**			
PHYSICO-CHEMICAL CATEGORY					**B**			
BOUNDARY CATEGORY								

3.8 Motivations for response curves

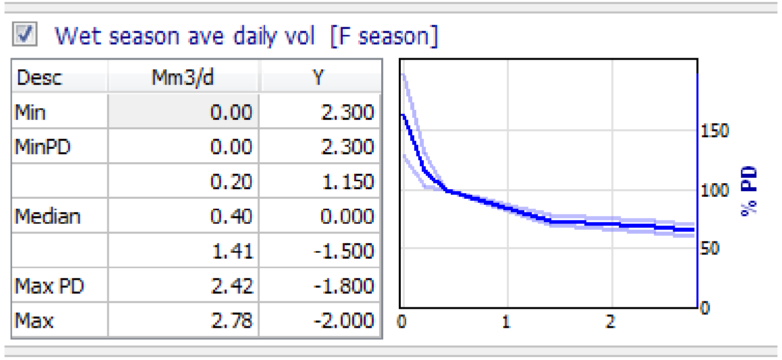
Examples of the response curves are given for EWR Site MA1. Response curves of the other sites and their reasoning are available in the Usuthu-Mthlatuze DRIFT DSS. Response curves provided below and those in the DSS MAY differ very slightly as a result of final calibration, but the overall shape and reasoning remains the same.

3.8.1 Electrical conductivity

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


☑ Dry season ave daily vol [D season]

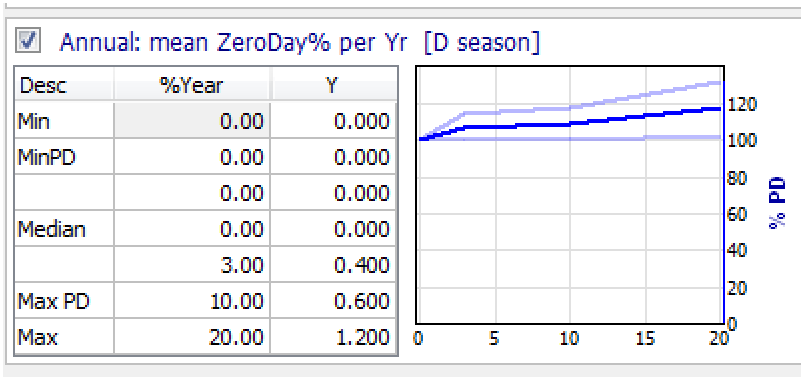
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.300</td></tr>
<tr><td></td><td>0.04</td><td>1.200</td></tr>
<tr><td>Median</td><td>0.07</td><td>0.000</td></tr>
<tr><td></td><td>0.25</td><td>-0.700</td></tr>
<tr><td>Max PD</td><td>0.43</td><td>-1.300</td></tr>
<tr><td>Max</td><td>0.49</td><td>-1.400</td></tr>
</table>

</td><td>Salinity is slightly impacted at this site (PES median EC = 35 mS/m; category =good). It rises to a 95%ile of 51 mS/m. Salinity does not change with season at this site and thus is independent of flow.</td><td>Low (It was not possible to construct Q-C plots for this site because of a lack of data also the data are from another catchment (Mhlatuze)).</td></tr>
<tr><td>


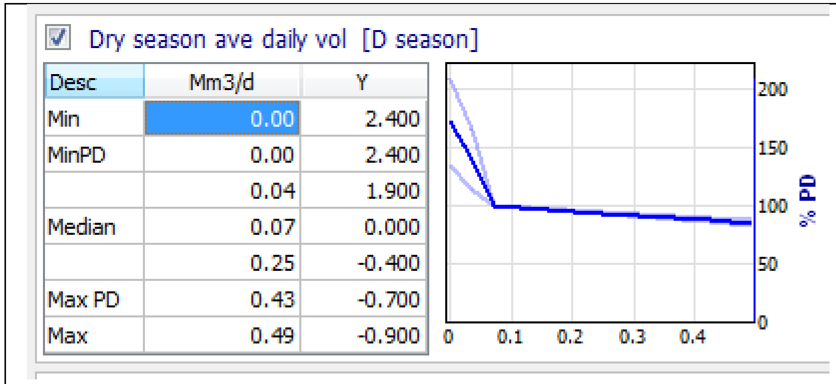
☑ Wet season ave daily vol [F season]

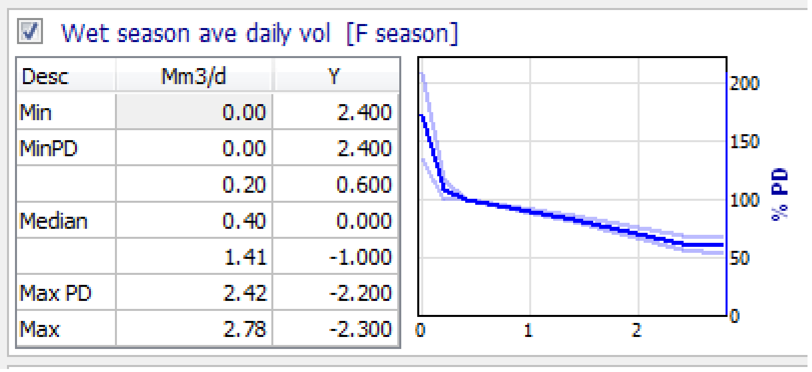
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.300</td></tr>
<tr><td></td><td>0.20</td><td>1.150</td></tr>
<tr><td>Median</td><td>0.40</td><td>0.000</td></tr>
<tr><td></td><td>1.41</td><td>-1.500</td></tr>
<tr><td>Max PD</td><td>2.42</td><td>-1.800</td></tr>
<tr><td>Max</td><td>2.78</td><td>-2.000</td></tr>
</table>

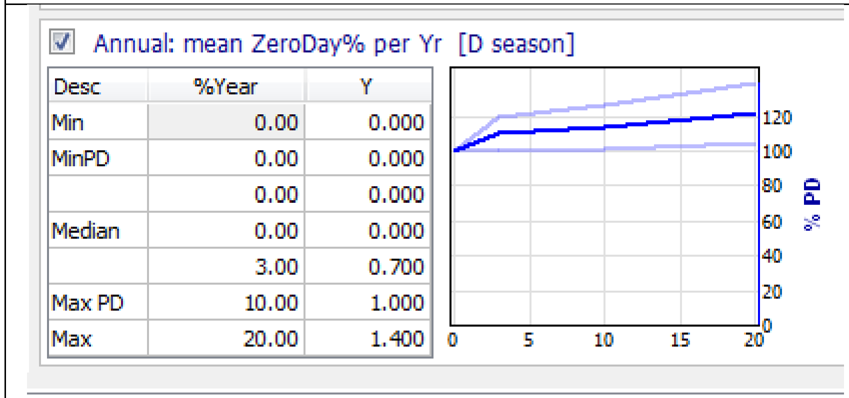
</td><td>The EC does not appear to decrease in the wet season (possibly because of wash-off of salts from the surrounding landscape). Reduced flow during this period would have an effect on EC.</td><td>Low</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Annual: mean ZeroDay% per Yr [D season]
<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>0.400</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>0.600</td></tr>
<tr><td>Max</td><td>20.00</td><td>1.200</td></tr>
</table>
</td><td>As the number of days of no flow increase, salinity will increase as effluent becomes an increasing proportion of the flow. In addition, as pools are formed evaporation of water will cause salts to increase. Without any data linking the number of zero-flow days to salinity it is difficult to predict this quantitatively.</td><td>Low</td></tr>
</table>

3.8.2 Sulphate

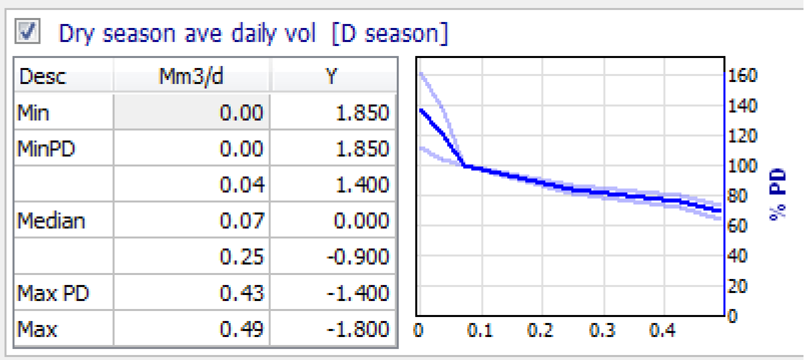
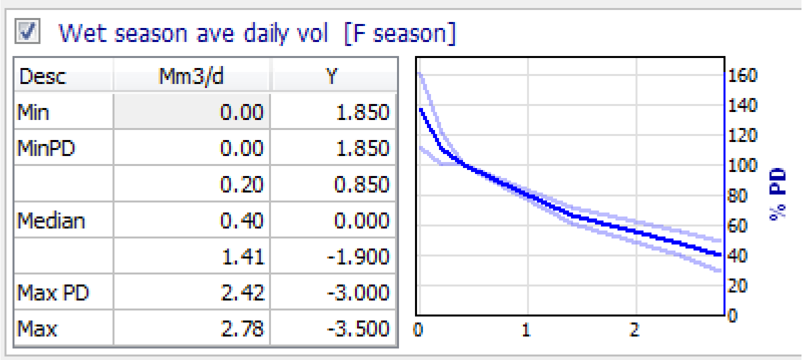
<table>
<tr><td>
☑ Dry season ave daily vol [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.400</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.400</td></tr>
<tr><td></td><td>0.04</td><td>1.900</td></tr>
<tr><td>Median</td><td>0.07</td><td>0.000</td></tr>
<tr><td></td><td>0.25</td><td>-0.400</td></tr>
<tr><td>Max PD</td><td>0.43</td><td>-0.700</td></tr>
<tr><td>Max</td><td>0.49</td><td>-0.900</td></tr>
</table>
</td><td>Sulphate is very low at this site and would not be expected to increase markedly with decreased flows. Similarly since it is already so low (PES median = 9 mg/L) it would not be expected to decrease very much if flow is increased.</td><td>Low</td></tr>
</table>

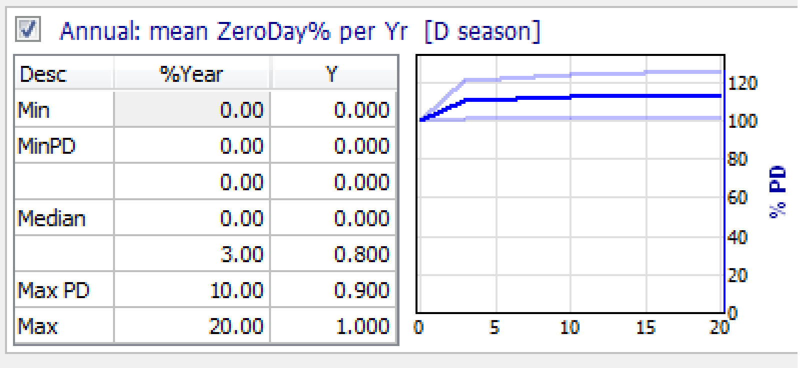
<table>
<tr>
<td>


☑ 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>2.400</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.400</td></tr>
<tr><td></td><td>0.20</td><td>0.600</td></tr>
<tr><td>Median</td><td>0.40</td><td>0.000</td></tr>
<tr><td></td><td>1.41</td><td>-1.000</td></tr>
<tr><td>Max PD</td><td>2.42</td><td>-2.200</td></tr>
<tr><td>Max</td><td>2.78</td><td>-2.300</td></tr>
</table>
</td>
<td>There is currently no difference between the median values of sulphate in the dry and wet seasons. This is probably because the overall levels are so low.</td>
<td>Low</td>
</tr>
<tr>
<td>


☑ Annual: mean ZeroDay% per Yr [D season]
<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>0.700</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>20.00</td><td>1.400</td></tr>
</table>
</td>
<td>As the number of days of zero flow increases, isolated pools will start forming in the run of the river. Evaporation of water from the pools will occur and salt levels in general, including sulphate will increase.</td>
<td>Low</td>
</tr>
</table>

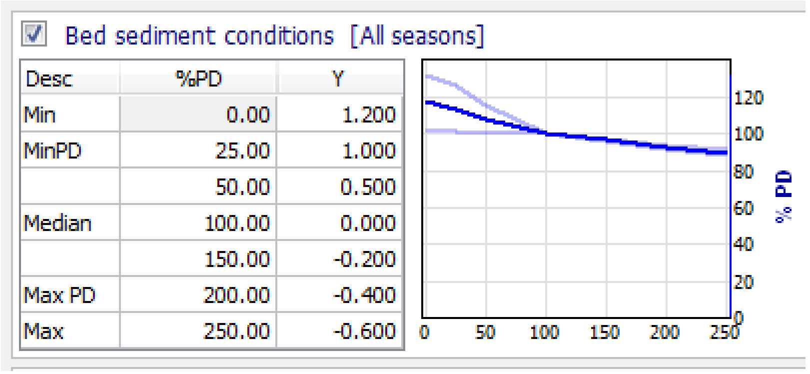
3.8.3 Total inorganic nitrogen

 ☑ Dry season ave daily vol [D season] Desc / Mm3/d / Y Min / 0.00 / 1.850 MinPD / 0.00 / 1.850 / 0.04 / 1.400 Median / 0.07 / 0.000 / 0.25 / -0.900 Max PD / 0.43 / -1.400 Max / 0.49 / -1.800 	Present day TIN concentrations are very low at this site (PES median = 0.22 mg/L and thus rating =0; no change from natural). Concentrations rise to roughly 0.38 mg/L which is a rating = 1. Levels of TIN are higher in the dry season than the wet season.	**Low**
 ☑ Wet season ave daily vol [F season] Desc / Mm3/d / Y Min / 0.00 / 1.850 MinPD / 0.00 / 1.850 / 0.20 / 0.850 Median / 0.40 / 0.000 / 1.41 / -1.900 Max PD / 2.42 / -3.000 Max / 2.78 / -3.500 	TIN concentrations will decrease with increasing flow but only up to a point, where after they will level out.	**Low**

<table>
<tr>
<td>


☑ Annual: mean ZeroDay% per Yr [D season]

<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>0.800</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>0.900</td></tr>
<tr><td>Max</td><td>20.00</td><td>1.000</td></tr>
</table>

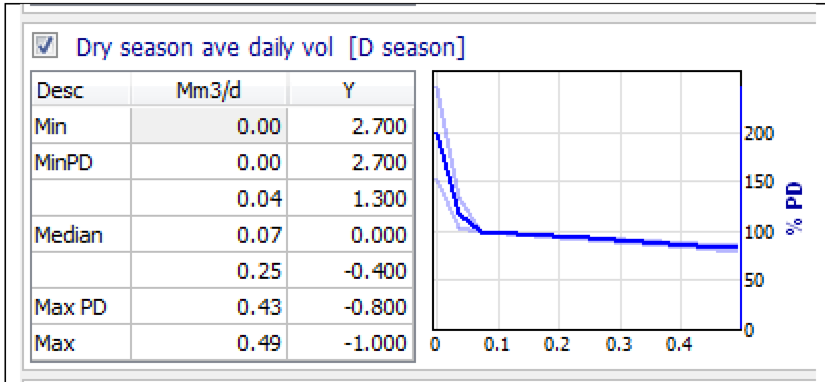
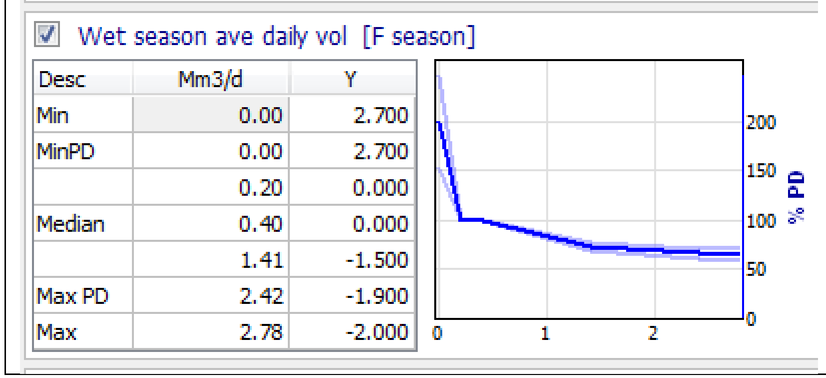
</td>
<td>As for phosphates and salts.</td>
<td>Low</td>
</tr>
<tr>
<td>


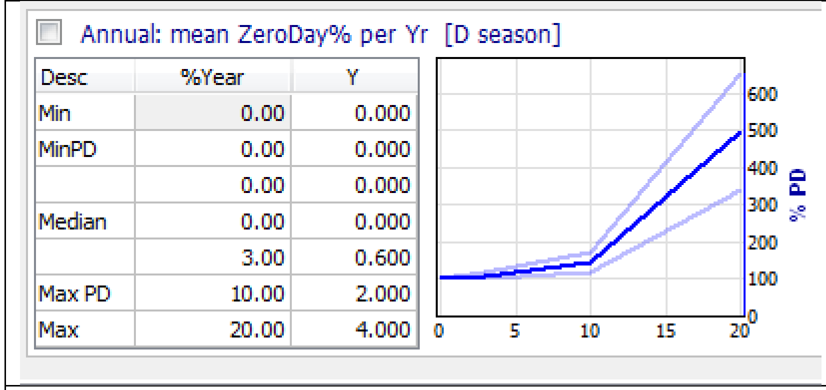
☑ Bed sediment conditions [All seasons]

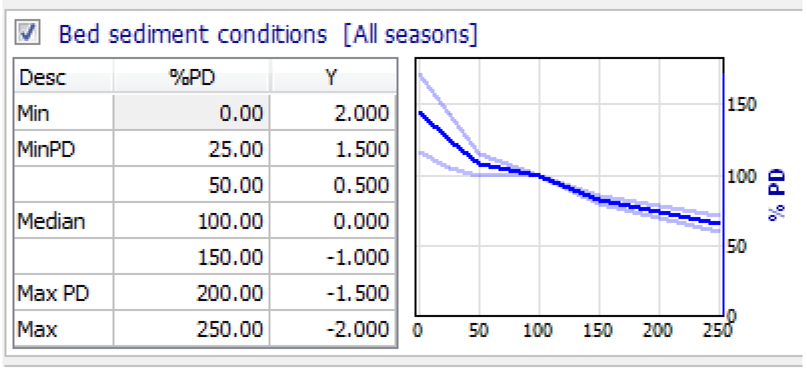
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.200</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>1.000</td></tr>
<tr><td></td><td>50.00</td><td>0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.400</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.600</td></tr>
</table>

</td>
<td>Like phosphorus, nitrogen also is associated with sediments but to a much lesser extent. Thus nitrogen will be associated with fine sediments and floods are required to flush this nutrient out of the system. The levels of N are not likely to be high in this river and thus only a small proportion will be bound.</td>
<td>Low</td>
</tr>
</table>

3.8.4 Phosphate

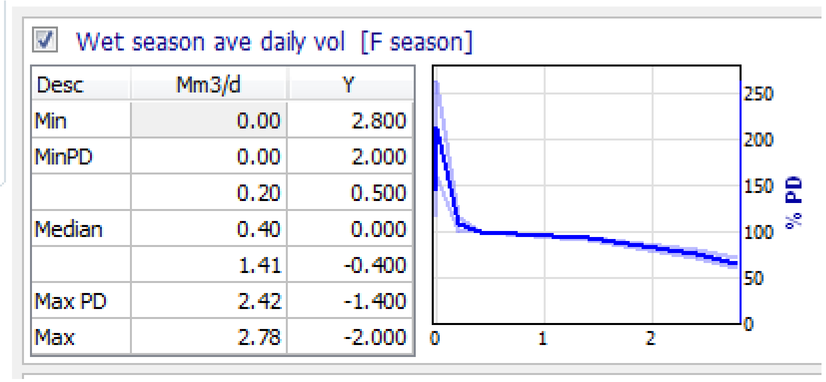
<table>
<tr>
<td>
☑ Dry season ave daily vol [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.700</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.700</td></tr>
<tr><td></td><td>0.04</td><td>1.300</td></tr>
<tr><td>Median</td><td>0.07</td><td>0.000</td></tr>
<tr><td></td><td>0.25</td><td>-0.400</td></tr>
<tr><td>Max PD</td><td>0.43</td><td>-0.800</td></tr>
<tr><td>Max</td><td>0.49</td><td>-1.000</td></tr>
</table>
</td>
<td>Phosphate levels are low (median = 0.22 mg/L) at this site but do increase in the dry season.</td>
<td>Low</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>2.700</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.700</td></tr>
<tr><td></td><td>0.20</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.40</td><td>0.000</td></tr>
<tr><td></td><td>1.41</td><td>-1.500</td></tr>
<tr><td>Max PD</td><td>2.42</td><td>-1.900</td></tr>
<tr><td>Max</td><td>2.78</td><td>-2.000</td></tr>
</table>
</td>
<td>Phosphate is higher during the dry season than the wet.</td>
<td>Low</td>
</tr>
</table>

<table>
<tr>
<td>

☐ Annual: mean ZeroDay% per Yr [D season]
<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>0.600</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>2.000</td></tr>
<tr><td>Max</td><td>20.00</td><td>4.000</td></tr>
</table>

</td>
<td>As the number of days of no flow increase, phosphates will increase as pools are formed evaporation of water will cause phosphates to increase. Without any data linking the number of zero-flow days to phosphates it is difficult to estimate the predicted deviation from PD phosphates.</td>
<td>Low</td>
</tr>
<tr>
<td>

☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>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>-1.000</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>Some of the phosphorus load will be bound to sediments, especially fine silt. Thus in order to lower phosphorus the silt load needs to be lowered. Therefore there is a link with bed sediment condition. (The lower the bed sediment condition value the finer the sediment and the higher the phosphorus load). The proportion of Total Phosphorus bound to sediment is temporally and spatially variable in South Africa. But can be quite high. For example for W2H022 the % PO4 (i.e. dissolved P) of total P is 20% i.e. is not bound to sediments). No data for TP could be found for the W5 catchment. But this shows that a significant proportion of phosphorus could be associated with sediments.</td>
<td>Low</td>
</tr>
</table>

3.8.5 Summer water temperature

<table>
<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>2.800</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.000</td></tr>
<tr><td></td><td>0.20</td><td>0.500</td></tr>
<tr><td>Median</td><td>0.40</td><td>0.000</td></tr>
<tr><td></td><td>1.41</td><td>-0.400</td></tr>
<tr><td>Max PD</td><td>2.42</td><td>-1.400</td></tr>
<tr><td>Max</td><td>2.78</td><td>-2.000</td></tr>
</table>

</td>
<td>The buffering capacity of the river will decrease as the volume of water decreases. This will lead to a wider variation in water temperature. In summer (hot ambient air temperatures) if flow is reduced, water temperature will increase. Dry season flow has not been considered because this is when air temperatures are lower. If flow is increased relative to PD the buffering capacity of the river will be increased only up to a certain point after which it will not increase. Even if flow is decreased severely water temperature is unlikely to increase more than 25% from PD. However since there are no temperature data for this river it is difficult to be definitive.</td>
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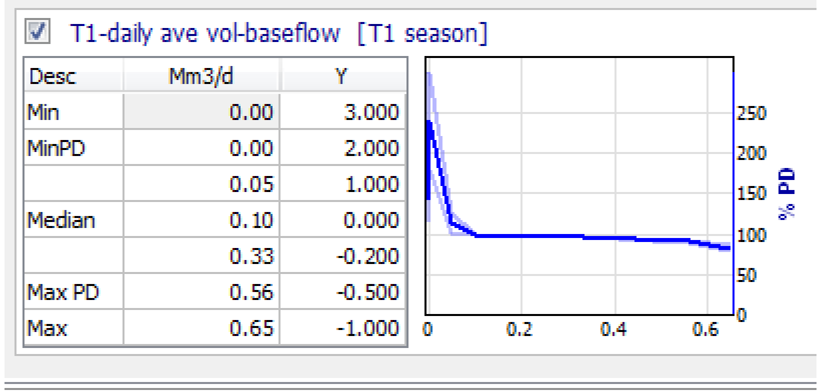
</tr>
<tr>
<td>

☑ T1-daily ave vol-baseflow [T1 season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>3.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>2.000</td></tr>
<tr><td></td><td>0.05</td><td>1.000</td></tr>
<tr><td>Median</td><td>0.10</td><td>0.000</td></tr>
<tr><td></td><td>0.33</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>0.56</td><td>-0.500</td></tr>
<tr><td>Max</td><td>0.65</td><td>-1.000</td></tr>
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</td>
<td></td>
<td>Low</td>
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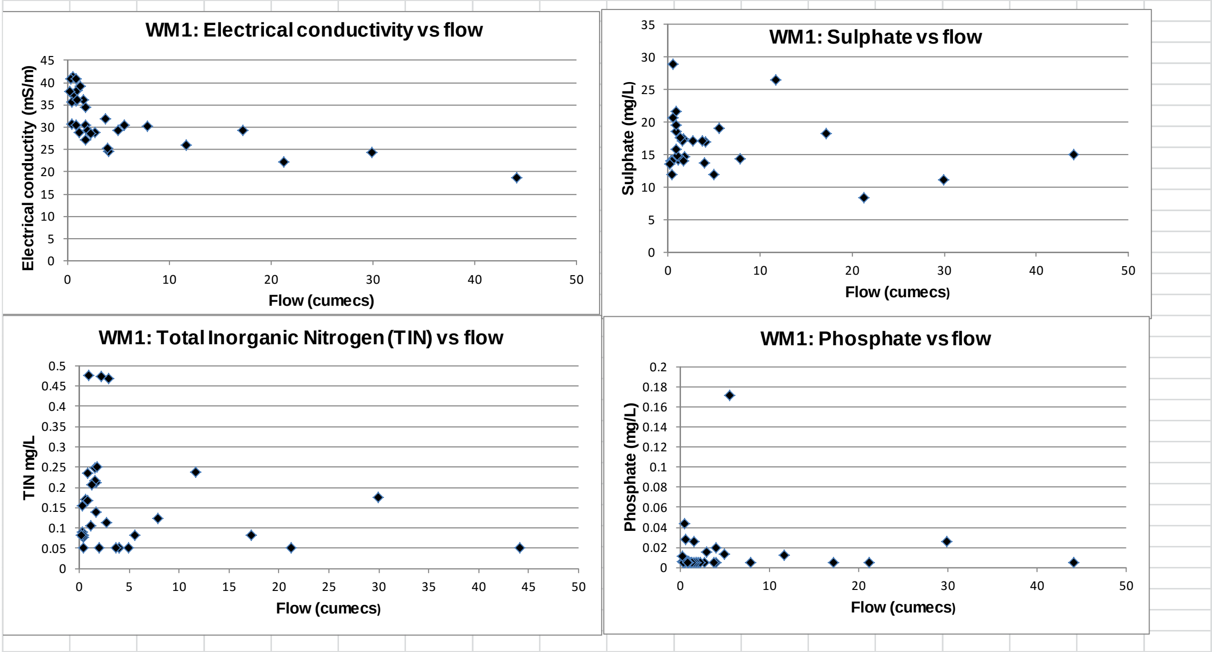
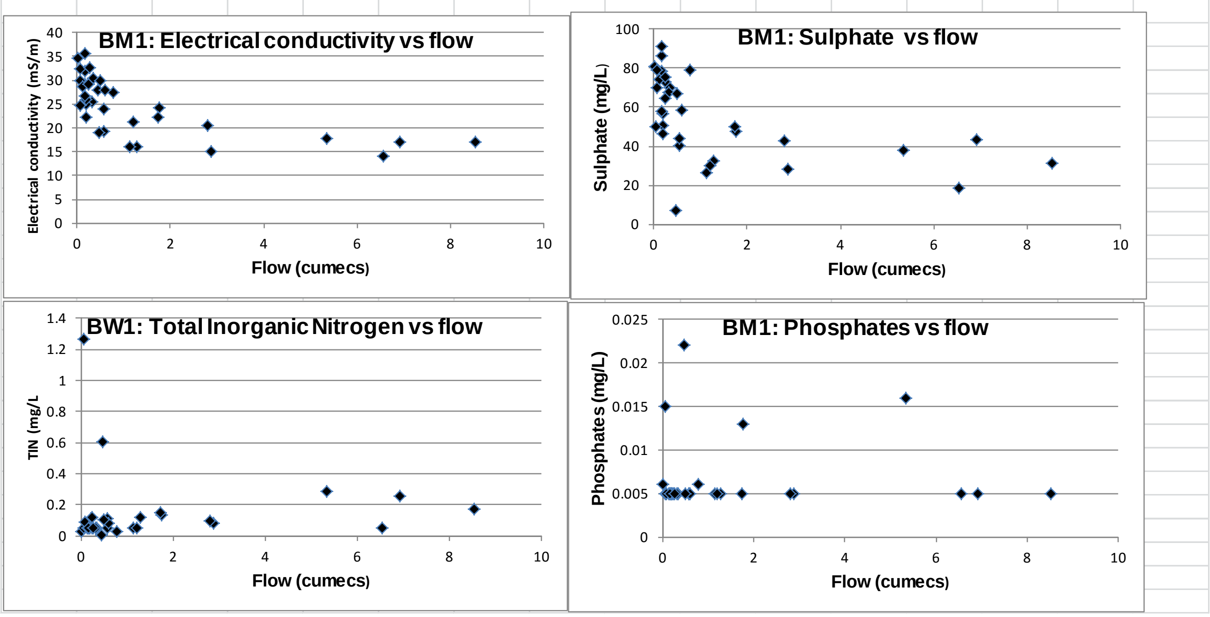
3.9 Q-C plots

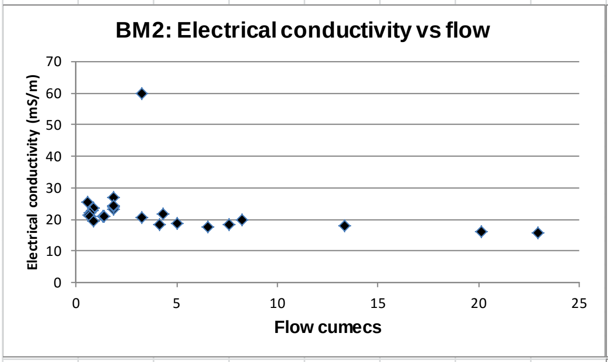
3.9.1 White Mfolozi (W2H005)

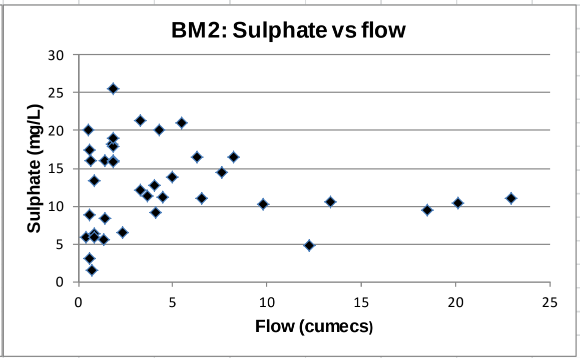


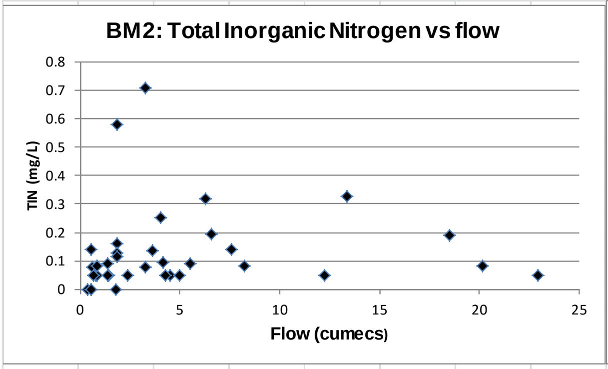
3.9.2 Black Mfolozi 1 (W2H028)

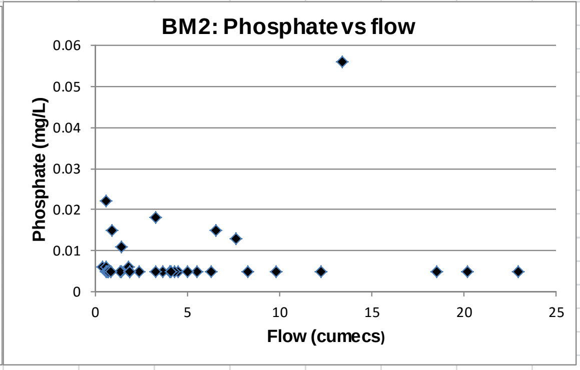


3.9.3 Black Mfolozi 2 (W2H006)

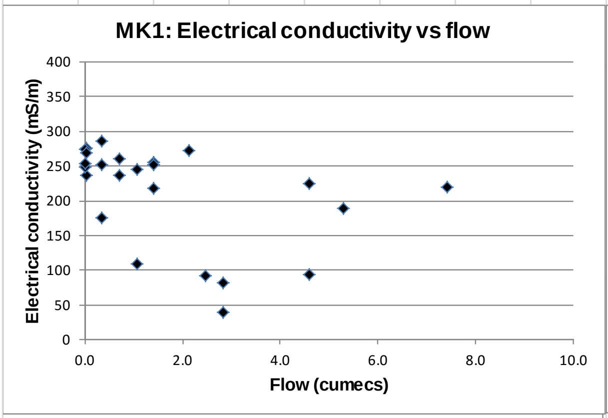

BM2: Electrical conductivity vs flow

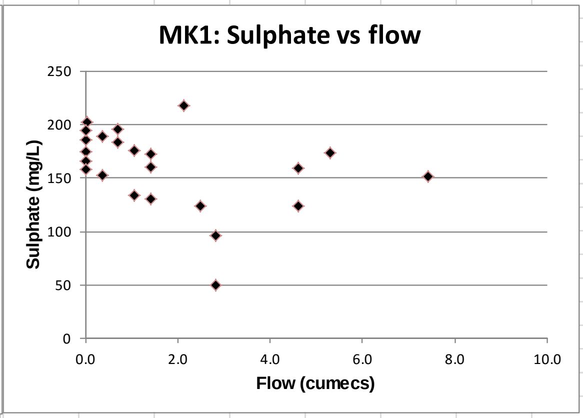

BM2: Sulphate vs flow

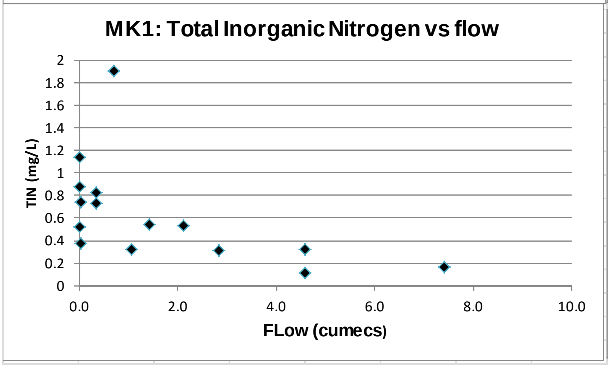

BM2: Total Inorganic Nitrogen vs flow

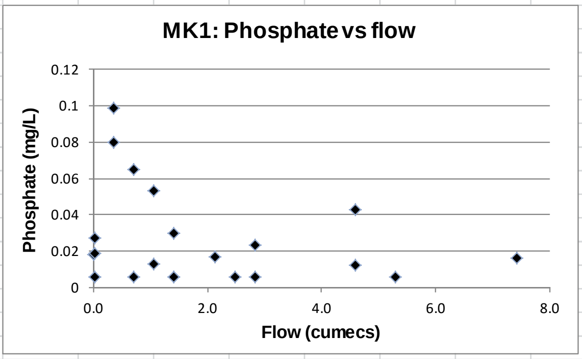

BM2: Phosphate vs flow

3.9.4 Mkuze (W3H003)

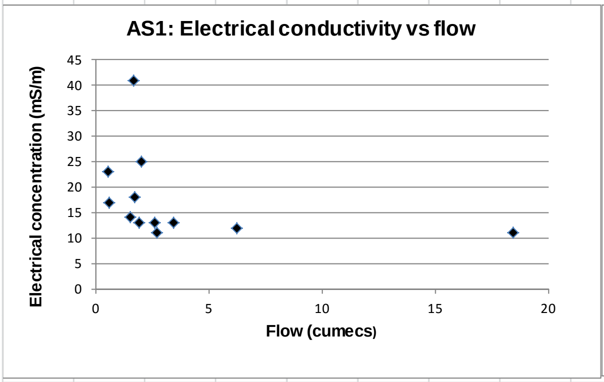

MK1: Electrical conductivity vs flow

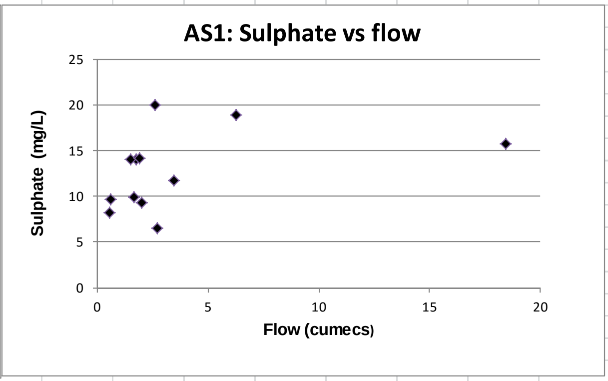

MK1: Sulphate vs flow

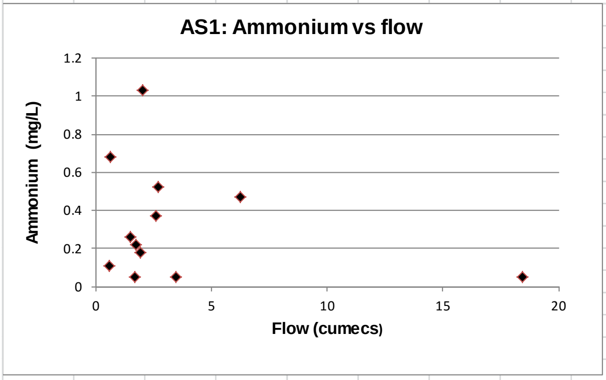

MK1: Total Inorganic Nitrogen vs flow


MK1: Phosphate vs flow

3.9.5 Assegaai (W5H022)







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4 GEOMORPHOLOGY: SPECIALIST REPORT

4.1 Introduction

1.1.1 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 EWR assessment, 34 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 Tlou Consulting *viz*.:

- Familiarise yourself to the extent possible with the study area, including:
    - The character of the rivers 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 reach analysis for the study river.
- Provide detailed information for eight EWR 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 EWR assessment.
- 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.
- Prepare data files for use at the DRIFT Workshop, and make statements about the confidence level of your outputs. Develop information on the following relationships:
    - altered flow regime-sediment transport potential

  - changes in habitat types with changes in the flow regime.
  - any other relevant data as your experience suggests.
- Attend PMC meetings if and as required (additional time will be made available).
- Assist with capacity building of an allocated DWA staff member, if and when required.
- Attend the DRIFT Workshop(s), prepared to provide in and to populate the DRIFT response curves for invertebrates.
- Prepare response curve motivation tables, and make statements about the confidence level of your outputs.

4.1.1 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 EWR 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.
- Data and the details of analyses performed.
- Ecospecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to geomorphology.

4.2 Description of the study area, with the focus on geomorphology

Northern Zululand, the region where the EWR sites are located, has a subtropical climate characterised by humid summers and moderately warm winters. Most of the annual rainfall occurs during the summer (September to March). Preston-Whyte and Tyson (1988) note that the region is affected by tropical systems during late summer (February to March) when exceptional heavy rainfall can occur. During winter (June to August) the influences of the middle latitude cyclones and frontal systems generally prevail to produce widespread, gentle rainfall, whilst during spring (September to November), frequent thunderstorms create intense, short duration storms that often occur (Kelbe 1988).

Sand based soils predominate across most of the study area, being the result of weathering of quartzite, tillite and granite (DWAF 2000). Three main soil groupings are found in the catchment are sandy clays (dominating the upper catchments), sandy loam in the middle reaches of most of the river catchments, and thereafter the rivers flow out across the sandy Zululand coastal plain, which widens progressively to the north of the study area. These lower reaches on the coastal plain flow over underlying geology that is mainly of relativelky recent marine origin, and is covered by very recent aeolian deposits, hence the very sandy nature of this zone.

4.3 Literature review

A previous catchment assessment undertaken for the study area (DWAF 2007) indicated that there were no geomorphology data or descriptions to inform the PES assessments within the WMA, nor Reference Condition data. This is not entirely accurate, since historical aerial photographs are available for most of the study area for the periods of 1935-1944; 1951-1957; 1961-1970 and 1973-1977 and from the 1990's, as well as more recent high resolution satellite imagery. These data were sourced for the study sites from the National Geo-spatial Information (formerly the Chief Directorate – Surveys and Mapping) office in Cape Town and used to aid the description of the EWR sites and determination of the Geomorphological Reference Conditions and PES.

Results from research on the dynamics of the Pongola floodplain (e.g. Breen *et al.* 1998), data and field notes from a previous consulting study on the Usutu River (Rountree, unpublished data) and the outcome of work done on the sediment yield and sources of erosion in the Mfolozi catchment (Watson and Ramokgopa 1997; Waston *et al*. 1996) were also used.

Of greatest geomorphological interest are the recorded cross-sectional changes to the Pongolo and Black and White Mfolozi rivers following the very large 1894 Domonia floods (DWA 1985). These data provided invaluable records of the effects of large reset flood events on the geomorphology of the rivers in this region.

4.4 Description of the EWR sites

See

Figure 1-1 for a map showing the location of the EWR sites. Tabulated characteristics of the EWR sites (Table 4-1) and morphological descriptions of each of the EWR sites are provided in this section. The morphological descriptions are obtained from a combination of field assessment (undertaken during July 2014) and analysis of relevant literature and available historical aerial photography and Google Earth imagery which attests to the longer term planform dynamics of the sites and reaches.

Table 4-1 Characteristics of the EWR sites

Quaternary catchment	River	EWR site Name	Topo. map sheet	Latitude and Longitude	Altitude at EWR site (masl)	Slope	River zone type*
W51D	Assegaai	AS1	2730BB	27º’44.28”S 30º 59’19.68”E	1000-1020	0.00345	Lower Foothills

Quaternary catchment	River	EWR site Name	Topo. map sheet	Latitude and Longitude	Altitude at EWR site (masl)	Slope	River zone type*
W42E	Upper Pongola	UP1	2730BD	27º 21'50.88"S 30º 58'10.62"E	800-820	0.00952	Upper Foothills
W31J	Mkuze	MK1	2732CA	27º 35'31.56"S 32º 13'4.80"E	40-60	0.00097	Lowland River
W22C	Black Mfolozi	BM1	2731CC	27º 56'20.04"S 31º 12'37.08"E	600-620	0.00625	Upper Foothills
W22C	Black Mfolozi	BM2	2831AB	28º 0'50.04"S 31º 19'27.48"E	460-480	0.00690	Upper Foothills
W21H	White Mfolozi	WM1	2831AA	28º 13'53.24"S 31º 11'17.97"E	620-640	0.00426	Lower Foothills
W12H	Nseleni	NS1	2831DB	28º 38'2.76"S 31º 55'51.24"E	20-40	0.00233	Lower Foothills
W11B	Matigulu	MA1	2931AB	29º 1'12.36"S 31º 28'13.44"E	40-60	0.00769	Upper Foothills

*after the Rowntree and Wadeson (1999) classification of river zones for southern Africa.

4.4.1 Assegai River (EWR Site AS1)

The EWR site is located within a pool-riffle sequence of a bedrock controlled reach. The bed of the active channel is dominated by cobbles and boulders (Figure 4-1), but gravel and sands are also present. *Miscanthus* and *Salix* vegetation occur along the marginal zone of the active channel.

The cross-section at the site runs directly through a riffle, and there is a large flood channel adjacent to the right bank (Figure 4-2). The flood channel makes the flood hydraulics very complex at this site due to the upstream pool causing a much higher water level in the flood channel than in the riffle active channel at the cross-section site during high flows. The flood hydraulics may therefore need to be interpreted with some caution and results of a lower confidence due to the site complexity.

Large woody debris deposited in the riparian zone and strandlines on the banks indicate that a very large flood occurred in the previous wet season. The Heyshope Dam is located upstream of the EWR site. This large dam became operational in the mid-1980's. Downstream of the dam, extensive afforestation occurs, as well as the town of Piet Retief. The dam and downstream landuses can be expected to impact upon the EWR site.

Figure 4-1 The active channel at the cross section of Assegaai EWR AS1

At the site, silt drapes and algae over the cobbles and boulders of the slower flowing channel areas, with clean gravels and small cobbles only present in the fastest sections of the channel, suggest that floods have been reduced. Recent high flows and floods (especially a large flood in early 2014) may have revitalised the bed conditions leading up to the site visit of July 2014, so it is possible that, at the time of the site visit, the reach may be in a better condition than in average years. The hydrology summary provided by Aurecon indicates that the PD MAR and flood discharges have declined by half relative to the naturalised flow conditions, with MAR declining from 278 Mm^3 (under naturalised conditions) down to 134 Mm^3 (under present day conditions).

The reduced scour events would account for the encroachment of vegetation visible in the historical aerial photographic record and the stabilised and embedded bed conditions observed at the site. These effects are primarily due to reduced floods as a consequence of the operation of the upstream Heyshope Dam.

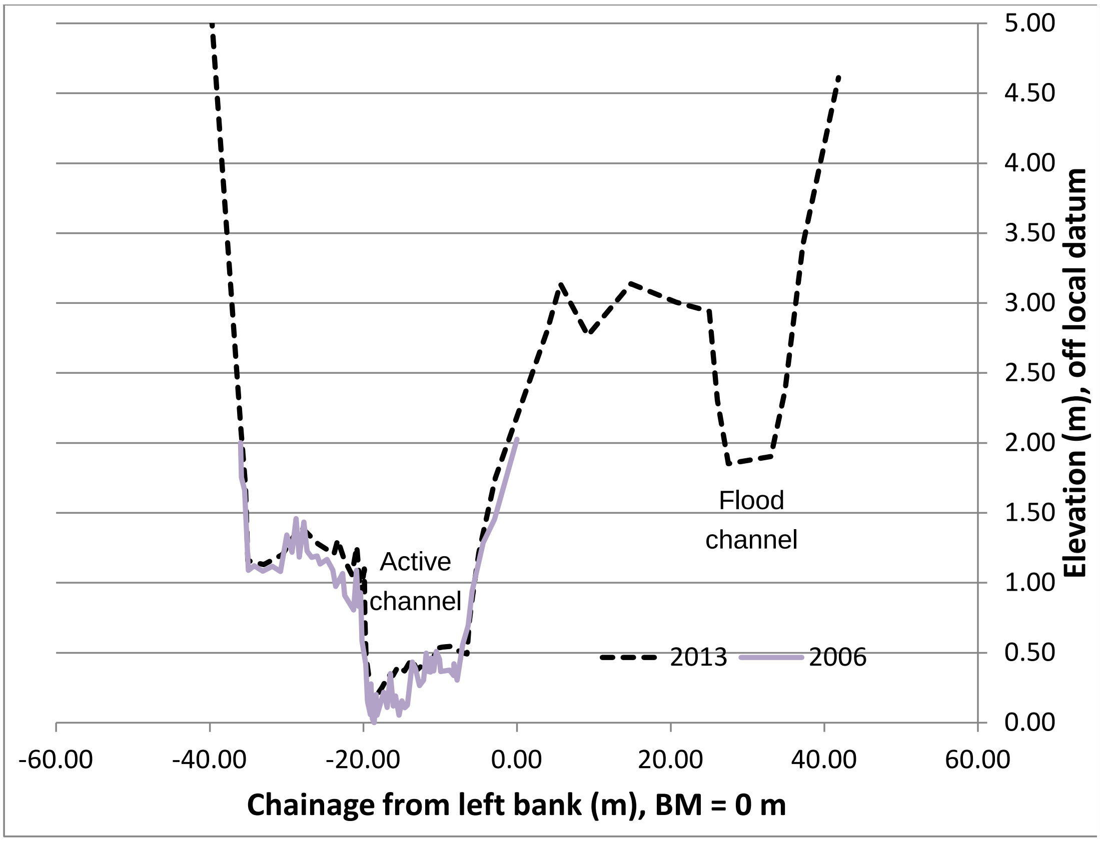
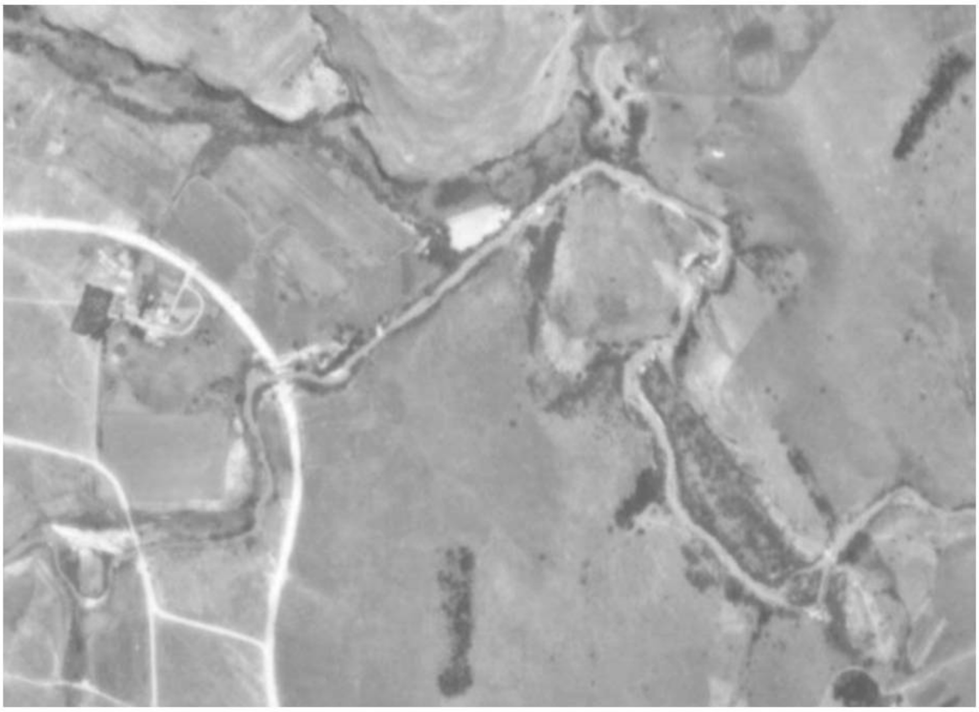


Figure 4-2 **Cross section at EWR site AS 1 showing the comparison between the 2007 survey and 2013 survey. The 2007 survey, for a rapid EWR study, does not show the flood channel indicated in the 2013 survey. A downstream pool cross-section was used to model sediment transport to reduce the hydraulic complexities which would otherwise be introduced by high flows from the flood channel.**

Analysis of historical aerial photographs show some channel responses to very large flood events, but the gross morphology is largely stable although there is some evidence of channel narrowing, likely in response to the upstream dam and associated reduced flood flows (Table 4-2).

Table 4-2 Historical aerial photographic record of the reach at EWR Site AS1.



April 1979

July 1977

June 1961

4.4.2 Upper Pongola River (EWR Site UP1)

This pool rapid site is located within an anastomosing reach, with many secondary channels in the anastomosing reaches up and downstream of the EWR site. The cross section is through a boulder and bedrock dominated rapid (Figure 4-3). The active channel is composed of bedrock, boulders, cobble, sand and gravel. Alien trees (Saligna, Eucalyptus, wattle) are present but at low densities on the banks, with indigenous willows, *Phragmites* and *Miscanthus.* in the marginal zone.

Limited sand mining (at a subsistence scale) occurs at the site and at a few additional locations in the reach. The sandy lateral bars (seasonal/ephemeral features) and the riparian banks are affected by these activities. The sand load appears to be slightly elevated (probably due to catchment erosion), but the active channel at the time of the site visit was flowing strongly and instream habitat appeared to be in a good condition - cobbles were loose and gravels are cleaned of fines. This was despite the mid-winter (low flow) timing of the field assessment.

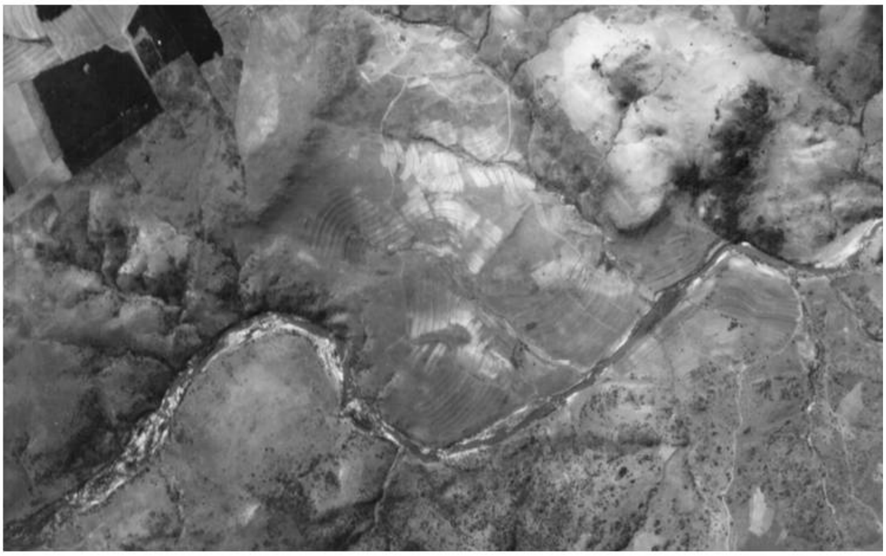
For managing flows at the site, it will be important to keep the sand load moving through this site, and the gravels and cobbles mobile to prevent embeddedness and maintain instream conditions.

The hydrological analysis provided by Southern Waters indicates that the PD flows of the Upper Pongola are similar to natural. MAR has decreased from a naturalised MAR of 405 to 353 Mm^3, but both intra-annual and large (inter-annual) floods are relatively unimpacted. The continued provision of floods is evident in the good quality instream bed sediment conditions.

Analysis of historical aerial photographs show some channel responses to very large flood events, but the gross morphology is largely stable and little evidence of channel narrowing or overall sedimentation of the reach (Table 4-3).

Figure 4-3 **The boulder dominated active channel with sandy lateral bars which have been affected at the EWR site by small scale sand mining.**

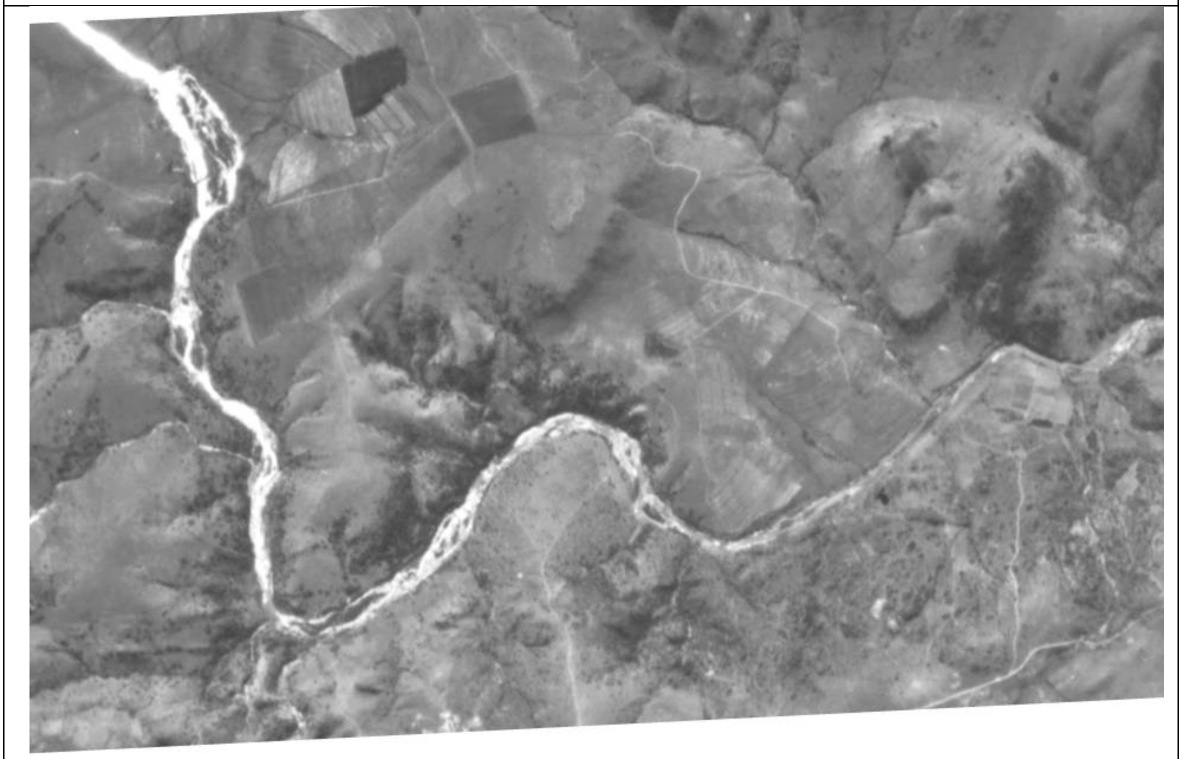
Table 4-3 Historical aerial photographic record of the reach at EWR Site UP1.



August 1961

May 1976

July 1977



May 1979

August 1990

November 2006

August 2013

4.4.3 Nseleni River (EWR Site NS1)

The EWR site on the Nseleni River is at a riffle located between two pools (Figure 4-4). The active channel is characterised by a cobble/boulder bed site with fines silt and organic matter. The large boulders at the EWR cross-section are predominantly in-situ material (arising from the dolerite dyke which coincides with the drift at the EWR cross-section location), with banks composed of fine silt, clay and sand, but interspersed with cobbles and gravels. The banks are very stable and densely vegetated with Ficus, Willows, Palms and dense stands of exotic herbaceous vegetation.

The hydrological analysis provided by Southern Waters indicates that the PD flows of the Nseleni are similar to natural. MAR has decreased from a naturalised MAR of 32 to 30 Mm^3 in this small, largely rural catchment. All flood classes (intra- and inter-annual) remain unimpacted relative to natural.

Analysis of historical aerial photographs show some channel responses to very large flood events, but the gross morphology is largely stable and little evidence of channel narrowing or overall sedimentation of the reach (**Table 4-4**).

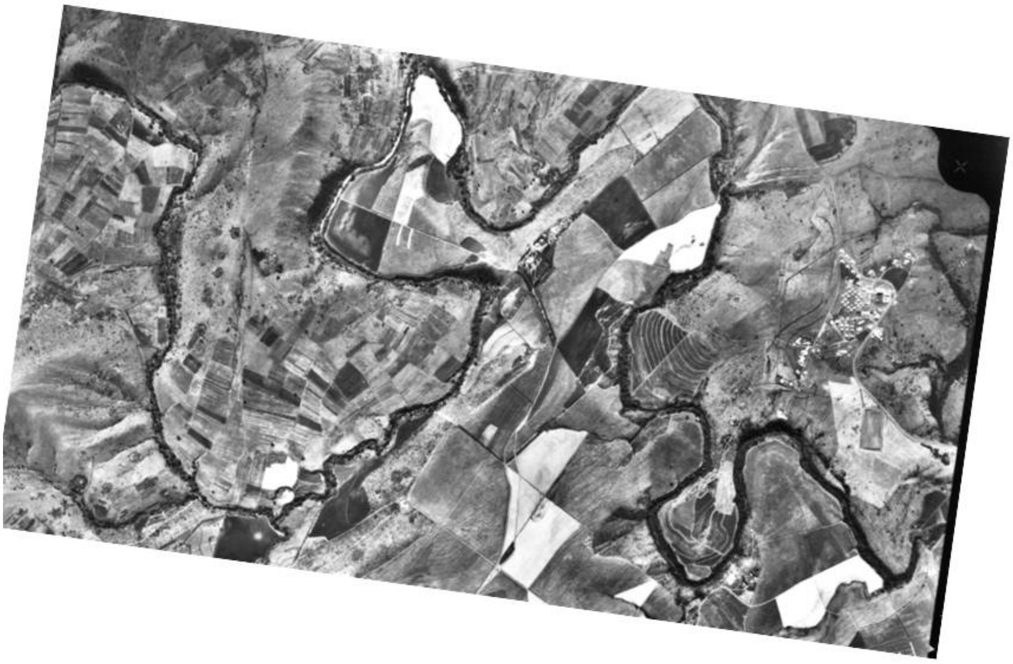
Flows are necessary in this reach to flush the riffles and runs, with regular floods to clear the pools and mobilize the small cobbles and gravels that characterise sections of the channel bed.

Figure 4-4 The cobble riffle at EWR AS1.

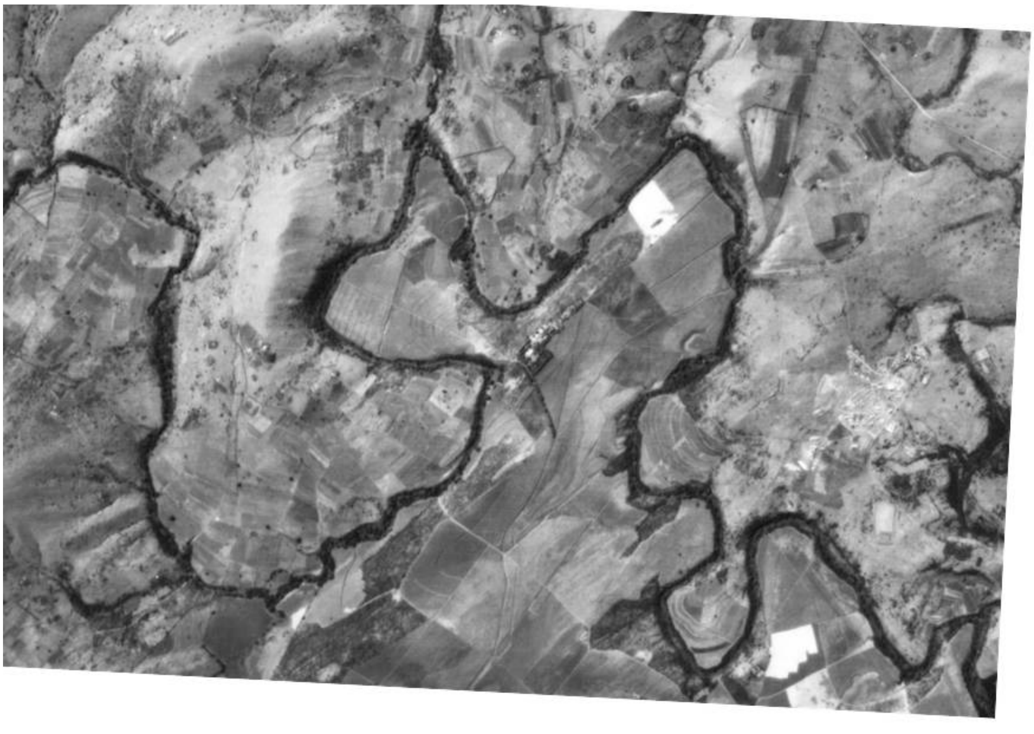
Table 4-4 Historical aerial photographic record of the reach at EWR Site NS1.

May 1957

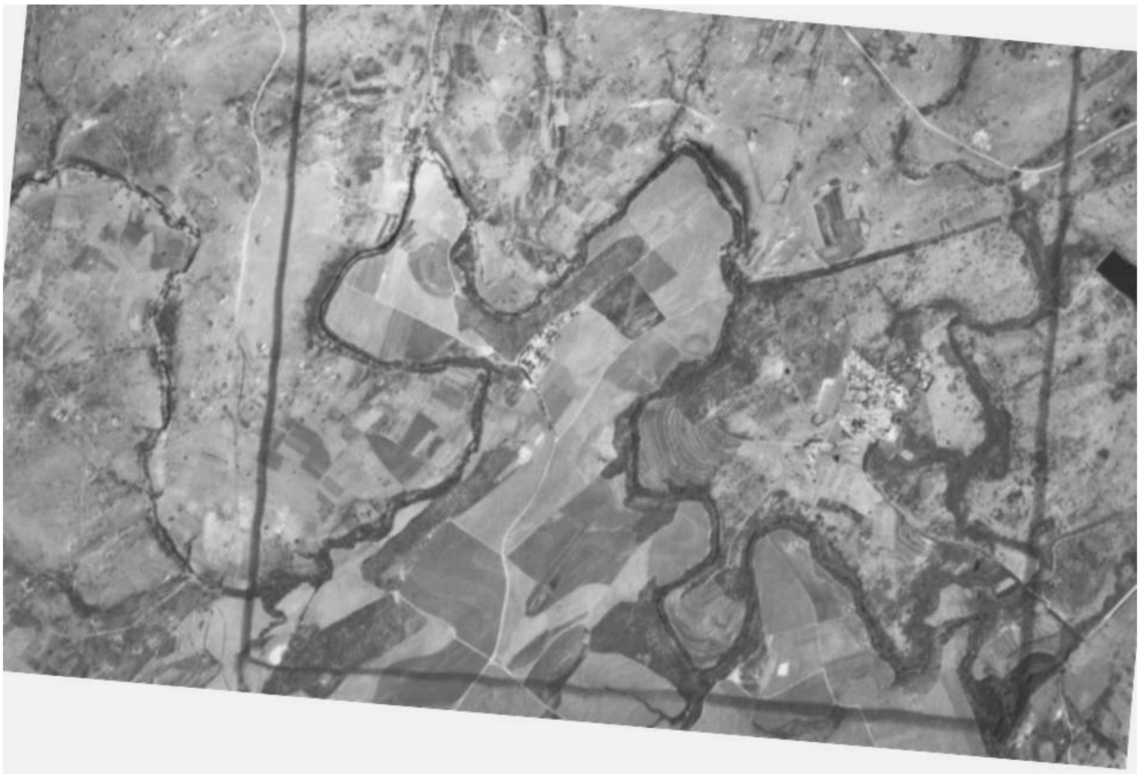
June 1960



August 1969

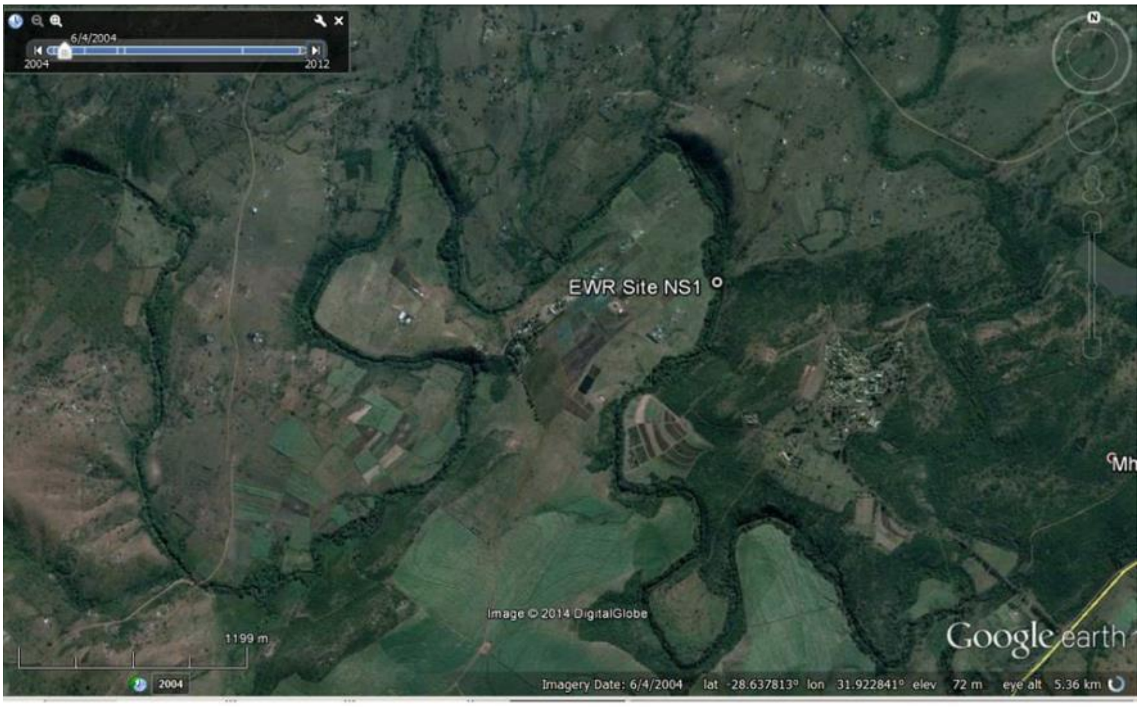


May 1975



March 1992

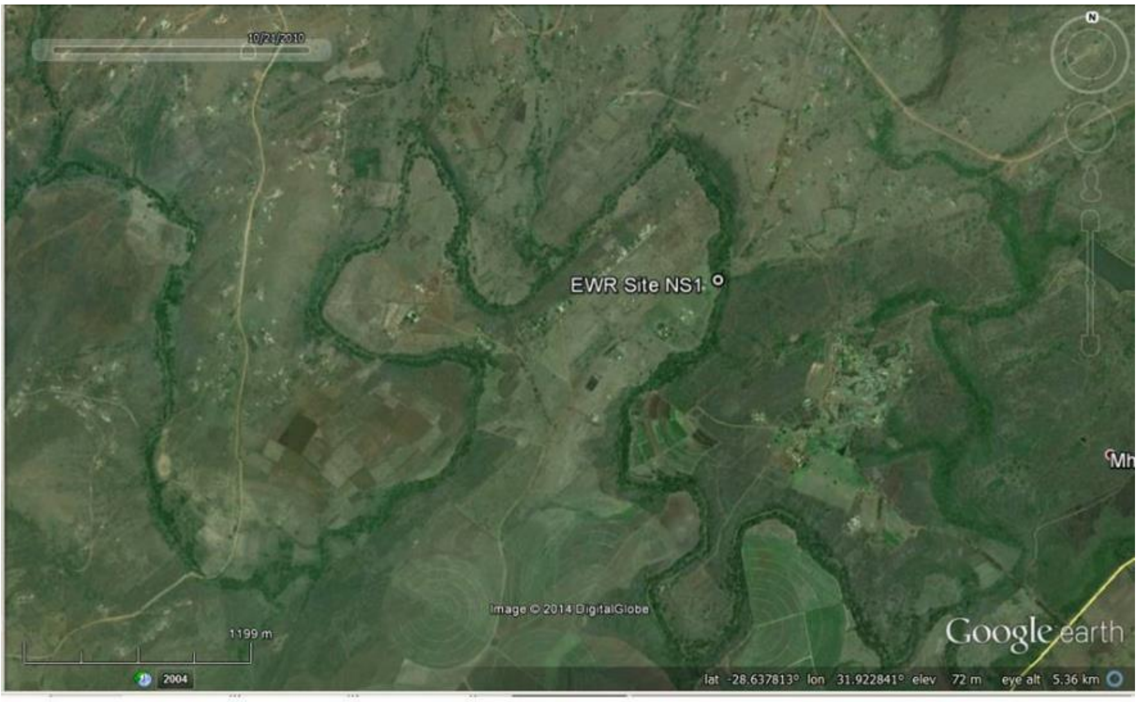
December 2004



June 2004

February 2005

April 2006



October 2010

November 2012

May 2014

4.4.4 Mkuze River (EWR Site MK1)

The EWR site is immediately adjacent to the Mkuze Game Reserve in a alluvial, meandering floodplain reach. The river channel is dominated by fine sands (Figure 4-5), and the banks and floodplain by sands and silty sediments. The microtopography of the channel bed, as well as the planform of the main channel itself, is highly dynamic. Analysis of historical aerial photographs show some channel responses to very large flood events, and evidence of the dynamic planform of this floodplain reach (**Table 4-5**).

At low flows, unstable, mobile sand bars appear. These are not vegetated. The active channel margin is dominated by *Phragmites* reeds whilst in the lower riparian zone, fever trees and *Ficus sycamorous* are common. Trees are being chopped down from the floodplain, presumably to open up areas for agriculture. Small scale sand extraction is also evident at the site.

In this reach, tributary lakes are present, and these become increasingly common, together with cut off meanders and floodplain oxbows/pans, downstream of the EWR cross section.

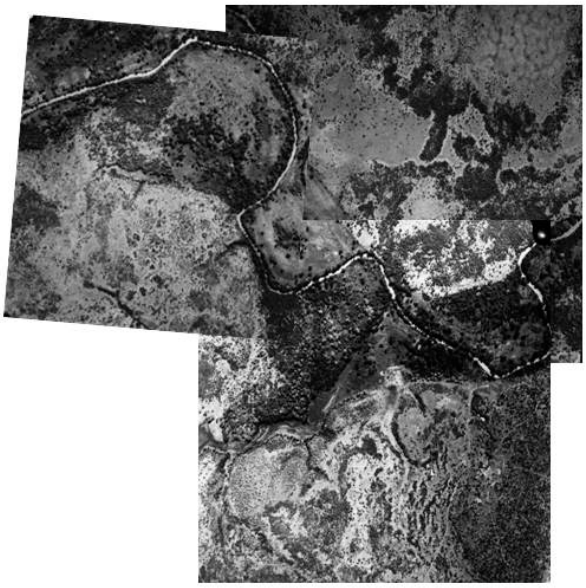
Catchment degradation has probably increased sediment yield, but the reach is fairly insensitive to this impact as it is a naturally depositional system. Flows in this reach would be important for:

1. maintaining sand movement and bed dynamics;
2. inundating the low levee on the lateral bar for recharge and maintaining sediment movement and dynamism of the reach, and
3. in the case of large floods, for activating secondary channels in order to recharge the pans.

Figure 4-5 The sandy bed of the Mkuze EWR site.

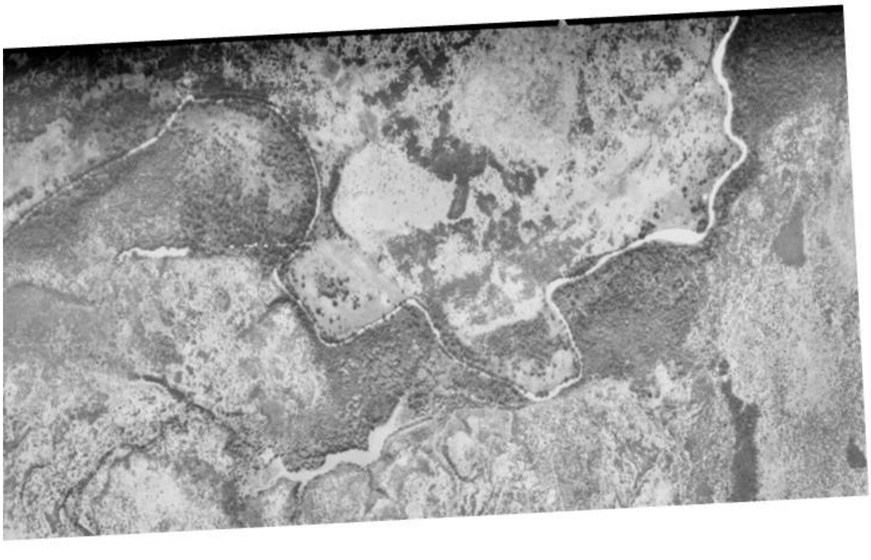
Table 4-5 Historical aerial photographic record of the reach at EWR Site MK1.

1942

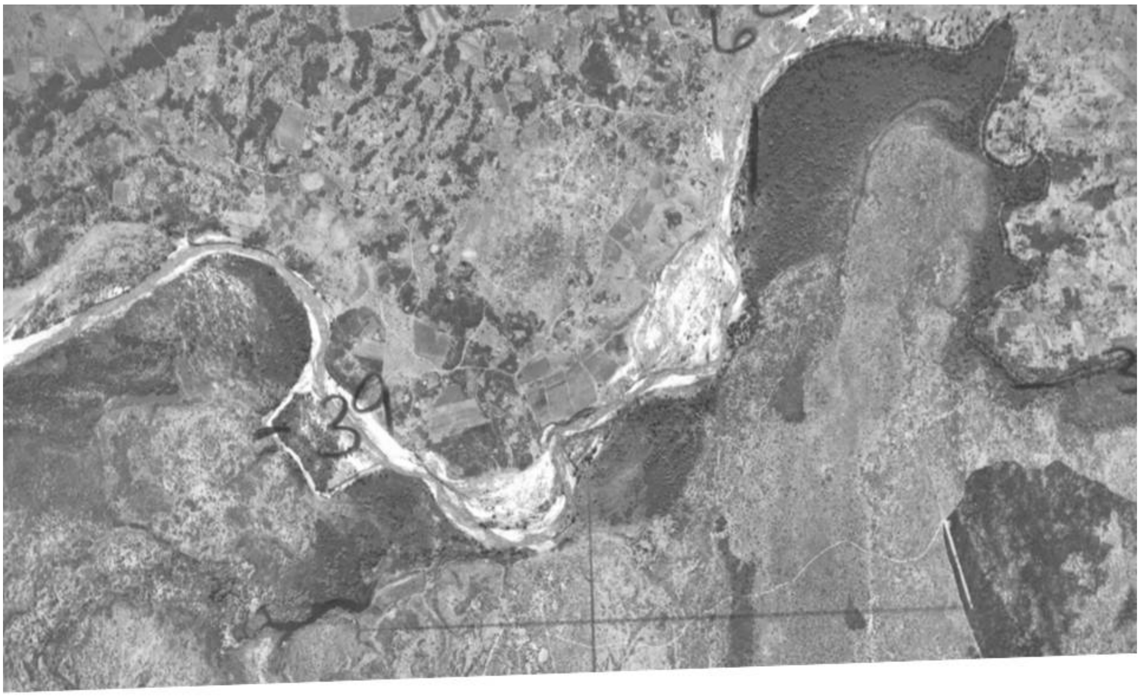


May 1955

June 1971



June 1975



August 1990

December 2003

September 2009

May 2011

4.4.5 Matigulu River (EWR Site MA1)

This river is a single channel with vegetated boulder and sand benches. *Miscanthus*, cyperus, sedges and *Phragmites* reeds are dominant in the marginal zone. In the channel, boulders and bedrock are dominant (Figure 4-6), with fines (sand and gravels) only present in the lee areas in the pools. No fines are present in the riffles. Despite the large bed sediment sizes, even the larger cobbles (approximately 20cm diameter) are relatively mobile at the site due to lack of embeddedness and probable regular occurrence of large floods.

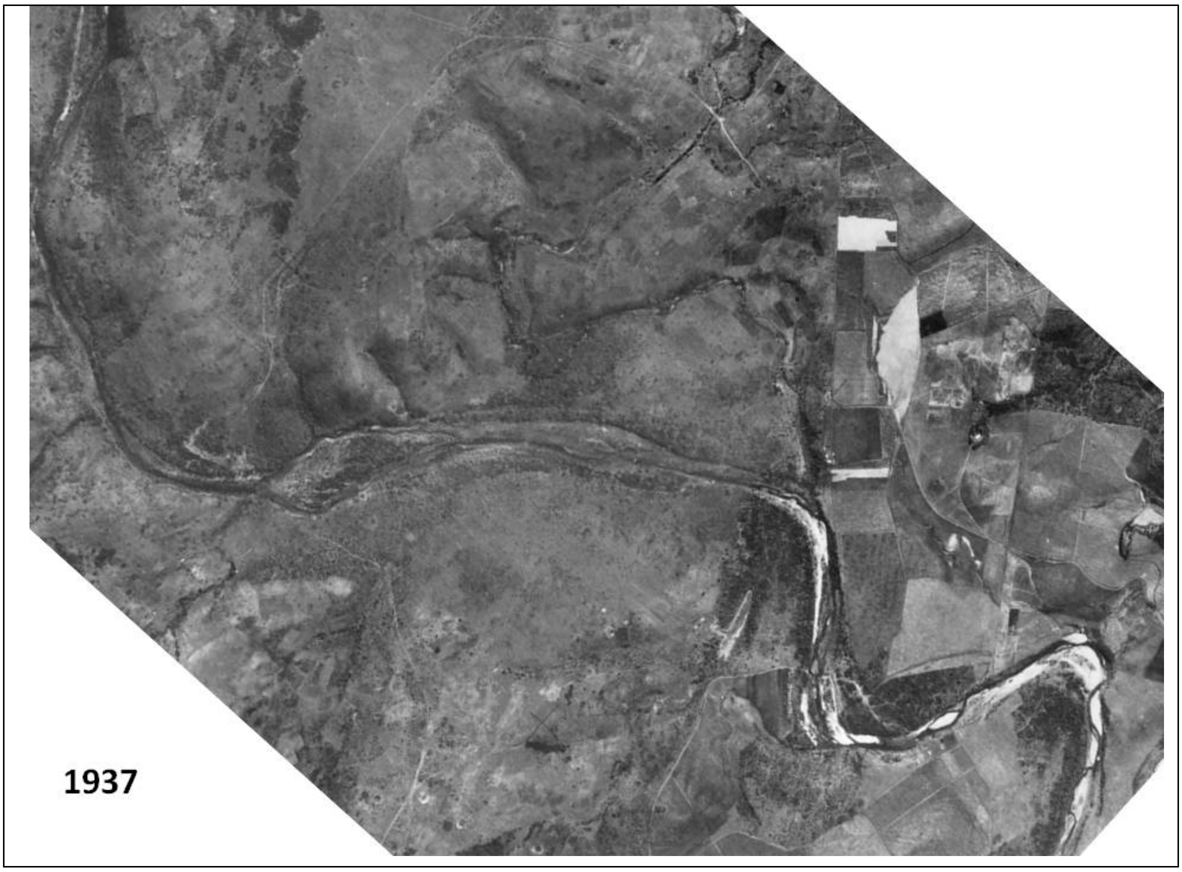
Figure 4-6 The boulder dominated reach at MA1.

The pools are boulder and bedrock dominated, with fines present at the margins only. Coarse sand is probably the most important bedload component at the site, but this carried through the site at the moment and therefore little sand is actually present on the bed. The pools downstrea of the cross section are also largely free of sands. One large weir (an old gauging weir) is located upstream of the site.

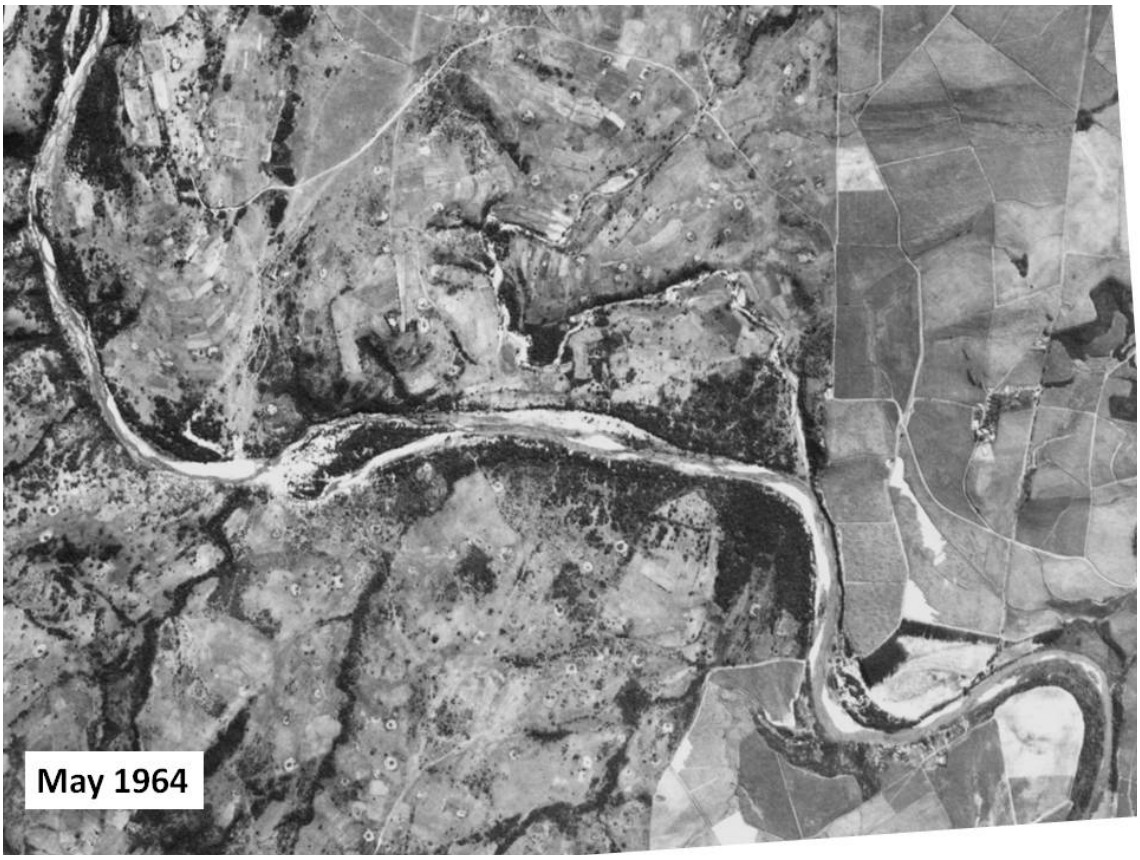
Flows at the site should seek to:
1) maintain sand movement (possibly the most important factor);
2) maintain cobble mobility, and
3) maintain the channel width and pool depths.

Analysis of historical aerial photographs show some channel responses to very large flood events, but the gross morphology is largely stable and little evidence of channel narrowing or overall sedimentation of the reach (Table 4-6).

Table 4-6 Historical aerial photographic record of the reach at EWR Site MA1.




1953


May 1964


September 1972


August 1989


Click to open the time options dialog.
/5/2009
2013
EWR Site MA1
August 2009
Image © 2014 DigitalGlobe
Googl
lon 31.489160° elev 49 m eye a


8/28/2013
EWR Site MA1
August 2013
Image © 2014 DigitalGlobe
Image © 2014 CNES / Astrium
Googl
489160° elev 49 m eye a

4.4.6 White Mfolozi River (EWR Site WM1)

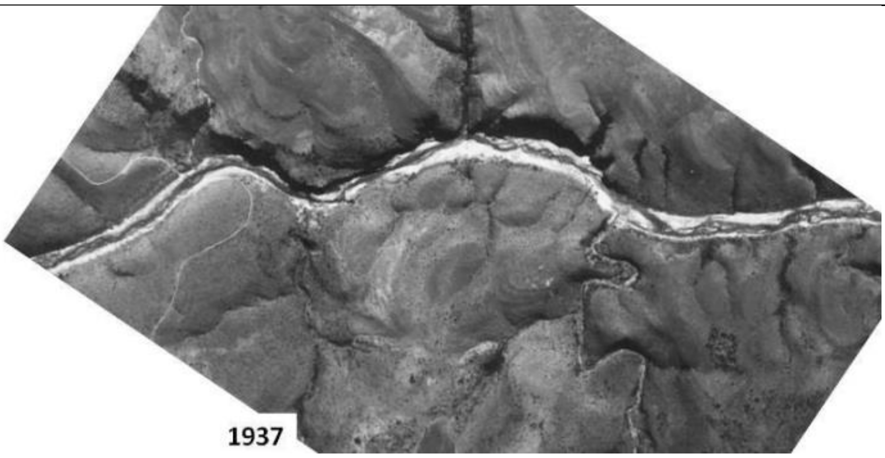
The site is at a sand and boulder dominated site (Figure 4-7). The uppermost outer banks have been eroded by a large flood, and the opposite banks represent the stable bedrock-controlled base of cliffs which become more extensive downstream of the cross-section.

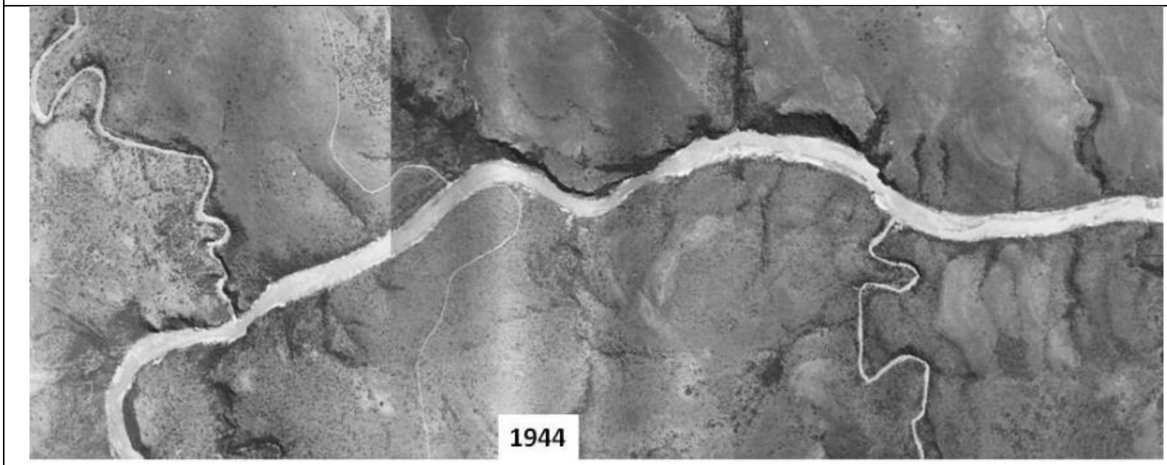
The sand load is important to manage at this site (as sand waves may smother the inchannel habitat). At the time of the July 2014 site visit, the hydraulician indicated that there has been a large increase in sand deposited at the site since his earlier December 2013 site visit. To a lesser extent, it is important to manage for the large gravels and small cobble bed sediments

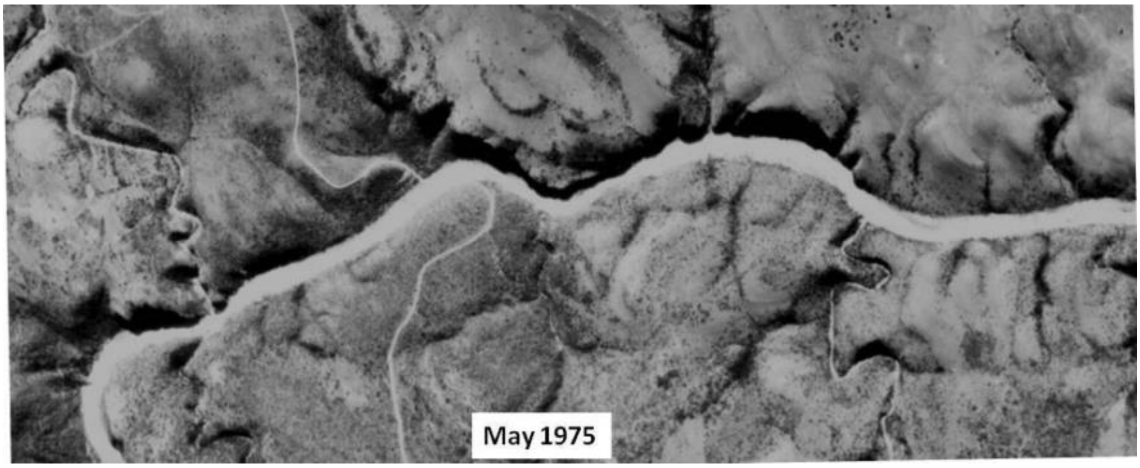
Analysis of historical aerial photographs show some channel responses to very large flood events, but the gross morphology is largely stable and little evidence of channel narrowing or overall sedimentation of the reach (Table 4-7).

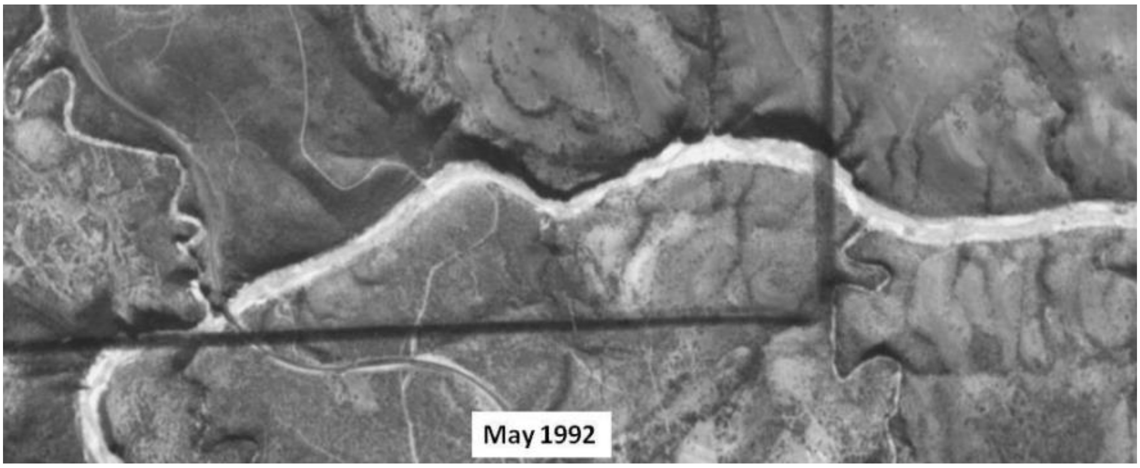
Figure 4-7 The sand and boulder dominated bed conditions of EWR site WM1.

Table 4-7 Historical aerial photographic record of the reach at EWR Site WM1.









4.4.7 Black Mfolozi River (EWR Site BM1)

This bedrock and cobble site is located downstream of a small gauging weir. There are extensive marginal reedbeds (*Phragmites*) in the long pool downstream of the cross section site, with dominant bedrock sections on the bed and banks (Figure 4-8). The actual cross-section site is probably impacted by localised scour due to the upstream weir.

Analysis of historical aerial photographs show some channel responses to very large flood events, but the gross morphology is largely stable and little evidence of channel narrowing or overall sedimentation of the reach (Table 4-8).

Figure 4-8 EWR site BM1 is characterised by bedrock outcrops and long pools with *Phragmites* marginal vegetation fringing the pools.

Table 4-8 Historical aerial photographic record of the reach at EWR Site BM1.

September 1977

August 1990

EWR Site BM1

August 2014

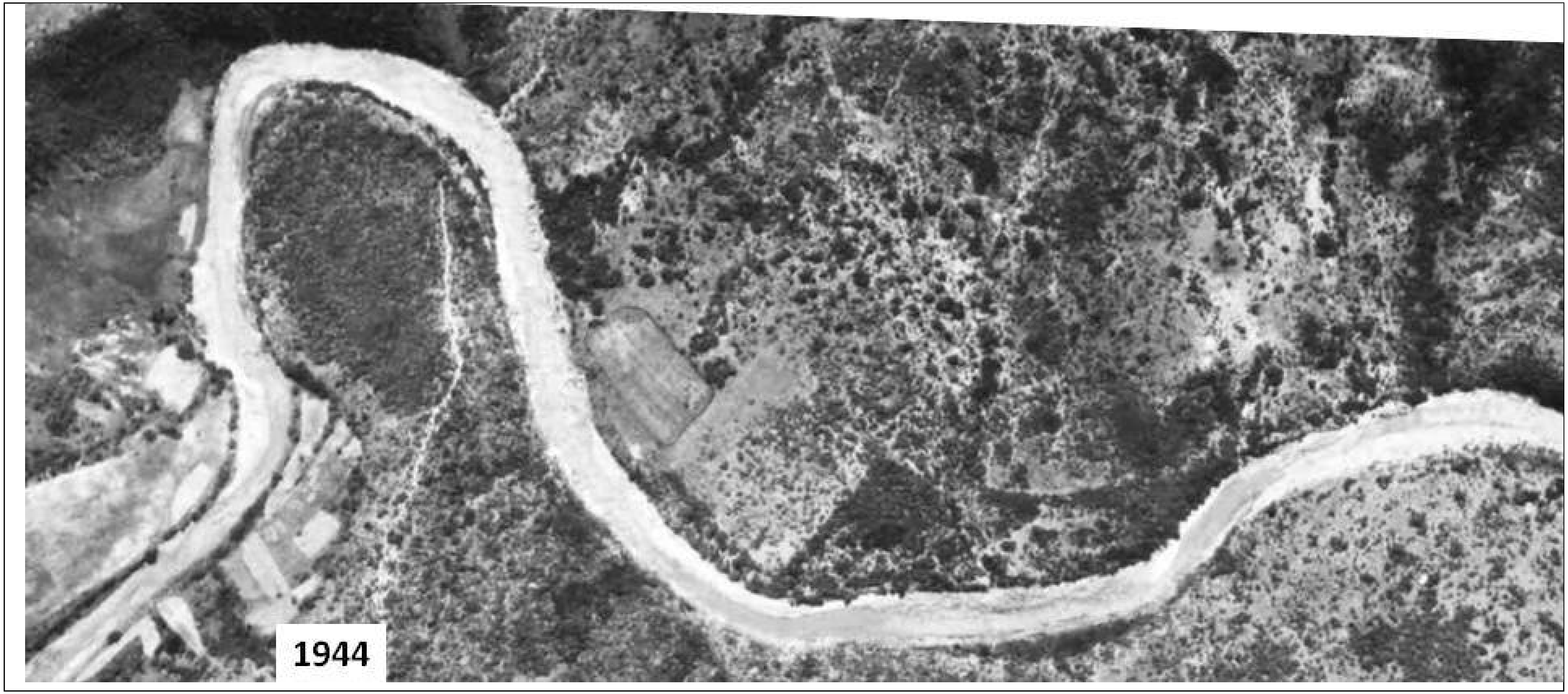
4.4.8 Black Mfolozi River (EWR Site BM2)

This site is located in a bedrock pool/riffle river reach immediately upstream of a gorge. Local residents confirmed that crocodiles are present in the reach. The river channel bed is cobble dominated with bedrock pavement in places, with a fairly uniform cobble size. Cobbles overlie the underlying bedrock. Flows to maintain the movement of sand, and thus keep cobbles clean, as well as occasional floods to activate the cobbles, would be important at this site.

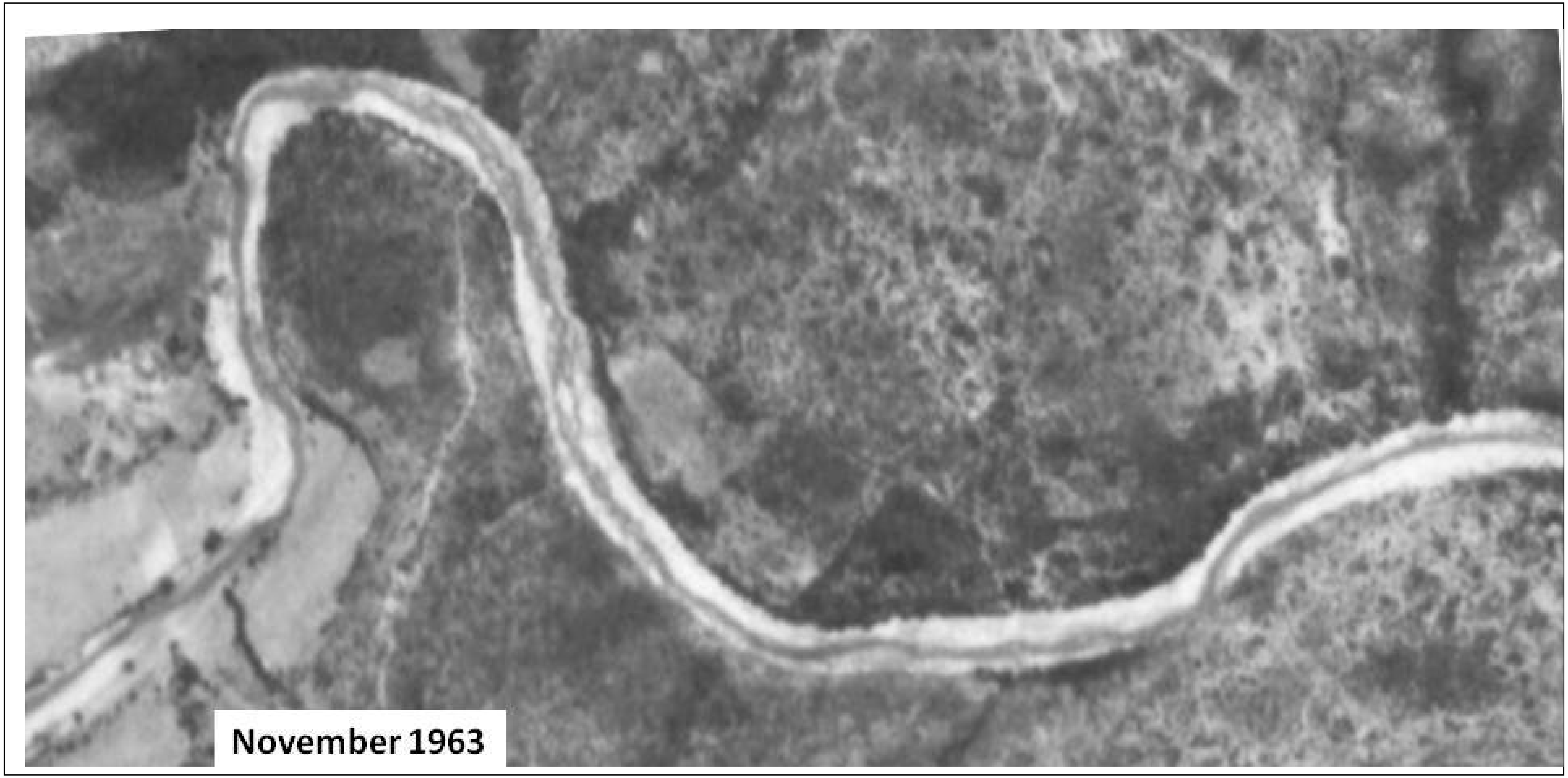
Analysis of historical aerial photographs show some channel responses to very large flood events, but the gross morphology is largely stable and little evidence of channel narrowing or overall sedimentation of the reach (**Table 4-9**).

Figure 4-9 The BM2 EWR site is characterised by extensive bedrock and cobbles

Table 4-9 Historical aerial photographic record of the reach at EWR Site BM2.

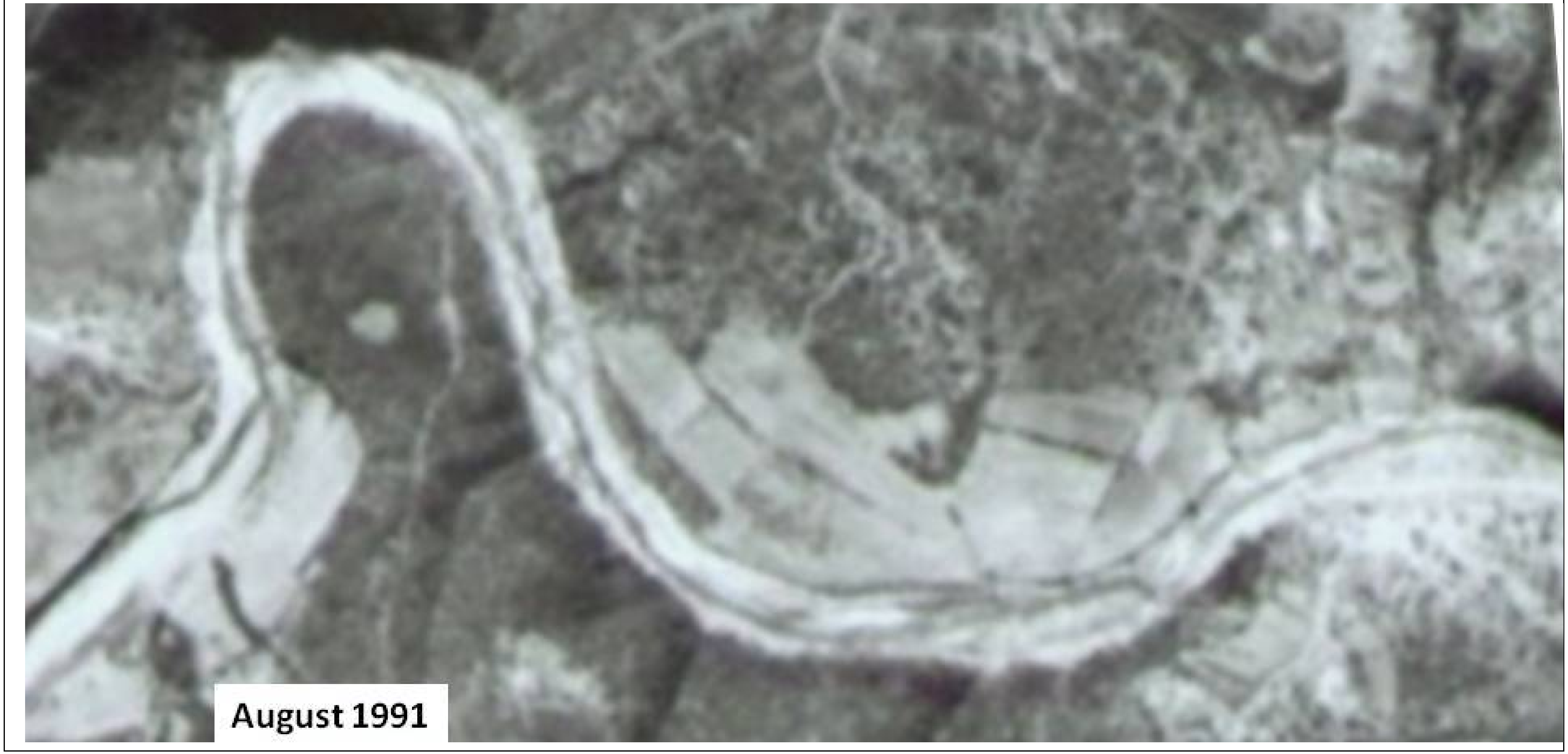

1944

September 1956


November 1963


June 1970


May 1975


August 1991


August 2013

4.5 Ecoclassification of river reaches represented by the EWR sites

The Present Ecological State of the geomorphology at each EWR site was assessed using the Department of Water Affairs' Level 4 version of the Geomorphological Assessment Index (GAI) (Rowntree and du Preez, in press).

4.5.1 Assegai River (EWR Site AS1)

Algae over the cobbles and boulders of the slower flowing channel areas are likely due to nutrient enrichments from the upstream settlements and towns. Clean gravels and small cobbles are only present in the fastest sections of the channel, and vegetation encroachment in to the channel silt drapes in slower flowing areas are a result of reduced floods. The hydrology summary provided by Southern Waters indicates that the PD MAR and flood discharges have declined by half relative to the naturalised flow conditions. These reduced floods are primarily due to altered flows as a consequence of the operation of the upstream Heyshope Dam. In addition to the reduced flows, sediment trapping impacts from the dam reduce sediment delivery to the site, but this is offset by increased erosion from the extensive afforestation areas between the dam and the EWR site. The PES is in a low C (65%), and the trend is likely to be declining as the site continues to adjust to flow modifications of the upstream dam.

4.5.2 Upper Pongola River (EWR Site UP1)

The hydrological analysis comparing PD and naturalised flows indicates a minor reduction in MAR (from 405 Mm^3 to the PD of 353 Mm^3) and little measureable change in intra-annual floods (Class I, II, II and IV) or larger intra-annual (1:2, 1:5 and 1:10 year) floods. Floods and high flows are thus relatively unimpacted, but the extensive afforestation of the catchment is likely to have significantly reduced the lowflows. In terms of sediment yield, the numerous forestry roads and areas of the catchment affected by heavy grazing pressure and dense rural settlements would have resulted in an increased sediment yield and load at the EWR site, although this has not increased sufficiently to cause planform changes at the reach scale. The PES (87%) is in a high B category as, although there is elevated sediment loads, there is little flow impact and no clear reach-wide sedimentation impacts. Flows and floods are thus sufficiently maintained to offset the elevated sediment loads, maintaining a close to natural condition of the reach.

4.5.3 Nseleni River (EWR Site NS1)

The Nseleni EWR site (NS 1) is in a B/C category (PES=81.7%). Catchment erosion from agriculture (sugar cane), extensive rural settlements and associated roads creates an increase in sediment loads in the river, exacerbated by reduced flows due to some upstream dams.

4.5.4 Mkuze River (EWR Site MK1)

PES is in an A/B (89%) EC. Small dams and associated reduced flows together with some increased catchment erosion from rural settlements and agricultural areas has increased sediment loads, but the EWR reach remains near pristine. Loss of vegetation at the site (removal of riparian forest) will reduce flood attenuation and bank protection of the floodplain.

4.5.5 Matigulu River (EWR Site MA1)

PES is in a B (86.6%) EC. The impacts are a few small farm dams which slightly alter floods and trap sediment, but catchment erosion and donga formation overides this impact. Limited afforestation, sugarcanw, rural roads and homesteads and numerous woodlots would be responsible for the increased catchment sediment yield and subsequent slightly higher than natural sediment load.

4.5.6 Black Mfolozi River (EWR Site BM1)

PES is in an A/B (89%) EC. There is some afforestation in the upper catchment, but wide appropriate buffers are present in most areas. Catchment erosion, from vegetation removal, the limited forestry (woodlots) sugarcane, roads and rural homesteads are likely to result in an elevated sediment load.

4.5.7 Black Mfolozi River (EWR Site BM2)

PES is in a B (83%) EC. As with BM1, there is some afforestation in the upper catchment, but wide appropriate buffers are present in most areas. Catchment erosion, from vegetation removal, the limited forestry (woodlots) sugarcane, roads and rural homesteads are likely to result in an elevated sediment load. Lower in the catchment and on subsequent tributaries downstream of BM1, irrigation agriculture is more comment, as is presumably reduced flows. The few dams present here can be expected to reduce flows and attenuate small floods.

4.5.8 White Mfolozi River (EWR Site WM1)

PES is in a C (77.3%) EC. Irrigation agriculture, mines, afforestation, settlements and towns reduce water availability. There are some small farm dams and one medium dam at Vryheid which reduce floods and alter baseflow conditions. These impacts have had a small impact on bed conditions.

4.6 Field data collection and analysis to assess EWRs

The EWR sites were visited in July 2014. At each site, a representative sample of the mobile channel bed surface sediment was sampled using a step-point survey method.

Key alluvial morphological features were surveyed in to the cross sections, and notes on the general condition of the site and reach, and likely issues with regard to habitat and channel maintenance, made from these field observations. Google Earth and topographical maps were assessed to evaluate the catchment landuse conditions.

4.6.1 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.

4.6.1.1 Morphological Cues

The rivers in this study area are not alluvial depositional systems. The sites have at best paired terraces within their incised macro-channels; the channels themselves often flowing along the underlying bedrock of the area. Morphological cues, usually associated with depositional alluvial environments, are thus often weakly developed. Where paired terraces and benches were identified, these were surveyed in to the hydraulic cross sections to enable these features to be linked to specific discharge ranges. These and other morphological features, such as backwaters, sedimentary bars and secondary channels, are 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.

4.6.1.2 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). Whilst it is possible to manage flows in the 5 to 0.1% range of the flow duration curve, the large “re-set” events are not manageable events. The focus of flow requirement assessments is therefore focussed on the 5 to 0.1% range of flows, and on the bed sediments of the rivers that threaten to infill deeper instream habitats.

4.6.1.3 Methods used to identify geomorphologically effective flows

The methods employed to determine geomorphologically effective flows are described below. Where available, the observed daily flows from the nearest DWA flow gauge, together with the 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:

1. The bed material sampled at the site is representative of the supply of bed material to the channel;
2. Bed material sampling can be averaged at each EWR site and used to represent the cross-section;
3. 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; and that
4. 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. At some sites components of the bed sediment are derived *in situ* (in this case, from the weathering of or adjacent bedrock exposures), and thus the cobbles and boulders observed in the river channel at such sites are not indicative of the flow regime nor related to sediment transport patterns of the river. In these cases, only the mobile component of the bed material at this site – the gravels and fines that overlay the bedrock/fixed boulder bed and are transported by contemporary flow regime - are considered in the determination of channel maintenance.

Potential Bed Material Transport (PBMT) modelling of sediment was undertaken at the EWR sites where historical flow records were available from nearby flow gauges. 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).

For sites where no or insufficient flow records exist, morphological cues linked to the hydraulically rated cross-sections were used to identify important floods.

4.6.2 Impacts water resource developments on downstream sediments

Dams act as sediment traps, causing a loss of sediment supply and distribution 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). Traditionally most impact assessment studies have focussed on the impacts of dams within the reservoir basin and the downstream impacts have not received the same focus or detail despite the spatial extent of impacts being much greater.

Downstream of large dams, water releases are largely sediment free due to the deposition of bedload and suspended load within the reservoir. Sediment is replaced in the water column through erosion of the beds, banks, bars and islands, but with no opportunity for sediment replenishment from upstream the reaches downstream of dams experience vastly enhanced erosive action relative to the pre-dam situation in the river. Changes downstream of dams typically include:

- decreased suspended sediment loads;
- 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 disruption of longitudinal connectivity – specifically 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.

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 a dam is a combination of dam size, dam operation and the sensitivity of the downstream river reaches to flow-induced change.

4.6.3 Suspended sediment loads at EWR sites

There are no long term observed sediment measurements near the EWR sites, studies of catchment degradation have been done in some catchments catchment (Watson and Ramokgopa 1997; Watson *et al.* 1996) and observations of the catchment landuse impacts from the field visit and Google Earth imagery and visible impacts of this at EWR sites attests that some of the degradation observed at the EWR sites is due to catchment degradation and an increase in the sediment yield relative to the expected natural (Reference) conditions. At EWR AS1, the upstream Heyshope Dam traps much of the sediment from the catchment. The natural levels of sediment load are thus usually more, would thus , as a percentage relative to present day levels, be lower except at EWR AS1 ().

Table 4-10 Estimated levels of natural sediment load at the EWR sites, as a percentage relative to Present Day (PD) levels.

EWR Site	PD %	Natural %	Motivation
AS 1	100	110	The upstream Heyshope Dam has reduced sediment supply to the downstream reaches, but this reduction is probably offset by the increased catchment erosion from the extensive afforestation downstream of the dam.
UP1	100	95	Extensive catchment development - increased roads, catchment denudation
NS1	100	95	Extensive catchment development
MK1	100	95	Extensive catchment development
BM1	100	95	The reported increased erosion of the Mfolozi catchment (Watson and Ramokgopa 1997; Watson et al. 1996) suggests that the natural sediment loads would have been lower than the Present Day conditions.
BM2	100	95	The reported increased erosion of the Mfolozi catchment (Watson and Ramokgopa 1997; Watson et al. 1996) suggests that the natural sediment loads would have been lower than the Present Day conditions.
WM1	100	95	The reported increased erosion of the Mfolozi catchment (Watson and Ramokgopa 1997; Watson et al. 1996) suggests that the natural sediment loads would have been lower than the Present Day conditions.
MA1	100	95	Extensive catchment development - increased roads, catchment denudation

In the event of a new dam being included in a scenario, the DRIFT database needs to take in to account the change in sediment supply downstream of the dam and the knock-on effects for the river physical habitat. To this end, a sediment indicator has been included in the DRIFT database for this study and can be "switched on" to account for the habitat changes that will result if new dams are incorporated in to the scenarios. This will prevent underestimations of the impacts of the scenarios from occurring if only the hydrological (flow) changes were accounted for.

4.7 Results

Observed sediment characteristics for the site or reach, together with local site hydraulics, were used to model the patterns of sediment transport over long term flow records. Where flow gauges which reliably record high flows and floods exist close to the EWR sites, those flow records have been used to model the PBMT at the site. If such records do not exist, the modelled daily Present Day flows have been used to model sediment transport and estimate effective discharges. Observed data are generally more reliable than modelled daily data due to potential errors in the disaggregation of the monthly to daily flows, but modelled daily flow data are considered to be able to provide indicative results of the likely patterns and sizes of floods and their associated sediment transport potential characteristics.

4.7.1 EWR Site AS 1 (Assegaai River)

We used daily flow data from gauge W5H022 which is located approx 1km downstream of the EWR site. Data were available for a long record, from 1968 to 2013, and based on field observations and correlated gauge and field measurements from the previous study, the gauge was identified as recording low flows relatively accurately. Large floods are also recorded at the gauge. Sediment transport (Figure 4-10) was modelled at the pool cross section to account for pool flushing and obtain more reliable flood hydraulics.

The historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as those associated with Cyclone Domoina in 1984) as well as the responses to long periods without large floods occurring.

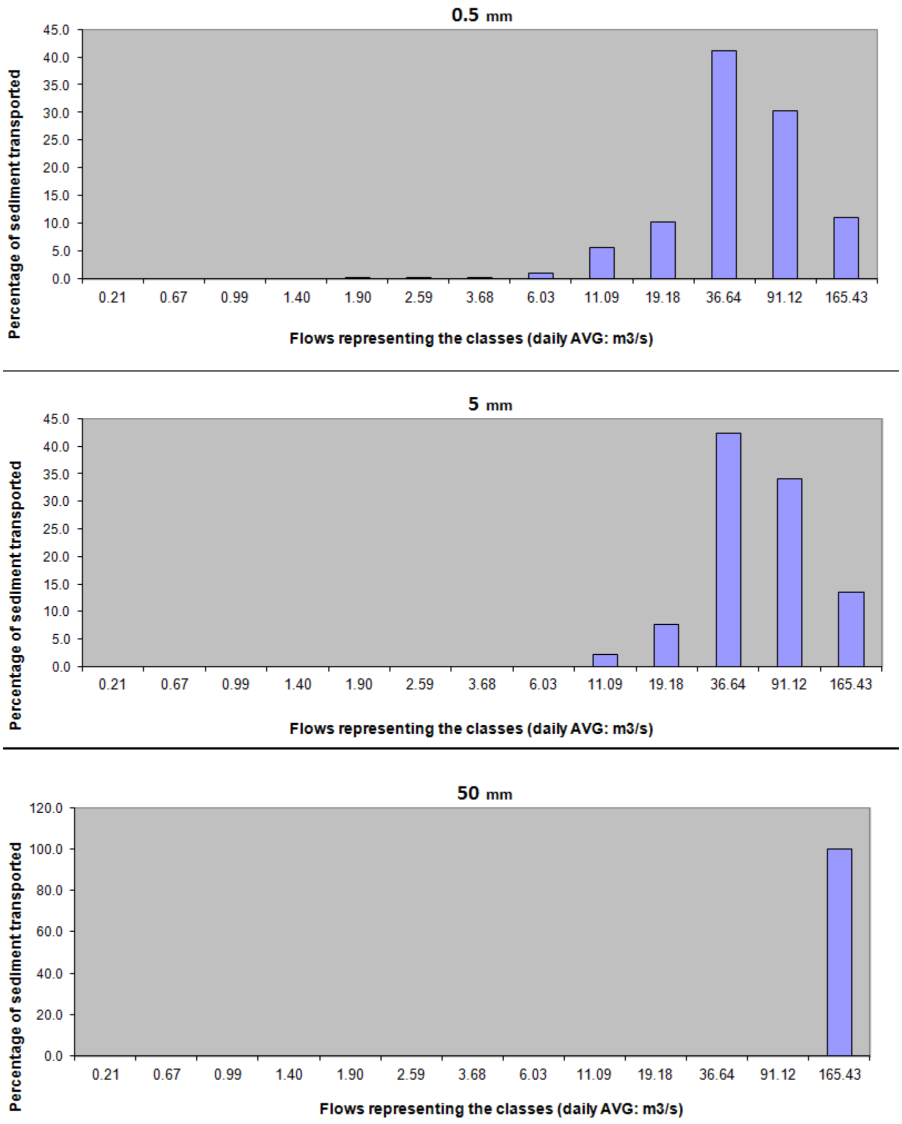


Figure 4-10 **PBMT results for the pool cross section at EWR AS1. The effective flood discharge class for sands and gravels is represented by the 90m^3/s discharge and for small cobbles (50mm diameter) by the flood class of 165m^3/s and greater.**

4.7.2 EWR Site UP 1 (Upper Pongola River)

There is no flow gauge nearby the EWR site. Morphological cues were used to identify important flow classes and the historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as Domoina in 1984) as well as the responses to long periods without large floods occurring. Modelled Present Day flows were used to undertake analyses of long term sediment transport patterns at the EWR site (Figure 4-11).

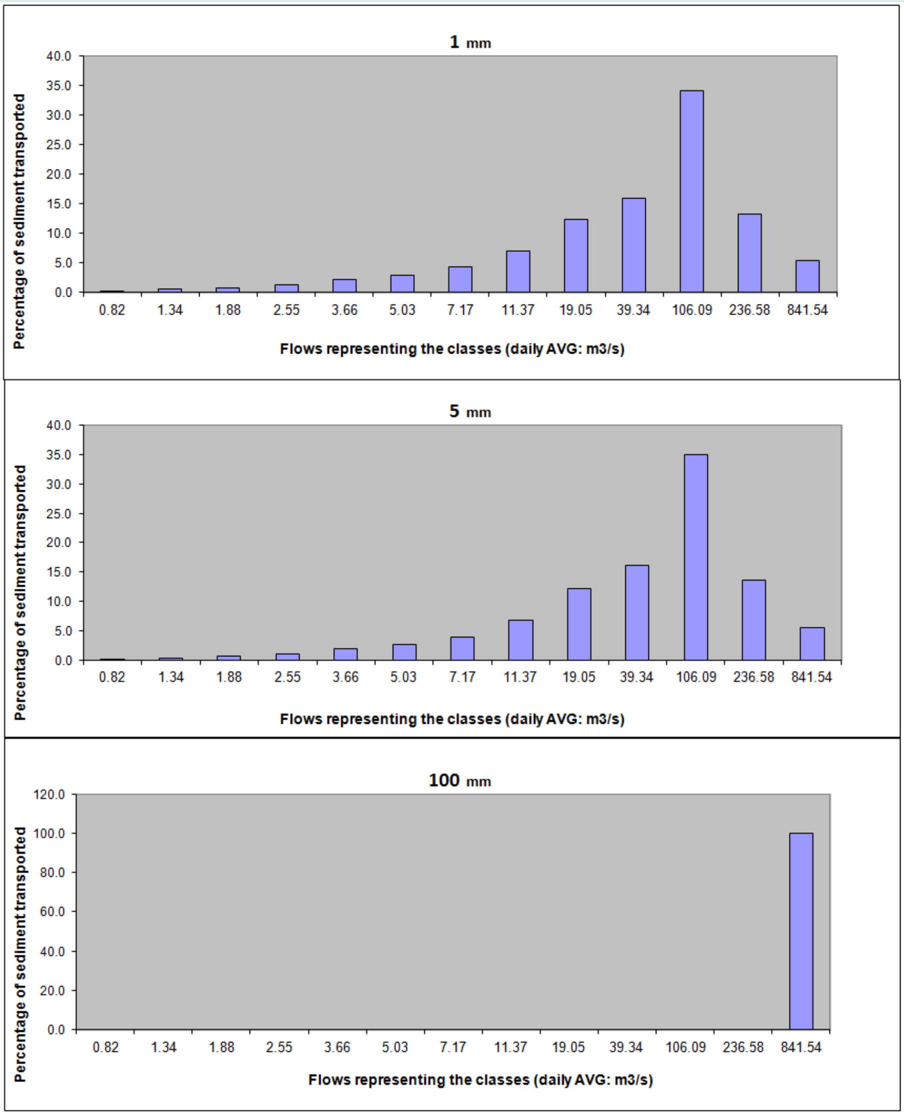


Figure 4-11 **PBMT results for the cross section at EWR UP1. The effective flood discharge class for sands and gravels is represented by the 106m^3/s discharge and for cobbles (100mm diameter) by the flood class of 841m^3/s and greater.**

4.7.3 EWR Site NS1 (Nseleni River)

The historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as Domoina in 1984) as well as the responses to long periods without large floods occurring. Modelled Present Day flows were used to undertake analyses of long term sediment transport patterns at the EWR site (Figure 4-12). The pattern of PBMT results reflect the hydraulics of the site in that, at the very large flood volumes predicted in the PD hydrology, the energies of the floods would be very low, hence almost no transport of sediment occurring at high discharges. This may be because of expected backup from the sea during hese very large floods. However, these high discharges would be important of the deposition of fines on the upper banks and terraces of the site.

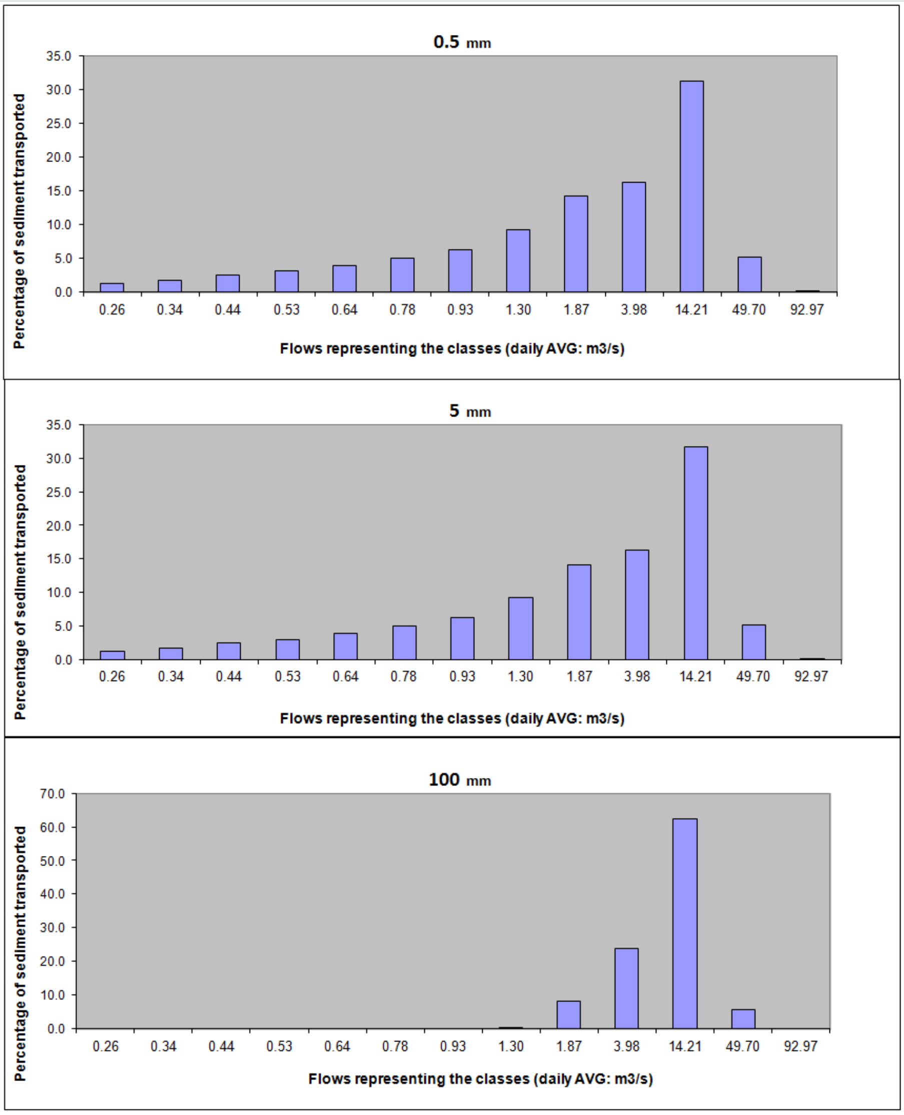


Figure 4-12 PBMT results for the cross section at EWR NS1. The effective flood discharge class for sands and gravels, as well as small cobbles, is represented by the 14m3/s discharge class.

4.7.4 EWR Site MK1 (Mkuze River)

The historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as Domoina in 1984) as well as the responses to long periods without large floods occurring.

The W3H008 weir is located 43km upstream of the EWR site, with only one small tributary coming in between the gauge and the EWR site. This weir has a long (1965-2014) flow record, but although the gauge seems to record low flows well, flood flows are not recorded as the weir drowns out at 23 m3/s and is therefore not useful for flood analysis or the associated sediment transport modelling approach. Another nearby gauge (W3H002) has many gaps in the data, so the modelled PD flows were used to estimate effective discharges for this site. Extreme flood size classes (Domoina etc) had to be constrained by the limitations of the hydraulic modelling, but this has not affected the floods which can be affected by operational scenarios.

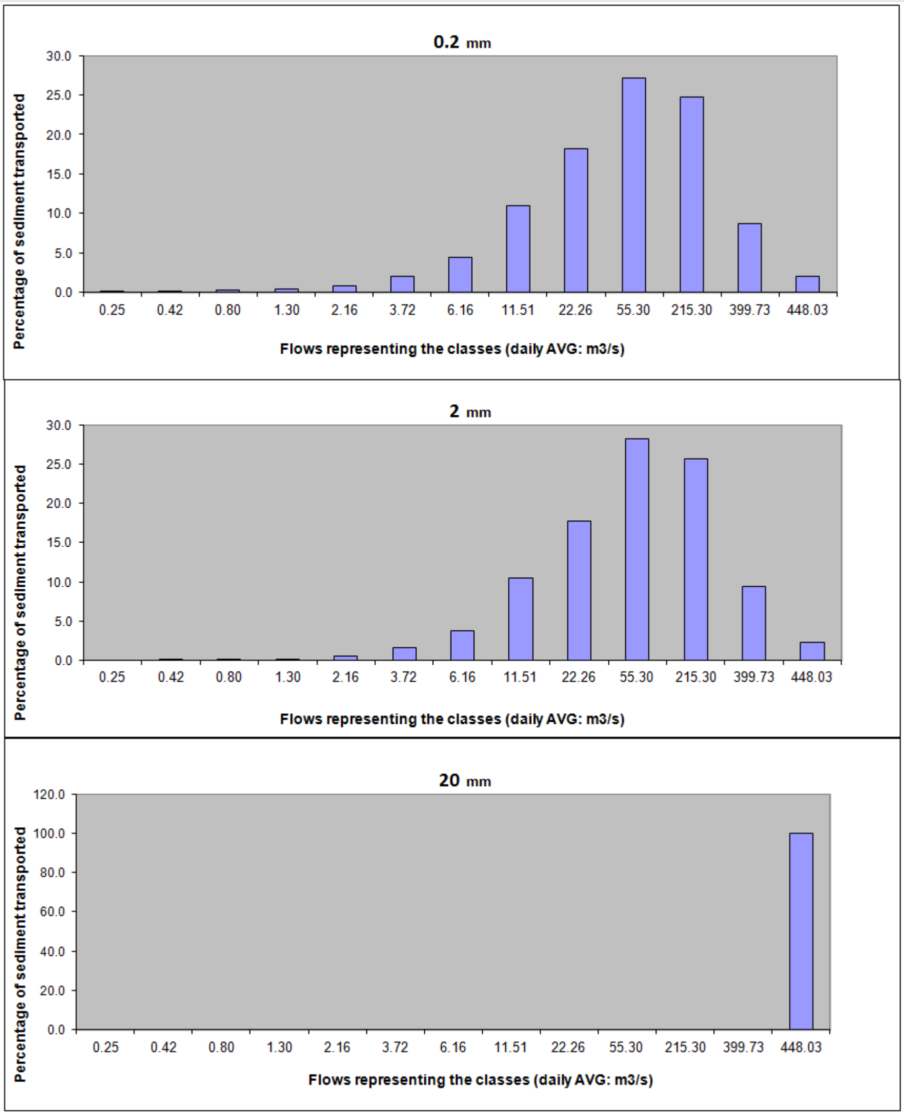


Figure 4-13 **PBMT results for the pool cross section at MK1. The effective flood discharge class for sands (dominant at the site) and fine gravel is represented by the 55m^3/s discharge and for small cobbles (20mm diameter) by the flood class of 448m^3/s and greater.**

4.7.5 EWR Site MA1 (Matigulu River)

The historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as Domoina in 1984) as well as the responses to long periods without large floods occurring. Modelled Present Day flows were used to undertake analyses of long term sediment transport patterns at the EWR site (Figure 4-14).

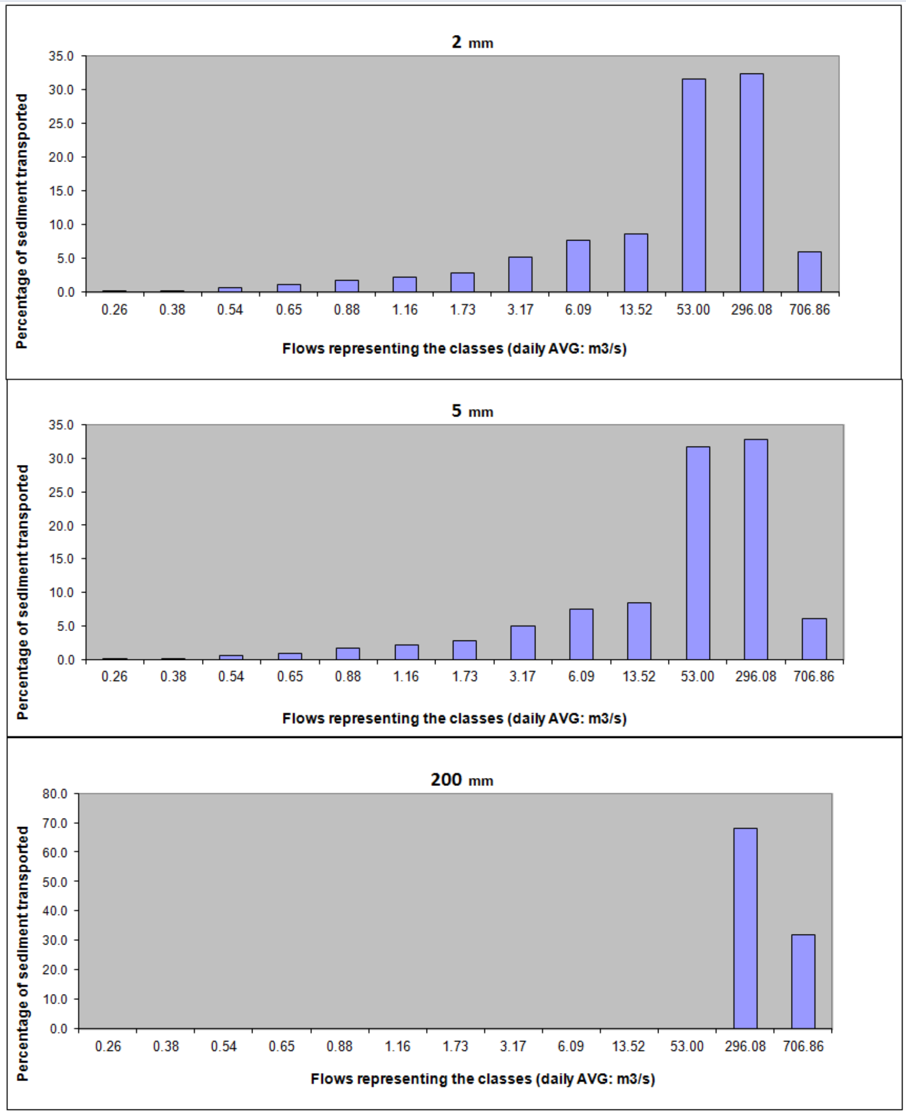


Figure 4-14 PBMT results for the cross section at EWR MA1. The effective flood discharge class for sands and gravels is represented by the 53 and 298m^3/s discharge classes. Cobbles would only be effectively moved during very high floods.

4.7.6 EWR Site WM1 (White Mfolozi River)

The historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as Domoina in 1984) as well as the responses to long periods without large floods occurring. Modelled Present Day flows were used to undertake analyses of long term sediment transport patterns at the EWR site (Figure 4-15Figure 4-14).

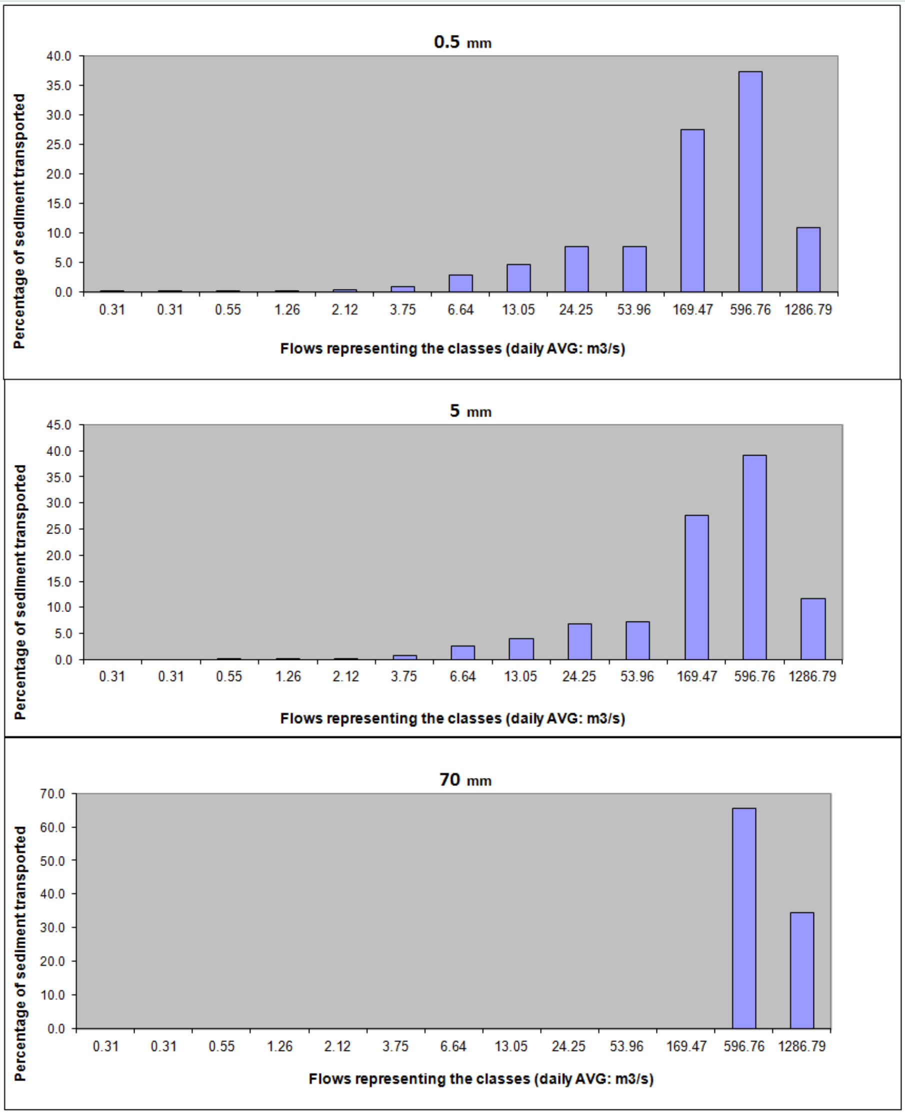


Figure 4-15 PBMT results for the cross section at EWR WM1. The effective flood discharge classes for sands and gravels are the flood classes represented by the 169 and 596m3/s discharges. Small cobbles would only be effectively moved during very high floods.

4.7.7 EWR Site BM1 (Black Mfolozi River)

The historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as Domoina in 1984) as well as the responses to long periods without large floods occurring. PBMT modelling was undertaken at BM1 using the modelled hydrological data for the EWR site (Figure 4-16).

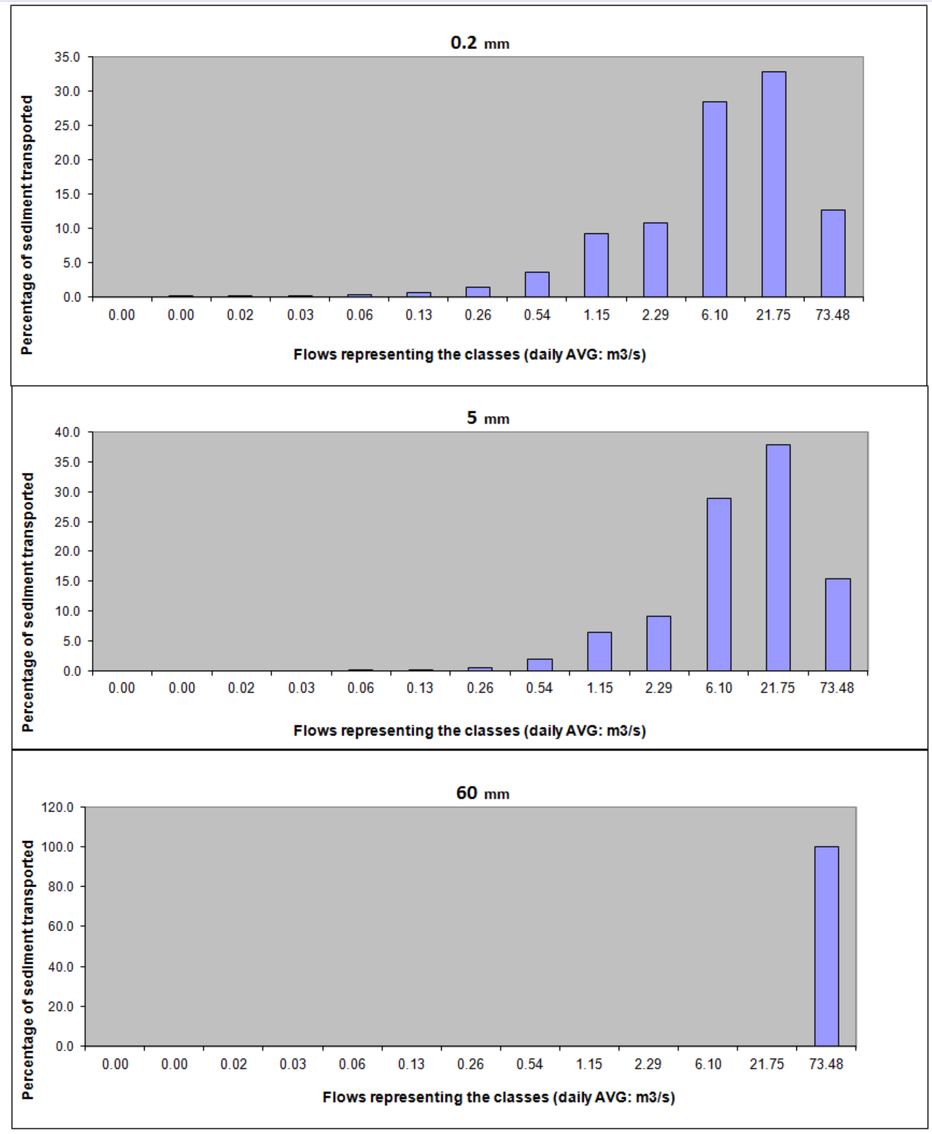


Figure 4-16 PBMT results for the pool cross section at BM1. The effective flood discharge class for sands and gravels is represented by the 21.7 m^3/s discharges, and for cobbles the flood class represented by the 73.5 m^3/s discharge class.

4.7.8 EWR Site BM2 (Black Mfolozi River)

No nearby flow gauge, so the information for the upstream EWR site BM1, together with local cues and site characteristics for BM2, were used to predict the relationships between hydrological and geomorphological indicators. Modelled Present Day flows were used to undertake analyses of long term sediment transport patterns at the EWR site (Figure 4-17Figure 4-14).

The historical aerial photographic record was used to identify larger scale channel planform changes in response to very large floods (such as Domoina in 1984) as well as the responses to long periods without large floods occurring.

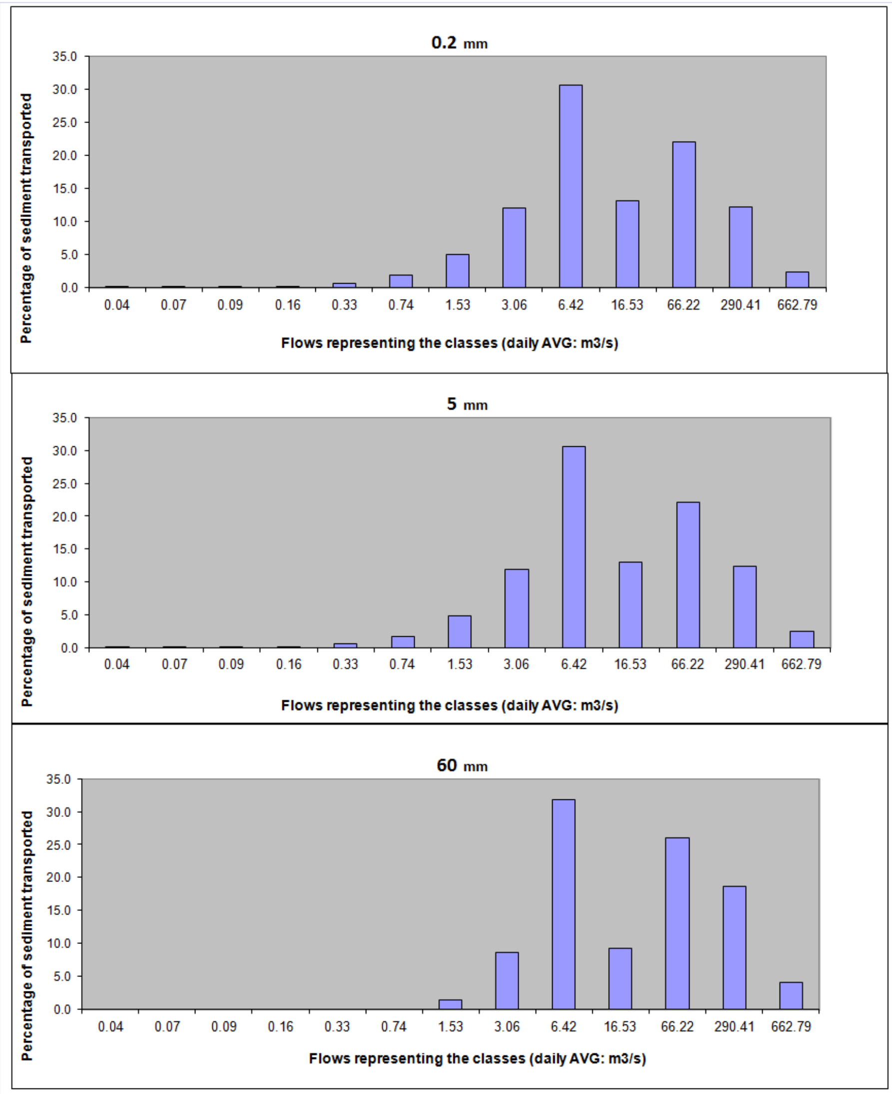


Figure 4-17 PBMT results for the pool cross section at BM2. The effective flood discharge class for sands, gravels and small cobbles is the discharge class represented by the 6 m^3/s flow.

4.8 Identification of indicators

4.8.1 Indicator list for Geomorphology

A list of geomorphology features and their reason for selection as indicators in the EWR assessments is given in Table 4-11. Their expected responses to flow changes are outlined in Table 4-12 and the links between the geomorphological indicators and their formative or controlling hydrological processes (indicted by the hydrological indicators) are shown in Table 4-13.

Table 4-11 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Channel width	Channel width indicates flood conveyance function as well as available aquatic habitat
Bed sediment size	Bed sediment size indicates the condition of the instream physical habitat of the channel bed
Secondary channels	Secondary channels and backwaters represent important instream habitats and offer refugia during high flow conditions
Pool depth	The depth of pools indicates the extent of low flow/drought instream habitat refugia
Extent of cut banks	The extent of cut banks can be used to indicate widespread channel incision and is an important indicator for alluvial river systems, especially where dams are being considered in future management scenarios.
Floodplain pans and lakes	This indicator, relevant for the reach downstream of Mkuze, denotes the area (as a percentage of PD conditions) of pans and lakes which would be filled with water during the dry season each year. These pans are important habitats for fish, avifauna, hippos and crocodiles on the floodplain.

Table 4-12 Indicators and their predicted direction of response to flow changes.

Indicator	Definition	Predicted change	References
Channel width	The average width of the low flow (active) channel.	Reduced flows, and reduced floods, tend to cause a reduction in channel size and thus aquatic habitat area.	DWA 1984; Bracher and Kovacz 1985
Bed sediment size	The average bed sediment size of the active channel.	Increased flows cause a coarsening (increase in size) of bed sediments.	
Secondary channels	The length or number of secondary channels and backwaters	Reduced floods tend to cause abandonment of secondary channels	
Pool depth	The depth of pools indicates the availability of low	Reduced floods means reduce scour and thus	DWA 1984; Bracher and Kovacz 1985

Indicator	Definition	Predicted change	References
	flow/drought refugia for fish and crocodiles.	shallower pools. Reduced low flows would slightly reduce the depth of the pool.	
Extent of cut banks	An indication of incision of the channel and may be important in the more alluvial reaches, especially if dams are planned.	Constant releases tend to cause channel incision and an increase in the extent of cut banks.	
Floodplain pans and lakes	The area of pans and lakes which would be filled with water during the dry season each year.	Reduced floods would result in less channel overtopping and less activation of secondary channels and thus less recharge of pans and lakes.	

Table 4-13 Geomorphological indicators and their linked hydrological indicators

Independent Indicator			Geomorphological (dependent) Indicator					
Indicator Category	Specific Indicator	Unit	Channel width	Bed sediment condition	Secondary channels	Pool depth	Extent of cut banks	Inundated floodplain pans
Sediment	Wet season suspended load	% of PD	x	x	x	x	x	x
Hydrology	Dry season duration	Days	x					x
	Dry season avg. volume	Mm^3		x		x		
	Wet season duration	Days		x	x	x	x	
	Wet max flood peak	m^3/s	x	x	x	x	x	x

4.8.2 Description and location of indicators

4.8.2.1 Active channel width

This indicator represents the width of the active (low flow) channel - i.e. the width between the marginal zones.

4.8.2.2 Bed sediment condition

This indicator reflects the condition of the bed sediments and provides an indication of interstitial spaces, bed fining and embeddedness (Table 4-14). This is an important indicator for instream biota.

Table 4-14 Bed sediment condition descriptions for EWR Site AS1

% of PD condition	Description of the active channel bed condition
0	Bed sediments are completely dominated by sand and silt
25	Surface is dominated by sand and silts, cobbles are embedded
50	50% more embeddedness than the PD condition
75	25% more embeddedness than the PD condition
100	Conditions of the bed as observed in July, 2014
150	More open cobbles with more and 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 and boulder bed with some cobbles. All finer material has been winnowed out of the site.

4.8.2.3 Secondary channels

This indicator reflects the availability of inundated secondary channels and backwaters. These low flow areas provide refugia for some instream biota.

4.8.2.4 Pool depth

This indicator reflects the depth of pools in the reach.

4.8.2.5 Extent of cut banks

This indicator reflects the extent of cut or near vertical low banks along the marginal zone of the active channel. These features are important in that they create deeper sections of the channel adjacent to the steep banks and are often associated with marginal overhanging vegetation.

4.8.2.6 Inundated floodplain pans

On the lower Mkuze River, floodplain pans are an important habitat associated with the river. Although our EWR site is located slightly upstream from where the main floodplain and floodplain pans begin, we believed it was important to try to reflect this habitat type within the DRIFT model. The confidence of this indicator is however low because we are not able to hydraulically link pan inundation with flows at the EWR site due to the location of the cross-section, but if the scenarios evaluated do not include dams then the risk of reduced pan inundation is likely to be low.

4.8.3 Integrity weighting of indicators between sites

The weighting of indicators between the sites reflects the relative proportions and importance of the different habitat types reflected by the geomorphological indicators.

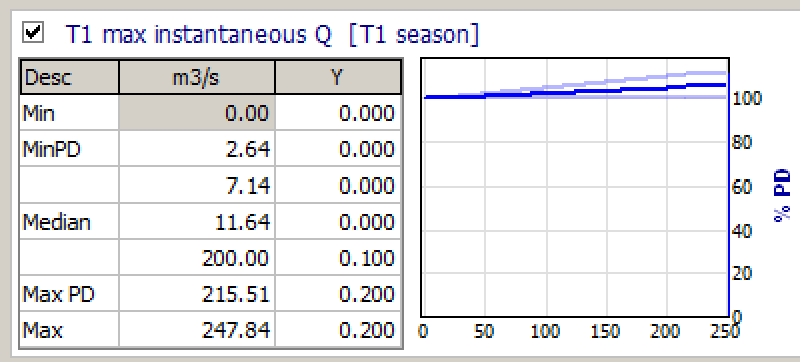
Table 4-15 Integrity weights of geomorphological indicators between sites

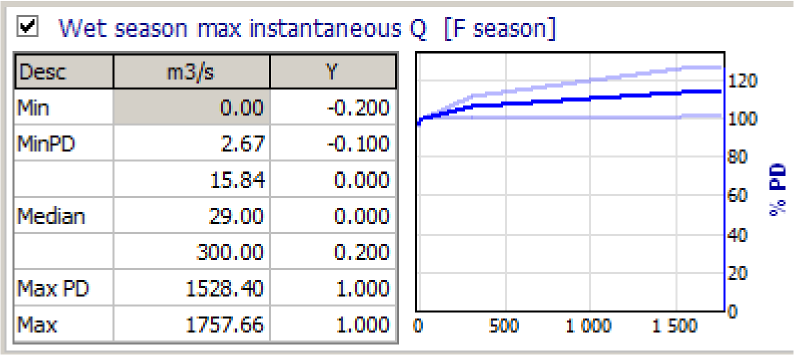
Indicator	Weight								Motivation
	AS1	UP1	NS1	MA1	BM1	BM2	WM1	MK1	
Channel width	2	2	2	2	2	2	2	2	Channel width is an important indicator of available instream habitat.
Extent of cut banks	1	1	1	1	1	1	1	2	Cut banks are associated with deeper instream areas, especially in alluvial rivers. some species are associated with these areas.
Secondary channels	1	3	1	1	1	1	1	2	Secondary channels provide important instream habitat and are weighted higher in reaches where braiding or anastomosing sections are common (i.e. where a high number of secondary channels are present).
Pool Depth	1	1	1	1	1	1	1	1	Deep pools provide habitat for a few species.
Bed sediment conditions	3	3	3	3	3	3	3	1	The condition of the bed is an important indicator of habitat conditions for most instream biota.
Inundated floodplain pans	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	We have very low confidence for this indicator due to the location of the EWR site. Although no pans are hydraulically linked to the EWR cross-section, pans in the lower Mkuze are important for biodiversity, fisheries and tourism, and we have made some estimations of the links to hydrology to incorporate this important habitat type.

4.9 Motivations for response curves

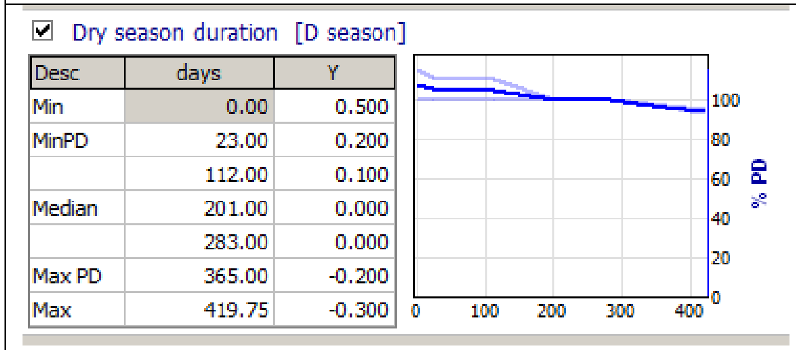
The response curves provided in this section are for EWR Site AS1. They are provided by way of example. Motivations for other response curves are available in the DRIFT DSS. Response curves provided below and those in the DSS MAY differ very slightly as a result of final calibration, but the overall shape and reasoning remains the same.

Table 4-16 Response curve motivations for the Active Channel Width indicator at the Assegaai River (AS1)

<table>
<tr><th>Response curve</th><th>Explanation</th></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>2.64</td><td>0.000</td></tr>
<tr><td></td><td>7.14</td><td>0.000</td></tr>
<tr><td>Median</td><td>11.64</td><td>0.000</td></tr>
<tr><td></td><td>200.00</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>215.51</td><td>0.200</td></tr>
<tr><td>Max</td><td>247.84</td><td>0.200</td></tr>
</table>

</td><td>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). Small floods would not keep encroachment in check, and may actually promote channel narrowing through enhanced vegetation growth.</td></tr>
<tr><td>

☑ Wet season max instantaneous 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>-0.200</td></tr>
<tr><td>MinPD</td><td>2.67</td><td>-0.100</td></tr>
<tr><td></td><td>15.84</td><td>0.000</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>300.00</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>1528.40</td><td>1.000</td></tr>
<tr><td>Max</td><td>1757.66</td><td>1.000</td></tr>
</table>

</td><td>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). Small floods would not keep encroachment in check, and may actually promote channel narrowing through enhanced vegetation growth.</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></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></td><td>112.00</td><td>0.100</td></tr>
<tr><td>Median</td><td>201.00</td><td>0.000</td></tr>
<tr><td></td><td>283.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.200</td></tr>
<tr><td>Max</td><td>419.75</td><td>-0.300</td></tr>
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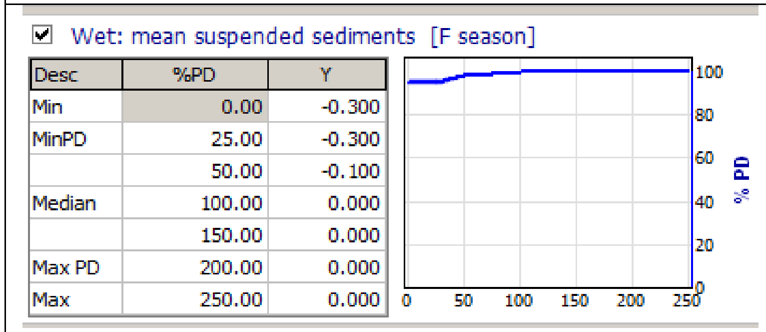
</td><td>This indicator represents the impact of the dry season on channel width. At EWR Site AS1, prolonged dry season flows would facilitate a small amount of additional encroachment in to the channel, creating a narrower (reduced width) active channel.</td></tr>
<tr><td>


☑ Wet: mean suspended sediments [F season]

<table>
<tr><th>Desc</th><th>%PD</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>-0.300</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>0.000</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>Suspended sediments in these scenarios represent suspended and bedload sediments. A reduction in wet season sediments due to, for example, a new upstream dam, would increase the erosive energy of the wet season high flows and floods and cause some incision of the active channel. This can be expected to cause some narrowing of the active channel.</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.

Dollar, E.S.J. 2002. Fluvial Geomorphology. Progress in Physical Geography, 26: 123-143.

DWA 1985. Documentation of the 1984 Domoina floods. Department of Water Affairs. Technical Report No. TR 122, Pretoria, South Africa.

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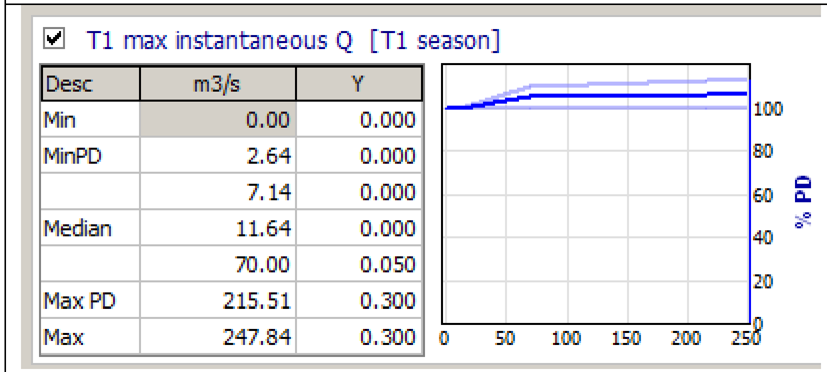
Kochel, R.C. 1988. Geomorphic Impact of Large Floods: review and new perspectives on magnitude and frequency. In Baker, V.R., Kochel, R.C. and Patton, P.C. (eds) Flood Geomorphology. Wiley-Interscience, New York, 169-87.

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.

Response curve	Explanation
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.	

Table 4-17 Response curve motivations for the Extent of Cut Banks indicator at the Assegaai River EWR Site (AS1)

Response curve	Explanation
	Small to moderate annual floods would scour the active channel, increasing cut banks, but very small floods would not have an impact.

☑ T1 max instantaneous Q [T1 season]

Desc	m3/s	Y
Min	0.00	0.000
MinPD	2.64	0.000
	7.14	0.000
Median	11.64	0.000
	70.00	0.050
Max PD	215.51	0.300
Max	247.84	0.300

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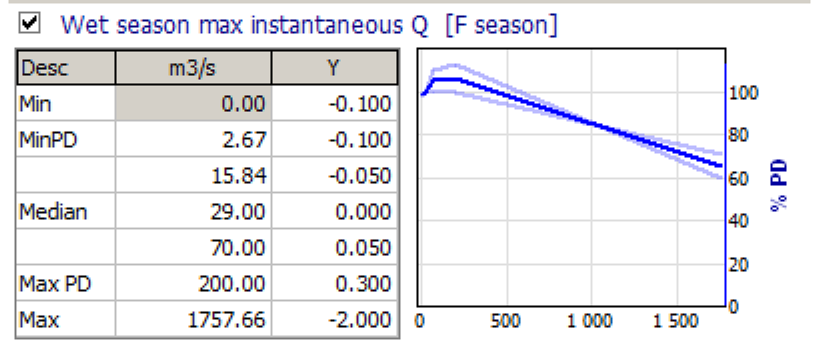
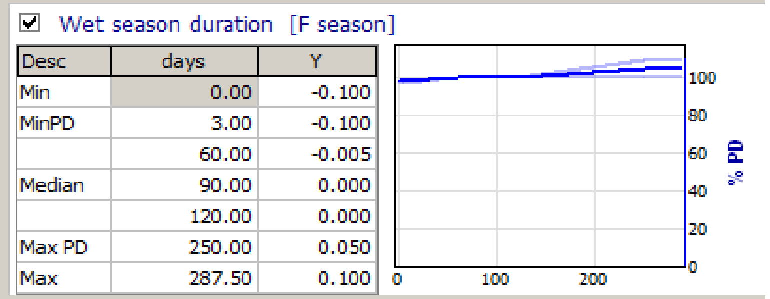
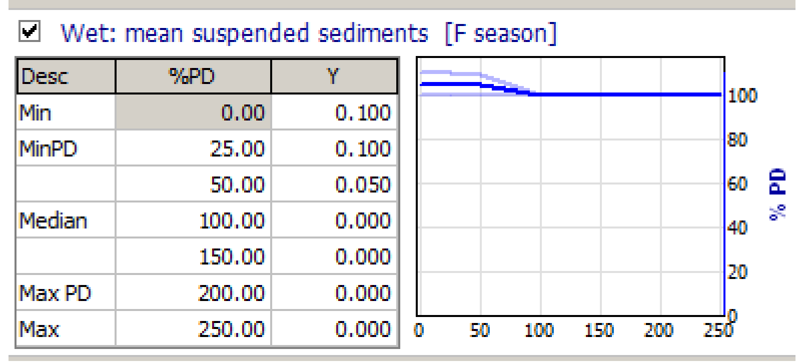


☑ Wet season max instantaneous Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>2.67</td><td>-0.100</td></tr>
<tr><td></td><td>15.84</td><td>-0.050</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>70.00</td><td>0.050</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.300</td></tr>
<tr><td>Max</td><td>1757.66</td><td>-2.000</td></tr>
</table>
</td><td>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. Small to moderate floods would scour the active channel, increasing cut banks, and very small floods would have not impact.</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>-0.100</td></tr>
<tr><td>MinPD</td><td>3.00</td><td>-0.100</td></tr>
<tr><td></td><td>60.00</td><td>-0.005</td></tr>
<tr><td>Median</td><td>90.00</td><td>0.000</td></tr>
<tr><td></td><td>120.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>250.00</td><td>0.050</td></tr>
<tr><td>Max</td><td>287.50</td><td>0.100</td></tr>
</table>
</td><td>Longer wet seasons can be expected to widen the active channel and create cut banks along the marginal zone. Short flood seasons may merely stimulate marginal vegetation growth and promote encroachment, thus slightly reducing the extent of cut banks.</td></tr>
<tr><td>


☑ Wet: mean suspended sediments [F season]
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<tr><th>Desc</th><th>%PD</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>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>0.000</td></tr>
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</table>
</td><td>Suspended sediments in these scenarios represent suspended and bedload sediments. A reduction in wet season sediments due to, for example, a new upstream dam, would increase the erosive energy of the wet season high flows and floods and cause some incision of the active channel. This would result in erosion of the marginal zones and an increase in cut banks.</td></tr>
<tr><td>References</td><td>Baker, V.R. 1977. Stream-channel response to floods, with examples from central Texas. *Geol. Soc. Am. Bull*., 88: 1057-1071.</td></tr>
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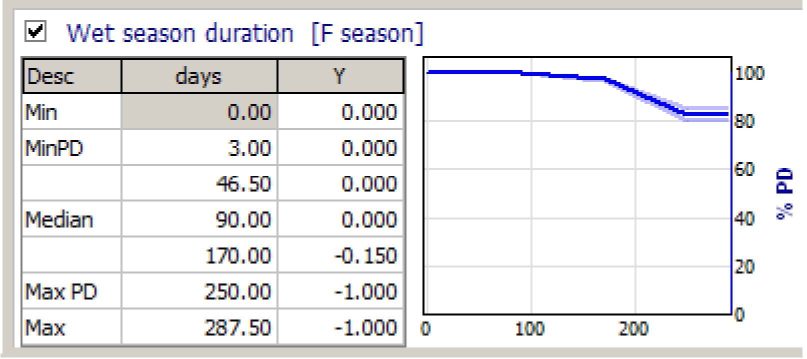
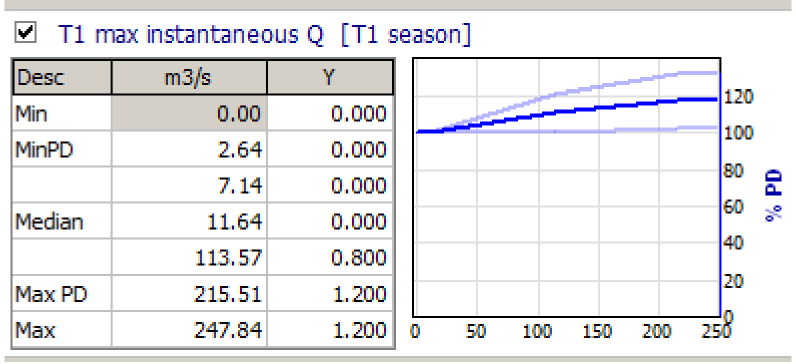
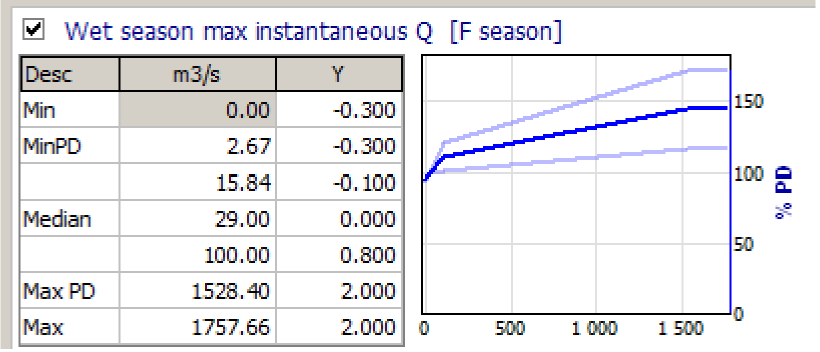
Response curve	Explanation
	Dollar, E.S.J. 2002. Fluvial Geomorphology. *Progress in Physical Geography*, 26: 123-143. DWA 1985. Documentation of the 1984 Domoina floods. Department of Water Affairs. Technical Report No. TR 122, Pretoria, South Africa. Gupta, A., Kale, V.S. and Rajaguru, S.N. 1999. The Narmada River, India, through space and time. In Miller, A.J. and Gupta, A.(eds), *Varieties of Fluvial Form*. Wiley and Sons, Chichester, U.K, 113-144. Kochel, R.C. 1988. Geomorphic Impact of Large Floods: review and new perspectives on magnitude and frequency. In Baker, V.R., Kochel, R.C. and Patton, P.C. (eds) *Flood Geomorphology*. Wiley-Interscience, New York, 169-87. 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. Tooth, S. 2000. Process, form and change in dryland rivers: a review of recent research. *Earth Surface Reviews*, 51: 67-107.

Table 4-18 Response curve motivations for the Secondary Channels at the Assegaai River EWR Site (AS1)

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


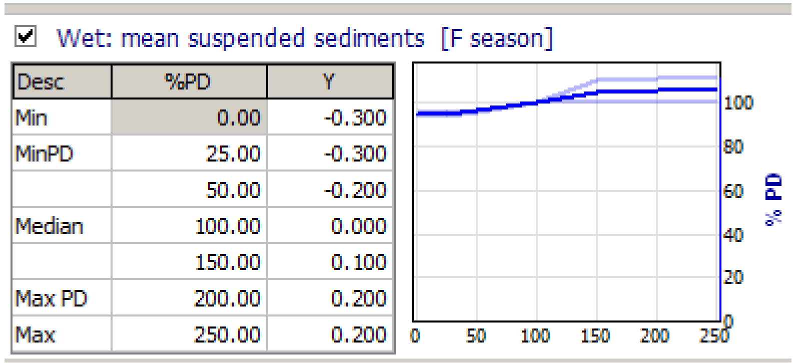
☑ Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>3.00</td><td>0.000</td></tr>
<tr><td></td><td>46.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>90.00</td><td>0.000</td></tr>
<tr><td></td><td>170.00</td><td>-0.150</td></tr>
<tr><td>Max PD</td><td>250.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>287.50</td><td>-1.000</td></tr>
</table>
</td><td>Long wet seasons are associated with prolonged periods of elevated flows, during which time the active channel is progressively scoured and, over very long wet seasons, secondary channels are abandoned as the capacity of the main channel is increased due to high flow erosion.</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>2.64</td><td>0.000</td></tr>
<tr><td></td><td>7.14</td><td>0.000</td></tr>
<tr><td>Median</td><td>11.64</td><td>0.000</td></tr>
<tr><td></td><td>113.57</td><td>0.800</td></tr>
<tr><td>Max PD</td><td>215.51</td><td>1.200</td></tr>
<tr><td>Max</td><td>247.84</td><td>1.200</td></tr>
</table>
</td><td>Whilst extremely large floods rework the most bed sediment and create the most braided sections through the newly mobile sediments and shallower channels, small to moderate floods of the T1 season would generally scour the main active channel and result in progressive abandonment of the secondary channels..</td></tr>
</table>

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


☑ Wet season max instantaneous 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>-0.300</td></tr>
<tr><td>MinPD</td><td>2.67</td><td>-0.300</td></tr>
<tr><td></td><td>15.84</td><td>-0.100</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>100.00</td><td>0.800</td></tr>
<tr><td>Max PD</td><td>1528.40</td><td>2.000</td></tr>
<tr><td>Max</td><td>1757.66</td><td>2.000</td></tr>
</table>

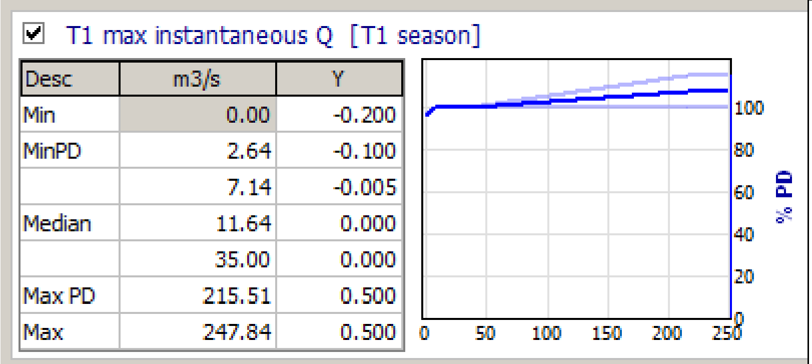
</td><td>Very large floods erode the lateral zones and redistribute sediment across the channel floor, raising the bed level of the active channel and creating secondary (braided) channels and reactivating and clearing out flood channels. These effects result in increased secondary channels and backwater areas being created or scoured out (Parsons et al. 2006; Rountree et al. 2001; Rountree et al. 2000; DWA 1985). Whilst extremely large floods rework the most bed sediment and create the most braided sections through the newly mobile sediments and shallower channels, small floods merely scour the main active channel and result in progressive abandonment of the secondary channels.</td></tr>
<tr><td>


☑ Wet: mean suspended sediments [F season]

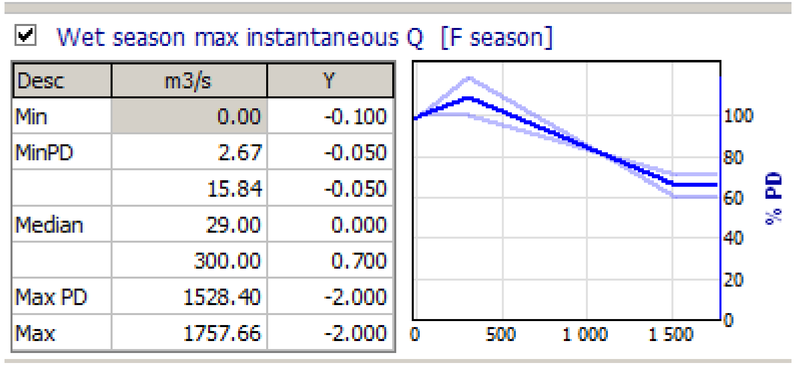
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.300</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</td></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>Suspended sediments in these scenarios represent suspended and bedload sediments. A reduction in wet season sediments due to, for example, a new upstream dam, would increase the erosive energy of the wet season high flows and floods and cause some incision of the active channel. This can be expected to cause some narrowing and deepening of the active channel and progressive abandonment of the secondary channels. Higher sediment loads, conversely, fill in the active channel and promote braiding and the development of secondary channels and backwaters.</td></tr>
<tr><td>References</td><td>DWA 1985. Documentation of the 1984 Domoina floods. Department of Water Affairs. Technical Report No. TR 122, Pretoria, South Africa.
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.</td></tr>
</table>

Table 4-19 Response curve motivations for the Bed Sediment Condition indicator at the Assegaai River EWR Site (AS1)

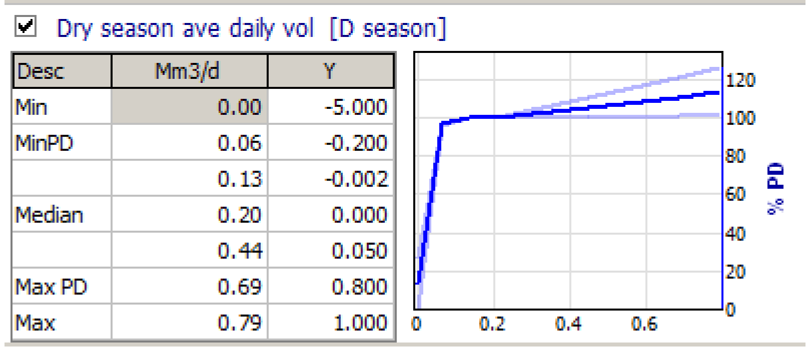
<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>


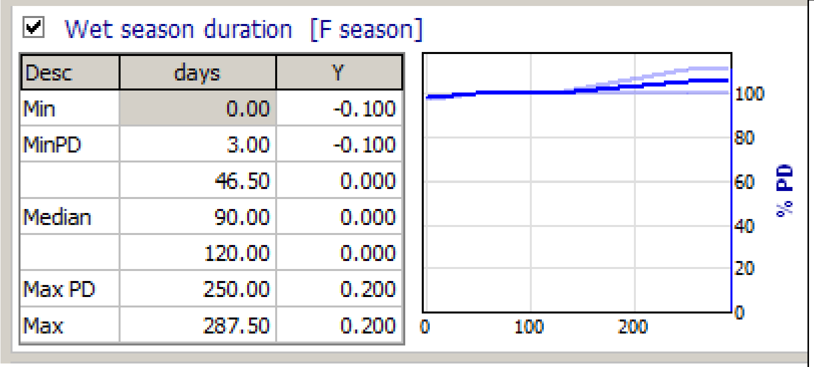
☑ T1 max instantaneous Q [T1 season]

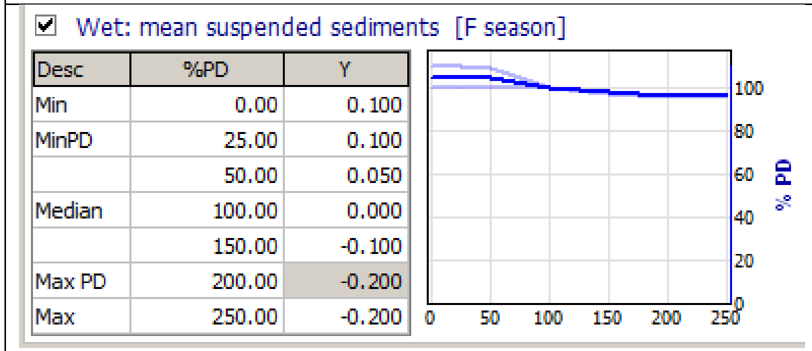
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.200</td></tr>
<tr><td>MinPD</td><td>2.64</td><td>-0.100</td></tr>
<tr><td></td><td>7.14</td><td>-0.005</td></tr>
<tr><td>Median</td><td>11.64</td><td>0.000</td></tr>
<tr><td></td><td>35.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>215.51</td><td>0.500</td></tr>
<tr><td>Max</td><td>247.84</td><td>0.500</td></tr>
</table>
</td><td>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. Mean flood years result in a slight decrease in bed condition (increased fines), whereas larger than median floods reset the bed condition due to scouring actions. Very large floods however redistribute sediment across the entire channel, resulting in an overall, large-scale fining of the bed.</td></tr>
<tr><td>


☑ Wet season max instantaneous 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>-0.100</td></tr>
<tr><td>MinPD</td><td>2.67</td><td>-0.050</td></tr>
<tr><td></td><td>15.84</td><td>-0.050</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>300.00</td><td>0.700</td></tr>
<tr><td>Max PD</td><td>1528.40</td><td>-2.000</td></tr>
<tr><td>Max</td><td>1757.66</td><td>-2.000</td></tr>
</table>
</td><td>Applying the sediment transport analyses methods of Dollar and Rowntree (2003), important flow classes for sediment movement were identified. These results have ben used to develop the relationship between bed sediment condition and max flood. Mean flood years result in a slight decrease in bed condition (increased fines), whereas larger than median floods reset the bed condition due to scouring actions. Very large floods however redistribute sediment across the entire channel, resulting in an overall, large-scale fining of the bed.</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>-5.000</td></tr>
<tr><td>MinPD</td><td>0.06</td><td>-0.200</td></tr>
<tr><td></td><td>0.13</td><td>-0.002</td></tr>
<tr><td>Median</td><td>0.20</td><td>0.000</td></tr>
<tr><td></td><td>0.44</td><td>0.050</td></tr>
<tr><td>Max PD</td><td>0.69</td><td>0.800</td></tr>
<tr><td>Max</td><td>0.79</td><td>1.000</td></tr>
</table>

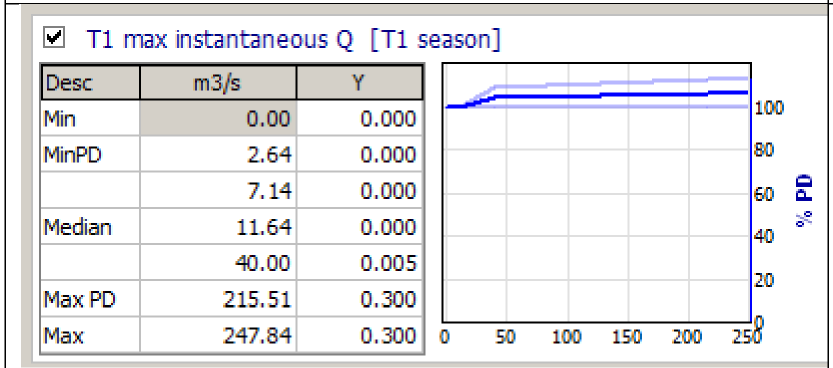
</td><td>Lower dry season volumes result in progressively more deposition of silts on the channel bed.</td></tr>
<tr><td>

☑ 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>-0.100</td></tr>
<tr><td>MinPD</td><td>3.00</td><td>-0.100</td></tr>
<tr><td></td><td>46.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>90.00</td><td>0.000</td></tr>
<tr><td></td><td>120.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>250.00</td><td>0.200</td></tr>
<tr><td>Max</td><td>287.50</td><td>0.200</td></tr>
</table>

</td><td>Short wet seasons, associated with rapid, flashy or small floods, would scour little of the bed, and bring in sediment from the catchment. Longer wet seasons would be associated with wetter catchment conditions (more vegetation cover and lower sediment yields) and a longer period of wet season flows to create clean cobbles and a channel relatively free of fine</td></tr>
<tr><td>

☑ Wet: mean suspended sediments [F season]
<table>
<tr><th>Desc</th><th>%PD</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>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>-0.100</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>Increasing sediment inflows from the catchment would result in a progressive fining of the bed (i.e. increasing proportions of sands and silts), and a decrease in sediment inflows would result in winnowing out of the finer sediments and an overall increase (coarsening) of the channel bed sediments.</td></tr>
</table>

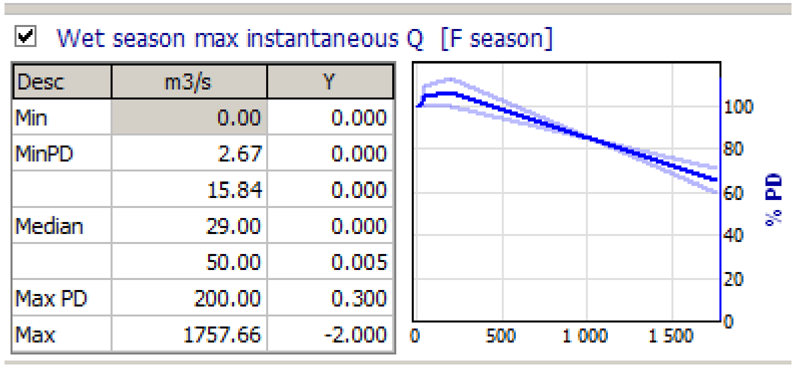
Response curve	Explanation
References	Dollar, E.S.J and Rowntree, K.M. (2003). Geomorphological Research for the Conservation and Management of Southern African Rivers. Volume 2: Managing Flow Variability: the geomorphological response. Water Research Commission Report No. 849/2/04, Pretoria.

Table 4-20 Response curve motivations for the Pool Depth indicator at the Assegaai River EWR Site (AS1)

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


☑ T1 max instantaneous Q [T1 season]

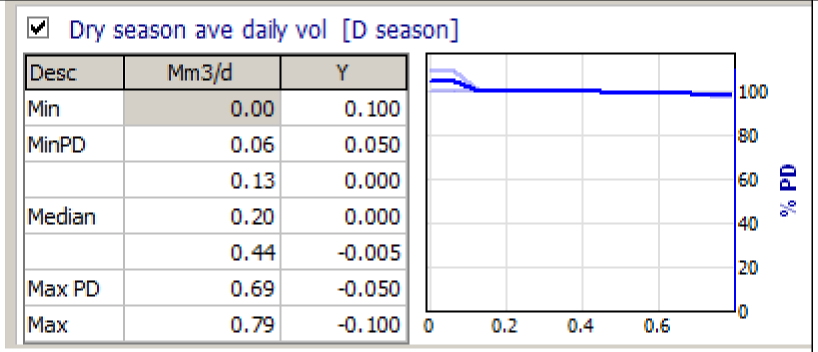
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>2.64</td><td>0.000</td></tr>
<tr><td></td><td>7.14</td><td>0.000</td></tr>
<tr><td>Median</td><td>11.64</td><td>0.000</td></tr>
<tr><td></td><td>40.00</td><td>0.005</td></tr>
<tr><td>Max PD</td><td>215.51</td><td>0.300</td></tr>
<tr><td>Max</td><td>247.84</td><td>0.300</td></tr>
</table>

</td><td>The small to moderate floods that occur in the T1 season would generally result in pool scouring and the removal of fines that accumulate here during moderate and low flow conditions. These response curves reflect the pattern of the modelled effective discharges for the site (important sediment transport) flows.</td></tr>
<tr><td>


☑ Wet season max instantaneous Q [F season]

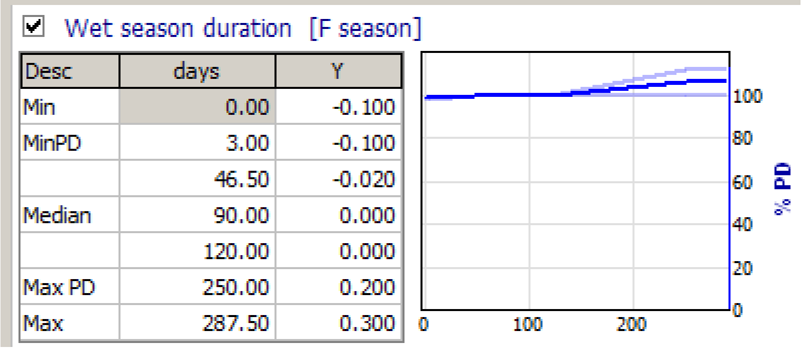
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>2.67</td><td>0.000</td></tr>
<tr><td></td><td>15.84</td><td>0.000</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.005</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.300</td></tr>
<tr><td>Max</td><td>1757.66</td><td>-2.000</td></tr>
</table>

</td><td>At AS1 pools are small and shallow, usually with a cobble bed. The range of natural variation can thus be expected to be small. The very large floods that occur in the eastern regions of South Africa typically erode the lateral banks and redistribute sediment across the channel floor, resulting in wider and usually shallower pools and active channels (Parsons et al. 2006; Rountree et al. 2001; Rountree et al. 2000; DWA 1985). Sediment transport undertaken in this study identified that small to moderate floods are responsible for the bulk of sand transport at the site. These floods would scour pools and remove fines that accumulate during moderate and low flow conditions. Small floods may only move sediment from runs and riffles in the pools as they may lack the capacity to scour. Small floods could thus reduce pool depth.</td></tr>
</table>

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


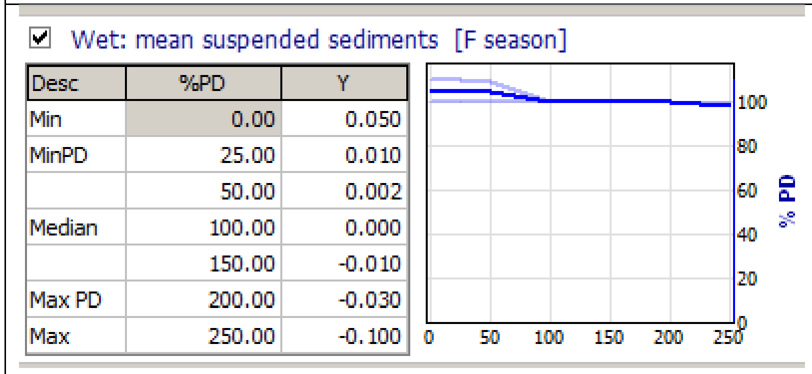
☑ Dry season ave daily vol [D season]

<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.100</td></tr>
<tr><td>MinPD</td><td>0.06</td><td>0.050</td></tr>
<tr><td></td><td>0.13</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.20</td><td>0.000</td></tr>
<tr><td></td><td>0.44</td><td>-0.005</td></tr>
<tr><td>Max PD</td><td>0.69</td><td>-0.050</td></tr>
<tr><td>Max</td><td>0.79</td><td>-0.100</td></tr>
</table>

</td><td>Higher dry season baseflows would allow more sediments to be transported in to the pools, where they would be deposited due to slower velocities in the deeper water. Low dry season flows would mean that there is little sediment input (and thus little reduction in pool depth) over the dry season.</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>-0.100</td></tr>
<tr><td>MinPD</td><td>3.00</td><td>-0.100</td></tr>
<tr><td></td><td>46.50</td><td>-0.020</td></tr>
<tr><td>Median</td><td>90.00</td><td>0.000</td></tr>
<tr><td></td><td>120.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>250.00</td><td>0.200</td></tr>
<tr><td>Max</td><td>287.50</td><td>0.300</td></tr>
</table>

</td><td>Longer wet season durations should be associated with greater scour of the pools due to the longer periods of elevated velocities.</td></tr>
<tr><td>


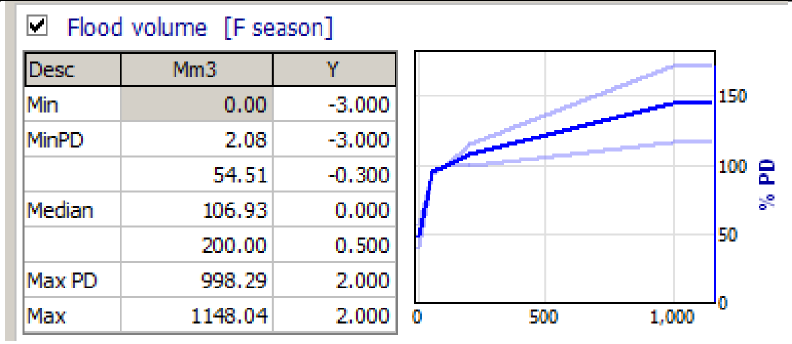
☑ Wet: mean suspended sediments [F season]

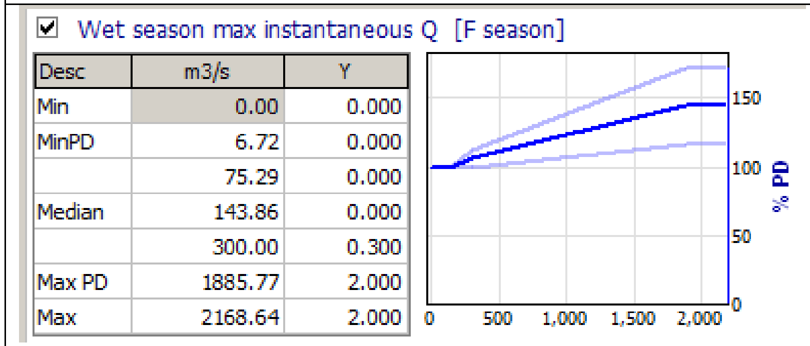
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.050</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.010</td></tr>
<tr><td></td><td>50.00</td><td>0.002</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.010</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.030</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.100</td></tr>
</table>

</td><td>Increased suspended loads would allow for increased deposition in the low velocity pools, thus reducing pool depths. Reduced suspended sediment loads should result in reduce deposition of fines and thus above-average pool depth.</td></tr>
</table>

Response curve	Explanation
References	DWA 1985. Documentation of the 1984 Domoina floods. Department of Water Affairs. Technical Report No. TR 122, Pretoria, South Africa. 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.Tooth, S. 2000. Process, form and change in dryland rivers: a review of recent research. *Earth Surface Reviews*, 51: 67-107.

Table 4-21 Response curve motivations for the Floodplain Pan indicator at the Mkuze River EWR Site (MK1)

<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>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>2.08</td><td>-3.000</td></tr>
<tr><td></td><td>54.51</td><td>-0.300</td></tr>
<tr><td>Median</td><td>106.93</td><td>0.000</td></tr>
<tr><td></td><td>200.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>998.29</td><td>2.000</td></tr>
<tr><td>Max</td><td>1148.04</td><td>2.000</td></tr>
</table>

</td><td>The larger the flood volume, the larger the area of floodplain that could be expected to be inundated. This is likely to be the main driver of floodplain inundation, since peaks, although also important, would quickly become attenuated on the flat floodplain.</td></tr>
<tr><td>

☑ Wet season max instantaneous 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>6.72</td><td>0.000</td></tr>
<tr><td></td><td>75.29</td><td>0.000</td></tr>
<tr><td>Median</td><td>143.86</td><td>0.000</td></tr>
<tr><td></td><td>300.00</td><td>0.300</td></tr>
<tr><td>Max PD</td><td>1885.77</td><td>2.000</td></tr>
<tr><td>Max</td><td>2168.64</td><td>2.000</td></tr>
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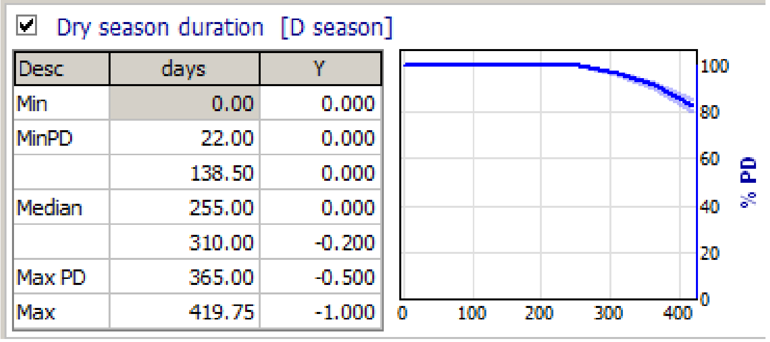
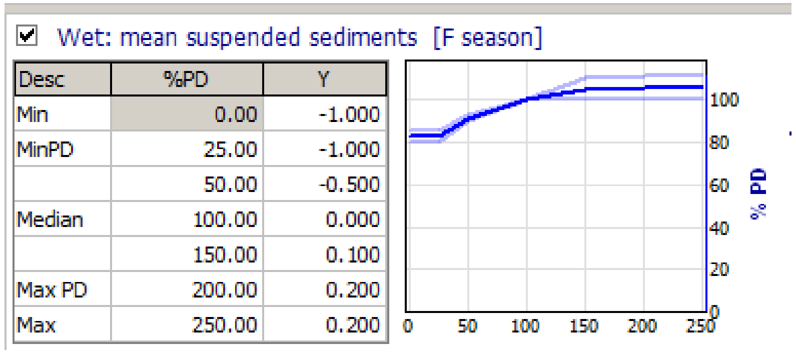
</td><td>The larger the flood peak, the larger the area of floodplain that could be expected to be inundated.</td></tr>
<tr><td>

☑ 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>22.00</td><td>0.000</td></tr>
<tr><td></td><td>138.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>255.00</td><td>0.000</td></tr>
<tr><td></td><td>310.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.000</td></tr>
</table>

</td><td>The longer the dry season, the longer the period between floods (recharge events), during which pans could become progressively smaller and dry out. Longer and longer dry seasons could therefore be expected to be associated withprogressively less area of pans on the floodplain.</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>Wet: mean suspended sediments

☑ Wet: mean suspended sediments [F season]
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<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
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<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>0.100</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>Suspended sediments in these scenarios represent suspended and bedload sediments. A reduction in wet season sediments due to, for example, a new upstream dam, would increase the erosive energy of the wet season high flows and floods and cause some incision of the active channel. This would favour channel incision and the abandonment of flood and secondary channels which are associated with recharge of floodplain pans. Reduced sediment loads could thus be expected to be associated with reduced pans.</td></tr>
</table>

4.10 Assumptions and limitations

DRIFT is a powerful scenario evaluation tool that allows decision makers to evaluate the consequences of numerous flow scenarios. 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 (e.g., Figure 4-18), 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 (such as at EWR BM1). A comparison of observed and modelled hydrology was made at each site and, at each site, particularly with respect to floods, the hydrological record deemed to provide a more accurate reflection of real flow patterns was used for sediment transport modelling. In this way the most accurate effective discharges (important floods for sediment movement and channel maintenance) could be determined.

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 EWR site.

Durations of dry and wet seasons are crucial for some geomorphological indicators, but these hydrological indicators were not available for the MA1 and NS1 EWR sites. Alternative indicators which are assumed to relate to the flow season durations were instead selected as follows:

- The average baseflow of the T1 season was selected as a proxy for dry season duration. Lower baseflows in the T1 season are expected to indicate an extended dry season.
- The average baseflow of the T2 season was selected as a proxy for wet season duration. Higher baseflows in the T2 season are expected to indicate an extended wet season.

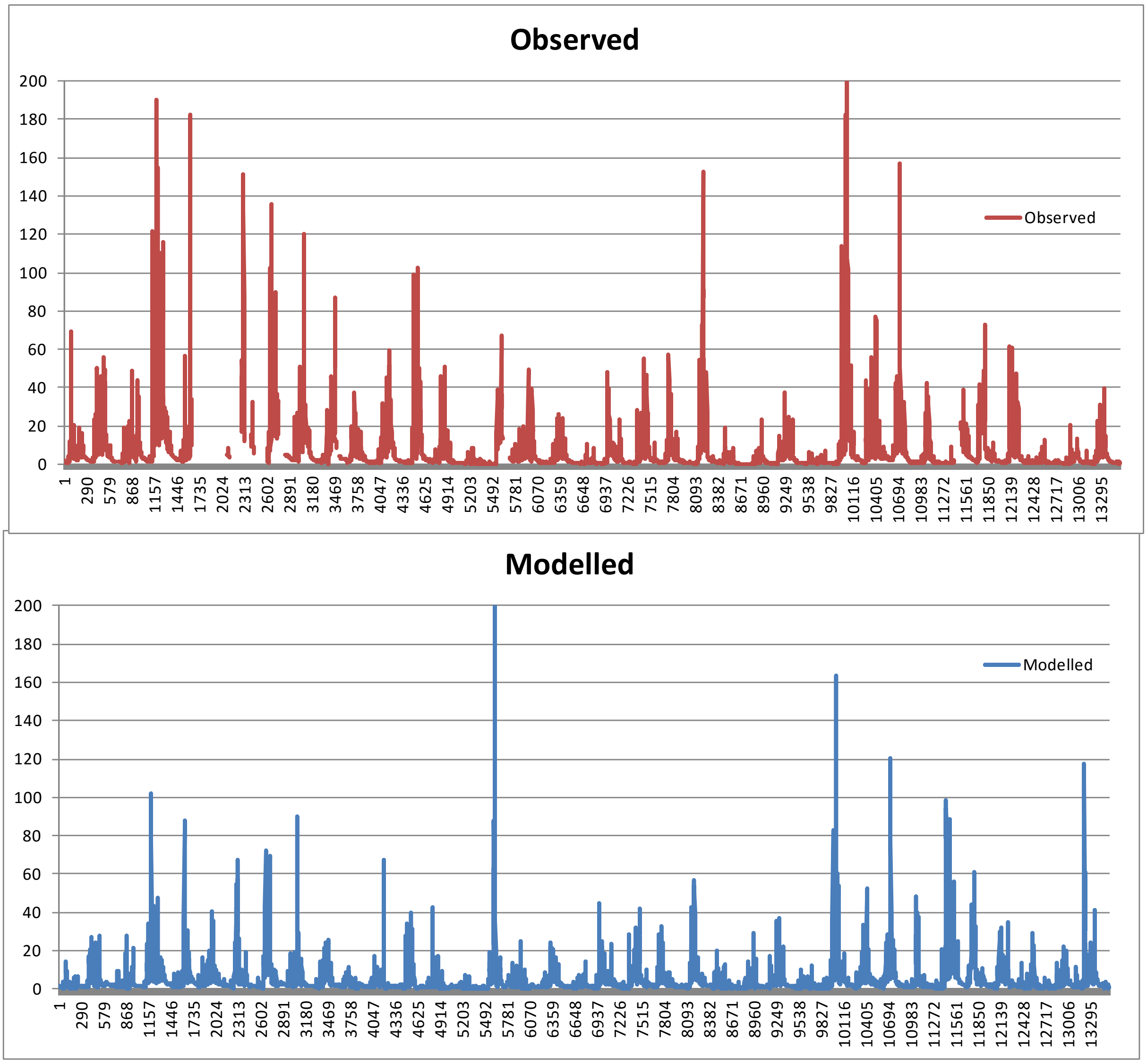

Figure 4-18 Comparison of the observed (from DWA gauge W5H022 located 1km downstream of EWR Site) and PD modelled data for the period 1968-2005 for EWR Site AS1. At this site, the modelled PD data generally underestimates the flood peaks, indicating a much lower frequency of large and moderate floods than is observed in the record.

On the lower Mkuze River, floodplain pans are an important habitat associated with the river. Although our EWR site is located upstream from where the main floodplain and floodplain pans begin, we believed it was important to try to reflect this habitat type within the DRIFT model so that this EWr site could represent the lower Mkuze system. The confidence of this indicator is however low because we are not able to hydraulically link pan inundation with flows at the EWR site due to the location of the cross-section, but if the scenarios evaluated do not include dams then the risk of reduced pan inundation is likely to be low.

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5 VEGETATION: SPECIALIST REPORT

5.1 Introduction

1.1.2 Objectives of the vegetation study

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

For the vegetation component of the EWR assessment, 34 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 Tlou Consulting *viz*.:

- Familiarise yourself to the extent possible with the study area, including:
    - The character of the vegetation of the rivers in the study area.
    - The character of the vegetation of the reaches encompassing the proposed 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.
- Take responsibility for the adequacy of the data collected for use in the vegetation component of the assessment.
- Select key species as indicators for the DRIFT assessment, and provide/develop information on:
    - descriptions of the species;
    - distribution and abundance (in particular, flow-related limitations to spatial distribution);
    - phenology;
    - anticipated sensitivity to change in the flow regime;
    - any additional relevant information on the species characteristic of each site, from the scientific literature or from data collections;
    - 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.

- Prepare data files for use at the DRIFT Workshop. Develop information on the following relationships:
    - altered flow regime-sediment transport potential
    - changes in habitat types with changes in the flow regime.
    - any other relevant data as your experience suggests.
- Attend the DRIFT Workshop(s) and populate the DRIFT response curves for riparian vegetation.
- Prepare response curve motivation tables, and make statements about the confidence level of your outputs.

5.1.1 Layout of this Section

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

- Overview of the study area, with focus on delineation of homogenous areas;
- For the EWR 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.
- Data and the details of any analyses performed.
- Ecospecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to vegetation.

5.2 Description of the study area, with the focus on vegetation

The study area spans three vegetation Biomes: Grassland (which includes the Assegaai and Upper Pongola sites); Savanna (which includes the Mkuze, Nseleni and Black and White Mfolozi sites) and; Indian Ocean Coastal Belt (which includes the Matigulu site) (Figure 5-1). The Mkuze EWR site (MK1) falls within the Maputaland Centre of plant endemism while the Matigulu (MA1), Nseleni (NS1), Black (BM1 and BM2) and White Mfolozi (WM1) EWR sites fall within the Maputaland-Pondoland Region of plant endemism (Figure 5-2).

5.3 Literature review

There is a considerable body of literature the WMA including water balances, budgets and situation reports but relatively little of this is relevant for riparian vegetation. Of the existing work, the most relevant is the Joint Maputo River Basin Water Resources Study – Mozambique, Swaziland and South Africa (EuropeAid/120802/D/SV/ZA), commissioned by the European Union in 2007.

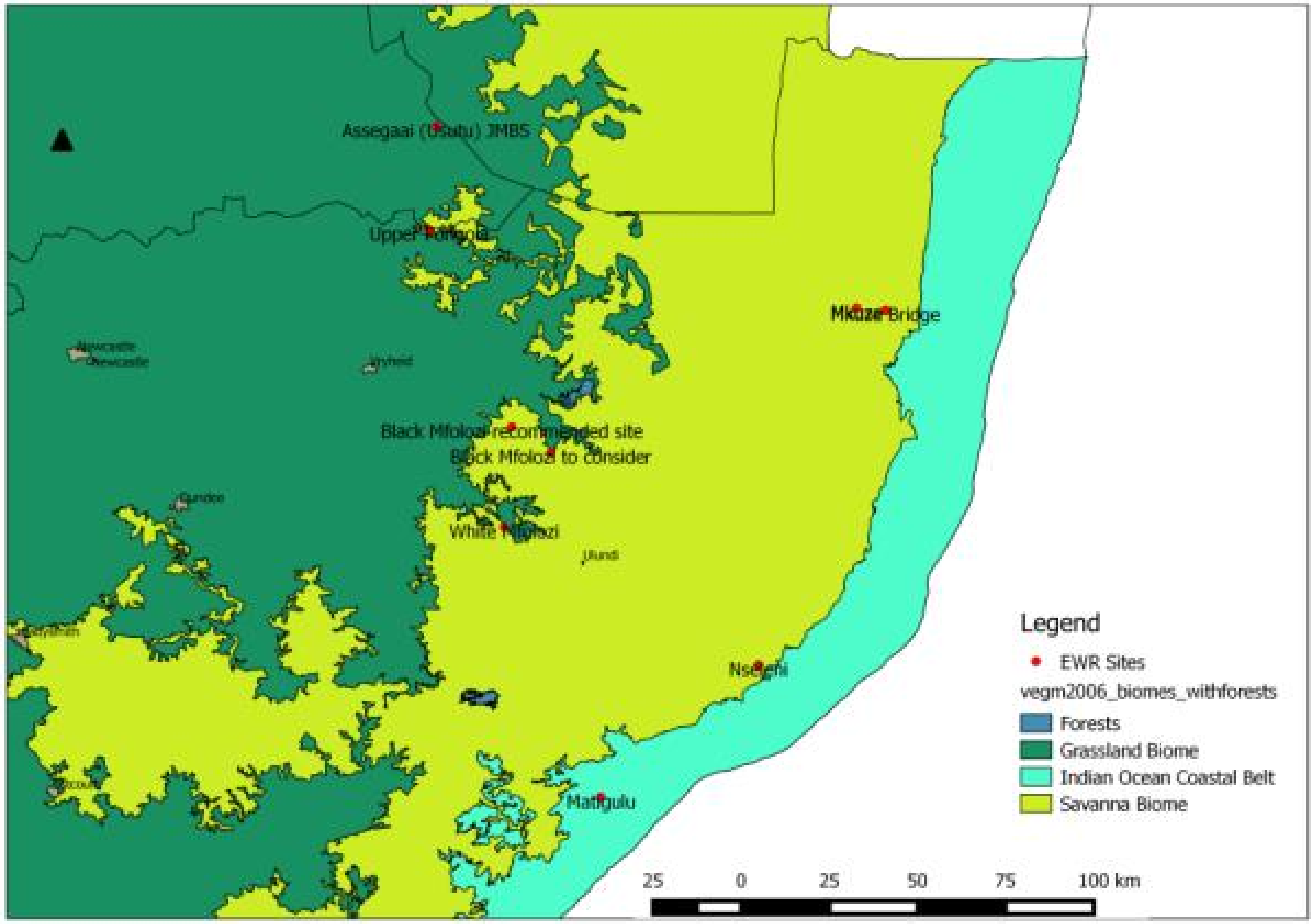


Figure 5-1 EWR sites in relation to vegetation Biomes (data after Mucina and Rutherford 2006).

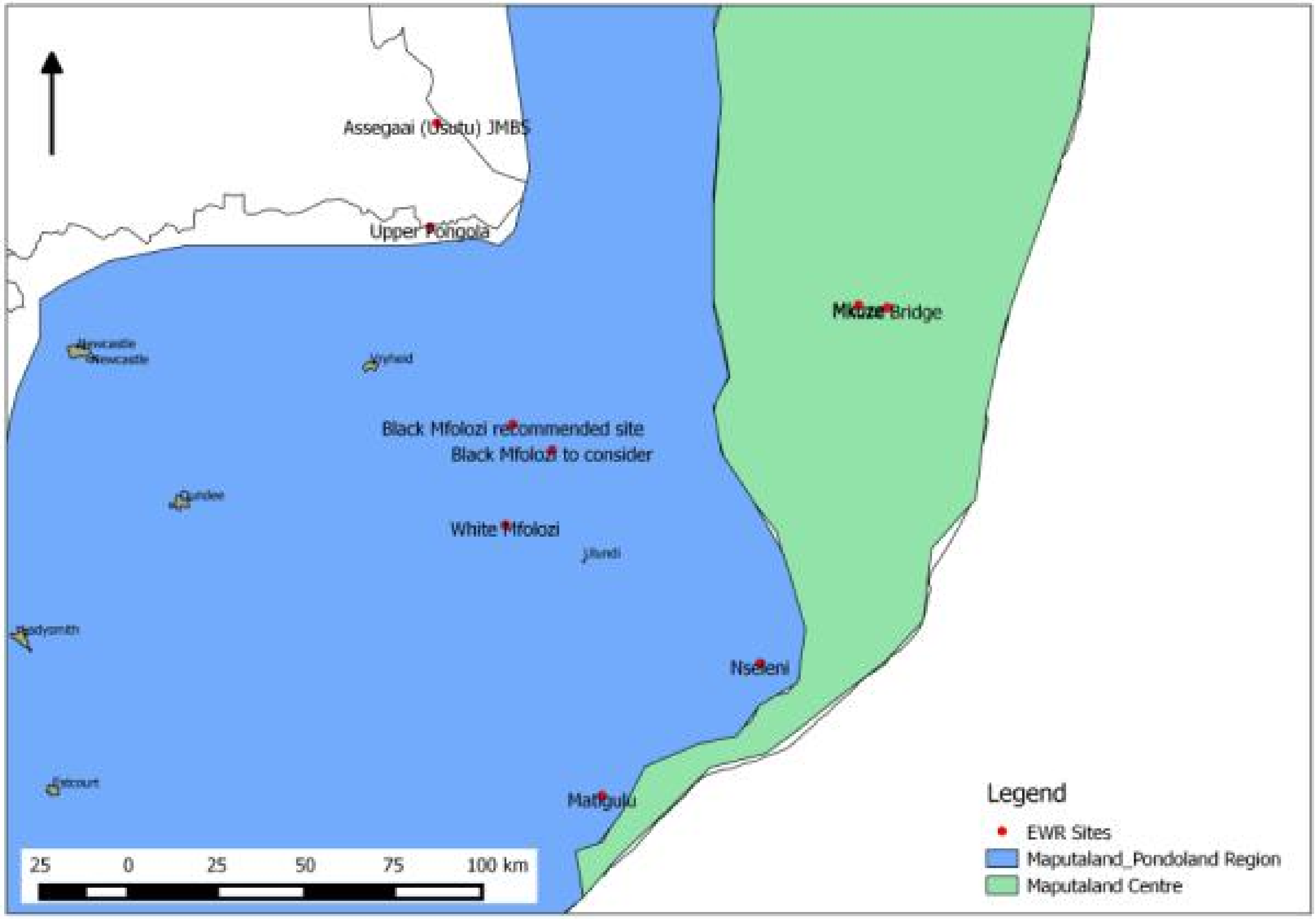


Figure 5-2 **Map showing relation between EWR sites, and centres and regions of plant endemism (Data after van Wyk and Smith 2001).**

The study included an assessment of the ecological status and a determination of environmental flows for the Maputo River and its tributaries. It was an international project involving Mozambique, Swaziland and South Africa. The study area focused on the main rivers within quaternary catchments of the Maputo River catchment. The Maputo River consists of the uSuthu and Phongolo Rivers, which become the Maputo River when they join on the South Africa - Moçambique border at the eastern corner of the Ndumu Game Reserve. The uSuthu River originates in South Africa and flows through Swaziland. The Phongolo River and most of its tributaries originate and flows through South Africa. Environmental flow requirement (EFR) sites were surveyed on the Ngempisi, Assegaai, Mkondvo and Maputo Rivers (Table 5-1). For each of these sites a level 4 VEGRAI was conducted. The results are summarised in Table 5-2.

Table 5-1 EFR sites with some detail.

EFR site no	***Site name***	***South***	***East***	***Quat[1]***	***EcoRegion II***	***Geomorphic zone***	***Altitude (m)***
EFR JMB1	*Lower Ngwempisi*	*26°41.832*	*31°22.26*	*W53G*	*4.06*	*Lower Foothills*	*361*
EFR JMB2	*Assegaai*	*27°03.737*	*30°59.323*	*W51D*	*4.06*	*Lower Foothills*	*1012*
EFR JMB3	*Lower Mkondvo*	*26°42.438*	*31°24.833*	*W51H*	*4.06*	*Lower Foothills*	*327*
EFR JMB4	*Maputo*	*26°48.0*	*32°26.797*	*W70CX*	*Not available*	*Lowland River*	*19*

1 Quaternary

Table 5-2 Summary of VEGRAI assessments for EFR sites.

EFR site no	***Site name***	***VEGRAI Score (%)***	***Category***
EFR JMB1	*Lower Ngwempisi*	68.2	C
EFR JMB2	***Assegaai***	***69.5***	***C***
EFR JMB3	***Lower Mkondvo***	***67.8***	***C***
EFR JMB4	***Maputo***	***69.0***	***C***

In May 2008 all existing data for the WMA was assessed for quality and extensiveness and summarise in a report called the “The ecological state of rivers (and wetlands) in the Usutu to Mhlatuze Water Management Area Phase 1: Inventory and Gap Analysis”. In that report national and priority wetlands were defined and outlined but the riparian data from the Joint Maputo Basin Study did not seem to be included. This report also contains and extensive list of references pertaining to the WMA but almost all vegetation-related literature refers to floodplains or wetlands with little to no coverage of riparian areas specifically.

In January 2011, the catchment of the entire Mfolozi (including upper reaches of the Black and White Mfolozi) was driven though in order to describe the present ecological state and ecological importance and sensitivity of the systems therein.

5.4 Description of the EWR sites

See

Figure 1-1 for a map showing the location of the EWR sites. At each site the riparian zone was delineated (DWAF 2008) to determine the upper limits of the assessment and the longitudinal limits of the assessment were determined by the variability and complexity of each site: each site for a VEGRAI assessment should be large enough to effectively represent the riparian vegetation variability and complexity.

5.4.1 Assegaai River (EWR Site AS1)

The extent of the assessment area for VEGRAI at the Assegaai River is shown in Figure 5-3 and a photograph showing typical riparian vegetation in Figure 5-4.

Figure 5-3 Extent of VEGRAI assessment area at the Assegaai River (upstream and downstream limits of site indicated by red lines)

Figure 5-4 Typical riparian vegetation at the Assegaai River, dominated by marginal and lower zone grasses, Cape Willow and Wattle.

5.4.2 Upper Pongola River (Site UP1)

The extent of the assessment area for VEGRAI at the Upper Pongola River is shown in Figure 5-5 and a photograph showing typical riparian vegetation in Figure 5-6.

Figure 5-5 **Extent of VEGRAI assessment area at the Upper Pongola River (upstream and downstream limits of site indicated by red lines).**

Figure 5-6 **Typical riparian vegetation at the Upper Pongola River, dominated by marginal and lower zone grasses and reeds, Cape Willow, Wattle, Sweet Thorn and upper zone grasses.**

5.4.3 Mkuze River (EWR Site MK1)

The extent of the assessment area for VEGRAI at the Mkuze River is shown in Figure 5-7 and a photograph showing typical riparian vegetation in Figure 5-8.

Figure 5-7 **Extent of VEGRAI assessment area at the Mkuze River (upstream and downstream limits of site indicated by red lines).**

Figure 5-8 **Typical riparian vegetation at the Mkuze River, dominated by marginal zone reeds and tall woody species forming riparian forest.**

5.4.4 Black Mfolozi (EWR Site BM1)

The extent of the assessment area for VEGRAI at the Black Mfolozi River (EWR Site BM1) is shown in Figure 5-9 and a photograph showing typical riparian vegetation in Figure 5-10.

Figure 5-9 Extent of VEGRAI assessment area at the Black Mfolozi (EWR Site BM1) River (upstream and downstream limits of site indicated by red lines)

Figure 5-10 Typical riparian vegetation at the Black Mfolozi River (EWR Site BM1), dominated by grass, reeds and sedges and a woody upper zone (not seen).

5.4.5 Black Mfolozi (EWR Site BM2)

The extent of the assessment area for VEGRAI at the Black Mfolozi (EWR Site BM2) River is shown in Figure 5-11 and a photograph showing typical riparian vegetation in Figure 5-12.

Figure 5-11 Extent of VEGRAI assessment area at the Black Mfolozi (EWR Site BM2) River (upstream and downstream limits of site indicated by red lines).

Figure 5-12 Typical riparian vegetation at the Black Mfolozi (EWR Site BM2) dominated by open bedrock with patches of hydrophilic grasses and sedges.

5.4.6 White Mfolozi (EWR Site WM1)

The extent of the assessment area for VEGRAI at the White Mfolozi River is shown in Figure 5-13 and a photograph showing typical riparian vegetation in Figure 5-14.

Figure 5-13 Extent of VEGRAI assessment area at the White Mfolozi River (upstream and downstream limits of site indicated by red lines).

Figure 5-14 Typically riparian vegetation was sparse at the White Mfolozi River with scattered grasses, sedges and a few riparian trees, mostly in shrub form.

5.4.7 Nseleni

The extent of the assessment area for VEGRAI at the Nseleni River is shown in Figure 5-15 and a photograph showing typical riparian vegetation in Figure 5-16.

Figure 5-15 Extent of VEGRAI assessment area at the Nseleni River (upstream and downstream limits of site indicated by red lines)

Figure 5-16 Typical riparian vegetation at the Nseleni River comprised dense woody mostly closed canopy forest and riparian trees (such as Wild Fig) with the channel well shaded.

5.4.8 Matigulu (EWR Site MA1)

The extent of the assessment area for VEGRAI at the Matigulu River is shown in Figure 5-17 and a photograph showing typical riparian vegetation in Figure 5-18.

Figure 5-17 Extent of VEGRAI assessment area at the Matigulu River (upstream and downstream limits of site indicated by red lines)

Figure 5-18 Typical riparian vegetation at the Matigulu River included grasses, sedges and reeds with scattered trees within the macro channel floor and more dense trees along the banks (background).

5.5 Ecoclassification of river reaches represented by the EWR sites

The ecological classification of EWR sites was done using VEGRAI level 4 (Kleynhans *et al.* 2007).

5.5.1 Assegaai River (EWR Site AS1)

Riparian vegetation: PES: C (69.9%), Confidence: 3.2

5.5.1.1 General Vegetation Overview

The site occurs within Ithala Quartzite Sourveld which refers to a terrestrial vegetation type within the Grassland Biome (Mucina and Rutherford 2006).

5.5.1.2 Reference State

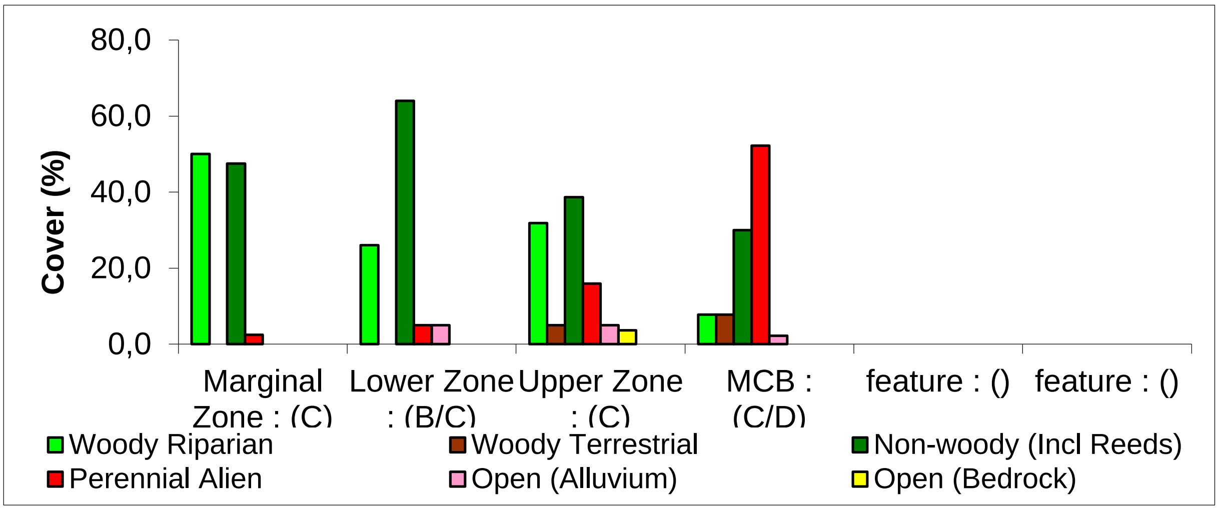
Aerial photographs from 1961 to 2013 show a slight increase in woody cover in places, while Google Earth images © show no noticeable change since 2009. The expected reference condition is likely to have been dominated by non-woody riparian vegetation such as grasses, sedges and reeds with scattered clumps of woody, trees and shrubs, particularly along banks and upper zone alluvial features.

5.5.1.3 Present State

Overall riparian vegetation cover at the Assegaai River is shown in Figure 5-19 and summary VEGRAI score in Table 5-3. Sub-zones are described below:

The marginal zone was dominated by a mixture of woody and non-woody vegetation, mostly dense; a likely response to flow regulation and reduced flooding disturbance (with Heyshope Dam upstream). Woody vegetation was dominated by *Salix mucronata* while non-woody vegetation was dominated by reeds, sedges and grasses. *Salix mucronata* provides good overhanging cover for instream fauna, as does *Ishaemum fasiculatum* which grows into the water. *Gomphostigma virgatum* was absent at the site, possibly due to competition (shading) from *S. mucronata*, again a likely response to flow regulation.

The lower zone consisted mostly of dense non-woody vegetation but with a dense band of *S. mucronata* along the stream side. Species were similar to the marginal zone with the addition of *Cynodon dactylon*. *Syzygium* species were absent in the zone.



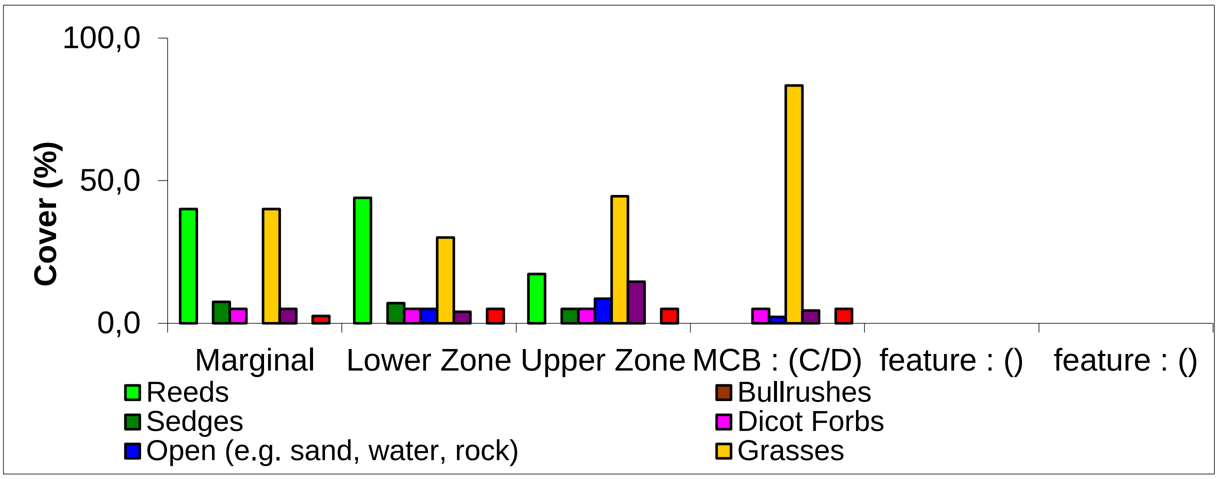


Figure 5-19 Graphical representation of woody (above) and non-woody (below) riparian vegetation cover at the Assegaai River (letters in brackets indicate the sub-zone Ecostatus score where applicable).

The upper zone consisted of a floodplain area with several high flow channels and backwater areas. Vegetation comprised a mix of woody and non-woody vegetation but dominated by woody vegetation with different species from the marginal and lower zones: Dominant woody species were *Searsia gerarrdii* and *Combretum erythrophyllum*. Perennial alien species such as *Sesbanea punicea* and *Acacia mearnsii* were present but with low cover (5%) of the zone. Recent flood damage was evident, but density of woody cover suggests the reduction of flooding disturbance in the flow regime. *Ziziphus mucronata* and *Syzygium* species were absent.

The bank was dominated by woody vegetation, mostly thicket, with some open grassland in places. Perennial alien species had invaded the banks with up to 50% cover in places. Dominant species were *A. mearnsii, A. melanoxylon, A. caffra, Lantana camara* and *Diospyros lyceoides*. *Ziziphus mucronata* was absent. Some wood harvesting was prevalent.

5.5.1.4 Trend

The trend is not likely stable as, if left unchecked, alien perennial species are likely to increase in cover and abundance.

Table 5-3 Summary detail of level 4 VEGRAI for the Assegaai River

LEVEL 4 ASSESSMENT		Assegaai River			26 November 2013	
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	76.9	6.2	3.2	1.0	8.0	Weighted according to extent
Lower Zone	78.5	9.4	3.0	2.0	12.0	Weighted according to extent
Upper Zone	70.5	42.3	3.4	3.0	60.0	Weighted according to extent
MCB	60.2	12.0	3.4	4.0	20.0	Weighted according to extent
feature	not assessed			5.0		
feature	not assessed			6.0		
LEVEL 4 VEGRAI (%)				69.9		
VEGRAI EC				**C**		
AVERAGE CONFIDENCE				3.2		

				Zone		
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**feature**	**feature**
VEGRAI % (Zone)	76.9	78.5	70.5	60.2	not assessed	not assessed
EC (Zone)	**C**	**B/C**	**C**	**C/D**		
Confidence (Zone)	3.2	3.0	3.4	3.4		

5.5.2 Upper Pongola River (EWR Site UP1)

Riparian vegetation: PES: C (70.0%), Confidence: 3.2

5.5.2.1 General Vegetation Overview:

The site occurs within Swaziland Sour Bushveld which refers to a terrestrial vegetation type within the Savanna Biome (Mucina and Rutherford 2006).

5.5.2.2 Reference State:

Aerial photographs from 1961 to 2013 show no noticeable change in woody cover. Similarly, Google Earth images © show no noticeable change since 2006. The expected reference condition is likely to have been dominated by a mix of woody and non-woody riparian vegetation.

5.5.2.3 Present State:

Overall riparian vegetation cover at the Upper Pongola River is shown in Figure 5-20 and summary VEGRAI scores in Table 5-4. Sub-zones are described below.

The marginal zone was dominated by non-woody vegetation but with the presence of *Salix mucronata*. *Gomphostigma virgatum* was absent. It consisted of a narrow band of vegetation with both alluvium and cobble. Dominant species were *P. australis, I. fasiculatum, C. longus, P. senegalensis* and *S. mucronata*. *Cyperus marginatus* and *Breonadia salicina* were absent from the site. Some weed species occured but in low abundance.

The lower zone was similar to the marginal zone with the addition of a few species, notably *Cynodon dactylon* and *Cyperus dives*. Perennial alien cover was between 10-20%, mainly *Sesbanea punicea*. *Syzygium* and *B. salicina* were absent from the site.

The upper zone consisted of mixed alluvium and cobble bars with mostly small woody vegetation displaying flood damage from recent floods. Alien invasion was high with up to 10% cover by *Sesbanea punicea* and *Lantana camara*. Non-woody ground cover was good. Some grazing occured and some wood harvesting was evident. *Ziziphus mucronata* and *A. karoo* were absent (may be an indication of harvesting).

The bank was dominated by woody vegetation, mostly *A. ataxycantha* and *Faurea saligna*. Cover of perennial aliens was around 20% with *M. azedarach, A. mearnsii* and *Eucalyptus* all present. Expect to find more *A. karoo* and *Spirostachys africana* was absent. Some erosion was evident and wood harvesting occurred.

5.5.2.4 Trend

The trend is not likely stable as, if left unchecked, alien perennial species are likely to increase in cover and abundance.

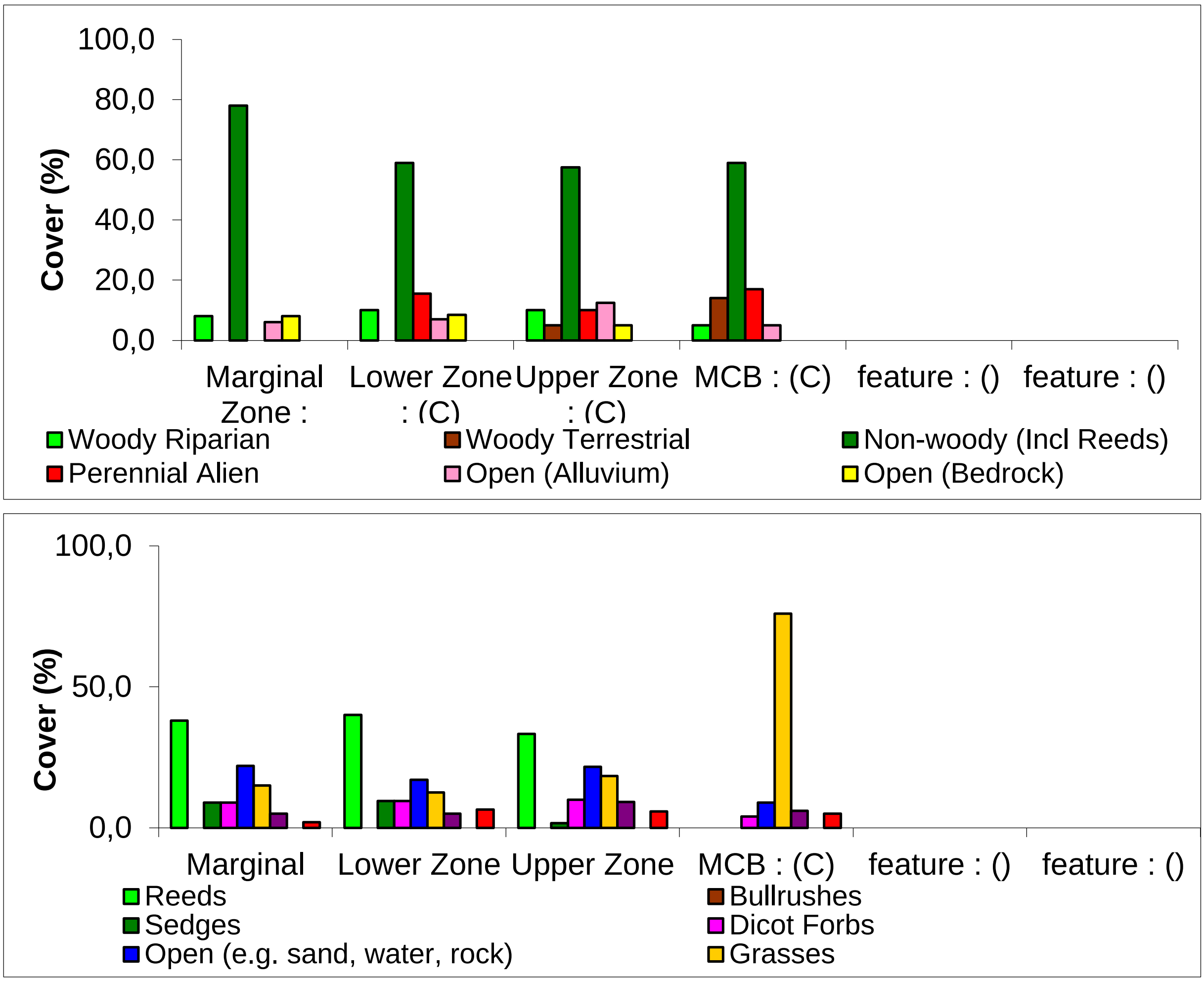


Figure 5-20 Graphical representation of woody (above) and non-woody (below) riparian vegetation cover at the Upper Pongola River (letters in brackets indicate the sub-zone Ecostatus score where applicable).

Table 5-4 Summary detail of level 4 VEGRAI for the Upper Pongola River.

LEVEL 4 ASSESSMENT	Upper Pongola River			27 November 2013		
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	79.0	5.6	3.1	1.0	7.1	Weighted according to extent
Lower Zone	77.0	8.3	3.0	2.0	10.7	Weighted according to extent
Upper Zone	67.0	7.2	3.3	3.0	10.7	Weighted according to extent
MCB	68.5	49.0	3.4	4.0	71.4	Weighted according to extent
feature	not assessed			5.0		
feature	not assessed			6.0		
LEVEL 4 VEGRAI (%)				70.0		
VEGRAI EC				**C**		
AVERAGE CONFIDENCE				3.2		

	Zone					
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**feature**	**feature**
VEGRAI % (Zone)	79.0	77.0	67.0	68.5	not assessed	not assessed
EC (Zone)	**B/C**	**C**	**C**	**C**		
Confidence (Zone)	3.1	3.0	3.3	3.4		

5.5.3 Mkuze River (EWR Site MK1)

Riparian vegetation: PES: C (73.0%), Confidence: 3.2

5.5.3.1 General Vegetation Overview

The site occurs within Lowveld Riverine Forest, a critically endangered but well protected Vegetation Type specifically riparian in nature. Lowveld Riverine Forest consists of tall dense forests fringing larger rivers where it forms gallery forest, frequently dominated by *Ficus sycomorus* and *Diospyros mespiliformis* (Mucina and Rutherford 2006).

5.5.3.2 Reference State

Aerial photographs from 1942 to 2013 show an increase in woody vegetation in places but reductions in others. Large events such as Demoina have had severe impacts and resulted in interesting vegetation (and channel) shifts. Google Earth images © since 2003 show a marked increase in woody cover in areas that were denuded but no change in areas that were already dense with woody vegetation. The expected reference condition is in keeping with the Vegetation Type: tall, dense galley forest.

5.5.3.3 Present State

Summary VEGRAI scores for the Mkuze are shown in Table 5-5. Sub-zones are described below:

The marginal zone was dominated by sandy features with two dominant vegetation types: dense woody, tall vegetation which overhangs into the water; and non-woody grass / sedge bars. Woody vegetation was mainly *Ficus sycomorus, F. caprefolia* and *A. sweinfurthii*. Non-woody vegetation was dominated by *Phragmites mauritianus, Arundinella napalensis* and *Ishaemum fasiculatum* which grew into the water. *Syzygium* was absent.

The lower zone consisted of densely vegetated unconsolidated alluvial deposits. Dominated by woody vegetation similar to the marginal zone, reed clumps and grass / sedge bars. *Syzygium* and *C. erythrophyllum* were absent.

The upper zone was similar to the lower zone but with less reeds and non-woody vegetation and taller more dense woody vegetation. Wood harvesting was prevalent.

The MCB consisted mostly of unconsolidated alluvium with 40-50% woody cover and 30-40% reeds and grass. Species and habitats were similar to the upper zone.

The floodplain was extensive and consisted of a mixture of tall trees with closed canopy and tall tree and shrub more open and scattered. *Ficus sycomorus* and *Acacia xanthophloea* dominated and *S. aficanus, F. albida* and *D. mespiliformis* were absent. Alien invasion was high (20-40% in places) and patchy i.e. related to disturbance. The floodplain was extensively disturbed, cleared and cultivated. Wood harvesting was intense as was grazing and browsing.

5.5.3.4 Trend

Despite the presence of aliens in the floodplain the trend is likely stable since much of the ecostatus score is related to the high level of clearing and disturbance on the floodplain. Should this stabilize or reduce the overall condition may even improve.

Table 5-5 Summary detail of level 4 VEGRAI for the Mkuze River

LEVEL 4 ASSESSMENT	**Mkuze River**			**30 November 2013**		
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	84.5	16.9	3.2	1.0	100.0	Weighted according to extent
Lower Zone	81.4	16.3	3.0	2.0	100.0	Weighted according to extent
Upper Zone	80.2	16.0	3.0	3.0	100.0	Weighted according to extent
MCB	80.0	16.0	3.3	4.0	100.0	Weighted according to extent
Floodplain	38.9	7.8	3.4	5.0	100.0	Weighted according to extent
feature	not assessed			6.0		

LEVEL 4 VEGRAI (%)	73.0
VEGRAI EC	**C**
AVERAGE CONFIDENCE	3.2

	Zone					
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**Floodplain**	**feature**
VEGRAI % (Zone)	84.5	81.4	80.2	80.0	38.9	not assessed
EC (Zone)	**B**	**B/C**	**B/C**	**B/C**	**D/E**	
Confidence (Zone)	3.2	3.0	3.0	3.3	3.4	

5.5.4 Black Mfolozi River ((EWR Site BM1)

Riparian vegetation: PES: C (74.9%), Confidence: 3.2

5.5.4.1 General Vegetation Overview

The site occurs within Northern Zululand Sourveld which refers to a terrestrial vegetation type within the Savanna Biome (Mucina and Rutherford 2006).

5.5.4.2 Reference State

Aerial photographs from 1943 to 2014 show no noticeable change in woody cover. The expected reference condition is likely to have been dominated by a mix of woody and non-woody riparian vegetation.

5.5.4.3 Present State

Overall riparian vegetation cover at the Black Mfolozi River is shown in Figure 5-21 and summary VEGRAI scores in Table 5-6. Sub-zones are described below:

The marginal zone was dominated by non-woody vegetation, but *Salix mucronata* was expected and appeared missing. Recent large flood disturbance was evident at the time of assessment. Reeds dominated pools and quiet areas, while sedges and grasses dominated elsewhere. Sedge and grass clumps also occured instream and were associated with cobble outcrops. *Breonadia salicina* was also absent.

The lower zone was dominated by non-woody vegetation, mainly grasses and sedges with some reeds near pools areas. All woody individuals were small, damaged or stunted and mostly alien. *Sesbanea* and *Lantana* cover was up to 20% in places and many weed species were present. *Syzygium guineense* and *Combretum erythrophyllum* were absent, although the latter was present in the upper zone. Grazing pressure and plant harvesting was high.

The upper zone was dominated by non-woody vegetation but wood remnants were visible. The prevalence of terrestrial woody (such as *D. cinerea* and *A. sieberiana*) and alien (*Sesbanea*, *Lantana* and *Melia*) species was high. Harvesting and overgrazing occured. Bedrock features were mostly clear of vegetation. Few individuals of *F. sycomorus, S. cordatum* and *C. erythrophyllum* existed and *S. guineense* was absent.

The MCB was dominated by thick and encroached woody vegetation, mainly terrestrial species. Dominant species were *C. erythrophyllum* and *A. sieberiana* and *S. africana* was absent. The RB comprised alluvium while the LB consisted predominantly of bedrock.

5.5.4.4 Trend

The trend is not likely stable as, if left unchecked, alien perennial species are likely to increase in cover and abundance.

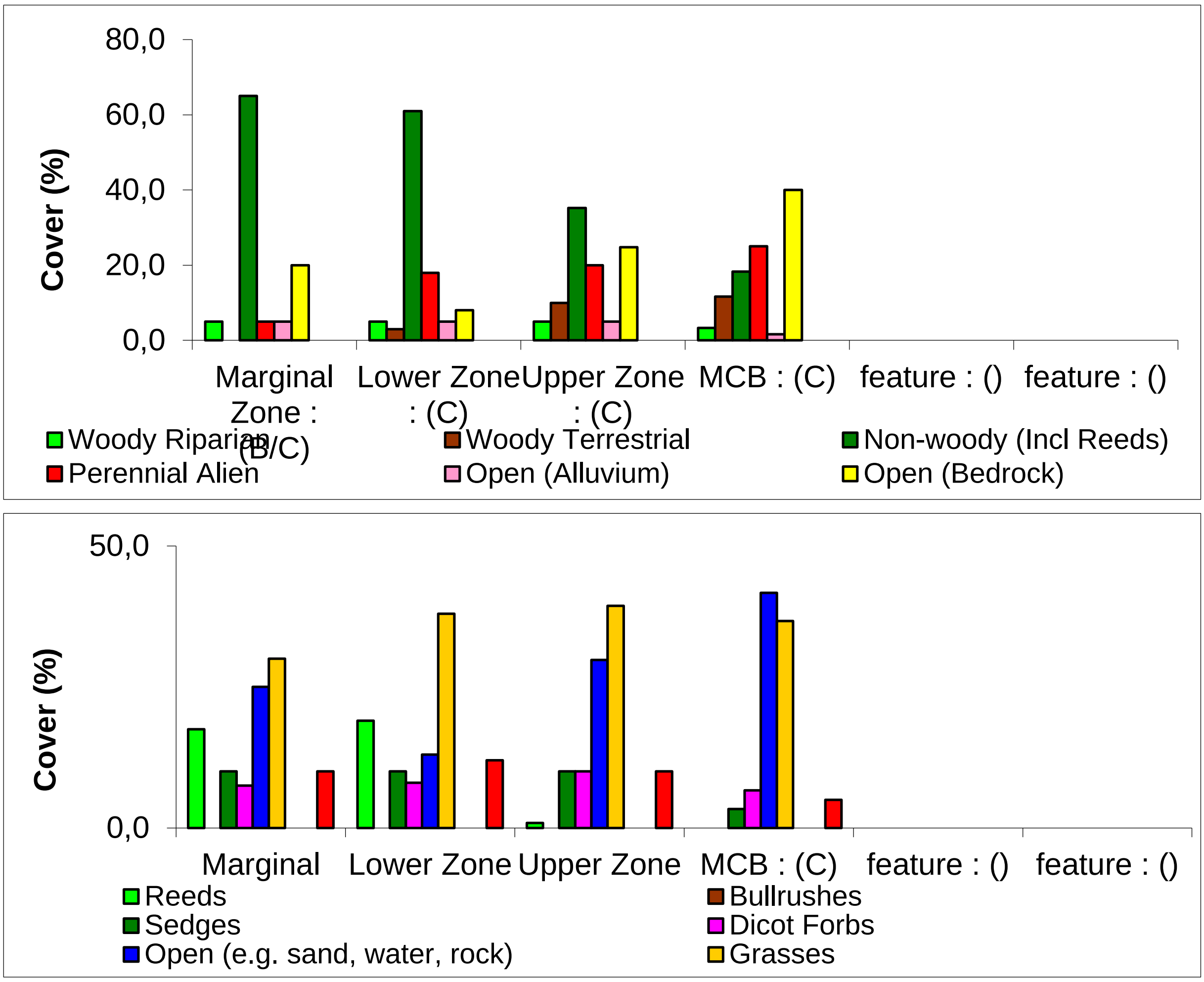


Figure 5-21 **Graphical representation of woody (above) and non-woody (below) riparian vegetation cover at the Black Mfolozi River (letters in brackets indicate the sub-zone Ecostatus score where applicable).**

Table 5-6 Summary detail of level 4 VEGRAI for the Black Mfolozi River ((EWR Site BM1)

LEVEL 4 ASSESSMENT	**Black Mfolozi River**			**28 November 2013**		
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	80.1	5.0	3.2	1.0	6.3	Weighted according to extent
Lower Zone	76.8	7.2	3.0	2.0	9.4	Weighted according to extent
Upper Zone	74.9	44.5	3.4	3.0	59.4	Weighted according to extent
MCB	72.9	18.2	3.4	4.0	25.0	Weighted according to extent
feature	not assessed			5.0		
feature	not assessed			6.0		
LEVEL 4 VEGRAI (%)				74.9		
VEGRAI EC				**C**		
AVERAGE CONFIDENCE				3.2		
				Zone		
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**feature**	**feature**
VEGRAI % (Zone)	80.1	76.8	74.9	72.9	not assessed	not assessed
EC (Zone)	**B/C**	**C**	**C**	**C**		
Confidence (Zone)	3.2	3.0	3.4	3.4		

5.5.5 Black Mfolozi River ((EWR Site BM2)

The second site on the Black Mfolozi was similar to the first in terms of vegetation, just with more influence by bedrock. Summary VEGRAI scores are shown in Table 5-7.

Table 5-7 Summary detail of level 4 VEGRAI for the Black Mfolozi River ((EWR Site BM2)

LEVEL 4 ASSESSMENT	Black Mfolozi River				28 November 2013	
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	84.5	5.3	3.2	1.0	6.3	Weighted according to extent
Lower Zone	76.8	7.2	3.0	2.0	9.4	Weighted according to extent
Upper Zone	74.9	44.5	3.4	3.0	59.4	Weighted according to extent
MCB	78.8	19.7	3.4	4.0	25.0	Weighted according to extent
feature	not assessed			5.0		
feature	not assessed			6.0		
LEVEL 4 VEGRAI (%)				76.7		
VEGRAI EC				**C**		
AVERAGE CONFIDENCE				3.2		
				Zone		
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**feature**	**feature**
VEGRAI % (Zone)	84.5	76.8	74.9	78.8	not assessed	not assessed
EC (Zone)	**B**	**C**	**C**	**B/C**		
Confidence (Zone)	3.2	3.0	3.4	3.4		

5.5.6 White Mfolozi River (EWR Site WM1)

Riparian vegetation: PES: B/C (81.3%), Confidence: 3.2

5.5.6.1 General Vegetation Overview

The site occurs within Northern Zululand Sourveld which refers to a terrestrial vegetation type within the Savanna Biome (Mucina and Rutherford 2006).

5.5.6.2 Reference State

Aerial photographs from 1937 to 2011 show no noticeable change in woody cover. The expected reference condition is likely to have been dominated by a mix of woody and non-woody riparian vegetation with the addition of kloof species as the reach passes through the gorge.

5.5.6.3 Present State

Overall riparian vegetation cover at the White Mfolozi River is shown in Figure 5-22 and summary VEGRAI scores in Table 5-8. Sub-zones are described below:

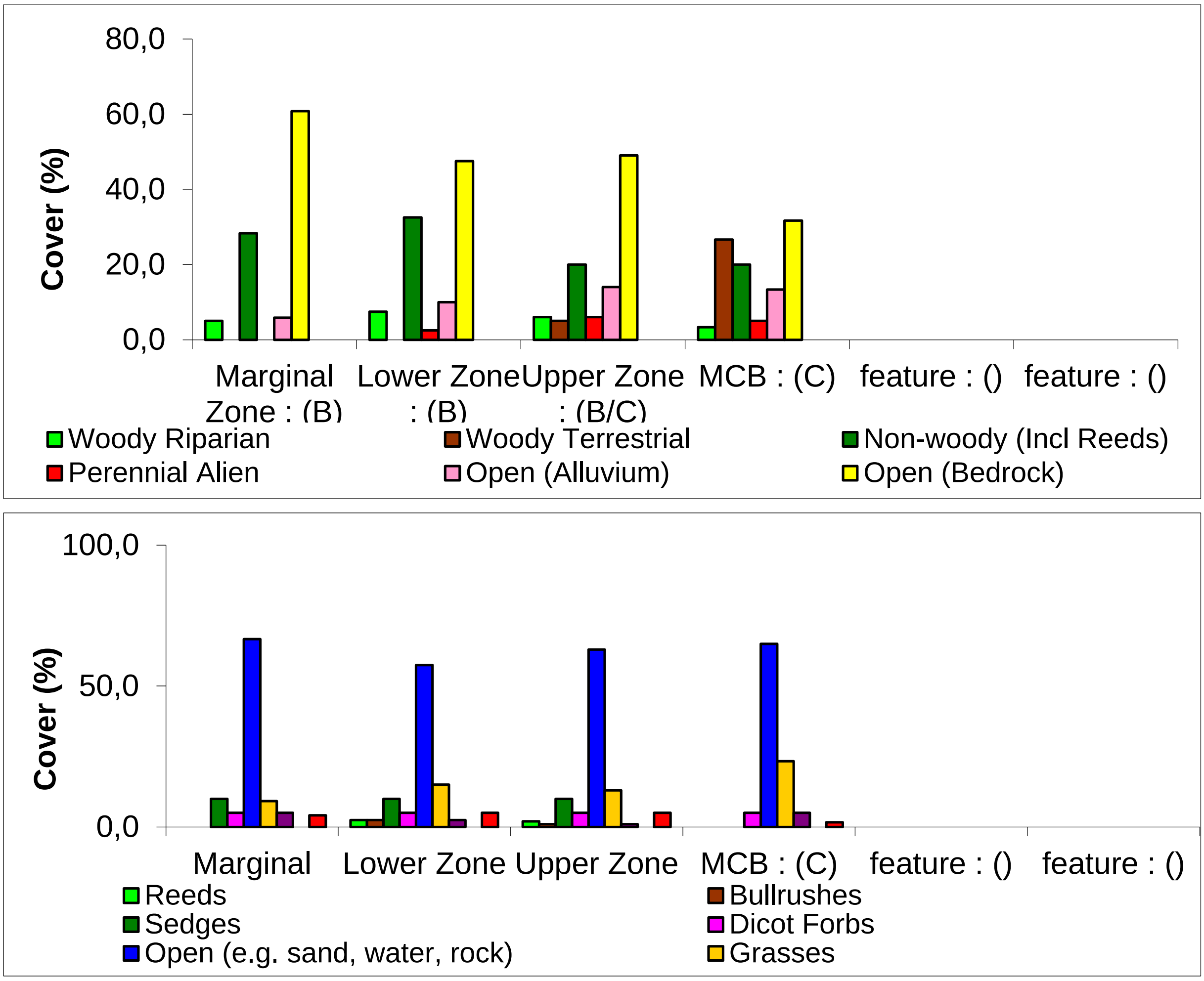


Figure 5-22 Graphical representation of woody (above) and non-woody (below) riparian vegetation cover at the White Mfolozi River (letters in brackets indicate the sub-zone Ecostatus score where applicable).

Table 5-8 Summary detail of level 4 VEGRAI for the White Mfolozi River.

LEVEL 4 ASSESSMENT	White Mfolozi River			29 November 2013		
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	84.1	21.0	3.1	1.0	25.0	Weighted according to extent
Lower Zone	84.8	12.7	3.0	2.0	15.0	Weighted according to extent
Upper Zone	80.1	40.0	3.3	3.0	50.0	Weighted according to extent
MCB	75.6	7.6	3.3	4.0	10.0	Weighted according to extent
feature	not assessed			5.0		
feature	not assessed			6.0		
LEVEL 4 VEGRAI (%)				81.3		
VEGRAI EC				**B/C**		
AVERAGE CONFIDENCE				3.2		

			Zone			
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**feature**	**feature**
VEGRAI % (Zone)	84.1	84.8	80.1	75.6	not assessed	not assessed
EC (Zone)	**B**	**B**	**B/C**	**C**		
Confidence (Zone)	3.1	3.0	3.3	3.3		

The marginal zone was scoured from recent floods at the time of the assessment. The zone was dominated by non-woody species, mostly sedges and grasses, but was mostly open cobble. Cattle on site indicate that grazing takes place but the site is remote within a gorge.

The lower zone was dominated by non-woody vegetation with scattered woody individuals and alien cover low (<10%). Vegetation had been recently scoured from floods. Dominant species similar to the marginal zone (grasses and sedges) but with *Nuxia oppositifolia, S. cordatum, S. gueneense, F. sur* and *P. reclinata*. *B. salicina* was absent.

The upper zone was similar to the lower zone.

The MCB was dominated by woody vegetation or open bedrock and is within a gorge environment with a cliff and bedrock. *Spirostachys africana* is absent.

5.5.6.4 Trend

The trend is likely stable.

5.5.7 Nseleni River (EWR Site NS1)

Riparian vegetation: PES: C (64.4%), Confidence: 3.2

5.5.7.1 General Vegetation Overview

The site occurs within Zululand Coastal Thornveld, which refers to a terrestrial vegetation type within the Savanna Biome (Mucina and Rutherford 2006).

5.5.7.2 Reference State

Aerial photographs from 1957 to 2014 show an increase in woody cover, especially where agriculture has pulled back off the river environment, a trend also apparent from Google Earth © imagery since 2004. The expected reference condition is likely to have been dominated by dense woody vegetation with the addition of kloof species.

5.5.7.3 Present State

Summary VEGRAI scores for the Nseleni River are shown in Table 5-9. Sub-zones are described below:

The marginal zone was mostly well shaded with steep banks where pools exist or else cobble areas with undercut roots. Instream root habitat and overhanging vegetation were dominant. The sub-zone was dominated by woody vegetation but where sunny more open areas exist, grasses and sedges occurred. A small amount of clearing existed for the crossing, otherwise impacts were low. Dominant species *included F. sycomorus, P. reclinata, C. sexangularis, I. fasiculatum* and *Stenotaphrum. Syzygium* and *G. virgatum* were absent.

The lower zone consisted mostly of mud banks that are well shaded and exposed roots were common. Some areas of cobble bed that are more open existed and were covered by grasses and sedges. Woody vegetation, frequently tall, with a closed canopy dominated and vegetation characteristics were similar to the marginal zone. *Nuxia oppositifolia* was also a lower zone dominant, in addition to the species found on the marginal zone. *Syzygium* was absent.

The upper zone consisted of steep alluvial banks with dense woody cover. The tree and shrub layer was closed canopy and shades out the understorey. Where areas have been cleared for access alien species have heavily invaded (mostly *Chromolaena odorata* and *Lipia*). *Syzygium* and *Combretum* were absent.

The banks were steep, dominated by woody vegetation and merge with terrestrial forest (kloof vegetation). Overall an effective riparian corridor existed (dense woody belt dominated by indigenous vegetation), but alien species invasion was high in cleared areas. The banks had been extensively cleared along security fences of property and for limited access to the river. *Ilex mitis* was not observed at the site.

5.5.7.4 Trend

The trend is likely stable, especially in areas that have not been cleared.

Table 5-9 Summary detail of level 4 VEGRAI for the Nseleni River.

LEVEL 4 ASSESSMENT	**Nseleni River**				**01 December 2013**	
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	85.0	6.1	3.1	1.0	7.1	Weighted according to extent
Lower Zone	78.1	8.4	3.3	2.0	10.7	Weighted according to extent
Upper Zone	61.8	6.6	3.1	3.0	10.7	Weighted according to extent
MCB	60.6	43.3	3.4	4.0	71.4	Weighted according to extent
feature	not assessed			5.0		
feature	not assessed			6.0		
LEVEL 4 VEGRAI (%)				64.4		
VEGRAI EC				**C**		
AVERAGE CONFIDENCE				3.2		

				Zone		
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**feature**	**feature**
VEGRAI % (Zone)	85.0	78.1	61.8	60.6	not assessed	not assessed
EC (Zone)	**B**	**B/C**	**C/D**	**C/D**		
Confidence (Zone)	3.1	3.3	3.1	3.4		

5.5.8 Matigulu River (EWR Site MA1)

Riparian vegetation: PES: B/C (79.4%), Confidence: 3.0

5.5.8.1 General Vegetation Overview

The site occurs within KwaZulu-Natal Coastal Belt which refers to a terrestrial vegetation type within the Indian Ocean Coatal Belt Biome (Mucina and Rutherford 2006).

5.5.8.2 Reference State

Aerial photographs from 1937 to 2013 show no noticeable trending change in woody cover other than localized oscillatory dynamics probably associated with large flooding events. Google Earth Imagery © since 2009 also show no evidence of trending changes to vegetation. The expected reference condition is likely to have been dominated by a mix of woody and non-woody riparian vegetation.

5.5.8.3 Present State

Summary VEGRAI scores for the Matigulu River are shown in Table 5-10. Sub-zones are described below:

The marginal zone was dominated by non-woody vegetation, mostly reeds, sedges and grasses, with high vegetative cover. The sub-zone was mostly cobble and boulder with some alluvial deposits. Dominant habitats included grass in the water (*Ishaemum*), sedge and grass banks and reed clumps in the water. Impacts were low, with cattle at the site (no overgrazing prevalent), low prevalence of aliens and no large dams upstream. Water abstraction and farm dams would have reduced flow however and resulted in some regulation.

The lower zone was dominated by non-woody vegetation but with scattered prevalence of *Syzygium gerrardii, S. cordatum* and *Ficus sycomorus*. Grasses dominated but common habitats included reed beds (patches) and cobble sedge / grass bars. *S. guieneense, B. salicina* and *C. erythrophyllum* were absent.

The upper zone consisted of mixed woody and non-woody vegetation with a distinct absence of tall trees. This may be due to recent large floods or wood harvesting. *C. erythrophyllum*, large *Ficus* and *T. emetica* were absent.

Table 5-10 Summary detail of level 4 VEGRAI for the Matigulu River.

LEVEL 4 ASSESSMENT	Matigulu River			02 December 2014		
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
Marginal Zone	85.4	6.1	3.1	1.0	7.1	Weighted according to extent
Lower Zone	79.8	8.6	2.8	2.0	10.7	Weighted according to extent
Upper Zone	69.3	7.4	2.8	3.0	10.7	Weighted according to extent
MCB	80.3	57.4	3.3	4.0	71.4	Weighted according to extent
feature	not assessed			5.0		
feature	not assessed			6.0		
LEVEL 4 VEGRAI (%)				79.4		
VEGRAI EC				**B/C**		
AVERAGE CONFIDENCE				3.0		

				Zone		
	Marginal Zone	**Lower Zone**	**Upper Zone**	**MCB**	**feature**	**feature**
VEGRAI % (Zone)	85.4	79.8	69.3	80.3	not assessed	not assessed
EC (Zone)	**B**	**B/C**	**C**	**B/C**		
Confidence (Zone)	3.1	2.8	2.8	3.3		

The MCB was mostly steep, dominated by woody vegetation and the prevalence of terrestrial species was high. This suggests reduced flooding disturbance. Woody vegetation was dominated by *Acacia* species, while *S. africana* was absent.

5.5.8.4 Trend

The trend is likely stable.

5.6 Identification of indicators

1.1.3 Indicator list for vegetation

A list of species/features and their reason for selection as indicators in the EWR assessments is given in Table 5-11. Their expected responses to flow changes are outlined in Table 5-11.

Table 5-11 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Algae	Algae provide food for instream fauna (fish and inverterbrates) and affect habitat quality.
Marginal zone graminoids	This guild includes grasses, sedges and reeds and is important for bank stabilisation, habitat creation for aquatic fauna (both inundated instream and overhanging vegetation) and for food (seeds, fruits, rotting leaf material).
Marginal zone trees	Marginal zone trees are important for bank stabilization, flood attenuation and provide overhanging shelter to instream fauna, particularly fish.
Lower zone graminoids	Like marginal zone graminoids this guild includes grasses, sedges and reeds growing in the lower zone. Non-woody vegetation in this zone is important for bank stabilization, grazing for animals and birds, and food and habitat for fish spawning during flooding.
Lower zone trees	Lower zone trees are important for bank stabilization, flood attenuation and the provision of food and habitat (including nesting sites) for riparian fauna.
Upper zone trees – riparian	Same function as lower zone trees but often more extensive in area and density and hence importance is elevated.
Upper zone trees – terrestrial	Terrestrialzation of the riparian zone occurs naturally to some extent but is kept at bay by the correct flooding regime, which affords the competitive edge to riparian trees. This indicator may be used as an integrity check for riparian zone structure and function.

Table 5-12 List of vegetation indicators and their predicted direction of response to flow changes.

Indicator	Definition	Predicted change	References
Algae	Aquatic, filamentous or benthic, green or brown.	Algae is favoured by reduced water depth and velocity. Higher flows and floods tend to scour the indicator.	Dallas and Day (2004).
Marginal zone graminoids	Grasses, sedges or reeds growing in the marginal zone	Winter base flows are important for survival while summer base flows for growth and reproduction. Small floods and freshets produce growth response and maintain reproductive success. Moderate to large floods will scour the indicator. Limited by water requirements and maximum rooting depths.	Canadell *et al*, (1996).
Marginal zone trees	Trees or shrubs growing in the marginal zone.	Winter base flows are important for survival while summer base flows for growth and reproduction. Small floods and freshets produce growth response and maintain reproductive success. Moderate to large floods will scour the indicator. Limited by water requirements and maximum rooting depths.	Canadell *et al*, (1996).
Lower zone graminoids	Grasses, sedges or reeds growing in the	Winter base flows are important for survival while summer base flows for	Canadell *et al*, (1996).

Indicator	**Definition**	**Predicted change**	**References**
	lower zone	growth and reproduction. Small to moderate floods produce growth response and maintain reproductive success. Large floods will scour the indicator and zero flow will cause desiccation stress. Limited by water requirements and maximum rooting depths.	
Lower zone trees	Trees or shrubs growing in the lower zone.	Winter base flows are important for survival while summer base flows for growth and reproduction. Small to moderate floods produce growth response and maintain reproductive success. Large floods will scour the indicator and zero flow will cause desiccation stress. Limited by water requirements and maximum rooting depths.	Canadell *et al*, (1996).
Upper zone trees – riparian	Trees or shrubs growing in the upper zone that are by definition riparian.	Depth to soil moisture should not exceed 4-4.5m. Zero flows may result in desiccation stress. Large floods are important for the maintenance of species diversity and recruiting opportunities.	Friedman and Lee (2002). Lite and Stromberg (2005). Leenhouts *et al.*, (2005).
Upper zone trees – terrestrial	Trees or shrubs growing in the upper zone that are by definition terrestrial.	Terrestrialisation of the upper zone occurs naturally, but the correct flooding regime is required to retard the process and maintain riparian species. Large floods provide riparian species with the competitive advantage.	Friedman and Lee (2002).

5.6.1 Description and location of indicators

Detail pertaining to species representation within indicator guilds is shown in Table 5-13 and flooding ranges for each indicator at each site in Table 5-14.

Table 5-13 Species pool for each indicator guild, showing representivity at different EWR sites

Indicator guild	Flow clade	Response drought	Response floods	Species pool	IUCN Listing	Endemic	Wetland Obligate	Protected	Rip Ind*	Assegaai	Black Mfolozi	Matigulu	Mkuze	Nseleni	Upper Pongolo	White Mfolozi
Marginal zone graminoids	Obligate	Drought sensitive, stream permanency and intra-annual depth to ground water fluctuation important	Scoured if bank erodes; floods required for growth and reproductive response	Cyperus congestus	LC		y		4		y					
				Cyperus digitatus subsp. auricomus	LC		y		4						y	
				Cyperus dives	LC		y		4					y		
				Cyperus longus	LC		y		4	y		y			y	y
				Cyperus sexangularis	LC		y		4					y		
				Ischaemum fasciculatum	LC		y		4		y		y		y	
				Juncus dregeanus subsp. dregeanus	LC		y		4		y					
				Juncus effusus	LC		y		4	y	y				y	y
				Juncus exsertus	LC		y		4		y					
				Juncus lomatophyllus	LC		y		4		y					
				Juncus oxycarpus	LC		y		4		y	y				
				Juncus punctorius	LC		y		4		y					
Marginal zone trees	Obligate	Drought sensitive, stream permanency and intra-annual depth to ground water fluctuation important	Scoured if bank erodes; floods required for growth and reproductive response; removal by larger events ensures	Salix mucronata subsp. woodii	LC				4	y					y	y
				Syzygium cordatum subsp. cordatum	LC				4	y	y	y				y
				Syzygium gerrardii	LC				3			y				
				Syzygium guineense subsp. guineense	LC				4	y						y

Indicator guild	Flow clade	Response drought	Response floods	Species pool	IUCN Listing	Endemic	Wetland Obligate	Protected	Rip Ind*	Assegaai	Black Mfolozi	Matigulu	Mkuze	Nseleni	Upper Pongolo	White Mfolozi
			woody : non-woody mix													
Lower zone graminoids	Obligate	Phreatophyte, tolerant, persists but depends on stream permanency and depth to ground water	Scoured if bank erodes; floods required for growth and reproductive response	Arundinella nepalensis	LC		y		3	y					y	y
				Cyperus textilis	LC		y		3			y				
				Miscanthus junceus	LC	SnA	y		3	y					y	y
				Stenotaphrum secundatum	LC		y		3					y		
Lower zone trees	Obligate	Phreatophyte, tolerant, persists but depends on stream permanency and depth to ground water	Floods required for recruiting opportunities and to prevent dispersal to lower sub-zones	Combretum erythrophyllum	LC	y			3		y				y	
				Ficus sycomorus subsp. sycomorus	LC				3				y	y		
				Nuxia oppositifolia	LC				3	y		y				y
Upper zone / bank trees	Facultative	Phreatophyte, tolerant, persists but depends on stream permanency and depth to ground water	Floods required for recruiting opportunities and to prevent dispersal to lower sub-zones	Acacia gerrardii subsp. gerrardii var. gerrardii	LC				1				y	y		
				Acacia robusta subsp. clavigera	LC				1			y		y		
				Acacia sieberiana var. woodii	LC				1		y					
				Acacia xanthophloea	LC				2				y			
				Ficus capreifolia	LC				2				y			
				Ficus sur	LC				2	y		y				y
				Phoenix reclinata	LC				2					y		
				Trichilia emetica subsp. emetica	LC				2				y	y		

Riparian Indicator*:

0 = terrestrial, but can be found in riparian zone/wetland/floodplain

1 = preferential riparian species
2 = upper zone riparian obligate / floodplain species / wetland obligate (temporary zone)
3 = lower zone riparian obligate / wetland obligate (seasonal zone) / hydrophyte
4 = marginal zone riparian obligate / rheophyte / helophyte / hydrophyte / wetland obligate (permanent zone) / sudd hydrophyte
5 = aquatic (epihydate, pleustophyte, vittate)

Table 5-14 Flooding ranges (peak discharge) for indicators at the EWR sites

Site	Indicator	Discharge (m^3/s):	
		Lower limit	Upper limit
Mkuze (MK 1)	marginal zone graminoids	0.122	5.539
	lower zone graminoids	5.539	19.807
	marginal zone trees	4.953	16.775
	lower zone trees	55.984	96.012
	upper zone trees (riparian)	87.963	448.031
	upper zone trees (terrestrial)	229.59	#N/A
	top of MCB and start of floodplain	177.853	#N/A
Black Mfolozi (BM 1)	marginal zone graminoids	0.001	3.342
	lower zone graminoids	3.02	14.382
	marginal zone trees	11.306	#N/A
	lower zone trees	12.287	#N/A
	upper zone trees (riparian)	345.794	#N/A
	upper zone trees (terrestrial)	345.794	#N/A
Upper Pongola (UP 1)	marginal zone graminoids	3.812	29.484
	lower zone graminoids	30.692	#N/A
	marginal zone trees	7.661	23.383
	lower zone trees	#N/A	#N/A
	upper zone trees (riparian)	73.209	216.505
	upper zone trees (terrestrial)	462.654	#N/A
Nseleni (NS 1)	marginal zone graminoids	0.287	6.307
	lower zone graminoids	5.024	7.219
	marginal zone trees	0.287	0.486
	lower zone trees	3.979	83.425
	upper zone trees (riparian)	29.022	#N/A
	upper zone trees (terrestrial)	83.425	#N/A
Matigulu (MA 1)	marginal zone graminoids	1.097	34.829
	lower zone graminoids	2.075	34.829
	marginal zone trees	3.844	134.203
	lower zone trees	5.886	134.203
	upper zone trees (riparian)	355.737	#N/A
	upper zone trees (terrestrial)	945.779	#N/A
Assegaai (AS 1)	*Persicaria lapathifolia*	0.931	6.078
	Cyperus marginatus	0.931	10.213
	Phragmites australis	0.931	21.4905
	Ischaemum fasciculatum	1.525	11.251
	Salix mucronata	2.3035	8.095
	Miscanthus junceus	17.599	#N/A
	Combretum erythrophyllum	20.7	47
	Diospyros lycioides	46.969	#N/A

Site	Indicator	Discharge (m^3/s):	
		Lower limit	Upper limit
White Mfolozi (WM 1)	marginal zone graminoids	0.107	13.606
	lower zone graminoids	7.406	99.187
	marginal zone trees	4.309	43.647
	lower zone trees	43.647	78.341
	upper zone trees (riparian)	362.158	#N/A
	upper zone trees (terrestrial)	#N/A	#N/A
	Marginal Zone	#N/A	73.921
	Lower Zone	2.751	46.947
	Upper Zone	7.015	362.158

5.6.2 Linked indicators

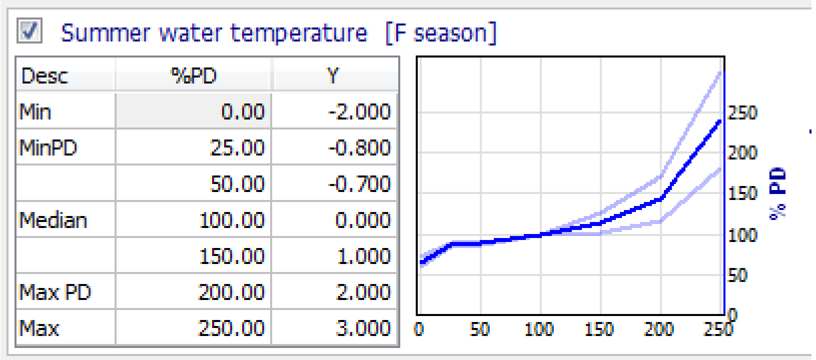
Table 5-15 Linked indicators and motivation

Indicator	Linked indicator	Motivation
Algae	Summer water temperature	Generally algae production will be favoured at higher temperatures and retarded at lower temperature.
Algae	Nutrients (Nitrogen)	Algae production will be favoured with increased nitrogen availability and become limited as concentrations decline.
Marginal zone graminoids	Channel width	If the channel width increases marginal zone graminoids will be lost due to permanent inundation or bank erosion. If the channel width reduces, marginal zone graminoids have the potential to encroach towards the shrinking channel.
Marginal zone trees	Channel width	The indicator has the potential to increase (encroach) as channel width decreases and to shrink if channel width increases.

5.7 Motivations for response curves

The detail listed below pertains to the Matigulu River, but generally the listed motivations for response curves apply to all sites. Response curves provided below and those in the DSS MAY differ very slightly as a result of final calibration, but the overall shape and reasoning remains the same.

5.7.1 Algae

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
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<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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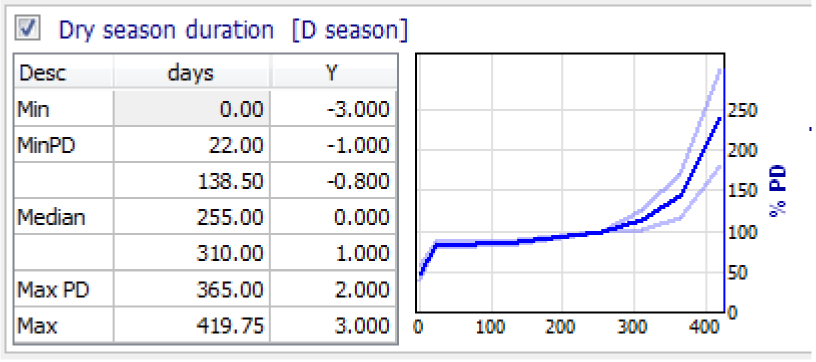
</td><td>Generally algae production will be favoured at higher temperatures and retarded at lower temperature.</td><td>Moderate</td></tr>
<tr><td>
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<tr><td>Max PD</td><td>365.00</td><td>2.000</td></tr>
<tr><td>Max</td><td>419.75</td><td>3.000</td></tr>
</table>
</td><td>Algae production is favoured when velocity is lower, depths are shallow and floods are absent i.e. dry season conditions favour increased production.</td><td>Moderate</td></tr>
</table>

<table>
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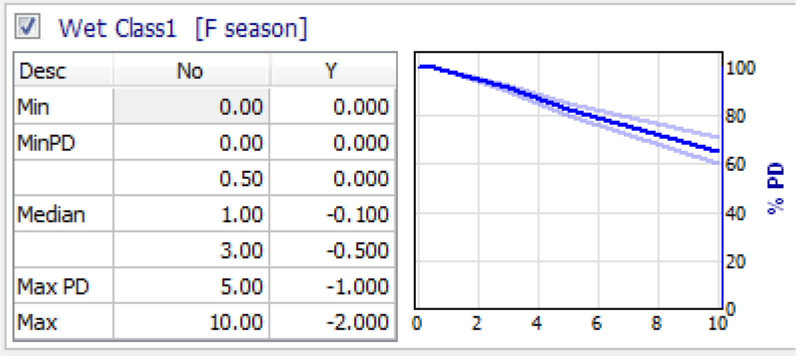
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<tr><td></td><td>3.00</td><td>-0.500</td></tr>
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<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
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</td><td>Generally floods will scour out algae in areas where velocity is high.</td><td>Moderate</td></tr>
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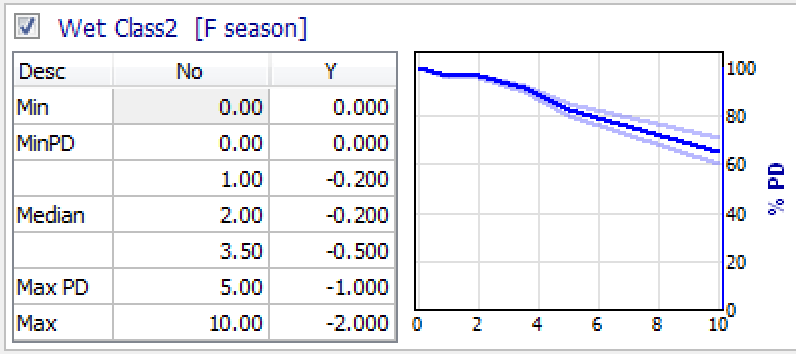
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<tr><td></td><td>3.50</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>5.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
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</td><td>Generally floods will scour out algae in areas where velocity is high.</td><td>Moderate</td></tr>
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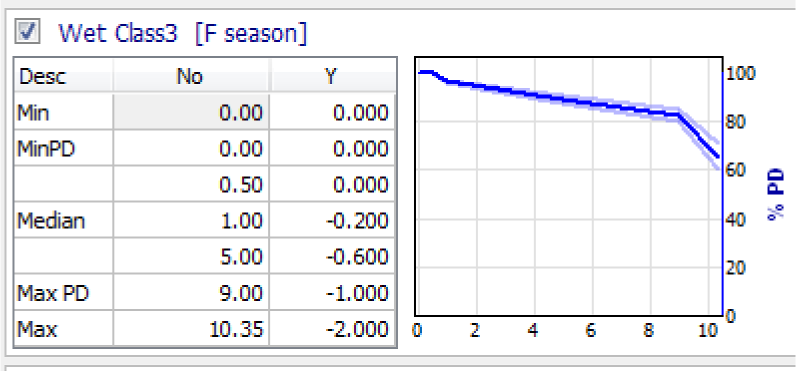
<tr><td>

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<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>-0.200</td></tr>
<tr><td></td><td>5.00</td><td>-0.600</td></tr>
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<tr><td>Max</td><td>10.35</td><td>-2.000</td></tr>
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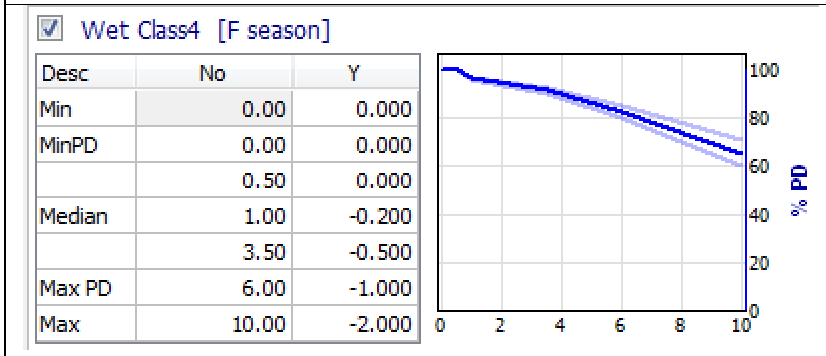
<tr><td>

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<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>-0.200</td></tr>
<tr><td></td><td>3.50</td><td>-0.500</td></tr>
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</table></td><td>Generally floods will scour out algae in areas where velocity is high.</td><td>Moderate</td></tr>
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<table>
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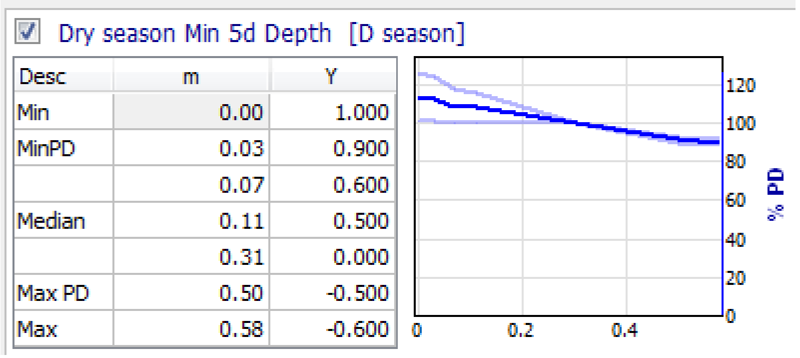
<tr><td>
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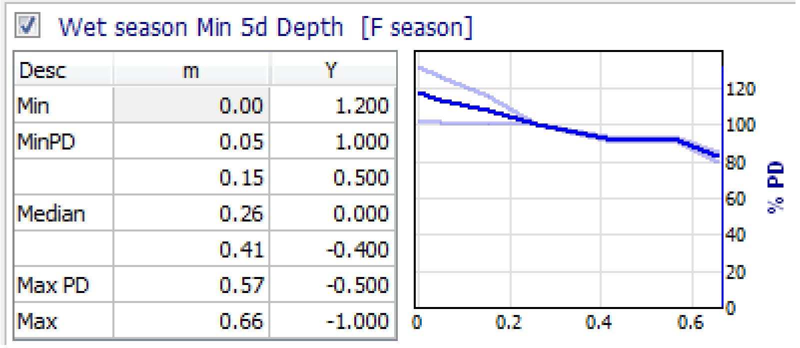
<tr><td>Max</td><td>0.58</td><td>-0.600</td></tr>
</table>
</td><td>As with dry season duration, algae production is favoured in the dry season and increases at low flows (more light, potentially more nutrients, less disturbance from high velocity flows). At zero flows algae will increase in pools if present.</td><td>Moderate</td></tr>
<tr><td>
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</table>
</td><td>Algae production is favoured when velocity is lower, depths are shallower and floods are absent. At zero depth algae will flourish in pools (as long as they contain water and if they are present).</td><td>Moderate</td></tr>
</table>

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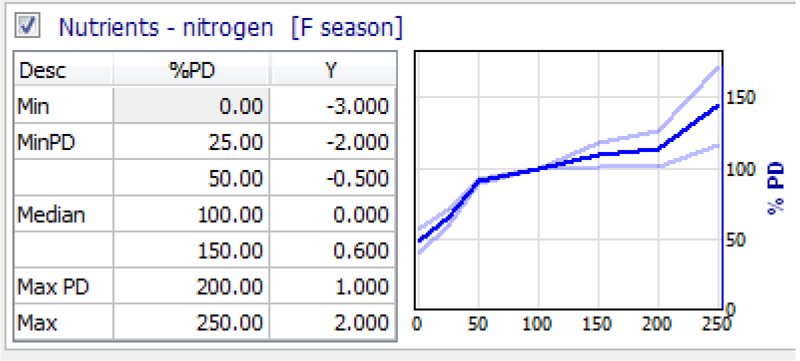

☑ Nutrients - nitrogen [F season]

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<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>
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</td><td>Algae production will be favoured with increased nitrogen availability and become limited as concentrations decline.</td><td>Moderate</td></tr>
<tr><td colspan="2">References</td><td></td></tr>
<tr><td colspan="2">Dallas, H.F. and Day, J. (2004). The effect of water quality variables on Aquatic Ecosystems: A Review. WRC Report Nr. TT 224/04.</td><td></td></tr>
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5.7.2 Marginal Zone Graminoids

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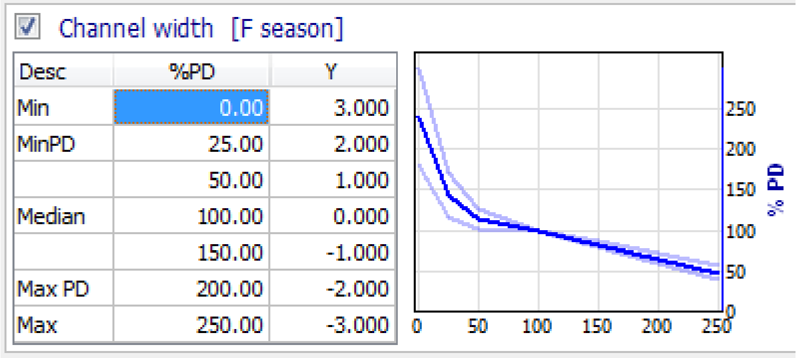
<tr><td>
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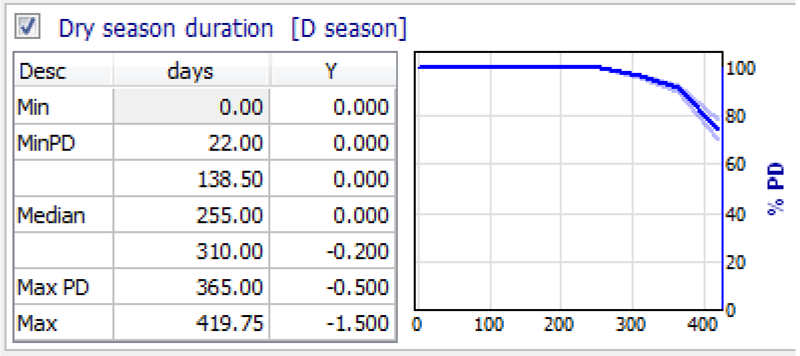
<tr><td>Max PD</td><td>200.00</td><td>-2.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>-3.000</td></tr>
</table>
</td><td>If the channel width increases marginal zone graminoids will be lost due to permanent inundation or bank erosion. If the channel width reduces, marginal zone graminoids have the potential to encroach towards the shrinking channel.</td><td>Moderate</td></tr>
<tr><td>
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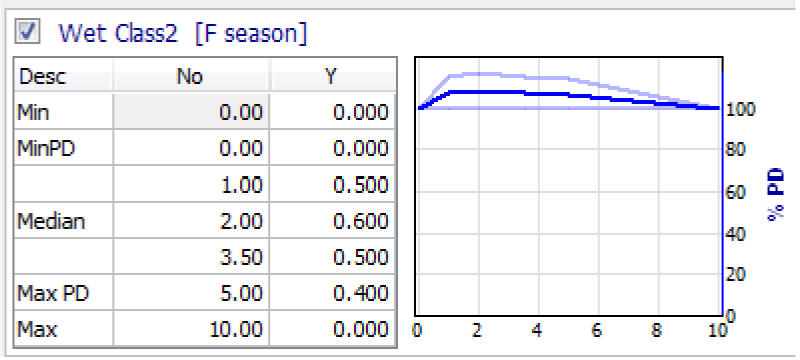
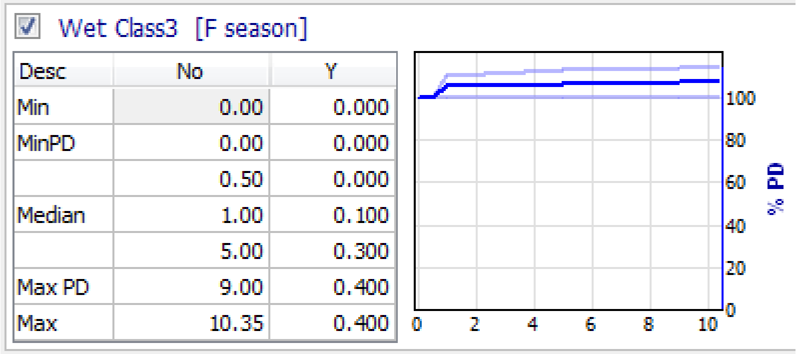
<tr><td>Max</td><td>419.75</td><td>-1.500</td></tr>
</table>
</td><td>The duration of the dry season (and by implication the wet season) is related to water (drought) stress (or the lack thereof) of marginal zone graminoids. Extended dry season will cause water stress during the growing and reproductive phase and result in decreased production or even mortality in extreme cases.</td><td>High</td></tr>
</table>

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


☑ Wet Class2 [F season]

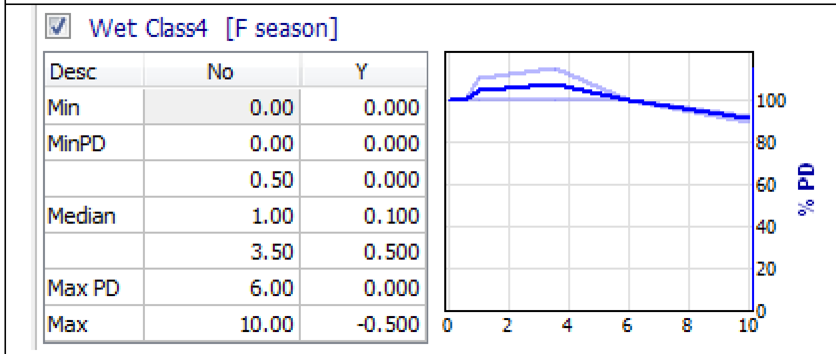
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>1.00</td><td>0.500</td></tr>
<tr><td>Median</td><td>2.00</td><td>0.600</td></tr>
<tr><td></td><td>3.50</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>5.00</td><td>0.400</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.000</td></tr>
</table>

</td><td>Class 2 flood is 16-32m^3/s. These events flood 100% of marginal zone graminoids with in the lowest limit of the indicator inundated up to 1.2m. These floods facilitate and sustain a growth response by marginal zone graminoids, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success. But they are also likely to result in scour at the lower limits of the indicators range.</td><td>High</td></tr>
<tr><td>


☑ Wet Class3 [F season]

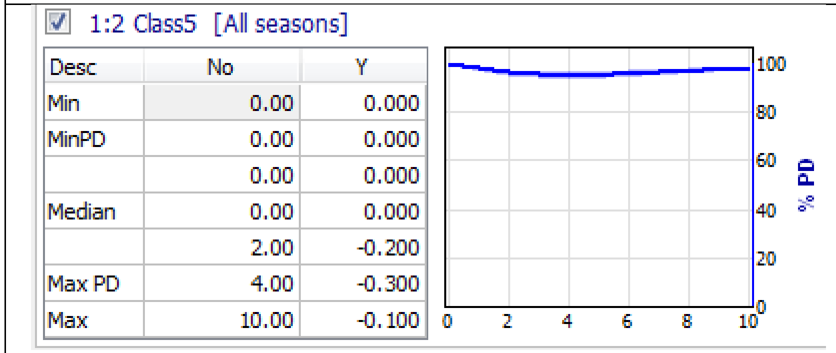
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.100</td></tr>
<tr><td></td><td>5.00</td><td>0.300</td></tr>
<tr><td>Max PD</td><td>9.00</td><td>0.400</td></tr>
<tr><td>Max</td><td>10.35</td><td>0.400</td></tr>
</table>

</td><td>Class 3 flood is 32-64m^3/s. This will flood 100% of marginal zone graminoids and at the lowest limit the indicator will be inundated in up to 1.7m of water. Some scour (loss of vegetation) is likely at the lower limit of the indicator, but growth and production is favoured in the upper portion of the indicators. This event will help prevent encroachment towards the channel over time but also establishes the zone.</td><td>High</td></tr>
</table>

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


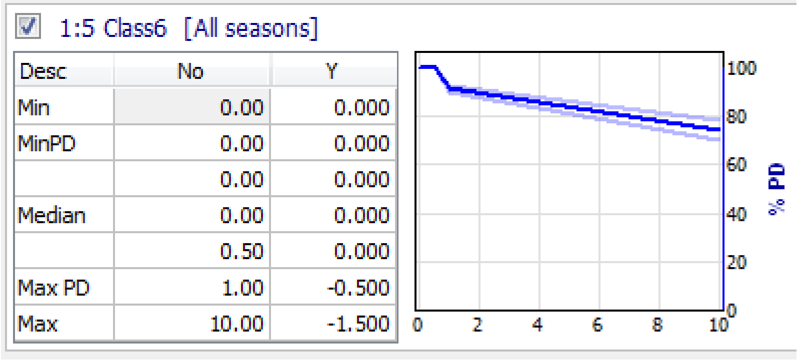
☑ Wet Class4 [F season]

<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.100</td></tr>
<tr><td></td><td>3.50</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.500</td></tr>
</table>

</td><td>Class 4 flood is 64-130m^3/s. This will flood 100% of marginal zone graminoids and at the lowest limit of the indicator will be inundated in up to 2.5m of water. Some scour (loss of vegetation) is likely but growth and recruitment will also follow.</td><td>High</td></tr>
<tr><td>


☑ 1:2 Class5 [All seasons]

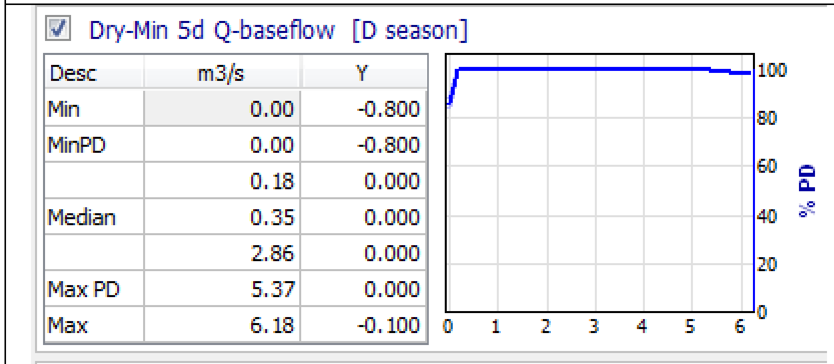
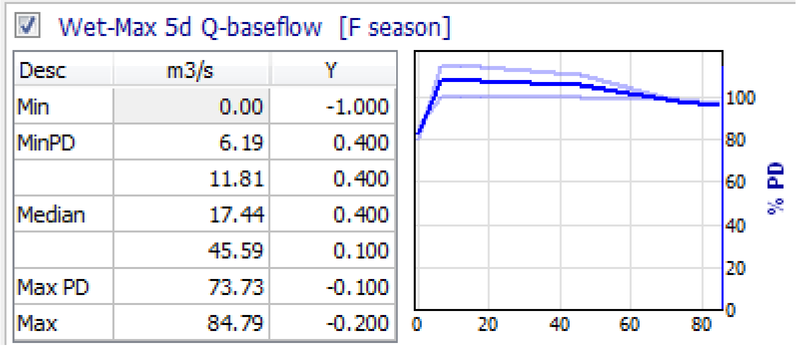
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>2.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>-0.300</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.100</td></tr>
</table>

</td><td>Event range : 130-372m^3/s; Indicator flood range: 0.12-5.5m^3/s: These large events flood and scour the marginal zone. They reduce the cover of marginal zone graminoids but are important to maintain heterogeneity and species diversity.</td><td>High</td></tr>
<tr><td>


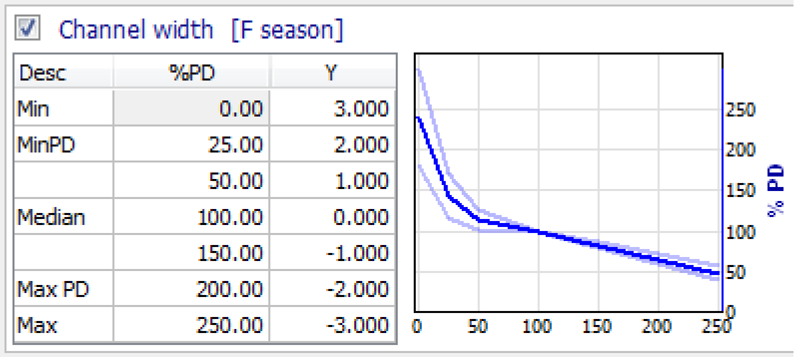
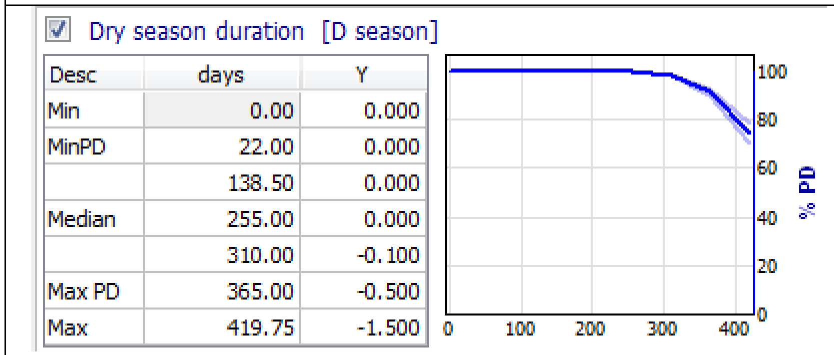
☑ 1:5 Class6 [All seasons]

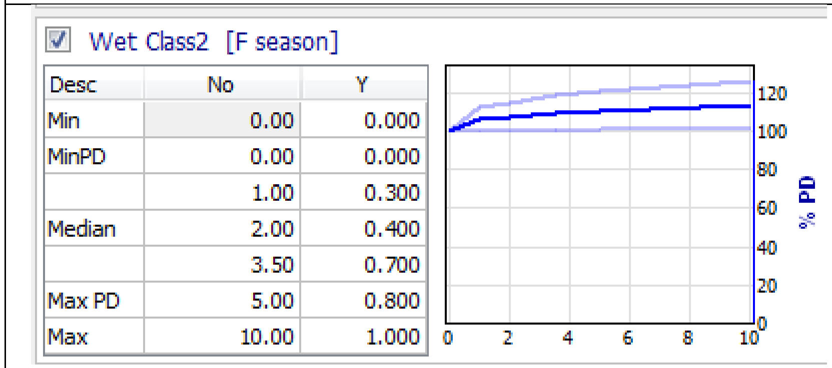
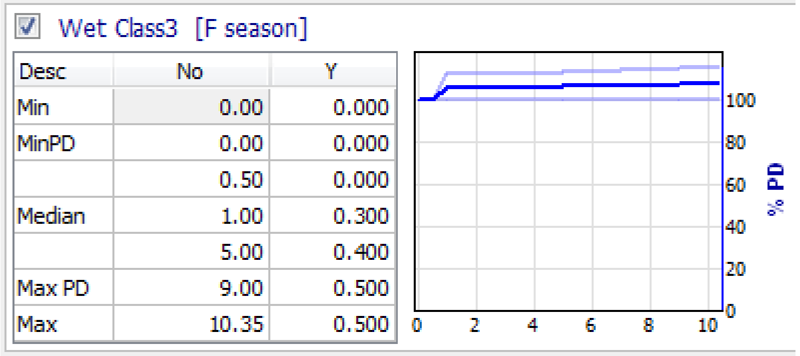
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.500</td></tr>
</table>

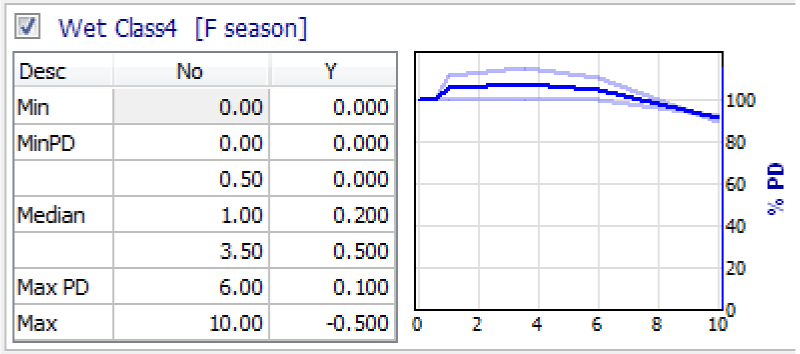
</td><td>Event range: 372-515m^3/s; Indicator flood range: 0.12-5.5m^3/s: These large events flood and scour the marginal zone. They reduce the cover of marginal zone graminoids but are important to maintain heterogeneity and species diversity.</td><td>High</td></tr>
</table>

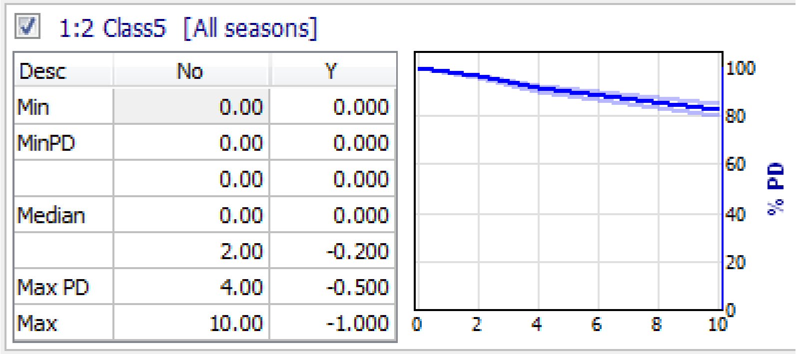
<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.800</td></tr>
<tr><td></td><td>0.18</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.35</td><td>0.000</td></tr>
<tr><td></td><td>2.86</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>5.37</td><td>0.000</td></tr>
<tr><td>Max</td><td>6.18</td><td>-0.100</td></tr>
</table>
</td><td>Marginal zone graminoids activate from 0.12 to 5.5m^3/s. The dry season base flow needs to provide enough soil moisture (but not undue inundation) to ensure survival and persistence during dormancy. At close to zero flow the indicator is up to 0.6m above the water level and die-off is unlikely. At 0.35m^3/s 10% of grasses and sedges are inundated, but only to 6cm. Inundation during dormancy may result in mortality if prolonged.</td><td>High</td></tr>
<tr><td>
☑ Wet-Max 5d Q-baseflow [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>6.19</td><td>0.400</td></tr>
<tr><td></td><td>11.81</td><td>0.400</td></tr>
<tr><td>Median</td><td>17.44</td><td>0.400</td></tr>
<tr><td></td><td>45.59</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>73.73</td><td>-0.100</td></tr>
<tr><td>Max</td><td>84.79</td><td>-0.200</td></tr>
</table>
</td><td>Marginal zone graminoids activate from 0.12 to 5.5m^3/s. Inundation and activation is important during the growing season to ensure sustained productivity and reproduction. At 17m^3/s 100% of marginal zone graminoids are inundated in up to 0.9m water depth. Persistence beyond this point is unlikely.</td><td>High</td></tr>
<tr><td colspan="2">References</td><td></td></tr>
<tr><td colspan="2">Canadell, J., Jackson, R.B., Ehleringer, H.A., Sala, O.E. and Schulze, E.D. (1996). Maximum rooting depth of vegetation types at the global scale Oecologia 108: 583-595 Springer-Verlag.</td><td></td></tr>
</table>

5.7.3 Marginal Zone Trees

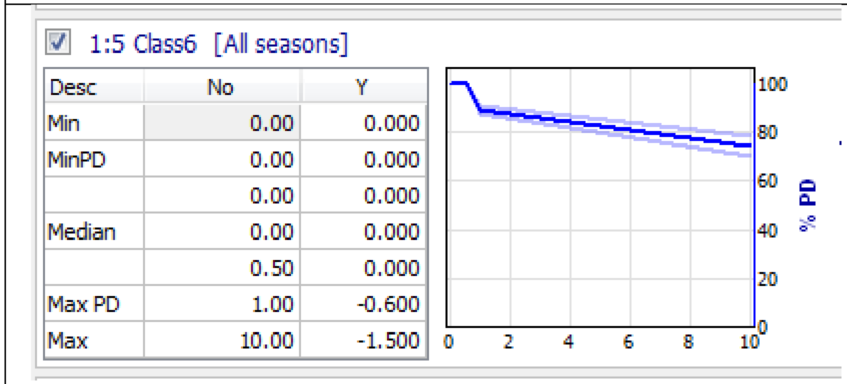
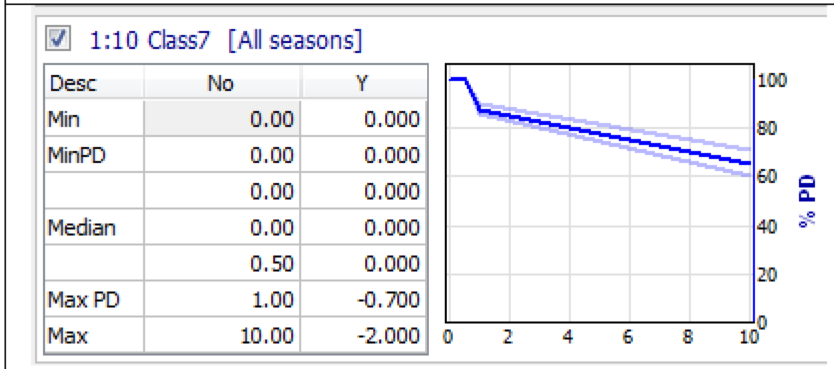
<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Channel width [F season]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>2.000</td></tr>
<tr><td></td><td>50.00</td><td>1.000</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>The indicator has the potential to increase (encroach) as channel width decreases and to shrink if channel width increases.</td><td>Moderate</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>22.00</td><td>0.000</td></tr>
<tr><td></td><td>138.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>255.00</td><td>0.000</td></tr>
<tr><td></td><td>310.00</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.500</td></tr>
</table>
</td><td>The duration of the dry season (and by implication the wet season) is related to water (drought) stress (or the lack thereof) of marginal zone trees. Extended dry season will cause water stress during the growing and reproductive phase and result in decreased production or even mortality in extreme cases.</td><td>High</td></tr>
</table>

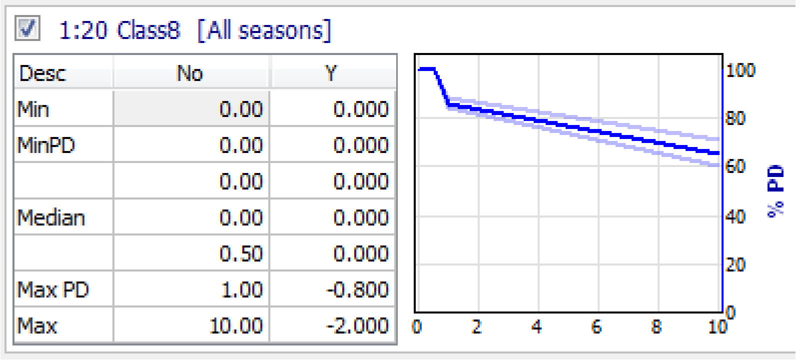
<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Wet Class2 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>1.00</td><td>0.300</td></tr>
<tr><td>Median</td><td>2.00</td><td>0.400</td></tr>
<tr><td></td><td>3.50</td><td>0.700</td></tr>
<tr><td>Max PD</td><td>5.00</td><td>0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>1.000</td></tr>
</table>
</td><td>Event range: 16-32m^3/s; Indicator flood range: 5-16m^3/s: The occurrence of these events in the growing season elicits a growing response and sustains growth demands by recharging soil moisture.</td><td>High</td></tr>
<tr><td>
☑ Wet Class3 [F season]
<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.300</td></tr>
<tr><td></td><td>5.00</td><td>0.400</td></tr>
<tr><td>Max PD</td><td>9.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>10.35</td><td>0.500</td></tr>
</table>
</td><td>Event range: 32-64m^3/s; Indicator flood range: 5-16m^3/s. The occurrence of these events floods the population and will elicit a growth response and sustain growth demands by recharging soil moisture. Recruitment opportunities are also created.</td><td>High</td></tr>
</table>

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

☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.200</td></tr>
<tr><td></td><td>3.50</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>0.100</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.500</td></tr>
</table>

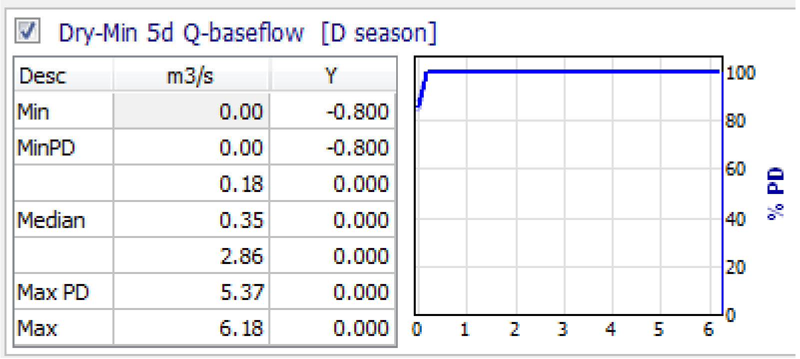
</td><td>Event range: 64-130m^3/s; Indicator flood range: 5-16m^3/s. The occurrence of these events floods the population (up to 2m water depth) and will elicit a growth response and sustain growth demands by recharging soil moisture. Recruitment opportunities are also created but some scour of marginal zone trees is likely.</td><td>High</td></tr>
<tr><td>

☑ 1:2 Class5 [All seasons]
<table>
<tr><th>Desc</th><th>No</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>2.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.000</td></tr>
</table>

</td><td>Event range: 130-372m^3/s; Indicator flood range: 5-16m^3/s. Indicator is flooded in up to 3.6m of water. Scour of lower limit individuals can occur but cleared areas and new sediment deposits also lend themselves to new recruitment which will maintain a population structure with all size classes represented.</td><td>High</td></tr>
</table>

Response curve	Explanation	Confidence
 ☑ 1:5 Class6 [All seasons] Desc | No | Y Min | 0.00 | 0.000 MinPD | 0.00 | 0.000 | 0.00 | 0.000 Median | 0.00 | 0.000 | 0.50 | 0.000 Max PD | 1.00 | -0.600 Max | 10.00 | -1.500 	Event range: 372-515m^3/s; Indicator flood range: 5-16m^3/s. Indicator is flooded in up to 4m of water. Scour of lower limit individuals likely.	High
 ☑ 1:10 Class7 [All seasons] Desc | No | Y Min | 0.00 | 0.000 MinPD | 0.00 | 0.000 | 0.00 | 0.000 Median | 0.00 | 0.000 | 0.50 | 0.000 Max PD | 1.00 | -0.700 Max | 10.00 | -2.000 	Event range: 515-741m^3/s; Indicator flood range: 5-16m^3/s. Large flooding disturbance. Clears out marginal zone trees and maintains habitat and species diversity of the sub-zone.	High

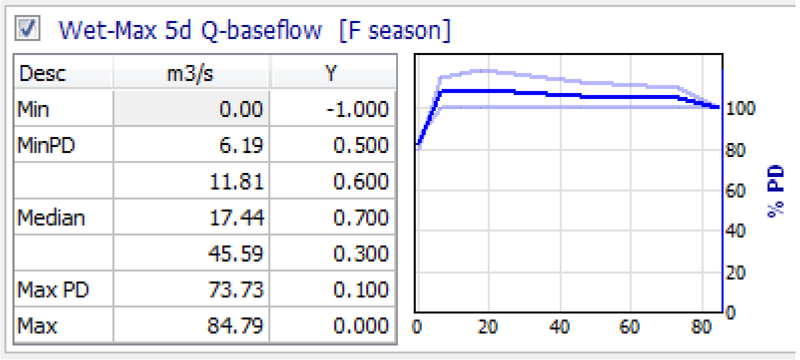
<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>


☑ 1:20 Class8 [All seasons]

<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
</table>
</td><td>Event range: >741m^3/s; Indicator flood range: Extreme event that clears out the marginal zone trees. This is essentially a "re-setting" event important for preventing long term dominance of the sub-zone by woody vegetation.</td><td>High</td></tr>
<tr><td>


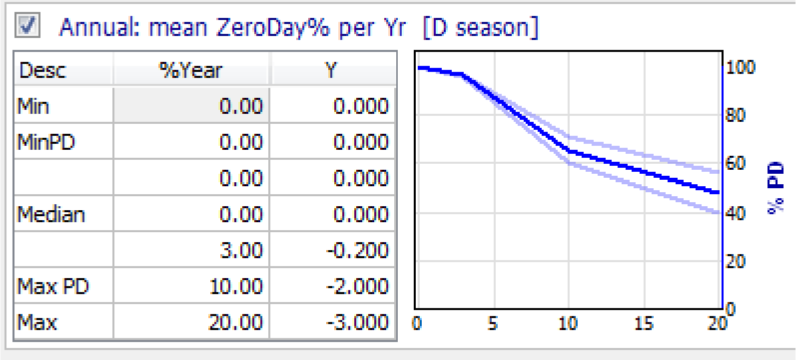
☑ Dry-Min 5d Q-baseflow [D season]

<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.800</td></tr>
<tr><td></td><td>0.18</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.35</td><td>0.000</td></tr>
<tr><td></td><td>2.86</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>5.37</td><td>0.000</td></tr>
<tr><td>Max</td><td>6.18</td><td>0.000</td></tr>
</table>
</td><td>Marginal zone trees activate from 5m^3/s. The dry season base flow needs to provide enough soil moisture (but not inundation) to ensure survival and persistence during dormancy. Zero flow may result in mortality from desiccation and inundation during dormancy from inundation stress.</td><td>High</td></tr>
</table>

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


☑ Wet-Max 5d Q-baseflow [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>6.19</td><td>0.500</td></tr>
<tr><td></td><td>11.81</td><td>0.600</td></tr>
<tr><td>Median</td><td>17.44</td><td>0.700</td></tr>
<tr><td></td><td>45.59</td><td>0.300</td></tr>
<tr><td>Max PD</td><td>73.73</td><td>0.100</td></tr>
<tr><td>Max</td><td>84.79</td><td>0.000</td></tr>
</table>

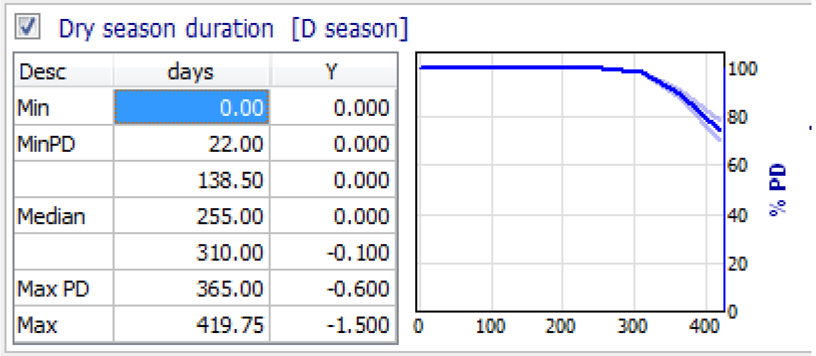
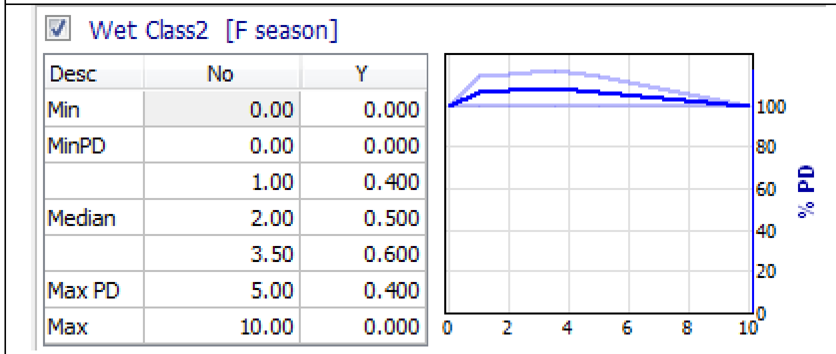
</td><td>Marginal zone trees activate from 5m^3/s. Flows below this range are likely to retard growth and reproduction but facilitate it within this range.</td><td>High</td></tr>
<tr><td>


☑ Annual: mean ZeroDay% per Yr [D season]

<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>-2.000</td></tr>
<tr><td>Max</td><td>20.00</td><td>-3.000</td></tr>
</table>

</td><td>X-Axis: 0,0,0,0,0,3,10,20. Stream permanency is important for persistence of marginal zone trees. Once stream permanency declines below 10% population density will decline and once stream permanency declines below 20% marginal zone tree species will likely disappear or be replaced by other hardy drought tolerant or terrestrial species. Lite and Stromberg (2007; modified); Leenhouts et al. (2005).</td><td>High</td></tr>
<tr><td colspan="2">References</td><td></td></tr>
<tr><td colspan="2">Leenhouts, J.M., Stromberg, J.C. and Scott, R.L. (2005). Hydrologic Requirements of and Evapotranspiration by Riparian Vegetation along the San Pedro River, Arizona U.S. Geological Survey Scientific Investigations Report 2005–5163.
Lite S.J. and Stromberg J.C. (2005). Surface water and ground-water thresholds for maintaining <i>Populus</i> - <i>Salix</i> forests, San Pedro River, Arizona. Biological Conservation 125: 153-167.</td><td></td></tr>
</table>

5.7.4 Lower Zone Graminoids

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></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>22.00</td><td>0.000</td></tr>
<tr><td></td><td>138.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>255.00</td><td>0.000</td></tr>
<tr><td></td><td>310.00</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.500</td></tr>
</table>
</td><td>The duration of the dry season (and by implication the wet season) is related to water (drought) stress (or the lack thereof) of marginal zone graminoids. Extended dry season will cause water stress during the growing and reproductive phase and result in decreased production or even mortality in extreme cases.</td><td>Moderate</td></tr>
<tr><td>
☑ Wet Class2 [F season]
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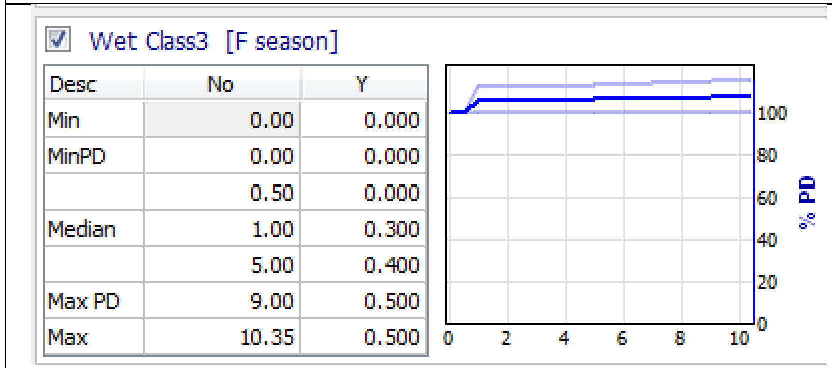
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>1.00</td><td>0.400</td></tr>
<tr><td>Median</td><td>2.00</td><td>0.500</td></tr>
<tr><td></td><td>3.50</td><td>0.600</td></tr>
<tr><td>Max PD</td><td>5.00</td><td>0.400</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.000</td></tr>
</table>
</td><td>Event range: 16-32m^3/s: Indicator flood range: 5.5-20m^3/s. These floods facilitate and sustain a growth response by lower zone graminoids, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.</td><td>High</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Wet Class3 [F season]
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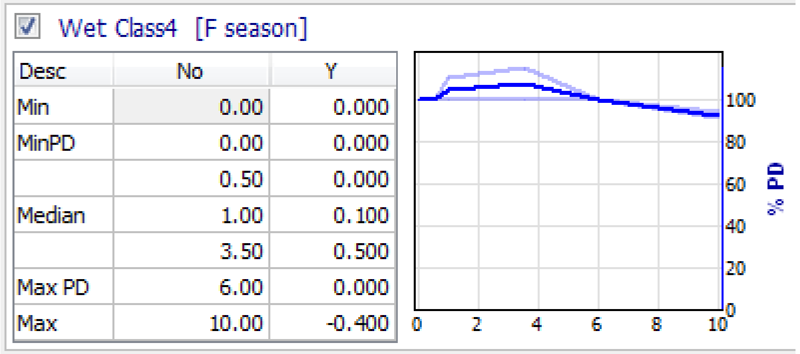
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.300</td></tr>
<tr><td></td><td>5.00</td><td>0.400</td></tr>
<tr><td>Max PD</td><td>9.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>10.35</td><td>0.500</td></tr>
</table>
</td><td>Event range: 32-64m^3/s: Indicator flood range: 5.5-20m^3/s. This will have a similar role to class 2 floods.</td><td>High</td></tr>
<tr><td>
☑ Wet Class4 [F season]
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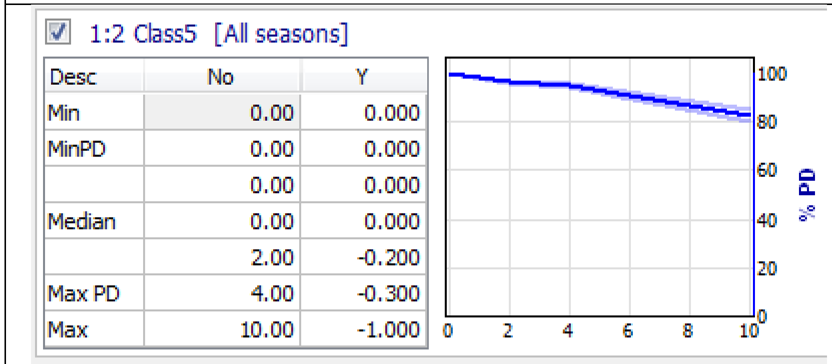
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.100</td></tr>
<tr><td></td><td>3.50</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.400</td></tr>
</table>
</td><td>Event range: 64-130m^3/s: Indicator flood range: 5.5-20m^3/s. While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.</td><td>High</td></tr>
</table>

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


☑ 1:2 Class5 [All seasons]

<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
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<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>2.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>-0.300</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.000</td></tr>
</table>

</td><td>Event range: 130-372m^3/s: Indicator flood range: 5.5-20m^3/s. These large events flood and potentially scour the lower zone. They reduce the cover of lower zone graminoids but are important to maintain heterogeneity and species diversity.</td><td>High</td></tr>
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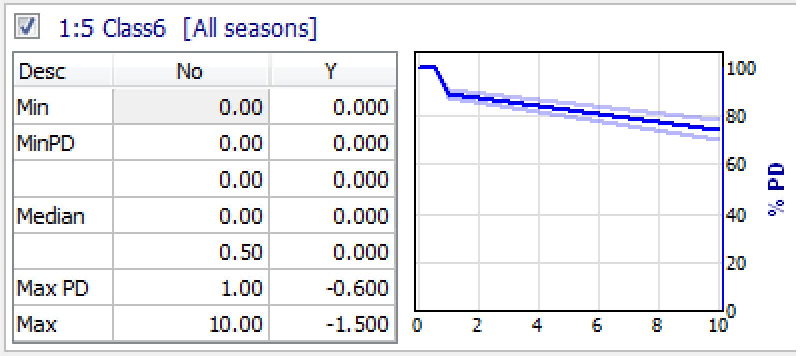

☑ 1:5 Class6 [All seasons]

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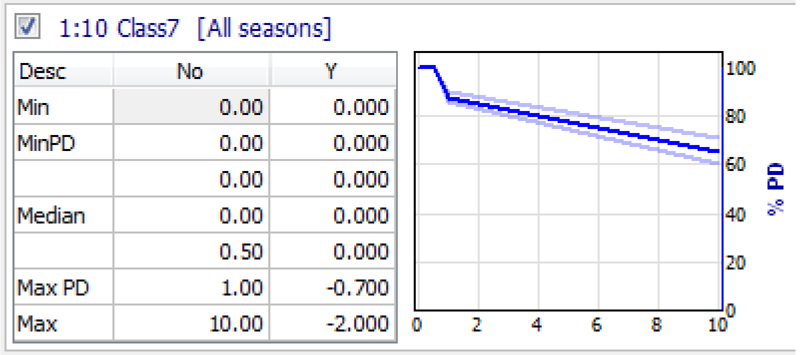
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.500</td></tr>
</table>

</td><td>Event range: 372-515m^3/s: Indicator flood range: 5.5-20m^3/s. These large events flood and scour the lower zone. They reduce the cover of lower zone graminoids but are important to maintain overall heterogeneity, species diversity and create new sites for post-flood recruitment.</td><td>High</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ 1:10 Class7 [All seasons]
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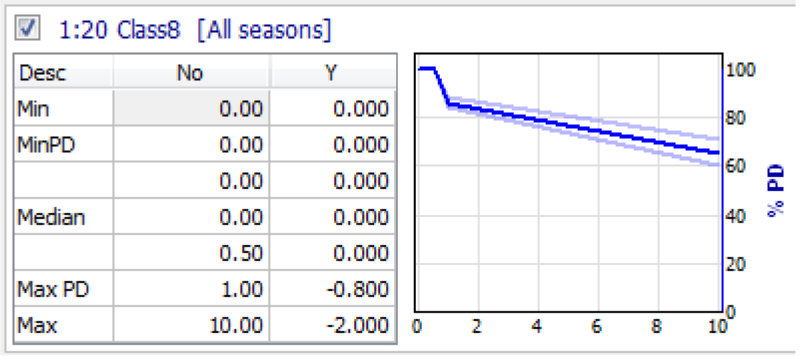
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.700</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
</table>
</td><td>Event range: 515-741m^3/2. Indicator flood range: 5.5-20m^3/s. Large flooding disturbance. Scours lower zone but maintains the mixture of woody and non-woody vegetation in the sub-zone and prevent dominance of woody vegetation.</td><td>High</td></tr>
<tr><td>
☑ 1:20 Class8 [All seasons]
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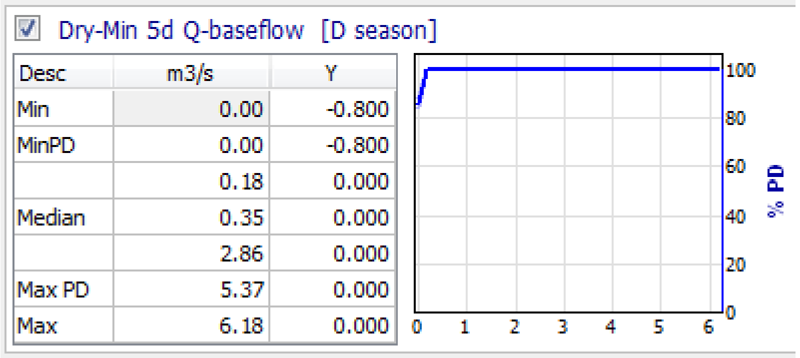
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
</table>
</td><td>Event range: >741m^3/2: Indicator flood range: 5.5-20m^3/s. Extreme event that clears out the lower zone graminoids. This is essentially a "re-setting" event important for preventing long term dominance of the sub-zone by woody vegetation, both riparian and terrestrial. These events also deposit new sediments (including nutrients) which are important for re-growth and post-flood recruitment.</td><td>High</td></tr>
</table>

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

☑ Dry-Min 5d Q-baseflow [D season]
<table>
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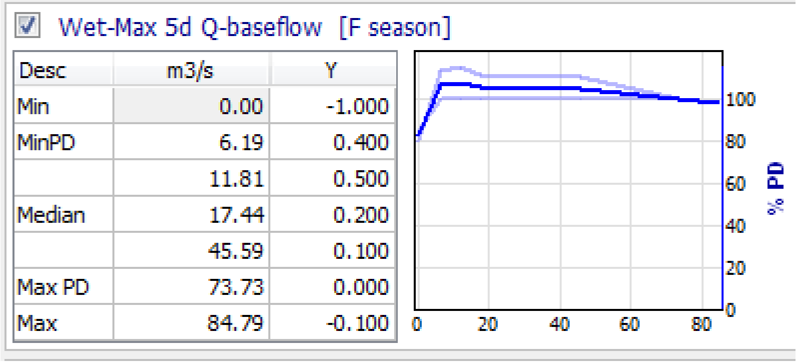
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.800</td></tr>
<tr><td></td><td>0.18</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.35</td><td>0.000</td></tr>
<tr><td></td><td>2.86</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>5.37</td><td>0.000</td></tr>
<tr><td>Max</td><td>6.18</td><td>0.000</td></tr>
</table>

</td><td>The dry season base flow needs to provide enough soil moisture to ensure survival and persistence during dormancy. Zero flow will result in mortality from desiccation. At low flows (close to zero) the population is at 0.6-1m above water level: rooting depth is sufficient for survival if stream permanence is maintained.</td><td>High</td></tr>
<tr><td>

☑ Wet-Max 5d Q-baseflow [F season]
<table>
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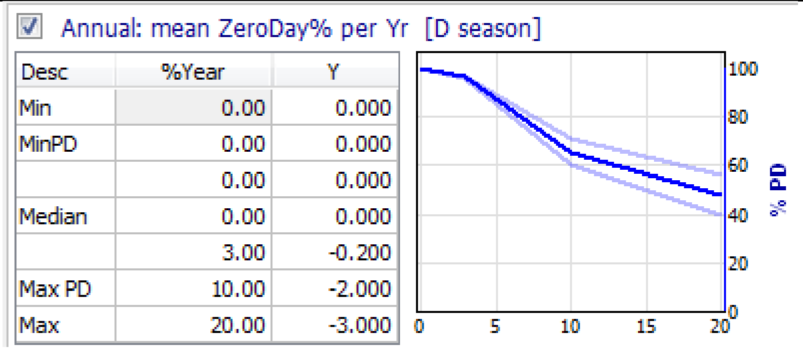
<tr><td>MinPD</td><td>6.19</td><td>0.400</td></tr>
<tr><td></td><td>11.81</td><td>0.500</td></tr>
<tr><td>Median</td><td>17.44</td><td>0.200</td></tr>
<tr><td></td><td>45.59</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>73.73</td><td>0.000</td></tr>
<tr><td>Max</td><td>84.79</td><td>-0.100</td></tr>
</table>

</td><td>The lower zone graminoids flood range is from 5.5-20m^3/s. Base flows in the wet season within this range will result in growth and successful reproduction.</td><td>High</td></tr>
<tr><td>

☑ Annual: mean ZeroDay% per Yr [D season]
<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>-2.000</td></tr>
<tr><td>Max</td><td>20.00</td><td>-3.000</td></tr>
</table>

</td><td>X-Axis: 0,0,0,0,0,3,10,20. Stream permanency is important for persistence of lower zone graminoids. Once stream permanency declines below 10% population density will decline and once stream permanency declines below 20% lower zone graminoids will likely desiccate. Lite and Stromberg (2007; modified); Leenhouts et al. (2005).</td><td>High</td></tr>
</table>

Response curve	Explanation	Confidence
References		
Canadell, J., Jackson, R.B., Ehleringer, H.A., Sala, O.E. and Schulze, E.D. (1996). Maximum rooting depth of vegetation types at the global scale Oecologia 108: 583-595 Springer-Verlag. Leenhouts, J.M., Stromberg, J.C. and Scott, R.L. (2005). Hydrologic Requirements of and Evapotranspiration by Riparian Vegetation along the San Pedro River, Arizona U.S. Geological Survey Scientific Investigations Report 2005–5163. Lite S.J. and Stromberg J.C. (2005). Surface water and ground-water thresholds for maintaining *Populus* - *Salix* forests, San Pedro River, Arizona. Biological Conservation 125: 153-167.		

5.7.5 Lower Zone Trees

<table>
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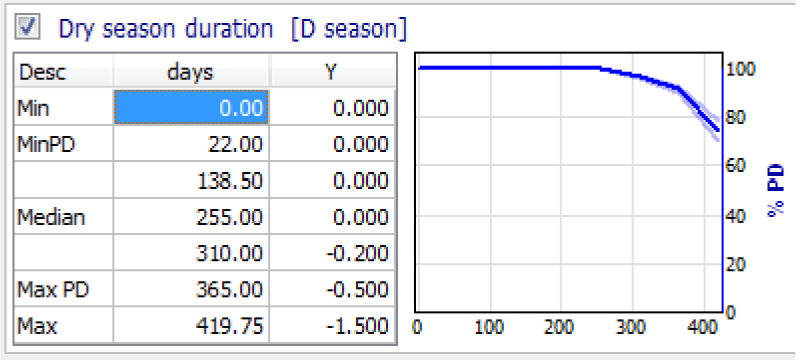
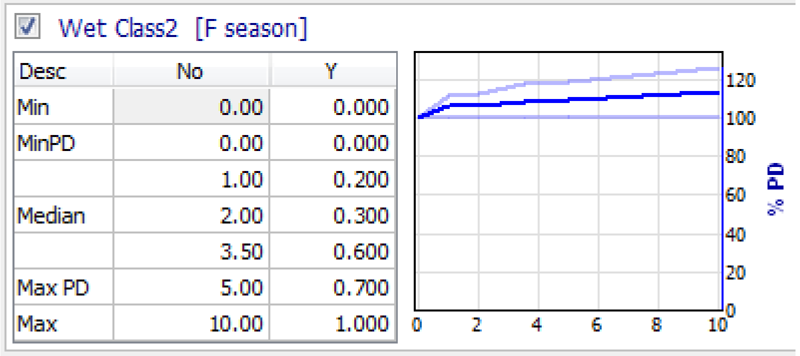
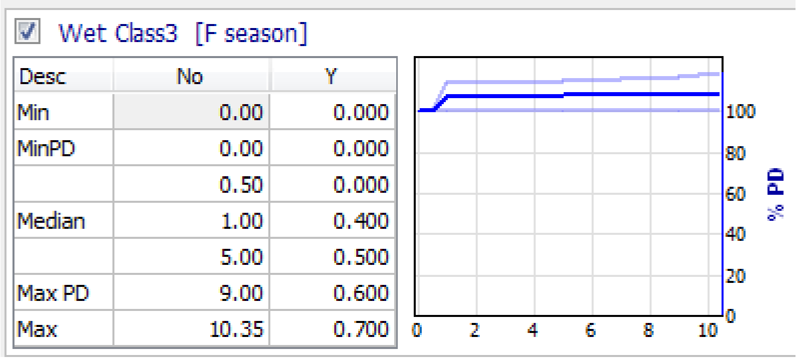
<tr><td>
☑ Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>22.00</td><td>0.000</td></tr>
<tr><td></td><td>138.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>255.00</td><td>0.000</td></tr>
<tr><td></td><td>310.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.500</td></tr>
</table>
</td><td>The duration of the dry season (and by implication the wet season) is related to water (drought) stress (or the lack thereof) of marginal zone graminoids. Extended dry season will cause water stress during the growing and reproductive phase and result in decreased production or even mortality in extreme cases.</td><td>Moderate</td></tr>
<tr><td>
☑ Wet Class2 [F season]
<table>
<tr><th>Desc</th><th>No</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>1.00</td><td>0.200</td></tr>
<tr><td>Median</td><td>2.00</td><td>0.300</td></tr>
<tr><td></td><td>3.50</td><td>0.600</td></tr>
<tr><td>Max PD</td><td>5.00</td><td>0.700</td></tr>
<tr><td>Max</td><td>10.00</td><td>1.000</td></tr>
</table>
</td><td>Event range: 16-32m^3/s; Indicator flood range: 56-96m^3/s. The occurrence of these events in the growing season elicits a growing response and sustains growth demands by recharging soil moisture.</td><td>High</td></tr>
</table>

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

☑ Wet Class3 [F season]
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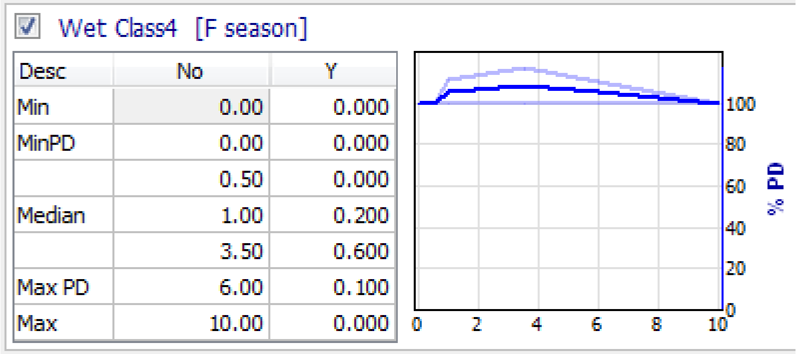
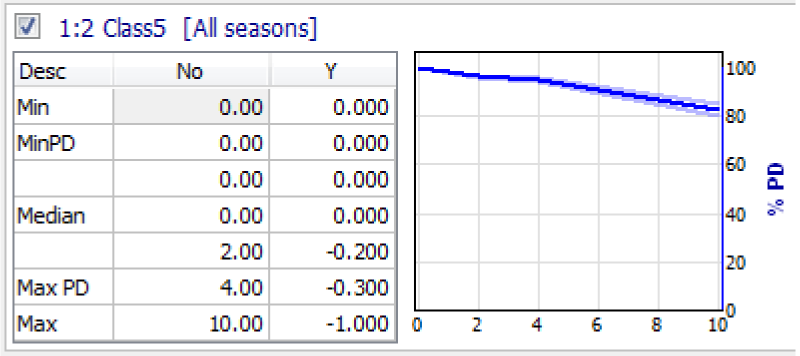
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.400</td></tr>
<tr><td></td><td>5.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>9.00</td><td>0.600</td></tr>
<tr><td>Max</td><td>10.35</td><td>0.700</td></tr>
</table>

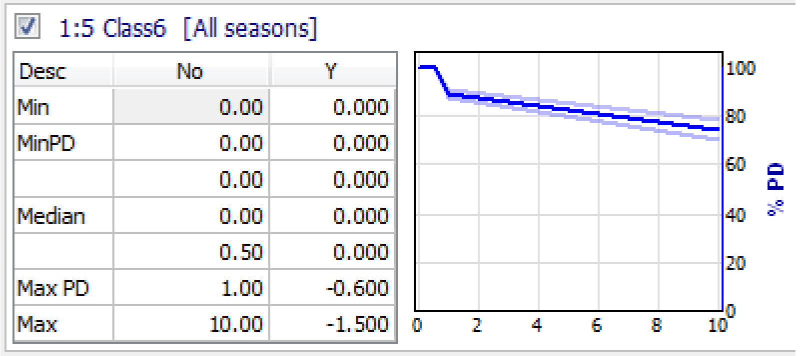
</td><td>Event range: 32-64m^3/s: Indicator flood range: 56-96m^3/s. The occurrence of these events activates the population and will elicit a growth response and sustain growth demands by recharging soil moisture. Recruitment opportunities are also created.</td><td>High</td></tr>
<tr><td>

☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.200</td></tr>
<tr><td></td><td>3.50</td><td>0.600</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>0.100</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.000</td></tr>
</table>

</td><td>Event range: 64-130m^3/s: Indicator flood range: 56-96m^3/s. The occurrence of these events floods 20-100% of the population (up to 0.8m water depth) and will elicit a growth response and sustain growth demands by recharging soil moisture. Recruitment opportunities are also created.</td><td>High</td></tr>
</table>

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


☑ 1:2 Class5 [All seasons]

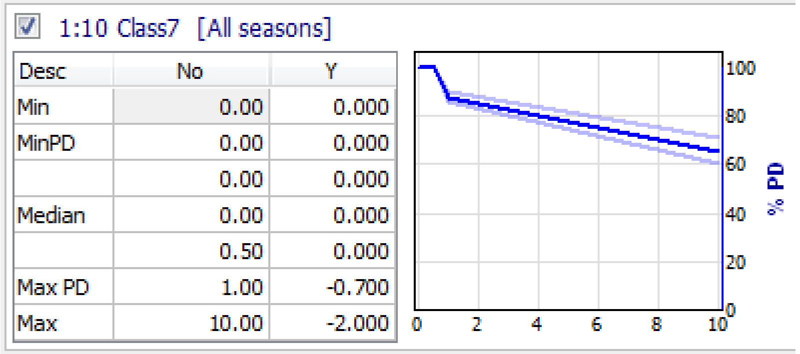
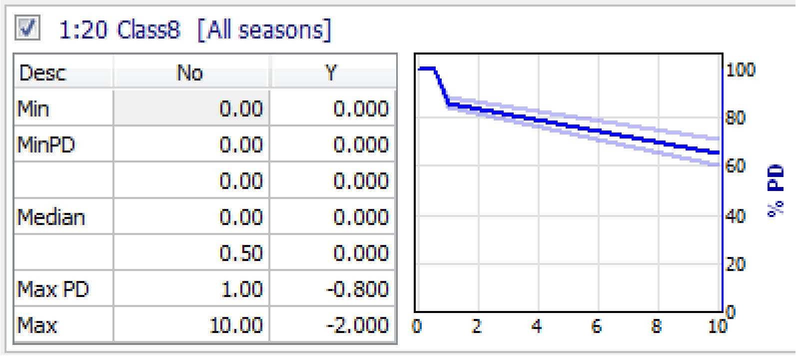
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>2.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>-0.300</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.000</td></tr>
</table>

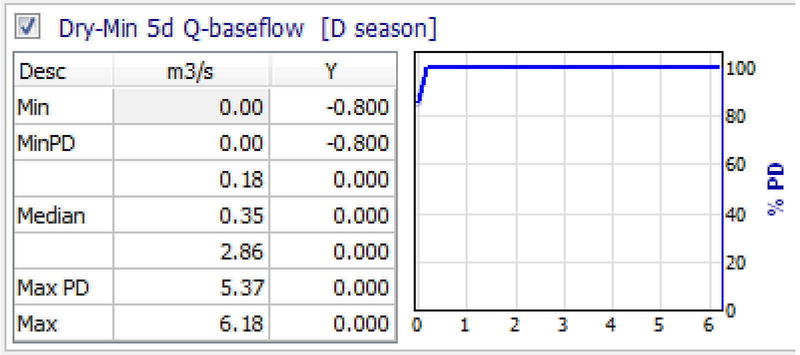
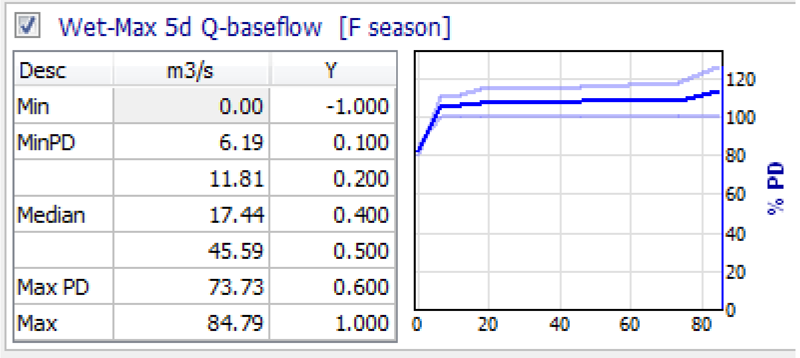
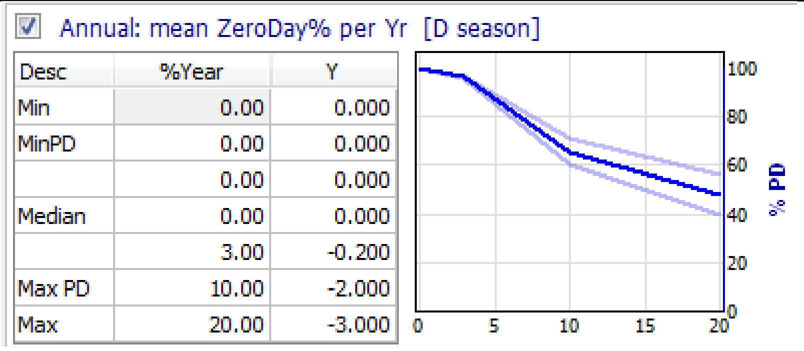
</td><td>Event range: 130-372m^3/s: Indicator flood range: 56-96m^3/s. Indicator is flooded in up to 2.5m of water. Scour of lower limit individuals can occur but cleared areas and new sediment deposits also lend themselves to new recruitment which will maintain a population structure with all size classes represented.</td><td>High</td></tr>
<tr><td>


☑ 1:5 Class6 [All seasons]

<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.500</td></tr>
</table>

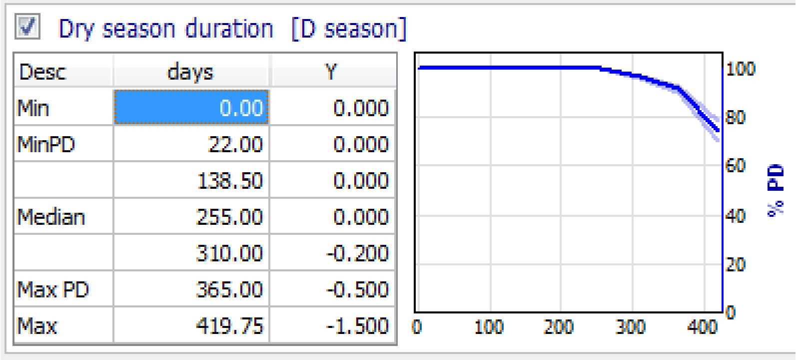
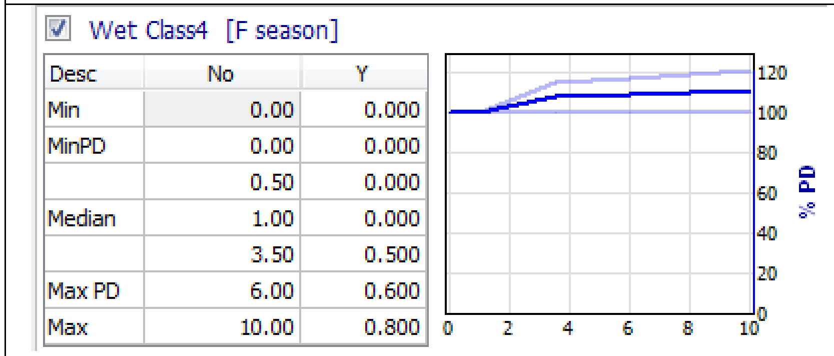
</td><td>Event range: 372-515m^3/s: Indicator flood range: 56-96m^3/s. Indicator is flooded in up to 2.9m of water. Scour of lower limit individuals likely but cleared areas and new sediment deposits also lend themselves to new recruitment which will maintain a population structure with all size classes represented.</td><td>High</td></tr>
</table>

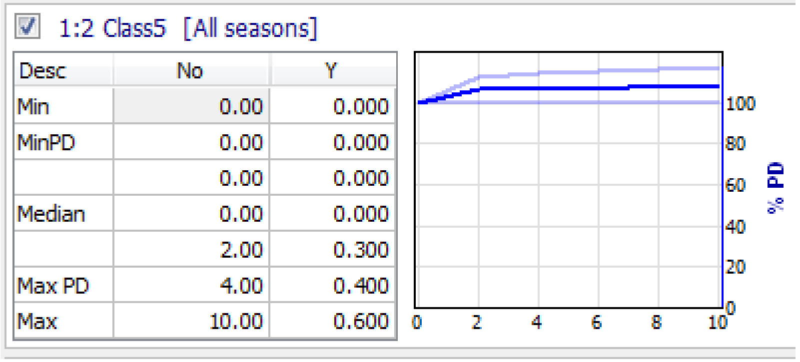
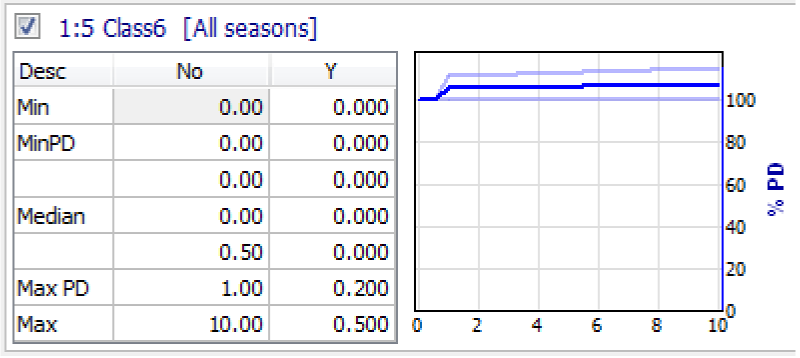
<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ 1:10 Class7 [All seasons]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.700</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
</table>
</td><td>Event range: 515-741m^3/s: Indicator flood range: 56-96m^3/s. Large flooding disturbance. Clears out marginal zone trees and maintains habitat and species diversity of the sub-zone.</td><td>High</td></tr>
<tr><td>
☑ 1:20 Class8 [All seasons]
<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
</table>
</td><td>Event range: >741m^3/s: Indicator flood range: 56-96m^3/s. Extreme event that clears out the marginal zone trees. This is essentially a "re-setting" event important for preventing long term dominance of the sub-zone by woody vegetation.</td><td>High</td></tr>
</table>

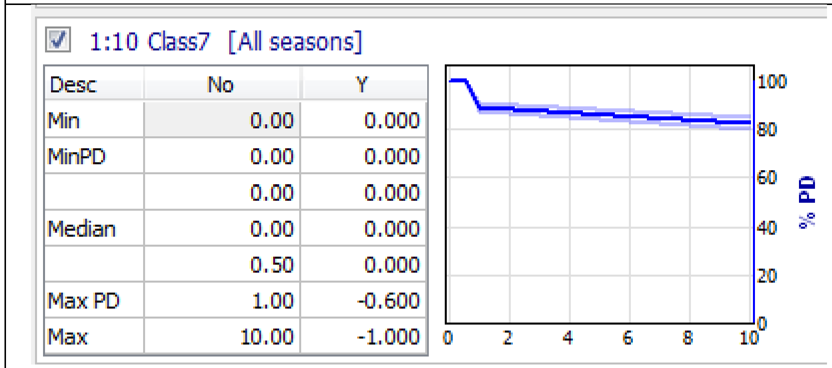
<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.800</td></tr>
<tr><td></td><td>0.18</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.35</td><td>0.000</td></tr>
<tr><td></td><td>2.86</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>5.37</td><td>0.000</td></tr>
<tr><td>Max</td><td>6.18</td><td>0.000</td></tr>
</table>
</td><td>Lower zone trees activate from 56m^3/s. The dry season base flow needs to provide enough soil moisture (but not inundation) to ensure survival and persistence during dormancy. Zero flow may result in mortality from desiccation and inundation during dormancy from inundation stress. At zero flow the indicator is from 0.55-1m above the water level and die-off, if it occurs will be due to drought stress and not from rooting depth limits.</td><td>High</td></tr>
<tr><td>
☑ Wet-Max 5d Q-baseflow [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>6.19</td><td>0.100</td></tr>
<tr><td></td><td>11.81</td><td>0.200</td></tr>
<tr><td>Median</td><td>17.44</td><td>0.400</td></tr>
<tr><td></td><td>45.59</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>73.73</td><td>0.600</td></tr>
<tr><td>Max</td><td>84.79</td><td>1.000</td></tr>
</table>
</td><td>Lower zone flood range: 56-96m^3/s. Flows far below this range are likely to retard growth and reproduction but facilitate it within and near this range.</td><td>High</td></tr>
<tr><td>
☑ Annual: mean ZeroDay% per Yr [D season]
<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>-2.000</td></tr>
<tr><td>Max</td><td>20.00</td><td>-3.000</td></tr>
</table>
</td><td>X-Axis: 0,0,0,0,0,3,10,20. Stream permanency is important for persistence of marginal zone trees. Once stream permanency declines below 10% population density will decline and once stream permanency declines below 20% marginal zone tree species will likely disappear or be replaced by other hardy drought tolerant or terrestrial species. Lite and Stromberg (2007; modified); Leenhouts et al. (2005)</td><td>High</td></tr>
</table>

Response curve	Explanation	Confidence
References		
Huxman, T.E., W Ilcox, B.P., Breshears, D.D., Scott, R.L., Snyder, K.A., Small, E.E., Hultine, K., P Ockman, W.T. And Jackson, R.B. (2005). Ecohydrological Implications Of Woody Plant Encroachment. Ecology, 86(2) pp. 308–319 Ecological Society of America. Leenhouts, J.M., Stromberg, J.C. and Scott, R.L. (2005). Hydrologic Requirements of and Evapotranspiration by Riparian Vegetation along the San Pedro River, Arizona U.S. Geological Survey Scientific Investigations Report 2005–5163. Lite S.J. and Stromberg J.C. (2005). Surface water and ground-water thresholds for maintaining *Populus* - *Salix* forests, San Pedro River, Arizona. Biological Conservation 125: 153-167.		

5.7.6 Upper Zone Trees - Riparian

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></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>22.00</td><td>0.000</td></tr>
<tr><td></td><td>138.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>255.00</td><td>0.000</td></tr>
<tr><td></td><td>310.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.500</td></tr>
</table>
</td><td>The duration of the dry season (and by implication the wet season) is related to water (drought) stress (or the lack thereof) of marginal zone graminoids. Extended dry season will cause water stress during the growing and reproductive phase and result in decreased production or even mortality in extreme cases.</td><td>Moderate</td></tr>
<tr><td>
☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.000</td></tr>
<tr><td></td><td>3.50</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>0.600</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.800</td></tr>
</table>
</td><td>Event range: 64-130m^3/s. Indicator flood range: 88-448m^3/s. Trees at -0.4-2.5m above water level; promotes growth and reproduction and recharges soils moisture important to all phreatophytes.</td><td>High</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ 1:2 Class5 [All seasons]
<table>
<tr><th>Desc</th><th>No</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>2.00</td><td>0.300</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>0.400</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.600</td></tr>
</table>
</td><td>Event range: 130-372m^3/s. Indicator flood range: 88-448m^3/s. Same function as class 4 flood.</td><td>High</td></tr>
<tr><td>
☑ 1:5 Class6 [All seasons]
<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>0.200</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.500</td></tr>
</table>
</td><td>Event range: 372-515m^3/s. Indicator flood range: 88-448m^3/s. Similar role to class 5. This event is also important for keeping upper zone trees in the upper zone and not encroaching into the lower zone and preventing terrestrialisation of the upper zone.</td><td>High</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ 1:10 Class7 [All seasons]
<table>
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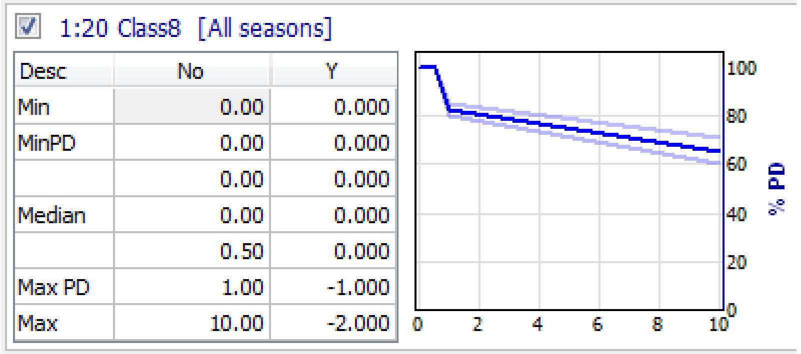
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.000</td></tr>
</table>
</td><td>Event range: 515-741m^3/s. Indicator flood range: 88-448m^3/s. A disturbance event which will scour upper zones trees, creating open areas and new microsites. Important to create some heterogeneity and maintain species diversity. Also prevents terrestrialisation.</td><td>High</td></tr>
<tr><td>
☑ 1:20 Class8 [All seasons]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
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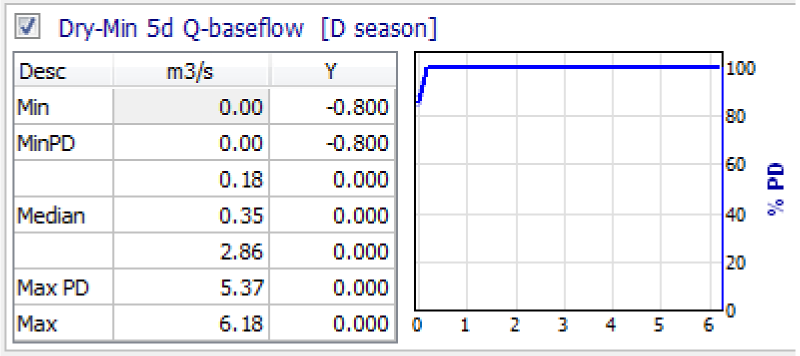
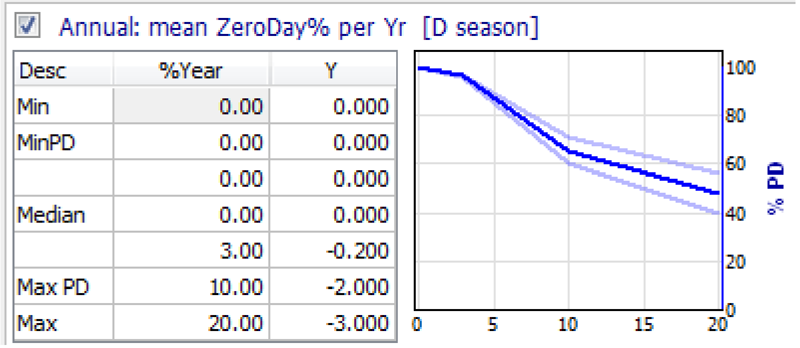
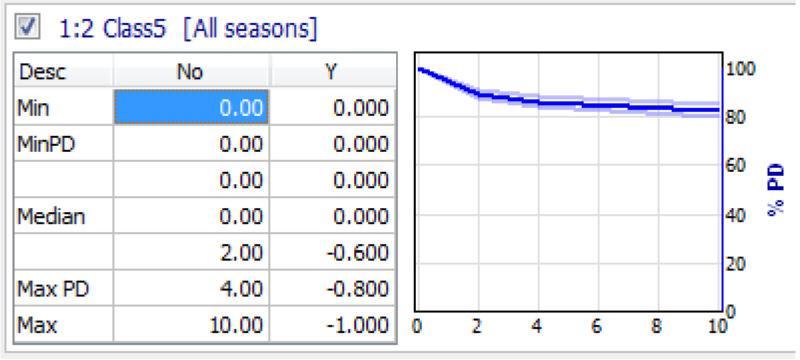
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
</table>
</td><td>Event range: >741m^3/s. Indicator flood range: 88-448m^3/s. Extreme event that scours the upper zone trees. This is essentially a "resetting" event important for maintaining diversity in the zone and preventing terrestrialisation.</td><td>High</td></tr>
</table>

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

☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.800</td></tr>
<tr><td></td><td>0.18</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.35</td><td>0.000</td></tr>
<tr><td></td><td>2.86</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>5.37</td><td>0.000</td></tr>
<tr><td>Max</td><td>6.18</td><td>0.000</td></tr>
</table>

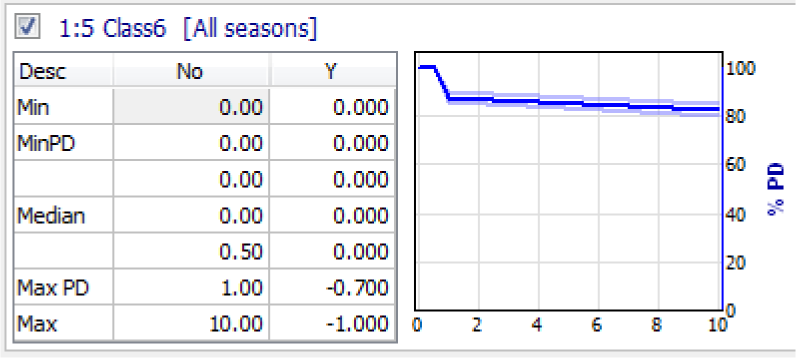
</td><td>Upper zone riparian trees are phreatophytic (A phreatophyte is deep-rooted and obtains a significant portion of its water from the phreatic zone (zone of saturation) or the capillary fringe above the phreatic zone) and at median flow the upper zone tree population is from 2-4.9m above water level. Based on rooting depths it is assumed that access to soil moisture is sufficient as long as there is flow in the channel.</td><td>High</td></tr>
<tr><td>

☑ Annual: mean ZeroDay% per Yr [D season]
<table>
<tr><th>Desc</th><th>%Year</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>3.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>-2.000</td></tr>
<tr><td>Max</td><td>20.00</td><td>-3.000</td></tr>
</table>

</td><td>X-Axis: 0,0,0,0,0,3,10,20. Stream permanency is important for persistence of upper zone trees. Once stream permanency declines below 10% population density will decline and once stream permanency declines below 20% upper zone tree species will likely lose their competitive ability and be replaced by other hardy drought tolerant or terrestrial species. Lite and Stromberg (2007; modified); Leenhouts et al. (2005). This indicator links to terrestrial trees in the upper zone which will increase as riparian trees decline due to loss of stream permanency.</td><td>High</td></tr>
<tr><td colspan="2">References</td><td></td></tr>
<tr><td colspan="2">Friedman J.M. and Lee, V.J. (2002). Extreme Floods, Channel Change, and Riparian Forests along Ephemeral Streams. Ecological Monographs, 72(3), pp. 409–425. Ecological Society of America. Huxman, T.E., W Ilcox, B.P., Breshears, D.D., Scott, R.L., Snyder, K.A., Small, E.E., Hultine, K., P Ockman, W.T. And Jackson, R.B. (2005). Ecohydrological Implications Of Woody Plant Encroachment. Ecology, 86(2) pp. 308–319 Ecological Society of America.
Leenhouts, J.M., Stromberg, J.C. and Scott, R.L. (2005). Hydrologic Requirements of and Evapotranspiration by Riparian Vegetation along the San Pedro River, Arizona U.S. Geological Survey Scientific Investigations Report 2005–5163.
Lite S.J. and Stromberg J.C. (2005). Surface water and ground-water thresholds for maintaining <i>Populus</i> - <i>Salix</i> forests, San Pedro River, Arizona. Biological Conservation 125: 153-167.</td><td></td></tr>
</table>

5.7.7 Upper Zone Trees - Terrestrial

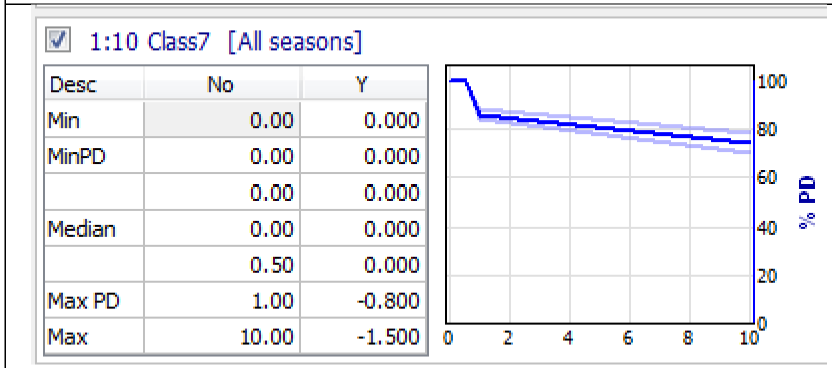
<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>


☑ 1:2 Class5 [All seasons]

<table>
<tr><th>Desc</th><th>No</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>2.00</td><td>-0.600</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>-0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.000</td></tr>
</table>
</td><td>Event range: 130-372m^3/s. Indicator flood range from 230m^3/s. This event inundates the indicator up to 0.8m and prevents terrestrialisation lower in the riparian zone.</td><td>High</td></tr>
<tr><td>


☑ 1:5 Class6 [All seasons]

<table>
<tr><th>Desc</th><th>No</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>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.700</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.000</td></tr>
</table>
</td><td>Event range: 90-234m^3/s. Indicator flood range from 230m^3/s. Similar role to class 5 and is also important for keeping upper zone trees in the upper zone and not encroaching into the lower zone and preventing terrestrialisation of the upper zone.</td><td>High</td></tr>
</table>

<table>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ 1:10 Class7 [All seasons]
<table>
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<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>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.500</td></tr>
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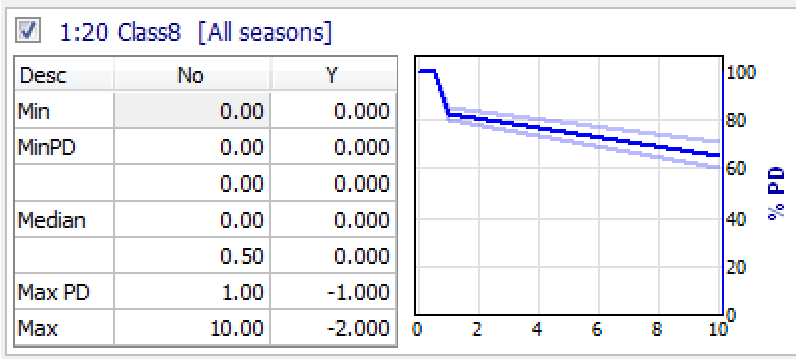
</td><td>Event range: 234-460m^3/s. Indicator flood range from 230m^3/s. Similar role to class 6. Also prevents terrestrialisation.</td><td>High</td></tr>
<tr><td>
☑ 1:20 Class8 [All seasons]
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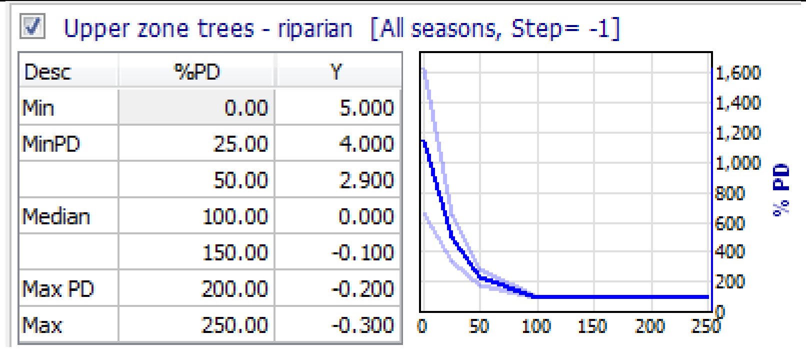
<tr><td>MinPD</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>-2.000</td></tr>
</table>
</td><td>Event range: >460m^3/s. Indicator flood range from 230m^3/s. Extreme event that scours the upper zone trees. This is essentially a "resetting" event important for maintaining diversity in the zone and preventing terrestrialisation.</td><td>High</td></tr>
<tr><td>
☑ Upper zone trees - riparian [All seasons, Step= -1]
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<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
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<tr><td>Max</td><td>250.00</td><td>-0.300</td></tr>
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</td><td>The link to upper zone riparian trees ensures that competition between the two guilds is considered. In the absence of floods riparian trees will be water stressed and terrestrial trees will have the competitive advantage. When flooding or inundation occurs riparian trees will have the competitive advantage.</td><td>Moderate</td></tr>
</table>

Response curve	Explanation	Confidence
References		
Friedman J.M. and Lee, V.J. (2002). Extreme Floods, Channel Change, and Riparian Forests along Ephemeral Streams. Ecological Monographs, 72(3), pp. 409–425. Ecological Society of America**.**		

5.8 Assumptions and limitations

The following assumptions apply to the determination of flow requirements for riparian vegetation in this study:

1) It is assumed that the magnitude of class-defined floods remains the same for scenario flow regimes
2) It is assumes that riparian indicators listed above effectively represent the riparian zone as a whole

The following limitations may apply to this study:

1) Seasonality and seasons within the DRIFT model are hydrologically defined. Temporal aspects related to timing of floods in relation to vegetation processes may not always be well represented.

5.9 References

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6 MACROINVERTEBRATE: SPECIALIST REPORT

6.1 Introduction

6.1.1 Objectives of the Macroinvertebrate study

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

For the macroinvertebrate component of the EWR assessment, 33 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 Tlou Consulting *viz*.:

- Familiarise yourself to the extent possible with the study area, including:
    - The character of the macroinvertebrate communities of the rivers in the study rivers.
    - Delineation of homogenous areas.
    - The character of the macroinvertebrate communities in the reaches encompassing the proposed sites.
- Attend the site visits with the rest of the team to:
    - where relevant, ensure that the hydraulic cross-section surveys record whatever information about your discipline that may assist with your analyses.
- Record at each site, where relevant, (i) the macroinvertebrate species, (ii) the arrangement of the macroinvertebrates relative to flow velocities, (iii) the nature and extent of instream or marginal habitat.
    - Identify macroinvertebrate specimens collected, to at least family and if possible species level/type.
    - Select key taxa as indicators for the EWR assessment, and provide information on: descriptions, distribution and abundance of the taxon (in particular, flow-related limitations to spatial distribution); habitat and microhabitat requirements in terms of water depth, water velocity and substratum type; life histories (e.g. egg-laying or emergence).
- Provide detailed information for eight EWR sites.
    - Provide information on anticipated sensitivity to change in the flow regime and additional relevant information on the taxa characteristic of each site, from the scientific literature or from data collections.
- Take responsibility for the adequacy of the data collected and provided by yourself for the macroinvertebrate component of the EWR assessment.
- Select key taxa as indicators for use in the DRIFT DSS, and provide/develop information on:

  - descriptions;
  - distribution and abundance (in particular, flow-related limitations to spatial distribution);
  - habitat and microhabitat requirements in terms of water depth, water velocity and substratum type, where available;
  - life histories (e.g. emergence);
  - anticipated sensitivity to change in the flow regime;
  - any additional relevant information on the taxa characteristic of each site, from the scientific literature or from data collections;
  - 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.
- Prepare data files for use at the DRIFT Workshop
- Assist with capacity building of an allocated DWA staff member, if and when required.
- Attend the DRIFT Workshop(s), prepared to provide in and to populate the DRIFT response curves for macroinvertebrate.
- Prepare response curve motivation tables, and make statements about the confidence level of your outputs.

6.1.2 Layout of this Section

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

- An overview of the study area, with focus on delineation of homogenous areas;
- For the EWR sites:
  - Ecoclassification assessments for macroinvertebrates, with supporting evidence;
  - the DRIFT indicators chosen, and reasons therefor;
  - the relationships between the chosen macroinvertebrate indicators and flow or other drivers, with referenced supporting motivations.
- Data and the details of any analyses performed (Appendix X).
- Ecospecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to macroinvertebrates.

6.2 Description of the study area, with the focus on macroinvertebrate communities

The Usutu to Mhlatuze Water Management Area (WMA) comprises the study area, with major rivers including the Usutu, Pongola, Mhlatuze, Mfolozi and Mkuze. Eight sites were selected within the study area, Figure 6-1, which occur within the North Eastern Highlands, North Eastern Uplands, North Eastern Coastal Belt and Lowveld Level I Ecoregions (Kleynhans et al. 2007). The North Eastern Highlands are a mountainous area characterised by closed hills and mountains with moderate to high relief and vegetation comprising North-Eastern Highveld Grassland and Lowveld Bushveld types. The North Eastern Uplands is a very diverse region with lowlands, hills and mountains with moderate and high relief, as well as closed hills and mountains with moderate and high relief, being the defining characteristics. The Lowveld Ecoregion is a hot and dry region and is characterised by plains with a low to moderate relief and vegetation consisting mostly of Lowveld Bushveld types. The North Eastern Coastal Belt consists of diverse terrain with closed hills and mountains with moderate to high relief being the most definitive (Kleynhans et al. 2007).

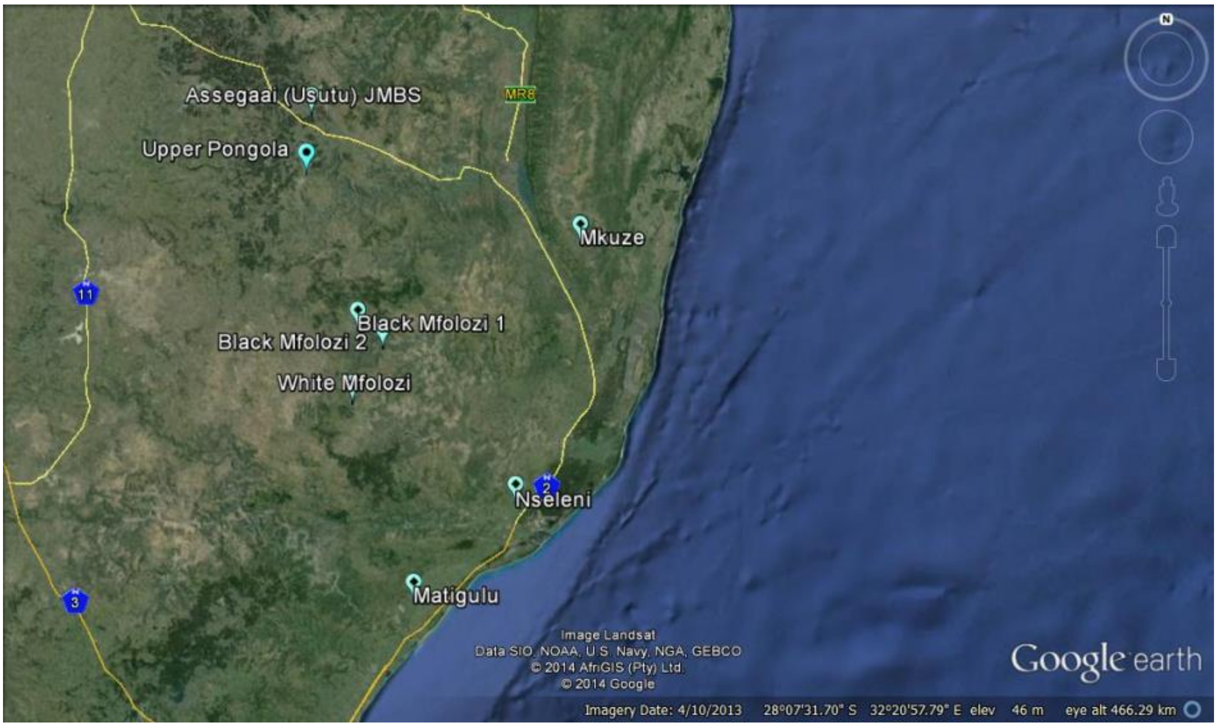


Figure 6-1 Map showing study sites

The eight sites occur within the Upper- and Lower Foothills geomorphological zonation, respectively (Rowntree and Wadeson 1999). Foothills are divided into those with a rocky bed and those with a sandy bed (Rowntree and Wadeson 1999). Rocky beds are those with a moderate gradient and are dominated by bedrock, boulders and stones, interspersed with patches of gravel and sand. Some epilithic growth and sparsely distributed emergent vegetation is also present. Fast flow is present, with slow flowing pools; low turbidity dominates but becomes turbid during flooding. Sandy beds are those with stony runs alternating with sand or sediment. Marginal vegetation is present with islands often forming within the river channel. Lower flow velocity is present but faster flow is present in rapids and during floods. Turbidity is variable, with turbidity present during floods. Characteristic channel features of Upper Foothills zones include moderately steep cobble-bed or mixed bedrock-cobble bed channel, with plane bed, pool-riffle or pool-rapid reach types. Lengths of pool and riffles/rapids sections are similar. Gradient class is between 0.005 – 0.019. Characteristic channel features of Lower Foothills zones are lower gradient mixed bed alluvial channel, with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types include pool-riffle or pool-rapid, with sand bars common in pools. Pools are of greater extent than rapids or riffles, with flood plains often present. Gradient class is between 0.001 – 0.005.

Table 6-1 Site information

Site	**AS1**	**UP1**	**MA1**	**NS1**	**MK1**	**BM1**	**BM2**	**WM1**
River	Assegaai	Pongola	Matigulu	Nseleni	Mkuze	Black Mfolozi	Black Mfolozi	White Mfolozi
Quaternary Catchment	W51E	W42E	W11A	W12G	W31J	W22A	W22C	W21H
Latitude	27.06155	27.36401	29.02006	28.63395	27.59228	27.93981	28.01432	28.2324
Longitude	30.98834	30.96945	31.47033	31.931	32.21863	31.21142	31.32372	31.18724
Altitude (m)	1014	814	63	49	60	630	483	641
Ecoregion	4.06	3.1	17.01	14.05	3.08	3.1	14.04	14.05
Geomorphological Zone	E	D	D	E	E	D	E	D

Macroinvertebrate distribution records were obtained from Resource Quality Services, DWS, with data obtained mainly from the Rivers Database for the purpose of compiling macroinvertebrate reference conditions for the various regions. Thirion (2014) contains distribution maps per family-level macroinvertebrate taxon with associated detail and is useful as a graphic means of interpreting macroinvertebrate distributions.

6.3 Literature review

Freshwater macroinvertebrates are organisms without backbones, living in various habitats in freshwater systems. Freshwater macroinvertebrate communities show preferences for particular aquatic habitats and are more or less adapted to the physical and biotic environment and its associated elements. Aquatic systems are immensely complex systems, with various combinations of factors influencing these systems. However, macroinvertebrates are extremely successful in these complex environments, due to adaptations for survival in their respective environments. Some of these adaptations include the stream-lined form of macroinvertebrates, powerful swimming legs with hairs, various respiration adaptations, for example blood gills with haemoglobin in Chironomid (midge) larvae (Usinger 1956). System variability includes that of climate, topography, underlying geology and amount and flow of water through a catchment. This variability is what determines the resultant fauna in these systems.

Table 6-2 Expected macroinvertebrate taxa and abundances per catchment

Taxon	Common Name	Catchment						
		Pongola	Assegaai	Black	Matigulu	Mkuze	White	Nseleni
		Black Mfolozi		Mfolozi			Mfolozi	
		(Lowveld)		(North Eastern				
				Uplands)				
PORIFERA	Sponges	A	B	A	A		A	A
TURBELLARIA	Flatworms	A	A	A	A		A	A
OLIGOCHAETA	Aquatic worms	A	A	A	A	A	A	A
HIRUDINEA	Leeches	A			A	A		
POTAMONAUTIDAE	Crabs	A	A	A	A	A	A	A
ATYIDAE	Shrimps	A	B	A	B	A	B	B
PALAEMONIDAE	Freshwater prawns	A			A	A	A	A
HYDRACARINA	Watermites	A	A	A	A	A	A	A
PERLIDAE	Stoneflies	A	A	A	A		A	A
BAETIDAE	Mayflies	B	B	B	B	A	B	B
CAENIDAE	Squaregills/Cainflies	A	B	A	A	A	A	A
HEPTAGENIIDAE	Flatheaded mayflies	A	B	A	A	A	A	A
LEPTOPHLEBIIDAE	Prongills	A	B	B	A	A	B	B
OLIGONEURIDAE	Brushlegged mayflies	A	A	A	A	A	A	A
POLYMITARCYIDAE	Pale burrowers	A	A	A		A	A	A
PROSOPISTOMATIDAE	Waterspecs	A	A	A		A	A	A
TRICORYTHIDAE	Stout crawlers	A	B	A	B	A	A	A
CALOPTERYGIDAE		A		A	A	A		A
CHLOROCYPHIDAE		A	A	A	A	A	A	A
SYNLESTIDAE/CHLOROLESTIDAE	Sylphs	A	A	A	A		A	A
COENAGRIONIDAE	Sprites and blues	A	A	B	B	B	B	B
LESTIDAE	Emerald damselflies		A	B	A		A	A
PLATYCNEMIDAE	Brook damselflies		A		A		A	A
PROTONEURIDAE			A		A		A	A
AESHNIDAE	Hawkers and emperors	A	A	A	A	A	A	A
CORDULIIDAE	Cruisers	A	A	A	A	A	A	A
GOMPHIDAE	Clubtails	A	A	B	A	A	A	A
LIBELLULIDAE	Darters	A	A	B	A	A	A	A
CRAMBIDAE (PYRALIDAE)	Aquatic caterpillars	A	A	A	A	A	A	A
BELOSTOMATIDAE	Giant water bugs	A	A	A	A	A	A	A
CORIXIDAE	Water boatmen	B	A	A	A	A	A	A
GERRIDAE	Pond skaters/water striders	B	A	B	B	A	B	B
HYDROMETRIDAE	Water measurers	A	A	A	A	A	A	A
NAUCORIDAE	Creeping water bugs	A	A	A	A	A	A	A
NEPIDAE	Water scorpions	A	A	A	A	A	A	A
NOTONECTIDAE	Backswimmers	A	A	A	A	A	A	A
PLEIDAE	Pygmy backswimmers	A	A	A	A	A	A	A
VELIIDAE/MESOVELIIDAE	Ripple bugs	B	A	A	A	A	A	A
DIPSEUDOPSIDAE				A	A	A	A	A
ECNOMIDAE	Caddisflies	A	A	A	A	A	A	A
HYDROPSYCHIDAE	Caddisflies	A	B	B	B		B	B
PHILOPOTAMIDAE	Caddisflies	A	A	A	A	A	A	A
POLYCENTROPODIDAE	Caddisflies	A	A					
CALAMOCERATIDAE	Cased caddis			A				
HYDROPTILIDAE	Cased caddis	A	A	A	A	A	A	A
LEPIDOSTOMATIDAE	Cased caddis		A	A	A			
LEPTOCERIDAE	Cased caddis	A	B	B	A	A	A	A
PISULIIDAE	Cased caddis			A				
DYTISCIDAE	Diving beetles	A	B	A	A	A	A	A
ELMIDAE/DRYOPIDAE	Riffle beetles	A	A	A	A		A	A
GYRINIDAE	Whirligig beetles	A	A	B	B	A	B	B
HALIPLIDAE	Crawling water beetles	A	A	A			A	A
HELODIDAE	Marsh beetles	A	A	A	A	A	A	A
HYDRAENIDAE	Minute moss beetles	A	A	A	A	A	A	A
HYDROPHILIDAE	Water scavenger beetles	A	A	A	A	A	A	A
PSEPHENIDAE	Water pennies	A	A		A		A	A
ATHERICIDAE		A	A	A	A	A	A	A
CERATOPOGONIDAE	Biting midges	A	A	A	A	A	A	A
CHIRONOMIDAE	Midges	A	B	B	A	A	A	A
CULICIDAE	Mosquitoes	A	A	B	A	A	A	A
DIXIDAE	Dixid midge	A	A	A	A	A	A	A
EMPIDIDAE	Dance flies	A	A	A		A	A	A
EPHYDRIDAE	Shore flies	A	A	A		A	A	A
MUSCIDAE	House flies, Stable flies	A	A	A		A	A	A
SIMULIIDAE	Blackflies	B	B	A	B	A	B	B
TABANIDAE	Horse flies	A	A	A	A	A	A	A
TIPULIDAE	Crane flies	A	A	A	A	A	A	A
ANCYLIDAE	Limpets	A	A	A	A	A	B	B
BULININAE		A			A	A	A	A
LYMNAEIDAE	Pond snails	A	A	A	A	A	A	A
PLANORBINAE	Orb snails	A	B	A	A	A	A	A
THIARIDAE		A	A	A	A	A	A	A
CORBICULIDAE		A	A	A	A	A	A	A
SPHAERIIDAE	Pills clams	A	A	A	A	A	A	A
UNIONIDAE	Perly mussels	A		A		A	A	A
No. of families expected		68	67	68	65	60	69	70
A = 1-10; B = 11-100 individuals								

Literature pertinent to the macroinvertebrates of the Usutu-Mhlatuze catchment was sought and assessed in terms of the following general criteria:

1. Flow and habitat preferences of macroinvertebrate taxa (indicator taxa as well as other macroinvertebrate taxa considered relevant);
2. Ecological requirements, including life histories of macroinvertebrate taxa (indicator taxa and other related taxa);
3. Macroinvertebrate distributions relevant to the study area. These search criteria provide information considered relevant and necessary in order to fulfil the requirements of predicting responses of selected indicator taxa to changes in different flow regimes.

It should be noted that literature relevant to South African macroinvertebrate histories is sparse due to a paucity of local published studies (H. Barber-James *Pers. comm.* July 2014).

Various natural and anthropogenic factors impact on aquatic systems. These include biological, chemical and physical factors. These factors influence and determine the resultant biological community. The main factors influencing an aquatic biological community include (Dallas and Day 2004):

- Water quality;
- Available biotope;
- Hydrology;
- Historical species distribution; and
- Other components of the biota, for example parasites, predators.

Bunn and Arthington (2002) proposed four principles related to the influence of flow regimes on aquatic biodiversity, namely that 1) flow is the major determinant of physical habitat, which determines the biodiversity of invertebrates present; 2) aquatic invertebrates have evolved life history strategies in response to the natural flow regime; 3) longitudinal and lateral connectivity in a river is essential to the maintenance of the aquatic biodiversity and 4) the invasion of exotic and introduced species is usually a direct result of altering the flow regime.

Flow and habitat preferences for taxa mostly at family level are derived mainly from the MIRAI model (Thirion 2007) as well as other relevant literature, including Agnew (1962), Thirion (2014); Rivers-Moore and de Moor (2008); Rivers-Moore *et al.* (2006) and Schoonbee (1973).

Table 6-3 Macroinvertebrate flow and substrate preferences (MIRAI 2007)

VSFS	SFS	FFS	VSCS	SCS	FCS	VFCS	VEG
Caenidae	Corbiculidae	Amphipoda	Leptophlebiidae	Chlorocyphidae	Barbarochthonidae	Blepharoceridae	Atyidae
Calamoceratidae	Corduliidae	Ephemeridae		Ecnomidae	Corydalidae	Ceratopogonidae	Belostomatidae
Dipseudopsidae	Limnichidae	Gomphidae		Pisuliidae	Elmidae	Dryopidae	Bulinae
Ephydridae	Sphaeridae				Heptageniidae	Empididae	Calopterygidae
Machadorythidae	Tabanidae				Libellulidae	Glossosomatidae	Chlorolestidae
Sialidae	Tipulidae				Potamonautidae	Hydropsalpingidae	Coenagrionidae
Syrphidae	Unionidae				Sericostomatidae	Hydropsychidae	Dytiscidae
						Notonemouridae	Haliplidae
						Oligoneuridae	Helodidae
						Paleomonidae	Hydraenidae
						Perlidae	Hydrobiidae
						Petrothrincidae	Hydrophilidae
						Philopotamidae	Hydroptilidae
						Polycentropodidae	Lestidae
						Prosopistomatidae	Lymnaeidae
						Psephenidae	Nepidae
						Psychomyiidae	Physidae
						Simuliidae	Planorbinae
						Telagonodidae	Platycnemidae
						Trichorythidae	Pleidae
						Turbellaria	Protoneuridae
						Xiphocentronidae	Pyralidae
							Thiaridae
							Viviparidae

FS Fine Substrate
CS Coarse Substrate
VS Very Slow
S Slow
F Fast
VEG Vegetation

The Guides to the Freshwater Invertebrates of Southern Africa published by the Water Research Commission (Volumes 7, 9 and 10) provide broad ecological information on the Ephemeroptera, Odonata, Diptera and Coleoptera. Pennak (1953), Barnard (1932 and 1934), Scholtz and Holm (1985), Crass (1947) and H. Barber-James (p*ers. comm.,* July 2014) provide insights to the general ecological requirements of certain taxa.

Mackay and Cyrus (2001) and Collocott *et al. (*2014) provide ecological information regarding the behaviour and community structure of the freshwater prawn, Palaemonidae (*Macrobrachium sp.*), which occurs in some of the rivers included in this study.

Information regarding taxa distribution within the study area was sourced from Thirion (2014), Albany Museum (2014), DWA (2014), and data received from C. Thirion, DWA RQS for macroinvertebrate reference conditions and present day data. Data gathered during the field trip of 7 – 13 July 2014 are also included as present day distribution data. Historic macroinvertebrate data was requested from various sources (Table 1-4), but had a very poor response. Thus macroinvertebrate data used for this study are derived mainly from the once-off field survey, with some data derived from the DWA Rivers Database.

Table 6-4 Macroinvertebrate Data Requested

Usutu/Mhlatuze Species or Family-level Macroinvertebrate Data Requested			
Who Approached	**Organization**	**When Requested**	**Response**
Digby Cyrus	University of Zululand	01-Jul-14	No data available
Leon Vivier	University of Zululand	01-Jul-14	No response to date
Mark Graham	Groundtruth Consulting	14-Jul-14	No response to date
Nicci Forbes	Marine & Estuarine Research	04-Jul-14	No data available
Petro Vos	Private Consultant	25-Jun-14	Macroinvertebrate information received
John Craigie	EKZNW	14-Jul-14	No data available
Sue van Rensburg	SAEON	04-Jul-14	No data available
Byron Grant	SEF	01-Jul-14	Report with SASS data received for the lower Mhlatuze River
Christa Thirion	DWA: RQS	25-Jun-14	Rivers Database SASS data; reference conditions for study areas

6.4 Description of the EWR sites

6.4.1 EWR Site AS1

Site AS1 on the Assegaai River occurs within the North Eastern Highlands Ecoregion 4.06, within the Lower Foothills geomorphological zone (Kleynhans et al. 2007). This area is characterised by mountains and closed hills with moderate to high relief. Instream habitat available includes stones in- and out of current, as well as boulders and some bedrock present. The stone in current biotope was considered of good quality, with diverse stones sizes represented in different velocities. However, some filamentous algae were present, as well as diatoms were noted on the stones. Marginal vegetation in current was adequately represented, with different vegetation types, including *Phragmites sp.* stems and leaves, as well as woody debris present which provided habitat for macroinvertebrates. Marginal vegetation out of current was also present. Gravel, sand and mud habitat were also presented.

Figure 6-2 Site AS1, Assegaai River. Looking downstream.

6.4.2 EWR Site UP1

Site UP1 on the Pongola River occurs within the Lowveld 3.1 Ecoregion, in the Upper Foothills geomorphological zone (Kleynhans et al. 2007). This area is characterised by open hills with high relief, and low mountains with high relief towards the boundary with the North Eastern Highlands. Instream habitat available includes stones in- and out of current biotope, with a large amount of bedrock and boulders present. Many of the stones in current occur in deeper, rapid sections that could not be sampled because they were too deep and fast flowing. Some filamentous algae and diatoms were observed on the stones. Most of the stones were fairly larger in size, >20cm. Measurement of a random set of velocities in stones in current habitats, yielded velocity from 0.11 m/s to 0.55 m/s. Marginal vegetation in- and out of current was poorly represented at the time of sampling, with mostly *Phragmites sp*. stems present on the left hand bank, which was inaccessible due to deep water levels present. Sand is well represented with some gravel and some mud present. The site is impacted by cattle grazing and trampling.

Figure 6-3 Site UP1, Pongola River. Looking upstream.

6.4.3 EWR Site MA1

Site MA1 on the Matigulu River occurs within the North Eastern Coastal Belt 17.01 Ecoregion, in the Upper Foothills geomorphological zone (Kleynhans et al. 2007). This area is characterised by closed hills and mountains with a moderate to high relief. Instream habitat available includes limited stones in current, with even less stones out of current available. The instream habitat is bedrock and boulder dominated with some stones available for sampling. The stones present are heavily embedded, with a large amount of silt on the stones. Diatoms were also observed on the stones. A limited amount of marginal vegetation in- and out-of current was available, including some grass, *Persicaria sp., Phragmites sp.,* stems and leaves and some submerged roots. Sand out of current was well represented, with gravel and mud sections also well represented.

Figure 6-4 Site MA1, Matigulu River. Looking downstream.

6.4.4 EWR Site NS1

Site NS1 on the Nseleni River occurs within the North Eastern Uplands 14.05 Ecoregion, in the Lower Foothills geomorphological zone (Kleynhans et al. 2007). This area is characterised by lowlands, hills and mountains with moderate to high relief. Instream habitat available consists of a small riffle section mainly with fairly small stones in current (<10 cm in diameter), limited stones out of current and very little bedrock available. Sedimentation is present at the site. No filamentous algae were observed instream, but with diatoms present on some rocks. Marginal vegetation in- and out of current was limited, with overhanging palm leaves, grass, reeds and *Persicaria sp.* creating marginal vegetation. Gravel, sand and mud are also present at the site. Slow to medium flow was present at the time of sampling. Cattle trampling and grazing is evident at the site.

Figure 6-5 Site NS1, Nseleni River. Looking upstream.

6.4.5 EWR Site MK1

Site MK1 on the Mkuze River occurs within the Lowveld 3.08 Ecoregion, in the Lower Foothills geomorphological zone (Kleynhans et al. 2007). This hot and dry area is characterised by plains with moderate to low relief and vegetation consisting mainly of

Lowveld Bushveld types. The instream habitat is dominated by sand with some marginal vegetation present. No stones in current are present for sampling. The river is > 10m wide. Slow flow is present over the sand biotope. *Phragmites sp.* stems and leaves, kikuyu, *Solanum sp.* stems and leaves support a diverse marginal vegetation biota. Logs with leaves growing from the logs provide aquatic vegetation and cover for some biota. The river is mostly shallow, 10 – 20 cm average depth with some deeper channels on the side of the river where bank scouring has occurred. Some filamentous algae are present. Cattle trampling and grazing occurs at the site. The marginal vegetation is an important habitat at this site, supporting a diverse and abundant macroinvertebrate community.

Figure 6-6 Site MW1, Mkuze River. Looking downstream.

6.4.6 EWR Site BM1

Site BM1 on the Black Mfolozi River occurs within the Lowveld 3.1 Ecoregion, in the Upper Foothills geomorphological zone (Kleynhans et al. 2007). Open hills and low mountains with high relief are present towards the west on the boundary with the North Eastern Highlands. Instream habitat is dominated by bedrock with stones in current and some stones out of current present. Diatoms are present on the stones and bedrock, with extensive sedimentation also present. Marginal vegetation in- and out of current is dominated by stems and leaves of *Phragmites sp.* Gravel beds are present, with more limited sand and mud areas. Random velocity measurements at depths ranging from 10 to 36 cm delivered velocities ranging from 0.16 m/s to 0.90 m/s in mainly the stones and bedrock biotopes. Cattle trampling and grazing is present at the site.

Figure 6-7 Site BM1, Black Mfolozi River. Looking downstream.

6.4.7 EWR Site BM2

Site BM2 on the Black Mfolozi River occurs within the North Eastern Uplands 14.04 Ecoregion, in the Lower Foothills geomorphological zone. This area is characterised with lowlands, hills and mountains with moderate to high relief. Instream habitat includes stones in- and out of current, with small riffle sections with small stones (<10 cm) that are highly moveable but with a high sedimentation. Bedrock is well represented at this site. No algae were noted at the site. Aquatic vegetation is present, as well as marginal vegetation in- and out of current. Sedimentation is prevalent. Random velocity measurements at depths ranging from 6 to 30 cm delivered velocities ranging from -0.02 to 0.91 m/s in mainly the stones, bedrock, gravel and sand biotopes. Cattle trampling and grazing is present at the site.

Figure 6-8 Site BM2, Black Mfolozi River. Looking upstream.

6.4.8 EWR Site WM1

Site WM1 on the White Mfolozi River occurs within the North Eastern Uplands 14.05 Ecoregion, in the Upper Foothills geomorphological zone. This site is characterised lowlands, hills and mountains with moderate to high relief. Instream habitat at this site is sand and bedrock/boulder dominated. Low flow over a riffle section is present, but mainly slow runs over bedrock/boulders and sand dominate this site. Stones in- and out of current are present. The stones are embedded and occur on sand. Some gravel is present between the stones. Diatoms are present, with no filamentous algae seen at the site. Limited gravel and mud is present. No aquatic vegetation is present, with limited marginal vegetation in- and out of current present, provided by sedges and a small amount of *Phragmites sp.* stems and leaves occurring. Random velocity measurements at depths ranging from 8 to 36cm delivered velocities ranging from -0.02 to 0.74 m/s in mainly the stones, boulder and sand biotopes.

Figure 6-9 Site WM1, White Mfolozi River. Looking downstream.

6.5 Ecoclassification of river reaches represented by the EWR sites

River	Site	MIRAI %	Macroinvertebrate EC
Assegaai	AS1	86.4	B
Pongola	UP1	79.5	B/C
Nseleni	NS1	79.5	B/C
Matigulu	MA1	80.9	B/C
Black Mfolozi	BM1	81.3	B/C
Black Mfolozi	BM2	79.8	B/C
White Mfolozi	WM1	81.1	B/C
Mkuze	MK1	76.9	C

6.6 Field data collection and analysis

Macroinvertebrate communities are useful biotic indicators of short-term integrated stressors on river resources. Macroinvertebrate community composition and abundance can be impacted due to flow alterations, habitat disturbance and water quality perturbations, or any combination of these stressors. Different macroinvertebrate taxa have different sensitivities to these three system drivers, which means that the proportion of these can be used to provide an indication of the overall disturbance to the ecological integrity of a river.

6.6.1 Macroinvertebrate sampling procedure

Sampling was conducted according to the SASS5, South African Scoring System Version 5 method, which is a rapid biomonitoring tool that was developed for lotic (flowing water) systems. The method assesses macroinvertebrate communities occupying different instream habitats and uses pre-determined sensitivity weightings assigned per taxon. Macroinvertebrates were identified mostly to family taxonomic level. The method gives an indication of water quality impairment and overall river integrity/health. Detail on the method can be obtained from Dickens and Graham (2002).

The Invertebrate Habitat Assessment System (IHAS) was also used to characterise the sampling site and stream condition (McMillan 1998). The IHAS criteria were used only insofar as the criteria assisted in analysing the habitat for macroinvertebrate communities and the IHAS scoring was not used as this still needs to be statistically tested. Sites were characterised using the Invertebrate field assessment forms created by Dallas 2005. Biotopes were also rated from 1 – 5 as per the SASS score sheet, with 1 = very poor (limited diversity), 5 = highly suitable (wide diversity).

In situ water quality parameters were measured on site, including that of temperature, pH, dissolved oxygen (mg/l and percentage) and electrical conductivity. Water clarity, turbidity, flow and other relevant observations were noted.

6.6.2 Data analysis

The MIRAI (Macroinvertebrate Response Assessment Index; reference) was used to analyse the SASS5 data collected. Present day, as well as relevant, historic data for sites within the same Ecoregion Level II and geomorphological zone were sourced. The MIRAI was developed to provide a habitat-based cause-and-effect foundation to interpret the deviation of the macroinvertebrate assemblage from reference condition (Thirion 2007). The MIRAI generates an Ecological Category (EC) for macroinvertebrates by integrating the ecological requirements of an assemblage and relating this to modified flow, instream habitat and water quality conditions. An EC was derived per site. Reference conditions for this project were set using historic SASS5 data, as well as specialist judgement provided by C.

Thirion, Resource Quality Services, DWS. Frequencies of Occurrence (FROCs) were set using the SASS5 data. The habitat data collected from the IHAS and RHP field characterisation sheets were used to interpret the data and for assistance with the flow, habitat and water quality metrics in the MIRAI model.

6.7 Results

Macroinvertebrates were sampled at eight sites during the field work conducted during 7 – 13 July 2014. *In situ* water quality parameters are presented below.

Table 6-5 *In situ* water quality measurements per site

Site	**AS1**	**UP1**	**MA1**	**NS1**	**MK1**	**BM1**	**BM2**	**WM1**
River	Assegaai	Pongola	Matigulu	Nseleni	Mkuze	Black Mfolozi	Black Mfolozi	White Mfolozi
Date	10/07/2014	10/07/2014	07/07/2014	08/07/2014	09/07/2014	12/07/2014	12/07/2014	11/07/2014
Time	09:50	14:30	12:50	10:20	12:10	15:10	10:15	14:00
Temp (°C)	9.36	10.27	15.63	15.24	18.96	12.14	10.16	11.19
pH	7.06	7.4	7.11	7.54	8.12	7.17	7.16	7.55
DO (mg/l)	11.56	12.18	7.82	7.63	7	11.13	11.33	11.78
DO %	100.6	108.4	78.8	76.1	75.9	103.3	100.82	107.4
Cond (µs/cm)	164	115	239	1226	1465	314	321	372

SASS scores and taxa collected per site are indicated below, with number of families collected compared to number of families expected. Abundances: A = 2 – 10; B = 11 -100, C = 101 – 1000 estimated individuals.

Table 6-6 SASS results per site

Taxon	AS1	UP1	MA1	NS1	MK1	BM1	BM2	WM1
	Assegaai	Pongola	Matigulu	Nseleni	Mkuze	Black Mfolozi	Black Mfolozi	White Mfolozi
	10/07/2014	10/07/2014	07/07/2014	08/07/2014	09/07/2014	12/07/2014	12/07/2014	11/07/2014
PORIFERA			B					
COELENTERATA								
TURBELLARIA	A		A				A	
OLIGOCHAETA	A	A	A	A		A	A	1
HIRUDINEA								
AMPHIPODA								
POTAMONAUTIDAE		A		A		A	1	
ATYIDAE	A		B	A	B	A	A	A
PALAEMONIDAE			B			A		1
HYDRACARINA	A		A	A	A		1	
NOTONEMOURIDAE								
PERLIDAE	A	A	A			B	B	
BAETIDAE 1 SP								
BAETIDAE 2 SP					B			
BAETIDAE > 2 SP	B	C	B	B		B	B	B
CAENIDAE	A	B	A	B	A	B	A	A
EPHEMERIDAE								
HEPTAGENIIDAE	A	B				A	B	A
LEPTOPHLEBIIDAE	B	B	B	C		B	B	A
OLIGONEURIDAE								
POLYMITARCYIDAE	1	A						
PROSOPISTOMATIDAE		1						
TELOGANODIDAE								
TRICORYTHIDAE							1	
CALOPTERYGIDAE					A			
CHLOROCYPHIDAE			A			A	A	
SYNLESTIDAE/CHLOROLESTIDAE								
COENAGRIONIDAE		A	A	B	C	A	B	A
LESTIDAE								
PLATYCNEMIDAE								
PROTONEURIDAE								
AESHNIDAE					A	A	A	
CORDULIIDAE								
GOMPHIDAE	A	A	B		B	B	B	A
LIBELLULIDAE		A	B		B	A	B	A
CRAMBIDAE (PYRALIDAE)	1	1						
BELOSTOMATIDAE			A	A	B			A
CORIXIDAE	A	A	B		A	A	A	A
GERRIDAE			B	A	A			
HYDROMETRIDAE								
NAUCORIDAE	B	A	1		A	A	A	1
NEPIDAE								
NOTONECTIDAE			1	A				
PLEIDAE	A				A			
VELIIDAE/MESOVELIIDAE			A	A	B	A	A	
CORYDALIDAE								
SIALIDAE								
DIPSEUDOPSIDAE								
ECNOMIDAE		1						
HYDROPSYCHIDAE 1 SP					1			
HYDROPSYCHIDAE 2 SP						B	B	B
HYDROPSYCHIDAE > 2 SP	B	B	B	B				
PHILOPOTAMIDAE	1	1	A			A		
POLYCENTROPODIDAE								
PSYCHOMYIIDAE/XIPHOCENTRONIDAE								
BARBAROCHTHONIDAE								
CALAMOCERATIDAE								
GLOSSOSOMATIDAE								
HYDROPTILIDAE					A	1		1
HYDROSALPINGIDAE								
LEPIDOSTOMATIDAE								
LEPTOCERIDAE	A	A	B	B	A	A	B	1
PETROTHRINCIDAE								
PISULIIDAE								
SERICOSTOMATIDAE								
DYTISCIDAE	A	1	A	A	A			
ELMIDAE/DRYOPIDAE	A	A	A	A		A		A
GYRINIDAE	A	A	B	B	B	B	B	A
HALIPLIDAE								
HELODIDAE								
HYDRAENIDAE								1
HYDROPHILIDAE								
LIMNICHIDAE								
PSEPHENIDAE	A	1				A		
ATHERICIDAE						A		A
BLEPHARICERIDAE								
CERATOPOGONIDAE	A	B		1	1	A		A
CHIRONOMIDAE	B	B	B	A	A	B	B	A
CULICIDAE				1			B	
DIXIDAE								
EMPIDIDAE								
EPHYDRIDAE								
MUSCIDAE	1	A						
PSYCHODIDAE								
SIMULIIDAE	B	B	B	B	B	B	A	B
SYRPHIDAE								
TABANIDAE	A	A	A	A		A	A	A
TIPULIDAE	A	A	1	A		A	A	
ANCYLIDAE	A		A	A		1		1
BULININAE								
HYDROBIIDAE								
LYMNAEIDAE	1							
PHYSIDAE			A					
PLANORBINAE								
THIARIDAE			B	A			1	
VIVIPARIDAE								
CORBICULIDAE	A		1	A			A	
SPHAERIIDAE								
UNIONIDAE								
SASS Score	207	204	204	140	125	210	178	158
No of Families	31	29	34	26	23	31	29	25
ASPT	6.68	7	6	5.38	5.4	6.77	6.14	6.32
No. of families expected	67	68	65	70	60	68	68	69

6.7.1 EWR Site AS1

A SASS total score of 207 and associated ASPT of 6.68 were recorded at A1. 31 taxa were collected compared to 67 taxa expected. Flow- and water quality sensitive taxa collected include Perlidae, Heptageniidae, Crambidae (Pyralidae), Philopotamidae, and Psephenidae. Of the 31 taxa collected, seven were air breathers belonging to the Hemiptera, Coleoptera and Gastropoda orders. Taxa expected but not observed include Oligoneuridae, Prosopistomatidae, Tricorythidae, Chlorocyphidae, Coenagrionidae, Aeshnidae, Libellulidae, Hydrophilidae, Dixidae, Planorbinae, Thiaridae.

6.7.2 EWR Site UP1

A total SASS score of 204 with an associated ASPT of 7.03 were recorded at UP1. Twenty nine taxa were collected compared to 68 taxa expected. Baetidae >2 spp. were collected with an estimated abundance of a C, indicating more than 100 individuals present, which is higher than the expected abundance of a B, i.e. between 11 – 100 individuals. Flow- and water quality sensitive taxa collected include Perlidae, Heptageniidae, Crambidae (Pyralidae), Hydropsychidae >2 spp., Philopotamidae and Psephenidae. Five air-breathing taxa were collected belonging to the Hemiptera and Coleoptera orders. Taxa expected but not observed include Atyidae, Palaemonidae, Tricorythidae, Chlorocyphidae, Aeshnidae, Athericidae, Dixidae, Planorbinae, Corbiculidae.

6.7.3 EWR Site MA1

A total SASS score of 204 with an associated ASPT of 6.0 were recorded at MA1. Thirty-four taxa were collected compared to 65 taxa expected. Flow- and water quality sensitive taxa collected include Perlidae, Baetidae >2 spp., Chlorocyphidae, Hydropsychidae >2 spp., and Philopotamidae. The freshwater prawn, Palaemonidae (Macrobrachium *sp.*) was also collected at this site. Eleven air breathing taxa were recorded from the Hemiptera, Coleoptera and Gastropoda orders. Abundances observed were generally within the expected abundances. Taxa expected buy not sampled include Potamonautidae, Heptageniidae, Tricorythidae, Aeshnidae, Psephenidae, Athericidae, Dixidae and Sphaeriidae.

6.7.4 EWR Site NS1

A SASS score of 140 and an associated ASPT of 5.38 were recorded at NS1. Twenty-six taxa were collected compared to 70 taxa that were expected at this site. Leptophlebiidae showed an estimated abundance of a C which is higher than the expected abundance of a B. Flow- and water quality sensitive taxa were scarce at this site, with Baetidae >2 spp. and Hydropsychidae >2 spp. collected. Air breathing taxa comprised eight of the families collected. Taxa expected but not sampled include Palaemonidae, Peridae, Heptageniidae, Prosopistomatidae, Tricorythidae, Chlorocyphidae, Gomphidae, Libellulidae, Psephenidae, Athericidae, Lymnaeidae and Planorbinae among others.

6.7.5 EWR Site MK1

A SASS total score of 125 with an associated ASPT of 5.4 were recorded at MK1. Twenty-three taxa were collected compared to 60 taxa expected. Of the taxa collected, eight were air breathers. The only water quality sensitive taxa collected were Calopterygidae with an associated sensitivity score of 10. Taxa expected but not observed include Heptageniidae, Leptophlebiidae, Tricorythidae, Palaemonidae, Hydropsychidae >2 pp., Philopotamidae, Simuliidae, Tipulidae, Lymnaeidae and Planorbinae.

6.7.6 EWR Site BM1 (Upstream Site)

A SASS total score of 210 and associated ASPT of 6.77 were recorded at BM1. Thirty-one taxa were collected versus 68 taxa expected. Of the taxa collected, five were air breathers belonging to the Hemiptera and Coleoptera orders. Flow- and water quality sensitive taxa observed include Perliae, Heptageniidae, Baetidae >2 spp., Chlorocyphidae, Psephenidae and Athericidae. Abundances observed were generally within the expected abundances per taxon. Taxa expected but not observed include Prosopistomatidae, Tricorythidae, Pyralidae, Hydropsychidae >2 spp., Dytiscidae, Lymnaeidae and Planorbinae.

6.7.7 EWR Site BM2 (Downstream Site)

A SASS total score of 178 and an associated ASPT of 6.14 were recorded at BM2. Twenty-nine taxa were collected compared to 68 taxa expected. Five of the taxa collected were air breathers. Flow- and water quality sensitive taxa collected include Perlidae, Baetidae >2 spp., Heptageniidae and Chlorocyphidae. Taxa expected but not observed include Prosopistomatidae, Polymitarcyidae, Hydropsychidae >2 spp., Philopotamidae, Psephenidae and Athericidae.

6.7.8 EWR Site WM1

A SASS total score of 158 and an associated ASPT of 6.32 was observed. Twenty-five taxa were collected compared to 69 taxa expected. Six of the taxa collected were air breathers. Flow- and water quality sensitive taxa collected include Baetidae >2 spp., Heptageniidae and Athericidae. Taxa expected but not observed include Potamonautidae, Perlidae, Prosopistomatidae, Tricorythidae, Chlorocyphidae, Aeshnidae, Hydropsychidae >2 spp., Philopotamidae, Psephenidae, Lymnaeidae, Thiaridae and Corbiculidae.

6.8 Identification of indicators

6.8.1 Indicator list for macroinvertebrates

A list of potential macroinvertebrate taxa considered as indicators in the EWR assessments and their expected response to flow changes is provided in Table 4-12-7.

Indicator taxa were selected according to the following criteria:

- Taxa must have a reasonably strong preference for a certain habitat type or velocity type, i.e normally a 4 or 5 preference value (as indicated in the MIRAI), sometimes even a 3 value is used when no other appropriate taxa are present;
- Taxa must occur frequently enough i.e. a FROC value of 4 or 5, or minimally at least 50% of the time;
- Taxa must be at least moderately sensitive to changes in water quality.

The following should also be taken into consideration:

- The data set available;
- The reference taxa list should also be consulted;
- Distribution data available.

Table 6-7 List of Potential macroinvertebrate indicator taxa

Macroinvertebrate Indicators, Groups and Taxa Per Catchment; Ticked-boxes are those indicators selected															
Group	**Taxon**	**Flow preference**	**Habitat preference**	**Water quality preference**	**QV**	**Air Breather**	**FFG**	**Matigulu**	**Nseleni**	**Mkuze**	**Pongola**	**Assegaai**	**White Mfolozi**	**Black Mfolozi U/S**	**Black Mfolozi D/S**
Vegetation dwellers with slow flowing water	Atyidae (Freshwater Shrimps)	Slow (0.1 - 0.3m/s)	Vegetation	Sensitive	8	No	CG					√		√	
	Coenagrionidae (Sprites & Blues)	Slow (0.1 - 0.3m/s)	Vegetation	Low	4	No	P	√	√	√	√		√		√
Cobble dwellers with fast flow	Palaemonidae (Freshwater Prawns)	Very fast (>0.6m/s)	Cobbles	Sensitive	10	No	S	√					*√	√	√
	Perlidae (Stoneflies)	Very fast (>0.6m/s)	Cobbles	Highly Sensitive	12	No	P	√			√	√		√	√
	Philopotamidae	Very fast (>0.6m/s)	Cobbles	Sensitive	10	No	F				*				
	Psephenidae (Water pennies)	Very fast (>0.6m/s)	Cobbles	Sensitive	10	No	SG				*				
	Hydropsychidae (Caddisflies)	Very fast (>0.6m/s)	Cobbles	Low to highly sensitive	4 - 12	No	F	√	√	*√	√	√	√	√	√
Cobble dwellers with moderate flow	Heptageniidae (Flatheaded mayfly)	Moderate (0.3 - 0.6m/s)	Cobbles	Highly Sensitive	13	No	CG				√	√	√	√	√
	Elmidae (Riffle Beetles)	Moderate (0.3 - 0.6m/s)	Cobbles	Sensitive	8	Yes	CG	√	√						
GSM dwellers	Gomphidae (Clubtails)	Slow (0.1 - 0.3m/s)	Gravel, sand, mud	Low	6	No	P	√		√	√	√	√	√	√
	Polymitarcyidae (Pale Burrowers)	Moderate (0.3 - 0.6m/s)	Gravel, sand, mud	Sensitive	10	No	CG					*			
Standing water over cobbles	Leptophlebiidae (Prongills)	Standing water (<0.1m/s)	Cobbles	Moderate	9	No	CG	√	√		√	√	√	√	√
All flow ranges, all habitat	Baetidae	Moderate (all flow ranges)	Cobbles, Veg, GSM	Low to highly sensitive	4 - 12	No	CG	√	√	√	√	√	√	√	√
	Chironomidae				2	No	CG	√	√	√	√	√	√	√	√
	Simuliidae	Preferably >0.3m/s	Cobbles, Veg, GSM (coarser substrate)		5	No	F	√	√	√	√	√	√	√	√
					TOTAL INDICATORS			10	7	6	9	9	9	10	10
Air-breather	Y	Yes													
	N	No			*	Found 1 individual only									
FFG = Functional Feeding Group	P	Predator													
	CG	Collector/Gatherer													
	F	Filterer													
	SG	Scrapers/Grazers													
	S	Shredders													
Habitat Preference	Veg	Vegetation													
	GSM	Gravel, sand, mud													
Flow Preference	Standing		<0.1m/s												
	Slow		0.1 - 0.3m/s												
	Moderate		0.3 - 0.6m/s												
	Very fast		>0.6m/s												
Note: Flow, habitat and water quality preferences derived mostly from the MIRAI model															
(Macroinvertebrate Response Assessment Index) model															
Others are professional judgement															
FFGs derived from Merrit & Cummins 1984, Palmer 2012.															
QV obtained from SASS5 score sheet (Dickens & Graham, 2002).															

Ecological attributes of macroinvertebrates are useful when characterising aquatic environments, especially those environments that present compromising circumstances, or with changes in flow pattern, for example no flow situations with only pools present, or systems with low dissolved oxygen. Some of these ecological attributes include the proportion of air-breathing taxa present in the water resource which gives an indication of the extent to which oxygen availability is limited, functional feeding groups which give an indication of the trophic structure of the macroinvertebrate assemblage present and general habitat, flow and water quality preferences.

Functional Feeding Groups (FFGs) are useful when attempting to characterise and assess the function and structure of an aquatic system and can provide descriptive macroinvertebrate information of use in this study. Merrit and Cummins (1984) devised an approach that relates FFGs to a certain trophic level (Table 6-8). This functional feeding group (FFG) classification of feeding adaptations distinguishes taxa that perform different functions within aquatic ecosystems with respect to processing of nutritional resource categories (Merrit and Cummins 1984). The role of the taxa in the system, as well as potential understanding of processes in aquatic systems may be possible using the FFG approach.

Table 6-8 Comparison of functional feeding groups and trophic levels (Merrit and Cummins 1984).

Functional Feeding Group	Trophic Level Based on Ingestion
Shredders (live or dead plant)	Detritivores, Herbivores, Carnivores,Herbivores
Collectors (filtering and gathering)	Detritivores, Herbivores, Carnivores
Scrapers (grazers)	Detritivores, Herbivores
Predators (engulfers)	Carnivores (Detritivores)
Piercers (plant or animal)	Unrecognizable fluids

Shredders include taxa that feed on detritus composed mainly of leaves from riparian vegetation, scrapers include taxa feeding on the epilithic layer of substrates, and collectors feed on fine detritus (Merrit and Cummins 1984). This system was largely used to allocate FFGs to indicator taxa in this study, however some modifications have been made as deemed relevant.

Table 6-9 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Atyidae	Freshwater shrimps are vegetation dwellers that prefer slow flowing water, i.e. 0.1 – 0.3 m/s, with a moderate to high sensitivity to changes in water quality. This taxon therefore represents the vegetation dwelling group of taxa.
Palaemonidae	Freshwater prawns are cobble dwellers that prefer very fast flowing water, i.e. >0.6 m/s. They are also sensitive to changes in water quality.
Perlidae	Perlidae show preference for the cobble biotope and prefer very fast flowing water, i.e. >0.6 m/s. They are highly sensitive to changes in water quality and as such are a very good indicator to these parameters.
Baetidae	Baetidae occur throughout the various habitats (Cobbles, bedrock/boulders/marginal vegetation/GSM/aquatic vegetation) present in a river, but show a slightly stronger preference for the cobble biotope. They are also a food source for certain fish species. The following fish species consume Baetidae at the different life stages indicated: *Amphilius uranoscopus*: all life stages *Labeobarbus marequensis*: juvenile *Labeobarbus natalensis*: juvenile *Barbus euteania*: all life stages *Barbus trimaculatus*: all life stages *Barbus paludinosus*: all life stages
Heptageniidae	The Heptageniidae show preference for the cobble biotope, prefer velocities from 0.3 – 0.6 m/s and are highly sensitive to changes in water quality.
Leptophlebiidae	These taxa show a preference for standing water, i.e. < 0.1 m/s and are moderately sensitive to changes in water quality. They show a preference for the cobble biotope.
Coenagrionidae	These taxa occur in the marginal vegetation and show a preference for slower flowing waters, i.e. 0.1 – 0.3 m/s. They have a low sensitivity to changes in water quality.
Gomphidae	Gomphidae occur in the GSM (Gravel, Sand and Mud) biotope and show a preference for velocities between 0.1 – 0.3 m/s. They have a low sensitivity to changes in water quality.
Hydropsychidae	These taxa show preference for very fast velocities, i.e. > 0.6 m/s, prefer the cobble biotope and have a range of sensitivities to water

Indicator	Reasons for selection as indicator
	quality, from low to highly sensitive taxa. Some species are able to withstand slower velocities.
Elmidae	Elmidae are sensitive to changes in water quality, occur in the cobble biotope and show preference for velocities between 0.3 – 0.6 m/s.
Chironomidae	Chironomidae occur in all the biotopes present, with a slightly stronger preference for cobbles and GSM and have a very low sensitivity to changes in water quality. The following fish species consume Chironomidae and Simuliidae at the different life stages indicated: *Amphilius uranoscopus*: all life stages *Labeobarbus marequensis*: juvenile *Labeobarbus natalensis*: juvenile *Barbus euteania*: all life stages *Barbus trimaculatus*: all life stages *Barbus paludinosus*: all life stages
Simuliidae	Simuliidae occur in all the different biotopes, but show a stronger preference for the cobble and bedrock/boulder biotopes. They show preferences for velocities > 0.3 m/s.

Table 6-10 List of macroinvertebrate indicators and their predicted direction of response to flow changes.

Indicator	Definition	Predicted change	References
Atyidae	Freshwater shrimps	With less discharge, a decrease in the depth and wetted perimeter will result and consequently a lower abundance of Atyidae will occur. With an increase in discharge, an increase in the abundance of Atyidae will occur due to an increase in the depth and wetted perimeter.	(Thirion 2007)
Palaemonidae	Freshwater prawns	Higher flows during the summer months benefit the Palaemonidae in terms of their movement downstream to brackish waters to reproduce.	(Collocott et al. 2014)
Perlidae	Stoneflies	Less discharge will have a	(Thirion 2007).

Indicator	Definition	Predicted change	References
		negative impact on Perlidae which are flow sensitive. An increase in discharge will result in an increase in ave and max velocities which will affect the Perlidae positively with a resultant increase in abundance. Perlidae show preferences for velocities >0.6 m/s.	
Baetidae	Minnow mayflies	Baetidae are multivoltine, with overlapping generations and continuous emergence. Baetidae occur within the full range of velocities, from standing water to very fast velocities.	(Brittain and Sartoi 2003) (Thirion 2014; Schoonbee 1973, Mathews 1968)
Heptageniidae	Flat headed mayflies	Less discharge will have a negative impact on Heptageniidae which are fairly flow sensitive. An increase in discharge will result in an increase in velocities with a resultant increase in Heptageniidae abundance. Heptageniidae prefer moderate flow (0.3-0.6m/s) (Thirion 2014), Crass 1947 in Schoonbee 1973 state that Heptageniidae prefer swift flowing water, with Schoonbee 1973 stating that most species occur in pools.	(Thirion 2007 2014)
Leptophlebiidae	Prongills	Leptophlebiidae mostly prefer slower velocity over cobbles, however some species prefer "swift" flow. Areas with slow flow begin to decrease with increasing discharge, which has a resultant negative effect on the Leptophlebiidae. A decrease in discharge increases the amount of slow flow available, which is generally a positive effect for the Leptophlebiidae.	(Thirion 2014) (Schoonbee 1973)

Indicator	Definition	Predicted change	References
Coenagrionidae	Sprites and blues	Wetted perimeter and depth increases with an increase in discharge, hence the increase in abundance of Coenagrionidae. Vice versa with a decrease in discharge. It must be noted that depending on the amount and quality of the marginal vegetation present, will have an effect on the predicted increase/decrease in the abundance of Coenagrionidae.	(Thirion 2007)
Gomphidae	Clubtails	Generally, an increase in discharge will have a resultant increase in wetted perimeter and GSM habitat, therefore an increase in abundance of Gomphidae.	(Thirion 2007)
Hydropsychidae	Netspinning Caddis flies	Less discharge will have a negative impact on Hydropsychidae which are flow sensitive. An increase in discharge will result in an increase in ave and max velocities which will affect the Hydropsychidae positively with a resultant increase in abundance. Some species are able to withstand slower velocities, hence less discharge will not have as severe a negative impact on Hydropsychidae.	(Thirion 2014)
Elmidae	Riffle beetles	A decrease in discharge will have a resultant decrease in velocities, which will have a resultant negative impact on Elmidae which show preference for velocities between 0.3 - 0.6 m/s.	(Thirion 2007)
Chironomidae	Midges	Chironomidae generally occur over a range of velocities. Chironomidae are characteristic of systems under stress, so when	(Thirion 2014) (Mackay and Cyrus 2001)

Indicator	Definition	Predicted change	References
		discharge is decreased, the Chironomidae can withstand these flow conditions to a large degree. However, generally, a decrease in discharge will have a lesser, smaller decrease in abundance of Chironomidae.	
Simuliidae	Black flies	Simuliidae are present in a range of velocities but show preference for fast velocities. An increase in discharge will favour the Simuliidae due to an increase in velocity and wetter perimeter.	(Thirion 2014)

6.8.2 Description and location of indicators

6.8.2.1 Name: Vegetation dwellers

Habitat: Marginal vegetation
Representative taxa: atyidae
Other characteristic taxa: Coenagrionidae
Flow-related concerns: Has a preference for slower velocities between 0.1 – 0.3 m/s, therefore this indicator requires inundation of marginal vegetation throughout the year.

6.8.2.2 Name: Vegetation dwellers

Habitat: Marginal vegetation
Representative taxa: Coenagrionidae
Other characteristic taxa: Atyidae .
Flow-related concerns: Has a preference for slower velocities between 0.1 – 0.3 m/s, therefore this indicator requires inundation of marginal vegetation throughout the year.

6.8.2.3 Name: Cobble dwellers with fast flow

Habitat: Cobbles
Representative taxa: Palaemonidae
Other characteristic taxa: Perlidae, Philopotamidae, Psephenidae, Hydropsychidae
Flow-related concerns: This taxon shows preference for velocities >0.6 m/s and requires higher flows during the summer months for migration from freshwater to brackish/estuarine waters for breeding purposes.

6.8.2.4 Name: Cobble dwellers with fast flow

Habitat: Cobbles
Representative taxa: Perlidae
Other characteristic taxa: Palaemonidae, Philopotamidae, Psephenidae, Hydropsychidae
Flow-related concerns: This taxon shows preference for velocities >0.6 m/s and requires fast flows over clean cobbles, i.e. no filamentous algae, sedimentation or embeddedness of cobbles. They are highly sensitive to changes in water quality and thus require very good water quality.

6.8.2.5 Name: Cobble dwellers with fast flow

Habitat: Cobbles
Representative taxa: Hydropsychidae
Other characteristic taxa: Palaemonidae, Philopotamidae, Psephenidae, Perlidae
Flow-related concerns: This taxon shows preference for velocities >0.6 m/s and requires fast flows over clean cobbles, i.e. no filamentous algae, sedimentation or embeddedness of cobbles. They range from low to highly sensitive to changes in water quality.

6.8.2.6 Name: Cobble dwellers with moderate flow

Habitat: Cobbles
Representative taxa: Heptageniidae
Other characteristic taxa: Elmidae
Flow-related concerns: This taxon shows preference for velocities ranging between 0.3 – 0.6 m/s. Clean cobbles, i.e. no filamentous algae, sedimentation or embeddedness of cobbles are required. Elmidae are sensitive to changes in water quality and thus require good water quality.

6.8.2.7 Name: Cobble dwellers with moderate flow

Habitat: Cobbles
Representative taxa: Elmidae
Other characteristic taxa: Heptageniidae
Flow-related concerns: This taxon shows preference for velocities ranging between 0.3 – 0.6 m/s. Clean cobbles, i.e. no filamentous algae, sedimentation or embeddedness of cobbles are required. Elmidae are sensitive to changes in water quality and thus require good water quality.

6.8.2.8 Name: GSM dwellers

Habitat: Gravel, Sand and Mud (GSM)
Representative taxa: Gomphidae
Other characteristic taxa: Polymitarcyidae

Flow-related concerns: This taxon shows preference for velocities ranging between 0.1 – 0.3 m/s. Therefore sections with slow flow over GSM is important for these taxa to survive.

6.8.2.9 Name: Standing water over cobbles

Habitat: Cobbles
Representative taxa: Leptophlebiidae
Other characteristic taxa: Some Baetidae, Chironomidae
Flow-related concerns: This taxon shows preference for slower velocities < 0.1 m/s. Therefore sections with slower flow over cobbles is important for these taxa to survive.

6.8.2.10 Name: All flow, all habitat

Habitat: Cobbles, Marginal vegetation, GSM
Representative taxa: Baetidae
Other characteristic taxa: Simuliidae generally occur in most biotopes.
Flow-related concerns: This taxon occurs over the range of velocities, and are thus not as important when setting flows as the other more sensitive taxa are.

6.8.2.11 Name: All flow, all habitat

Habitat: Cobbles, Marginal vegetation, GSM
Representative taxa: Chironomidae
Other characteristic taxa: Simuliidae generally occur in most biotopes (Cobbles, Bedrock/boulders, Vegetation, Gravel).
Flow-related concerns: This taxon occurs over the range of velocities, and are thus not as important when setting flows as the other more sensitive taxa are.

6.8.2.12 Name: Cobble/boulder/bedrock dwellers with moderate/fast flow

Habitat: Cobbles, Marginal vegetation, Gravel
Representative taxa: Simuliidae
Other characteristic taxa: Chironomidae
Flow-related concerns: This taxon prefers fast velocities > 0.6 m/s. Constant flows favour certain pest species of Simuliidae (e.g. *Simulium chutteri*) Simuliidae are most likely to become a problem with an outbreak of larvae with velocities > 1m/s (Rivers Moore and de Moor 2008).

6.8.3 Linked indicators

Table 6-11 Linked indicators and motivation

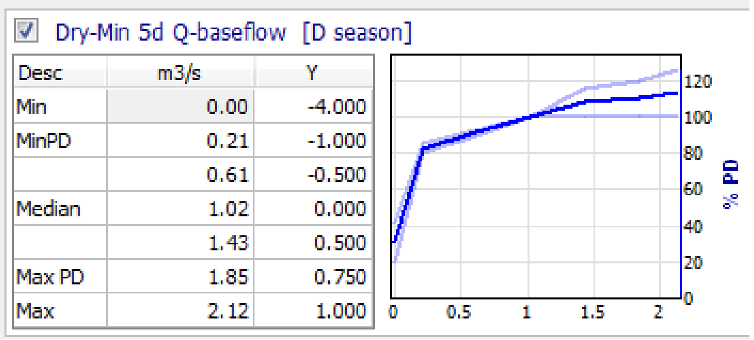
Indicator	Linked indicator	Motivation
Palaemonidae Perlidae Hydropsychidae Heptageniidae Elmidae Gomphidae Leptophlebiidae Baetidae Chironomidae Simuliidae Atyidae Coenagrionidae	Dry-Min 5d Q-baseflow	This will give an indication of the available habitat, i.e data provided in terms of include velocity, depth and wetted perimeter for the dry season.
Palaemonidae Perlidae Hydropsychidae Heptageniidae Elmidae Gomphidae Leptophlebiidae Baetidae Chironomidae Simuliidae Atyidae Coenagrionidae	Wet-daily ave vol-baseflow	This will give an indication of the available habitat, i.e data provided in terms of include velocity, depth and wetted perimeter for the wet season.
Atyidae Coenagrionidae	Marginal zone graminoids	These provide an indication of the habitat available for the Vegetation dweller group, i.e. the Coenagriondiae and the Atyidae.
Palaemonidae Perlidae Hydropsychidae Heptageniidae Elmidae Gomphidae Leptophlebiidae Baetidae Chironomidae Simuliidae Atyidae Coenagrionidae	Algae	This is important in terms of habitat modification, and is also a surrogate for temperature, dissolved oxygen and nutrients.

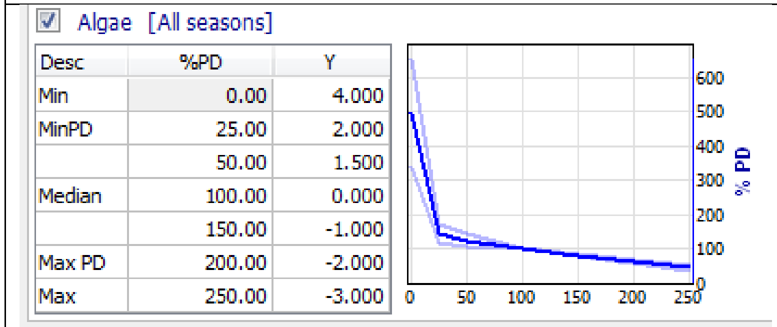
Indicator	Linked indicator	Motivation
Palaemonidae Perlidae Hydropsychidae Heptageniidae Elmidae Gomphidae Leptophlebiidae Baetidae Chironomidae Simuliidae	Bed condition	This is important in terms of the type and quality of habitat available.

6.9 Motivations for response curves

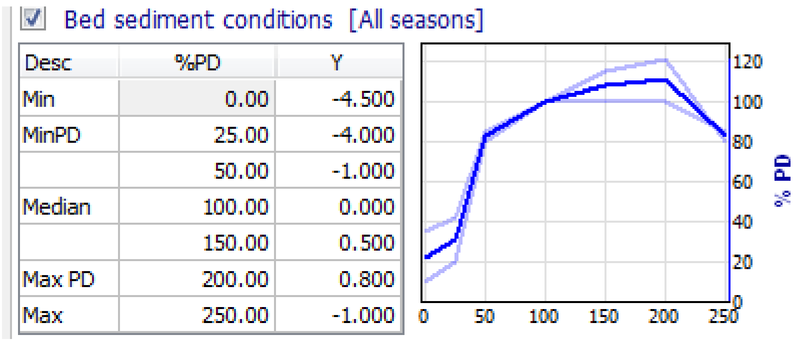
Response curves provided below and those in the DSS MAY differ very slightly as a result of final calibration, but the overall shape and reasoning remains the same.

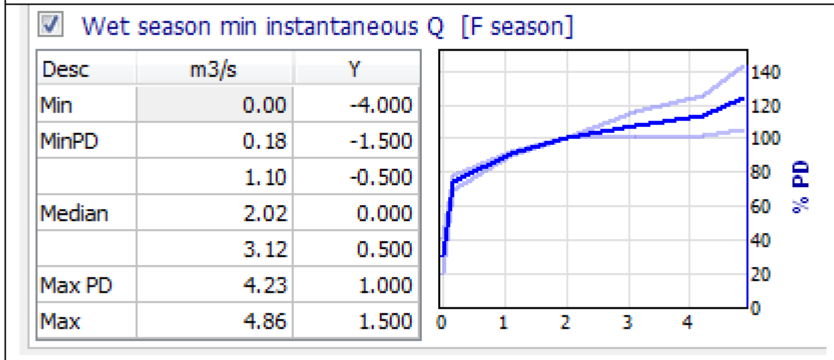
6.9.1 Indicator 1: Perlidae

<table>
<tr><td colspan="3">Perlidae</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry-Min 5d Q-baseflow [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>0.21</td><td>-1.000</td></tr>
<tr><td></td><td>0.61</td><td>-0.500</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>0.750</td></tr>
<tr><td>Max</td><td>2.12</td><td>1.000</td></tr>
</table></td><td>Less discharge will have a negative impact on Perlidae which are flow sensitive (Thirion 2014). An increase in discharge will result in an increase in ave and max velocities which will affect the Perlidae positively with a resultant increase abundance. [A 70% dependance on the previous year was assigned to the Perlidae as these taxa are not active flyers and tend to remain close to the river (www.discoverlife.org) Neoperla sp. lay approximately between 50 - 300 eggs per egg mass (Vaught 1972)].</td><td>High</td></tr>
<tr><td>

☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>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>-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>An increase in the amount of algae will have a negative impact on the abundance of Perlidae as it decreases the quality of cobbles available.</td><td>High</td></tr>
</table>

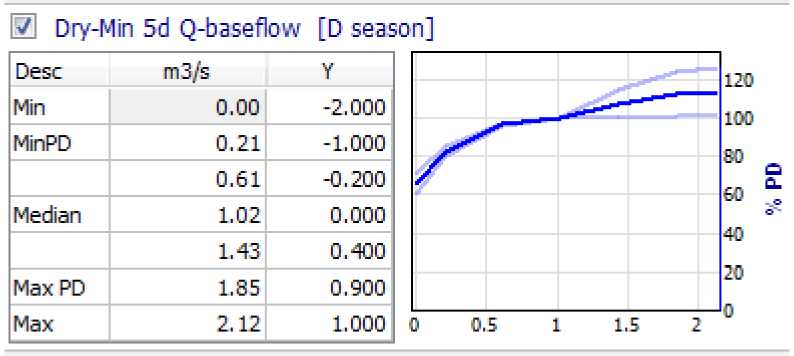
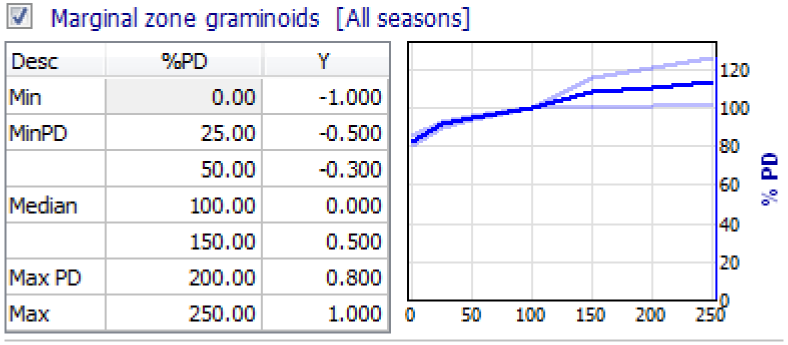
<table>
<tr><th colspan="3">Perlidae</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-4.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-4.000</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>0.800</td></tr>
<tr><td>Max</td><td>250.00</td><td>-1.000</td></tr>
</table>

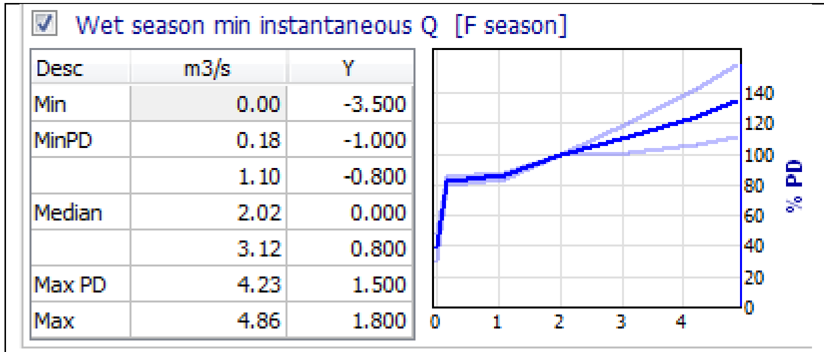
</td><td>Perlidae have a preference for the cobble biotope (Thirion 2007). An increase in the quality (less embeddedness and decreased sedimentation) of cobbles available for Perlidae, will result in an increase in the overall abundance of Perlidae present. Sediment is a stressor for macroinvertebrate assemblages (Braccia and Reese Voshell 2006) with direct effects including abrasion, clogging of filtration mechanisms, smothering, and also changes in the substrate composition (USEPA 2003).</td><td>High</td></tr>
<tr><td>

☑ Wet season min instantaneous 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>-4.000</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>-1.500</td></tr>
<tr><td></td><td>1.10</td><td>-0.500</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>1.000</td></tr>
<tr><td>Max</td><td>4.86</td><td>1.500</td></tr>
</table>

</td><td>Less discharge will have a negative impact on Perlidae which are flow sensitive (Thirion 2007 2014). An increase in discharge will result in an increase in ave and max velocities which will affect the Perlidae positively with a resultant increase in abundance.</td><td>High</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Braccia, A., Voshell, Jr, J. R. 2006. Environmental factors accounting for benthic macroinvertebrate assemblage structure at the sample scale in streams subjected to a gradient of cattle grazing. Hydrobiologia 573:55-73
Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report.
Thirion, C. 2014. The Determination of Flow and Habitat Requirements for Riverine Macroinvertebrates with Particular Emphasis on the Ephemeroptera, Coleoptera, Trichoptera and Diptera. Draft PhD thesis, University of North West</td></tr>
</table>

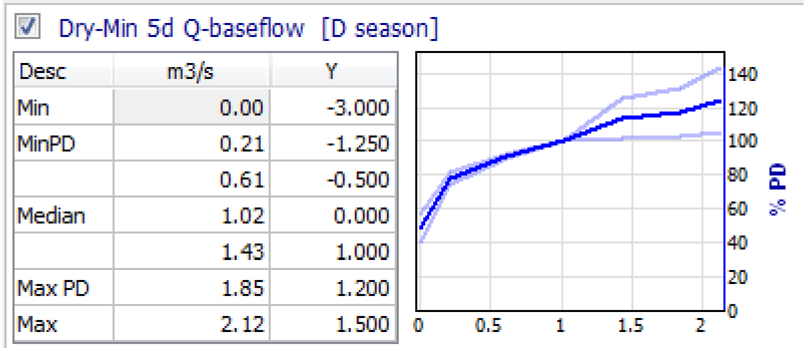
<table>
<tr><td colspan="3">Perlidae</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td colspan="3">USEPA 2003. The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems:
A Review Internal Report, United States Environmental Protection Agency
Vaught, G.L. 1972 The life history and ecology of the stonefly Neoperla clyment (Newman) (Plecoptera: Perlidae). MSc thesis of North Texas State University</td></tr>
</table>

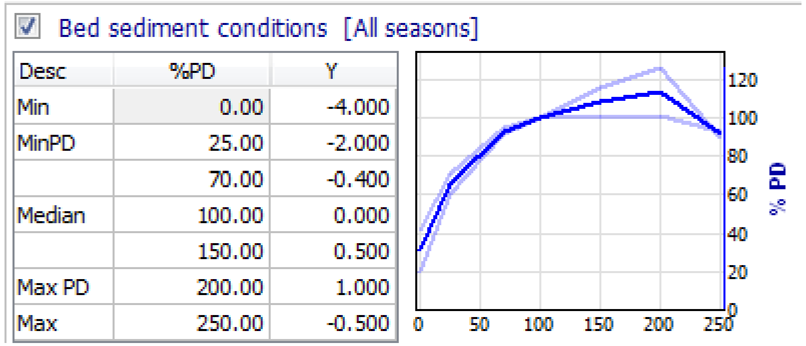
6.9.2 Indicator 2: Atyidae

<table>
<tr><td>Atyidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry-Min 5d Q-baseflow [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>0.21</td><td>-1.000</td></tr>
<tr><td></td><td>0.61</td><td>-0.200</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>0.400</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>0.900</td></tr>
<tr><td>Max</td><td>2.12</td><td>1.000</td></tr>
</table>
</td><td>With less discharge, a decrease in the depth and wetted perimeter will result and consequently a lower abundance of Atyidae will occur.</td><td>High</td></tr>
<tr><td>
☑ Marginal zone graminoids [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.300</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>0.800</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.000</td></tr>
</table>
</td><td>The quality and quantity of marginal zone graminoids are of importance for these vegetation dwelling macroinvertebrates (Thirion 2007). A diversity of leaves and stems, providing a diversity of niches and food sources will benefit the Atyidae.</td><td>High</td></tr>
</table>

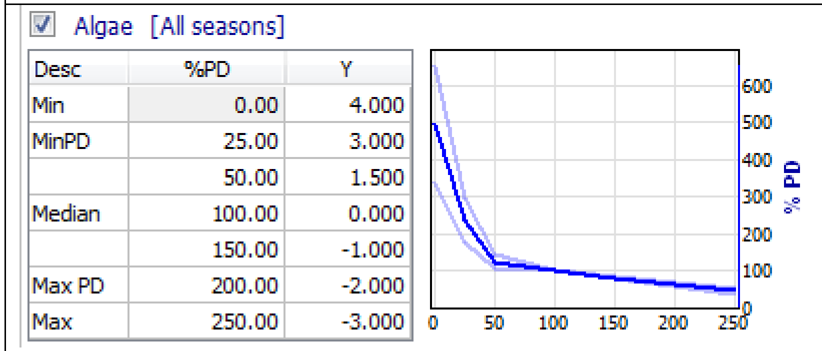
<table>
<tr><td>
☑ Wet season min instantaneous Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.500</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>-1.000</td></tr>
<tr><td></td><td>1.10</td><td>-0.800</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>0.800</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>1.500</td></tr>
<tr><td>Max</td><td>4.86</td><td>1.800</td></tr>
</table>
</td><td>With an increase in discharge, an increase in the abundance of Atyidae will occur due to an increase in the depth and wetted perimeter.</td><td>High</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report.</td></tr>
</table>

6.9.3 Indicator 3: Hydropsychidae

<table>
<tr><td>Hydropsychidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry-Min 5d Q-baseflow [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>0.21</td><td>-1.250</td></tr>
<tr><td></td><td>0.61</td><td>-0.500</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>1.200</td></tr>
<tr><td>Max</td><td>2.12</td><td>1.500</td></tr>
</table>
</td><td>Hydropsychidae seem to include univoltinism (Basaguren et al. 2002) as well as bi- and trivoltinism (Mackay 1984). Up to 800 eggs are laid at a time (de Moor and Scott 2003). They show preferences for very fast velocities (Thirion 2014). Decreased discharge, with resultant lower velocities, will therefore impact negatively on Hydropsychidae abundances.</td><td>High</td></tr>
</table>

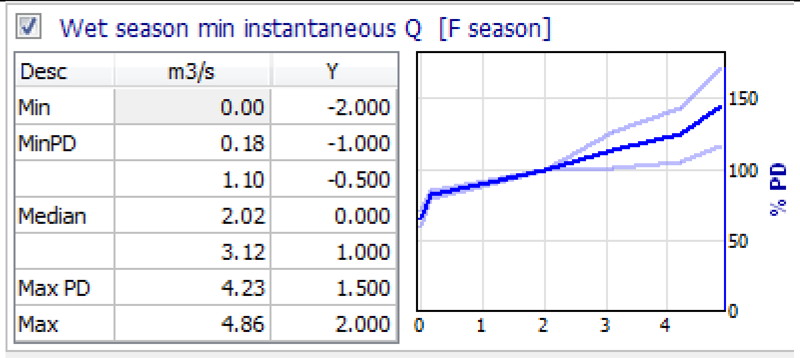
<table>
<tr>
<td>


☑ Bed sediment conditions [All seasons]

<table>
<tr><th>Desc</th><th>%PD</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>-2.000</td></tr>
<tr><td></td><td>70.00</td><td>-0.400</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>-0.500</td></tr>
</table>
</td>
<td>Hydropsychidae have a preference for the cobble biotope (Thirion 2007). Generally, they are sensitive to siltation (Scott 1988). An increase in the quality (less embeddedness and decreased sedimentation) of cobbles available for Hydropsychidae, will result in an increase in the overall abundance of Hydropsychidae present. Sediment is a stressor for macroinvertebrate assemblages (Braccia and Reese Voshell 2006) with direct effects including abrasion, clogging of filtration mechanisms, smothering, and also changes in the substrate composition (USEPA 2003).</td>
<td>High</td>
</tr>
<tr>
<td>


☑ Algae [All seasons]

<table>
<tr><th>Desc</th><th>%PD</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>1.500</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>An increase in the amount of algae will have a negative impact on the abundance of Hydropsychidae.</td>
<td>High</td>
</tr>
</table>

<table>
<tr>
<td>
☑ Wet season min instantaneous 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>-2.000</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>-1.000</td></tr>
<tr><td></td><td>1.10</td><td>-0.500</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>1.500</td></tr>
<tr><td>Max</td><td>4.86</td><td>2.000</td></tr>
</table>
</td>
<td>Less discharge will have a negative impact on Hydropsychidae which are flow sensitive (Thirion 2014). An increase in discharge will result in an increase in ave and max velocities which will affect the Hydropsychidae positively with a resultant increase in abundance. Some species are able to withstand slower velocities, hence less discharge will not have as severe a negative impact on Hydropsychidae.</td>
<td>High</td>
</tr>
<tr><td>References</td><td></td><td></td></tr>
</table>

Basaguren, A.P., Riano, P and J. Pozo. 2002. Life history patterns and dietary changes of several caddisfly (Trichoptera) species in a northern Spain stream. Archiv für Hydrobiologie 155 (1): 23-41

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Mackay, R.J. 1984. Life history patterns of Hydropsyche bronta and H. morose (Trichoptera: Hydropsychidae) in summer-warm rivers of southern Ontario Canadian Journal of Zoology, 1984, 62(2): 271-275.

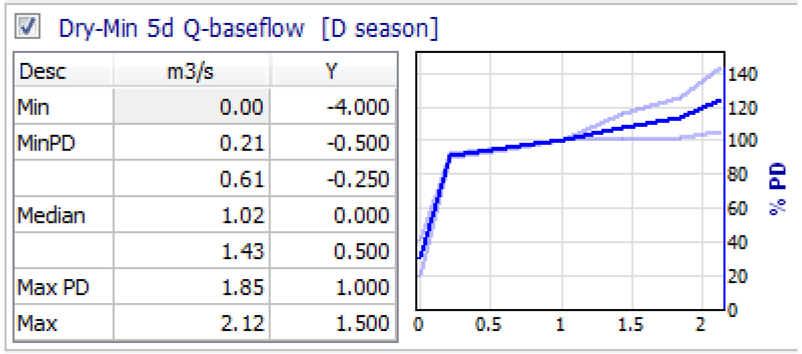
Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report

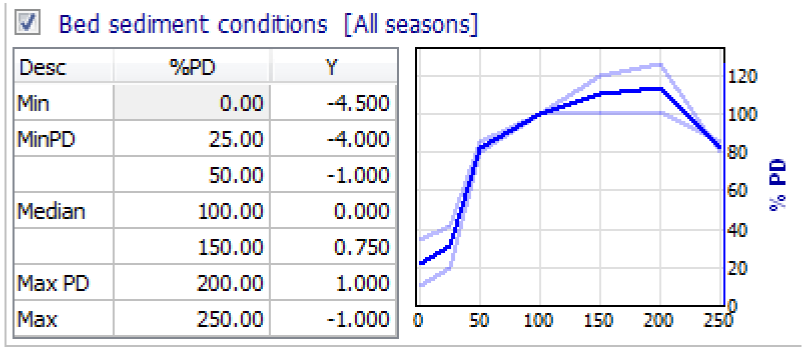
Thirion, C. 2014. The Determination of Flow and Habitat Requirements for Riverine Macroinvertebrates with Particular Emphasis on the Ephemeroptera, Coleoptera, Trichoptera and Diptera. Draft PhD thesis, University of North West

Braccia, A., Voshell, Jr, J. R. 2006. Environmental factors accounting for benthic macroinvertebrate assemblage structure at the sample scale in streams subjected to a gradient of cattle grazing. Hydrobiologia 573:55-73

USEPA 2003. The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review Internal Report, United States Environmental Protection Agency.

6.9.4 Indicator 4: Heptageniidae

<table>
<tr><td>Heptageniidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry-Min 5d Q-baseflow [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>0.21</td><td>-0.500</td></tr>
<tr><td></td><td>0.61</td><td>-0.250</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>1.000</td></tr>
<tr><td>Max</td><td>2.12</td><td>1.500</td></tr>
</table>

</td><td>Heptageniidae are multivoltine, asynchronous, have overlapping generations and continuous emergence, hence recruitment occurs throughout the year (Sivaruban et al. 2010). Heptageniidae prefer moderate flow (0.3-0.6m/s) (Thirion 2014), Crass 1947 in Schoonbee 1973 state that Heptageniidae prefer swift flowing water, with Schoonbee 1973 stating that most species occur in pools.</td><td>High</td></tr>
<tr><td>

☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-4.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-4.000</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>0.750</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>
</table>

</td><td>Heptageniidae have a preference for the cobble biotope (Thirion 2007; Mathews 1968). An increase in the quality (less embeddedness and decreased sedimentation) of cobbles available for Heptageniidae, will result in an increase in the overall abundance of Heptageniidae present. Sediment is a stressor for macroinvertebrate assemblages (Braccia and Reese Voshell 2006) with direct effects including abrasion, clogging of filtration mechanisms, smothering, and also changes in the substrate composition (USEPA 2003).</td><td>High</td></tr>
</table>

<table>
<tr>
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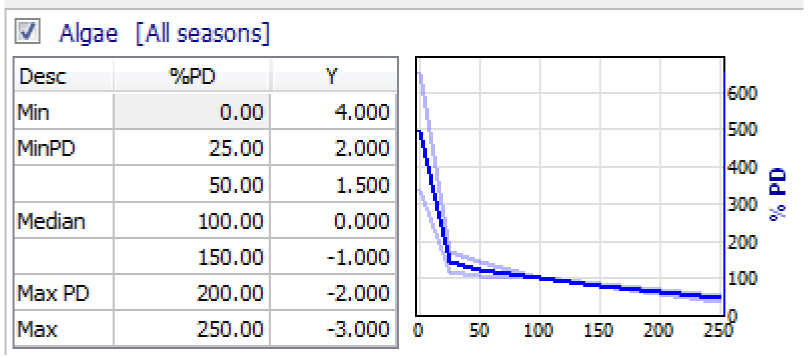
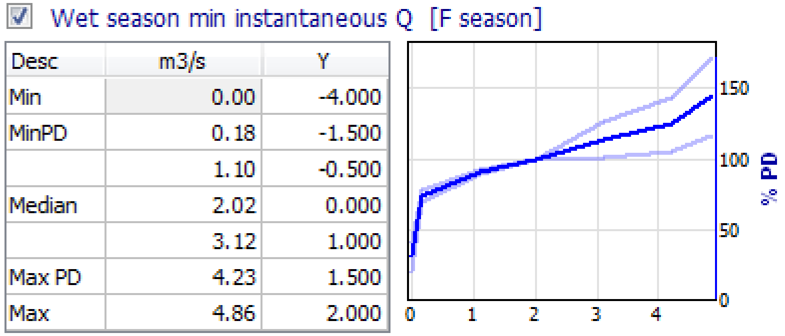


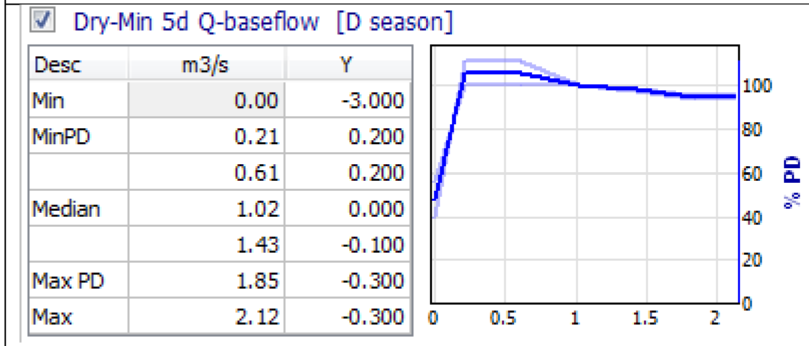
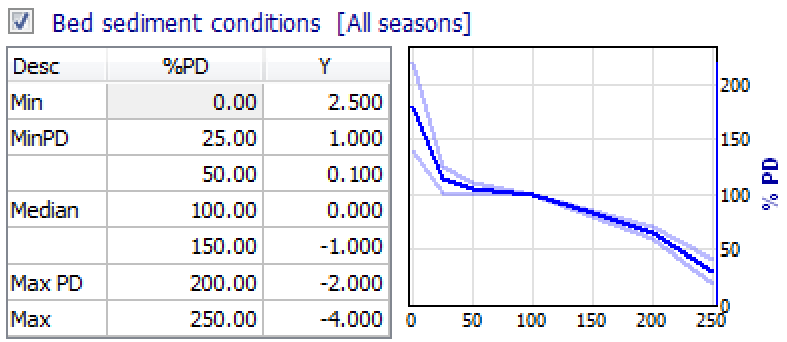
☑ Algae [All seasons]

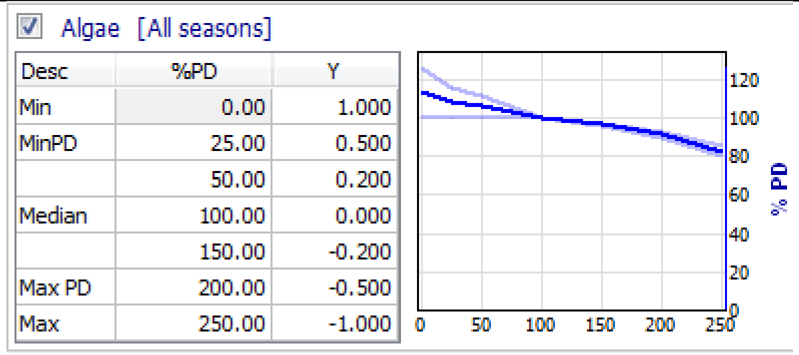
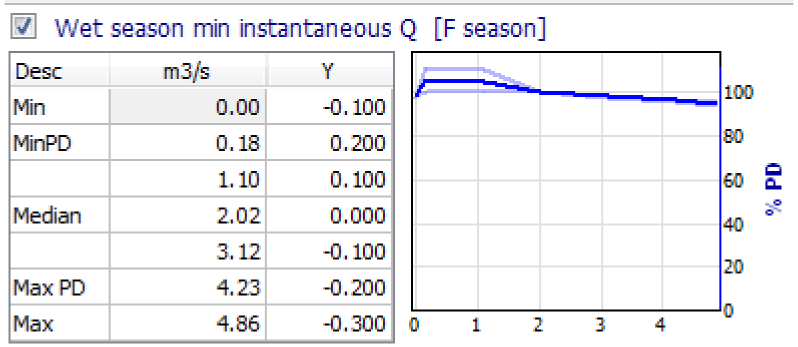
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>4.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>2.000</td></tr>
<tr><td></td><td>50.00</td><td>1.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-1.000</td></tr>
<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>An increase in the amount of algae will have a negative impact on the abundance of Heptageniidae as it decreases the quality of cobbles available.</td>
<td>High</td>
</tr>
<tr>
<td>


☑ Wet season min instantaneous Q [F season]

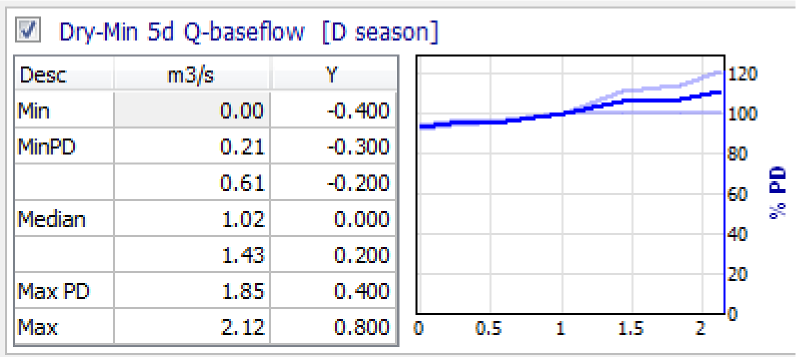
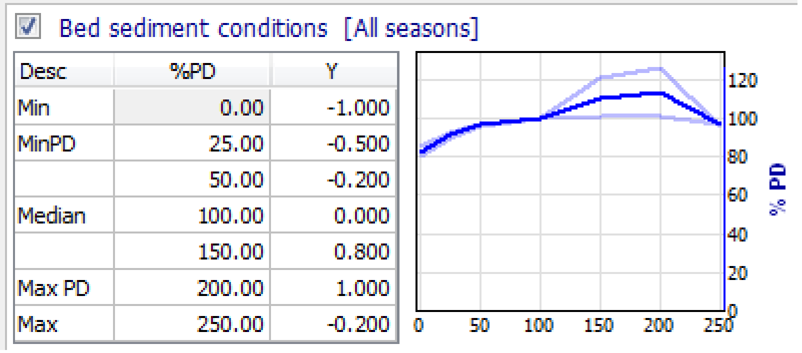
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-4.000</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>-1.500</td></tr>
<tr><td></td><td>1.10</td><td>-0.500</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>1.500</td></tr>
<tr><td>Max</td><td>4.86</td><td>2.000</td></tr>
</table>
</td>
<td>Less discharge will have a negative impact on Heptageniidae which are fairly flow sensitive (Thirion 2014). An increase in discharge will result in an increase in velocities with a resultant increase in Heptageniidae abundance.</td>
<td>High</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
</tr>
<tr>
<td colspan="3">
Schoonbee, H.J. 1973. The role of ecology in the species evaluation of the genus *Afronurus* Lestage (Heptageniidae) in South Africa. Offprint from the First International Conference on Ephemeroptera. Eds: W.L Peters and J.G. Peters.
Sivaruban, T., S. Barathy, K. Venkataraman, M. Arunachalam, 2010. Life cycle studies of Heptageniidae (Insecta Ephemeroptera) in Kumbbakarai Stream of Western Ghats, Tamil Nadu, India. Journal of Threatened Taxa, 2 (10) 1223-1226.
Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report
Thirion, C. 2014. The Determination of Flow and Habitat Requirements for Riverine Macroinvertebrates with Particular Emphasis on the Ephemeroptera, Coleoptera, Trichoptera and Diptera. Draft PhD thesis, University of North West.
</td>
</tr>
</table>

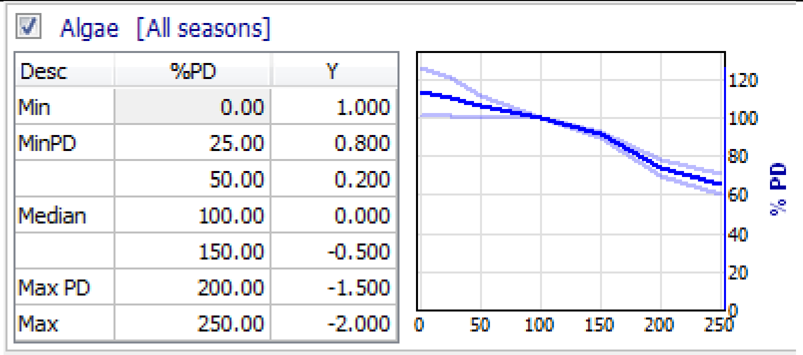
6.9.5 Indicator 5: Gomphidae

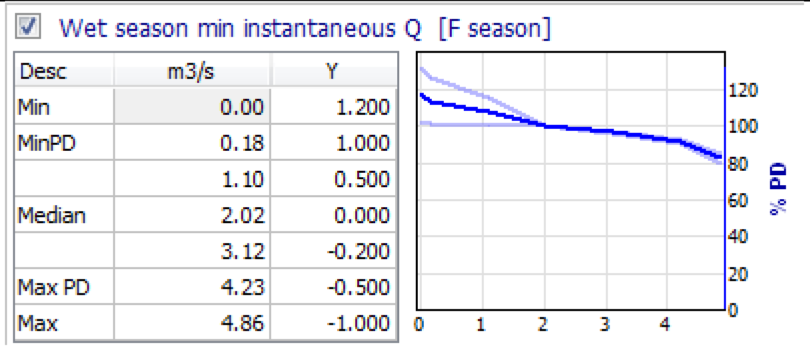
<table>
<tr><td>Gomphidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>0.21</td><td>0.200</td></tr>
<tr><td></td><td>0.61</td><td>0.200</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>-0.300</td></tr>
<tr><td>Max</td><td>2.12</td><td>-0.300</td></tr>
</table>
</td><td>Gomphidae are year-round residents that are non-dispersing (UNDP-GEF 2013). Literature shows them to be semivoltine - i.e. generation time is greater than one year (Burcher and Smock 2002). With increased discharge, less amounts of slow velocities are available for Gomphidae.</td><td>High</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>2.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>1.000</td></tr>
<tr><td></td><td>50.00</td><td>0.100</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>-4.000</td></tr>
</table>
</td><td>Gomphidae show preference for sand habitat with particle size 0.6 - 1mm (Huggins and DuBois 1982). As the amount of sand increases, so will the abundance of the Gomphidae.</td><td>High</td></tr>
</table>

<table>
<tr>
<td>
☑ Algae [All seasons]
<table><tr><th>Desc</th><th>%PD</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>0.200</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>An increase in algae will have a negative impact on Gomphidae. However, the GSM biotope is not present in high proportions in the channel at the site, although GSM will be more prevalent in the pool sections in the upper river channel.</td>
<td>High</td>
</tr>
<tr>
<td>
☑ Wet season min instantaneous 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>-0.100</td></tr><tr><td>MinPD</td><td>0.18</td><td>0.200</td></tr><tr><td></td><td>1.10</td><td>0.100</td></tr><tr><td>Median</td><td>2.02</td><td>0.000</td></tr><tr><td></td><td>3.12</td><td>-0.100</td></tr><tr><td>Max PD</td><td>4.23</td><td>-0.200</td></tr><tr><td>Max</td><td>4.86</td><td>-0.300</td></tr></table> </td>
<td>An increase in discharge provides less slow flow which will have a resultant decrease in Gomphidae abundance. An increase in discharge generally results in a decrease in the amount of fines available as biotope for Gomphidae. A decrease in discharge generally results in an increase in habitat up to a point, whereafter the amount of habitat begins to decrease (at zero discharge).</td>
<td>High</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
</tr>
<tr>
<td colspan="3">UNDP-GEF Orange-Senqu Strategic Action Programme. 2013. EFR Monitoring Programme. Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth.
BurcherC. L. and L. A. Smock. 2002. Habitat distribution, dietary composition and life history characteristics of odonate nymphs in a blackwater coastal plain stream. American Midland Naturalist 148:75–89.
Huggins, D. G and M. B. DuBois. 1982. Factors affecting microdistribution of two species of burrowing dragonfly larvae with notes on their biology (Anisoptera: Gomphidae). Odonatologica (1), 1-14.</td>
</tr>
</table>

6.9.6 Indicator 6: Leptophlebiidae

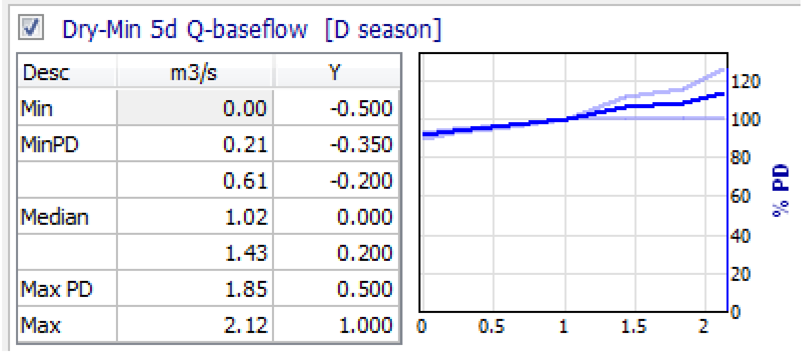
<table>
<tr><td>Leptophlebiidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td> ☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.400</td></tr>
<tr><td>MinPD</td><td>0.21</td><td>-0.300</td></tr>
<tr><td></td><td>0.61</td><td>-0.200</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>0.400</td></tr>
<tr><td>Max</td><td>2.12</td><td>0.800</td></tr>
</table></td><td>Leptophlebiidae are mostly bivoltine (Towns 1983, Scrimgeour 1991, Huryn 1996) with overlapping generations and cohorts (Towns 1983). Leptophlebiidae mostly prefer slower velocity over cobbles (Thirion 2014), however some species prefer "swift" flow (Schoonbee 1973). Decreased discharge will not impact as negatively on the Leptophlebiidae as the other mayfly flow sensitive taxa because they prefer slower velocities generally. Increased discharge will also not have such a significant positive effect on Leptophlebiidae for the same reason.</td><td>High</td></tr>
<tr><td> ☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.800</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>-0.200</td></tr>
</table></td><td>Leptophlebiidae are not as reactive to changes in the bed condition as other biota.</td><td>High</td></tr>
</table>

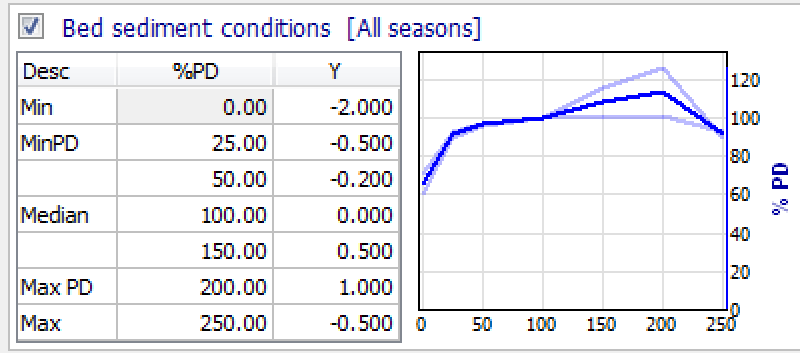
<table>
<tr>
<td>


☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.800</td></tr>
<tr><td></td><td>50.00</td><td>0.200</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 amount of algae will have a negative impact on the abundance of Leptophlebiidae as it decreases the quality of cobbles available. This will be more pronounced in the Leptophlebiidae abundances due to the fact that filamentous algae is often more prevalent in slower flowing areas than those with high flow where algae can be washed away.</td>
<td>High</td>
</tr>
<tr>
<td>


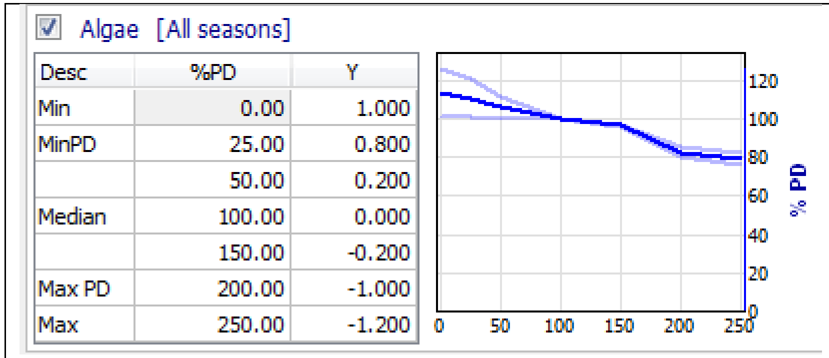
☑ Wet season min instantaneous Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.200</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>1.000</td></tr>
<tr><td></td><td>1.10</td><td>0.500</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>-0.500</td></tr>
<tr><td>Max</td><td>4.86</td><td>-1.000</td></tr>
</table>
</td>
<td>Areas with slow flow begin to decrease with increasing discharge, which has a resultant negative effect on the Leptophlebiidae. A decrease in discharge increases the amount of slow flow available, which is generally a positive effect for the Leptophlebiidae.</td>
<td>High</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
</tr>
<tr>
<td colspan="3">Towns, D.R. 1983. A revision of the genus *Zephlebia* (Ephemeroptera: Leptophlebiidae). New Zealand Journal of Zoology Volume 10 (1).
Schoonbee, H.J. 1973. The role of ecology in the species evaluation of the genus *Afronurus* Lestage (Heptageniidae) in South Africa. Offprint from the First International Conference on Ephemeroptera. Eds: W.L Peters and J.G. Peters.
Scrimgeour G.J. 1991. Life history and production of *Deleatidium* (Ephemeroptera: Leptophlebiidae) in an regimes on aquatic insect communities. *American Naturalist*, **115**, 667–695.
Huryn, A.D. (1996). Temperature-dependent growth and life cycle of *Deleatidium* (Ephemeroptera: Leptophlebiidae) in two high-country streams in New Zealand. *Freshwater Biology* 36: 351-361.</td>
</tr>
</table>

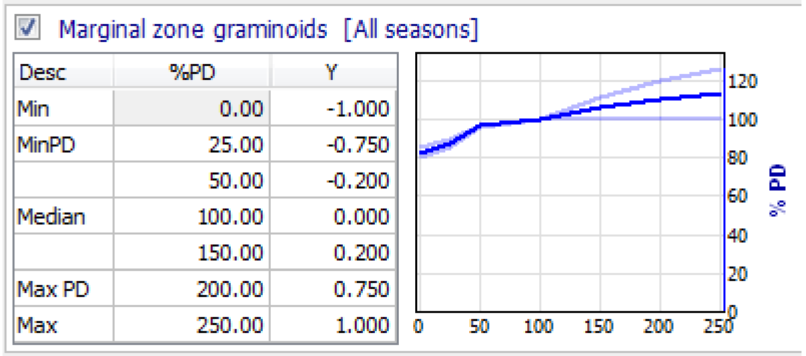
6.9.7 Indicator 7: Baetidae

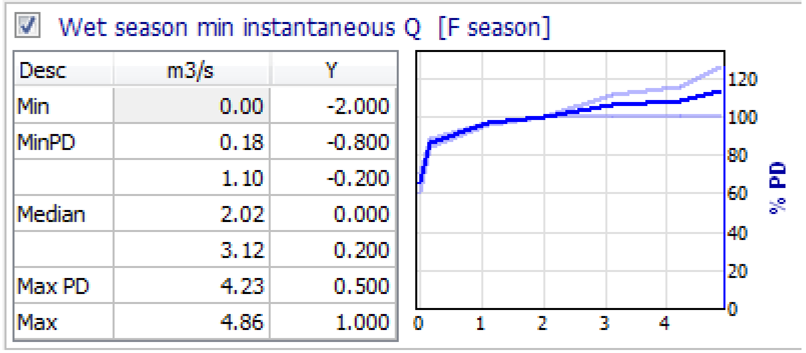
<table>
<tr><td>Baetidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>0.21</td><td>-0.350</td></tr>
<tr><td></td><td>0.61</td><td>-0.200</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>0.500</td></tr>
<tr><td>Max</td><td>2.12</td><td>1.000</td></tr>
</table></td><td>Baetidae are multivoltine (Vasquez et al. 2009), with overlapping generations and continuous emergence (Brittain and Sartoi 2003), hence occur throughout the year. Baetidae occur within the full range of velocities, from standing water to very fast velocities (Thirion 2014; Schoonbee 1973, Matthew 1968).</td><td>High</td></tr>
<tr><td>

☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>-0.500</td></tr>
</table></td><td>Baetidae occur in all types of biotopes, but show a slightly stronger preference for the cobble biotope (Thirion 2014).</td><td>High</td></tr>
</table>

<table>
<tr>
<td>

☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.800</td></tr>
<tr><td></td><td>50.00</td><td>0.200</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>-1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>-1.200</td></tr>
</table>

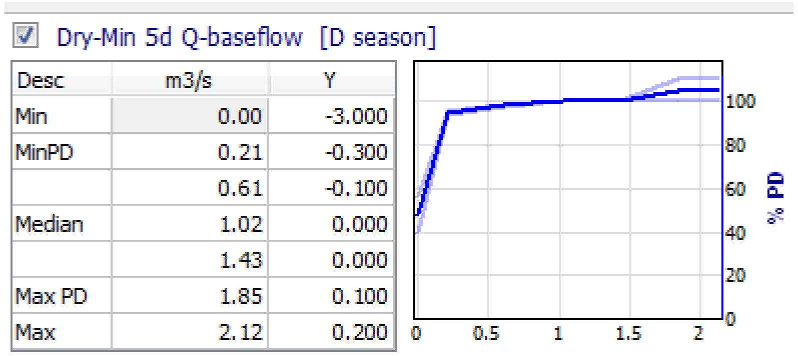
</td>
<td>An increase in the amount of algae will have a negative impact on the abundance of Baetidae as it decreases the quality of cobbles available.</td>
<td>High</td>
</tr>
<tr>
<td>

☑ Marginal zone graminoids [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.750</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.750</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.000</td></tr>
</table>

</td>
<td>The graminoids present are of a fair quality (mainly stems and some leaves), so a resultant increase in graminoids will not have a large increase in abundance of Baetidae. If the quality of vegetation were to improve, a larger increase in the Baetidae abundance would be expected.</td>
<td>High</td>
</tr>
<tr>
<td>

☑ Wet season min instantaneous 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>-2.000</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>-0.800</td></tr>
<tr><td></td><td>1.10</td><td>-0.200</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>0.500</td></tr>
<tr><td>Max</td><td>4.86</td><td>1.000</td></tr>
</table>

</td>
<td>Baetidae are multivoltine, with overlapping generations and continuous emergence (Brittain and Sartoi 2003). Baetidae occur within the full range of velocities, from standing water to very fast velocities (Thirion 2014).</td>
<td>High</td>
</tr>
</table>

References		
Brittain, J. E and M. Sartori. 2003. Ephemeroptera. In: Resh, V. H and R. T. Carde (Eds). Encyclopaedia of Insects, Academic Press, Amsterdam, 373 – 380. Matthew, J. 1968. ‘n Ondersoek na die verspreiding van sekere Ephemeroptera (Insecta) in die Komatirivierstelsel, Oos-Transvaal. MSc, Potchefstroom University. Schoonbee, H.J. 1973. The role of ecology in the species evaluation of the genus *Afronurus* Lestage (Heptageniidae) in South Africa. Offprint from the First International Conference on Ephemeroptera. Eds: W.L Peters and J.G. Peters. Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report Thirion, C. 2014. The Determination of Flow and Habitat Requirements for Riverine Macroinvertebrates with Particular Emphasis on the Ephemeroptera, Coleoptera, Trichoptera and Diptera. Draft PhD thesis, University of North West. Vasquez, D, Flowers, R. W. and M. Springer. Life history of five small minnow mayflies (Ephemeroptera: Baetidae) in a small tropical stream on the Caribbean slope of Costa Rica. Aquatic Insects, Volume 31, Supplement 1, 2009, pp. 319-332(14).		

6.9.8 Indicator 8: Chironomidae

Chironomidae		
Response Curve	Explanation	Confidence
	Chironomidae generally occur over a range of velocities (Thirion 2014). Chironomidae are characteristic of systems under stress (Mackay and Cyrus 2001), so when discharge is decreased, the Chironomidae can withstand these flow conditions to a large degree. Chironomidae are multivoltine (Phiri et al. 2012). Due to the fact that they are generally not flow sensitive, the focus is on the depth and wetted perimeter.	High

☑ Dry-Min 5d Q-baseflow [D season]

Desc	m3/s	Y
Min	0.00	-3.000
MinPD	0.21	-0.300
	0.61	-0.100
Median	1.02	0.000
	1.43	0.000
Max PD	1.85	0.100
Max	2.12	0.200

<table>
<tr>
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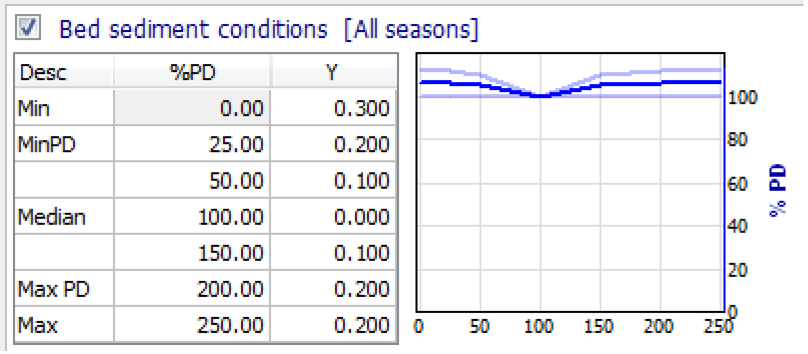
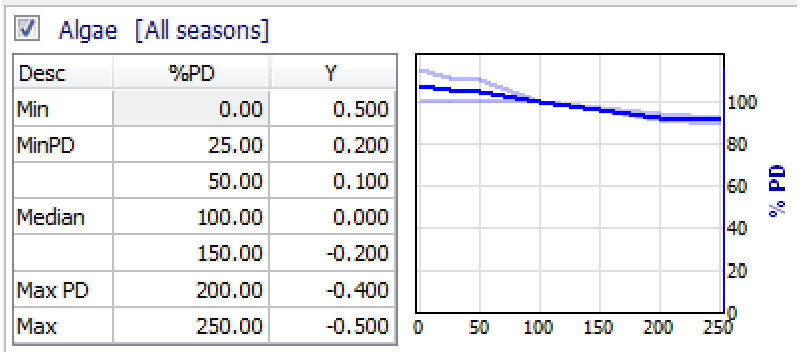
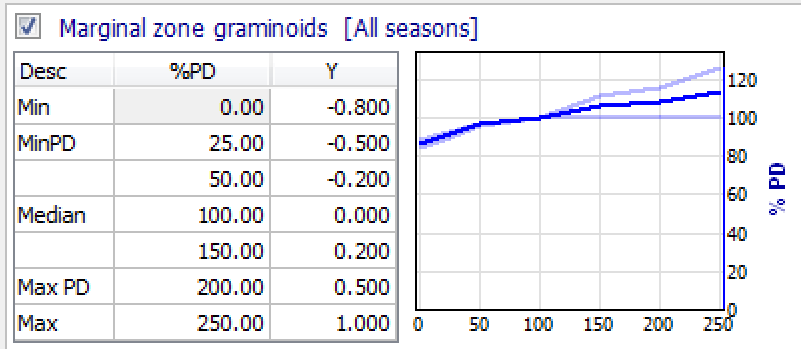


☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.300</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.200</td></tr>
<tr><td></td><td>50.00</td><td>0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</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>Chironomidae are generalists that occur in stones and GSM, with bedrock being the least favoured habitat (Thirion 2014).</td>
<td>High</td>
</tr>
<tr>
<td>


☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.200</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>-0.500</td></tr>
</table>
</td>
<td>An increase in filamentous algae will have a negative impact on Chironomidae. A reduction in algae will result in an increase in Chironomidae abundance but not to a marked degree.</td>
<td>High</td>
</tr>
<tr>
<td>


☑ Marginal zone graminoids [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>Chironomidae occur in graminoids (Thirion 2014). With a decrease in the amount and quality of marginal zone graminoids, an expected resultant decrease in the abundance of Chironomidae will occur.</td>
<td>High</td>
</tr>
</table>

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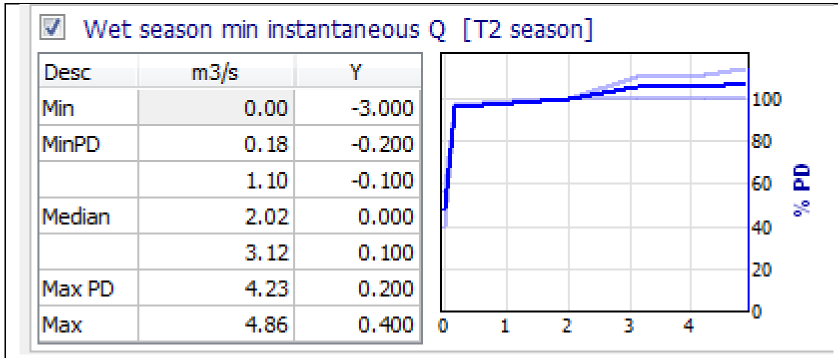
<tr>
<td>
☑ Wet season min instantaneous Q [T2 season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>-0.200</td></tr>
<tr><td></td><td>1.10</td><td>-0.100</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>0.200</td></tr>
<tr><td>Max</td><td>4.86</td><td>0.400</td></tr>
</table>
</td>
<td>Due to the fact that they are generally not flow sensitive, the focus is on the depth and wetted perimeter.</td>
<td>High</td>
</tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Thirion, C. 2014. The Determination of Flow and Habitat Requirements for Riverine Macroinvertebrates with Particular Emphasis on the Ephemeroptera, Coleoptera, Trichoptera and Diptera. Draft PhD thesis, University of North West.
Mackay, C. F and D.P Cyrus. 2001. Available information on macroinvertebrates of the Mhlathuze coastal lakes: setting the ecological reserve (lake water requirements). African Journal of Aquatic Science, Volume 26, Issue 2.
C Phiri, A Chakonan B and J.A Day. 2012. Body-zize distribution, biomass estimates and life histories of common insect taxa associated with a submerged macrophyte Lagarosiphon ilicifolius in the Sanyati Basin, Lake Kariba, Zimbabwe. *African Journal of Aquatic Science 2012, 37(3): 289–299.*</td></tr>
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6.9.9 Indicator 9: Simuliidae

Simuliidae		
Response Curve	Explanation	Confidence

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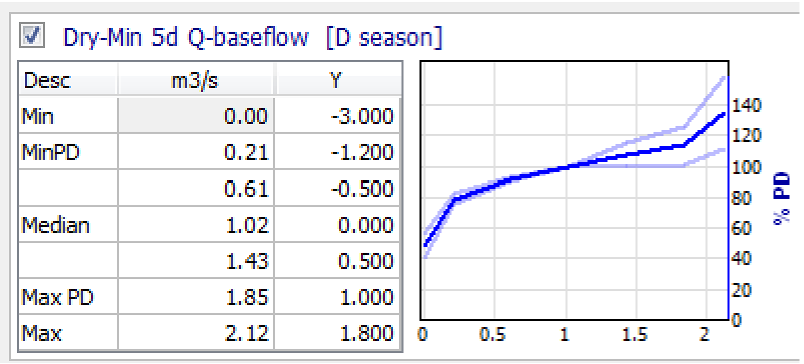
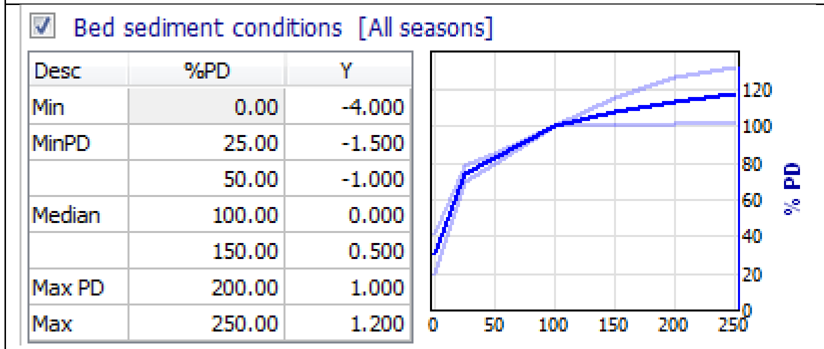
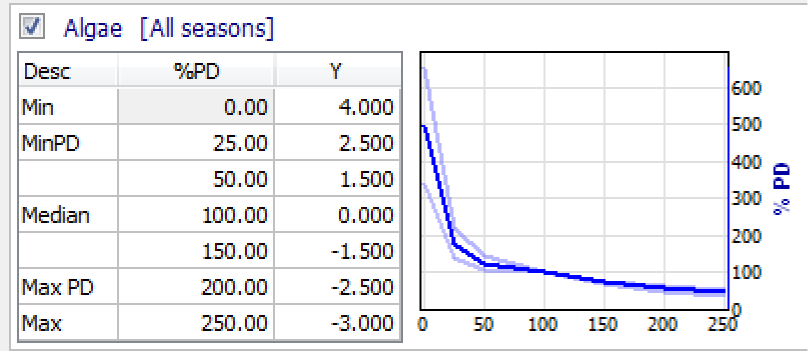
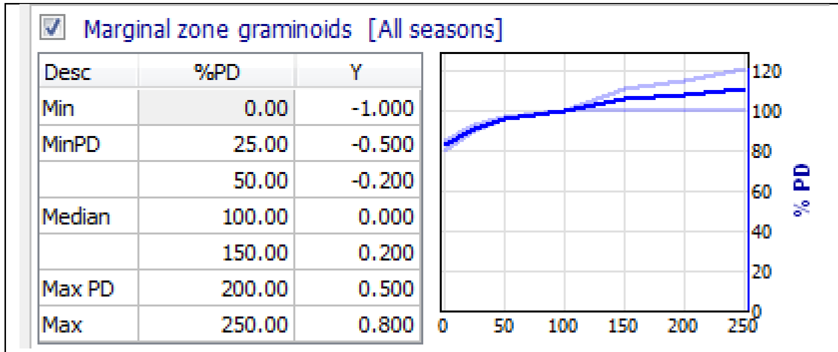
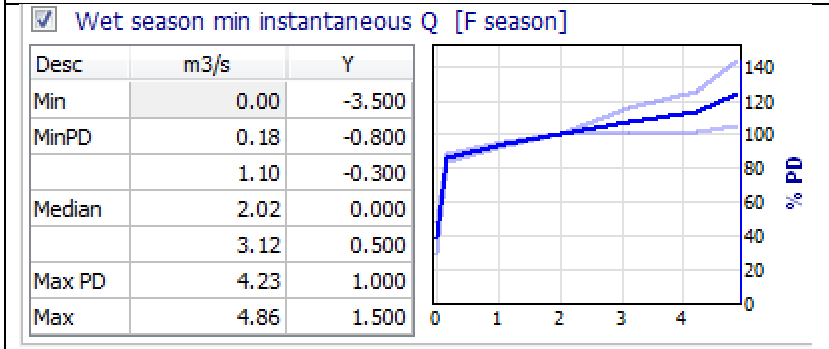

☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>0.21</td><td>-1.200</td></tr>
<tr><td></td><td>0.61</td><td>-0.500</td></tr>
<tr><td>Median</td><td>1.02</td><td>0.000</td></tr>
<tr><td></td><td>1.43</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>1.85</td><td>1.000</td></tr>
<tr><td>Max</td><td>2.12</td><td>1.800</td></tr>
</table>

</td>
<td>Simuliidae are present in a range of velocities but show preference for fast velocities (Thirion 2014). Less discharge results in fewer Simuliidae. Simuliidae are most likely to become a problem with an outbreak of larvae with velocities > 1m/s (Rivers Moore and de Moor 2008).</td>
<td>High</td>
</tr>
<tr>
<td>

☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-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>1.200</td></tr>
</table>

</td>
<td>Simuliidae occur in bedrock, cobble and GSM, with GSM being the least preferred habitat (Thirion 2014). Therefore an increased bed condition, will favour the Simuliidae and vice versa.</td>
<td>High</td>
</tr>
<tr>
<td>

☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>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>-1.500</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>An increase in algae will have a resultant decrease in Simuliidae abundance.</td>
<td></td>
</tr>
</table>

<table>
<tr>
<td>


☑ Marginal zone graminoids [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.200</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>0.800</td></tr>
</table>
</td>
<td>An increase in the amount of graminoids will result in an increase in Simuliidae abundance, though not to a large degree.</td>
<td></td>
</tr>
<tr>
<td>


☑ Wet season min instantaneous 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>-3.500</td></tr>
<tr><td>MinPD</td><td>0.18</td><td>-0.800</td></tr>
<tr><td></td><td>1.10</td><td>-0.300</td></tr>
<tr><td>Median</td><td>2.02</td><td>0.000</td></tr>
<tr><td></td><td>3.12</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>4.23</td><td>1.000</td></tr>
<tr><td>Max</td><td>4.86</td><td>1.500</td></tr>
</table>
</td>
<td>Simuliidae are present in a range of velocities but show preference for fast velocities (Thirion 2014). An increase in discharge will favour the Simuliidae due to an increase in velocity and wetter perimeter.</td>
<td></td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
</tr>
<tr>
<td colspan="3">Thirion, C. 2014. The Determination of Flow and Habitat Requirements for Riverine Macroinvertebrates with Particular Emphasis on the Ephemeroptera, Coleoptera, Trichoptera and Diptera. Draft PhD thesis, University of North West.
Rivers-Moore, N.A and F.C> de Moor. 2008. Impact of winter flow regulation on pest-level populations of blackfly (Diptera: Simuliidae) and non-target faunal communities in a South African river. African Journal of Aquatic Science 2008, 33(2): 125–134.</td>
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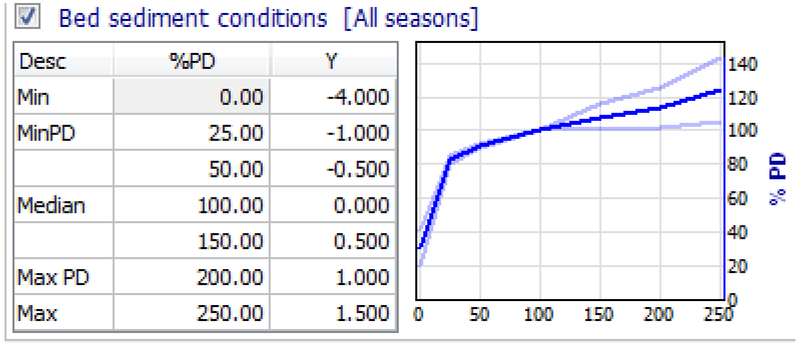
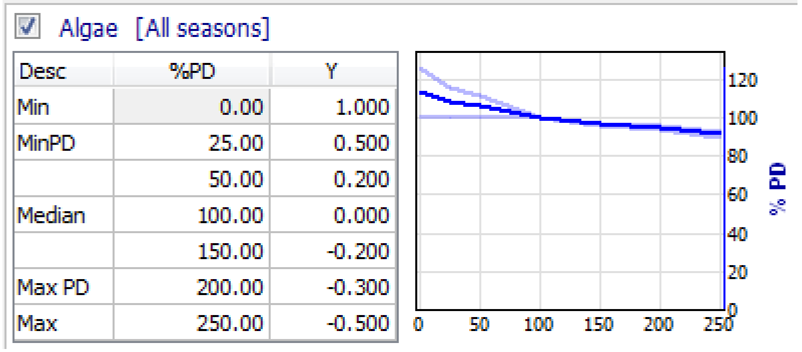
</table>

6.9.10 Indicator 10: Palaemonidae

<table>
<tr><td>Palaemonidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Bed sediment conditions [All seasons]

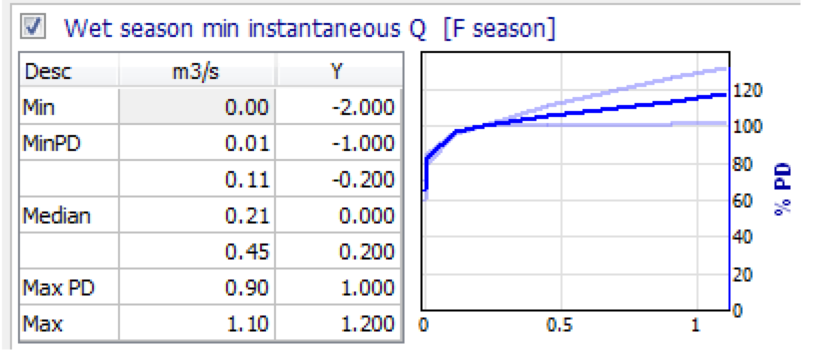
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-4.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.500</td></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>Voltinism: No literature references. Assumptions made: reproduce once a year, need to move from freshwater upstream to brackish/estuarine water downstream in summer months (Collocott et al. 2014). Some species lay hundreds to thousands of eggs per year (Maciel 2011). Palaemonidae show a preference for cobbles (Thirion 2007). Therefore an increase in fines and embeddedness will be detrimental to Palaemonidae.</td><td>Medium</td></tr>
<tr><td>


☑ Algae [All seasons]

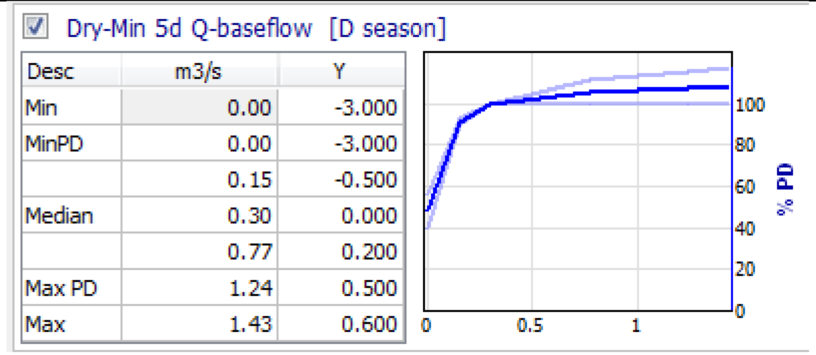
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.500</td></tr>
<tr><td></td><td>50.00</td><td>0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.300</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.500</td></tr>
</table>

</td><td>The assumption is made that an increase in filamentous algae will be detrimental to Palaemonidae.</td><td>Medium</td></tr>
</table>

<table>
<tr>
<td>


☑ Wet season min instantaneous 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>-2.000</td></tr>
<tr><td>MinPD</td><td>0.01</td><td>-1.000</td></tr>
<tr><td></td><td>0.11</td><td>-0.200</td></tr>
<tr><td>Median</td><td>0.21</td><td>0.000</td></tr>
<tr><td></td><td>0.45</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>0.90</td><td>1.000</td></tr>
<tr><td>Max</td><td>1.10</td><td>1.200</td></tr>
</table>

</td>
<td>Higher flows during the summer months benefit the Palaemonidae in terms of their movement downstream to brackish waters to reproduce (Collocott et al. 2014).</td>
<td>High</td>
</tr>
<tr>
<td>


☑ Dry-Min 5d Q-baseflow [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>0.00</td><td>-3.000</td></tr>
<tr><td></td><td>0.15</td><td>-0.500</td></tr>
<tr><td>Median</td><td>0.30</td><td>0.000</td></tr>
<tr><td></td><td>0.77</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>1.24</td><td>0.500</td></tr>
<tr><td>Max</td><td>1.43</td><td>0.600</td></tr>
</table>

</td>
<td>Less flow will inhibit the movement of Palaemonidae. At zero discharge, an average depth of 4cm with a max depth of 8cm occurs which will impact negatively on the Palemonidae.</td>
<td>Medium</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
</tr>
</table>

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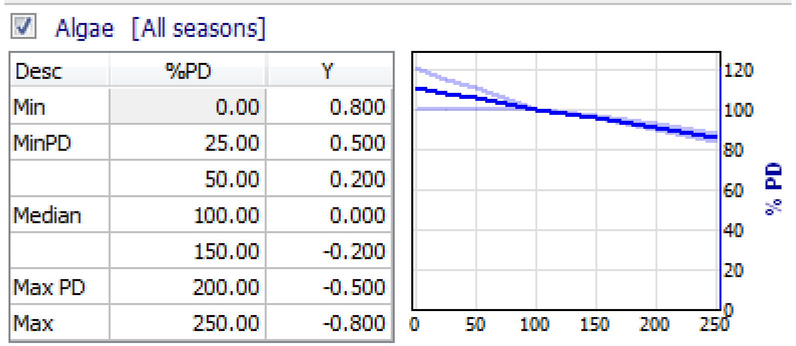
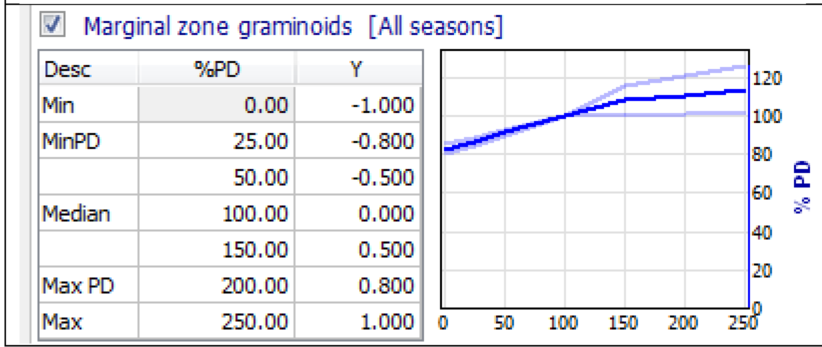
6.9.11 Indicator 11: Coenagrionidae

<table>
<tr><td>Coenagrionidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Algae [All seasons]

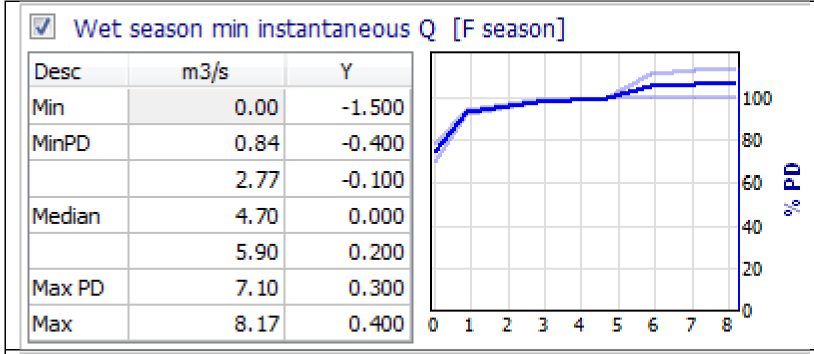
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.500</td></tr>
<tr><td></td><td>50.00</td><td>0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.800</td></tr>
</table>

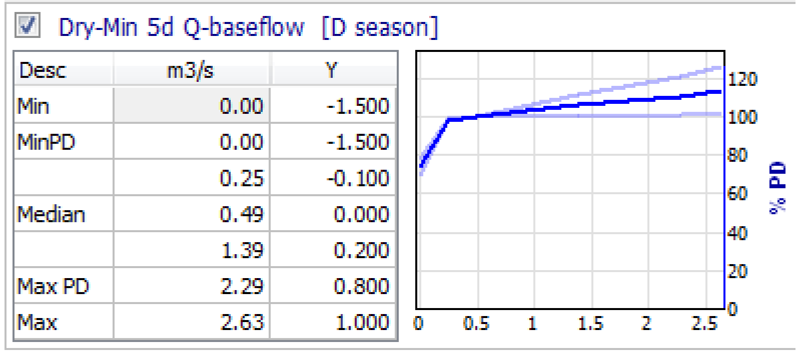
</td><td>An increase in the amount of algae will have a negative impact on the abundance of Coenagrionidae.</td><td>High</td></tr>
<tr><td>

☑ Marginal zone graminoids [All seasons]

<table>
<tr><th>Desc</th><th>%PD</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>-0.800</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>0.800</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.000</td></tr>
</table>

</td><td>An increase in the amount of marginal zone graminoids will have a resultant increase in the abundance of Coenagrionidae.</td><td>High</td></tr>
</table>

<table>
<tr>
<td>

☑ Wet season min instantaneous 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>-1.500</td></tr>
<tr><td>MinPD</td><td>0.84</td><td>-0.400</td></tr>
<tr><td></td><td>2.77</td><td>-0.100</td></tr>
<tr><td>Median</td><td>4.70</td><td>0.000</td></tr>
<tr><td></td><td>5.90</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>7.10</td><td>0.300</td></tr>
<tr><td>Max</td><td>8.17</td><td>0.400</td></tr>
</table>

</td>
<td>Most Coenagrionidae are univoltine, few bivoltine, others multivoltine (Phiri et al. 2012). Coenagrionidae prefer slow velocities (0.1 - 0.3 m/s) (Thirion 2007 2014). Wetted perimeter, depth and velocities decrease as discharge decreases. This means that there is less volume of water available. Trends are very slight, both positively and negatively.</td>
<td>High</td>
</tr>
<tr>
<td>

☑ Dry-Min 5d Q-baseflow [D season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-1.500</td></tr>
<tr><td></td><td>0.25</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.49</td><td>0.000</td></tr>
<tr><td></td><td>1.39</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>2.29</td><td>0.800</td></tr>
<tr><td>Max</td><td>2.63</td><td>1.000</td></tr>
</table>

</td>
<td>Coenagrionidae prefer slow velocities (0.1 - 0.3 m/s) (Thirion 2007 2014). Wetted perimeter, depth and velocities decrease as discharge decreases. This means that there is less volume of water available. Trends are very slight, both positively and negatively.</td>
<td>High</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
</tr>
<tr>
<td colspan="3">
C Phiri, A Chakonan B and J.A Day. 2012. Body-zize distribution, biomass estimates and life histories of common insect taxa associated with a submerged macrophyte Lagarosiphon ilicifolius in the Sanyati Basin, Lake Kariba, Zimbabwe. African Journal of Aquatic Science 2012, 37(3): 289–299.
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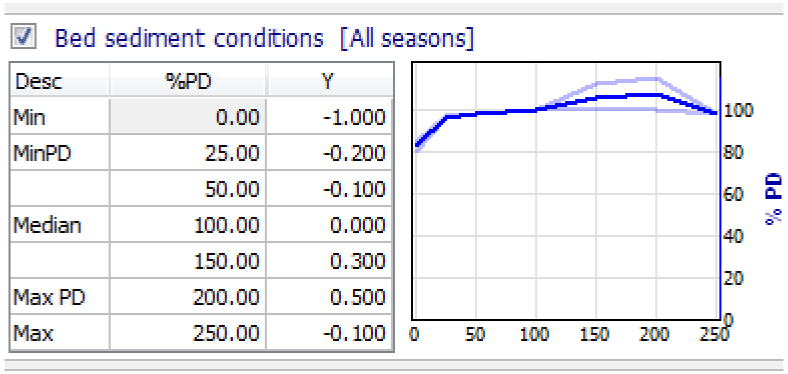
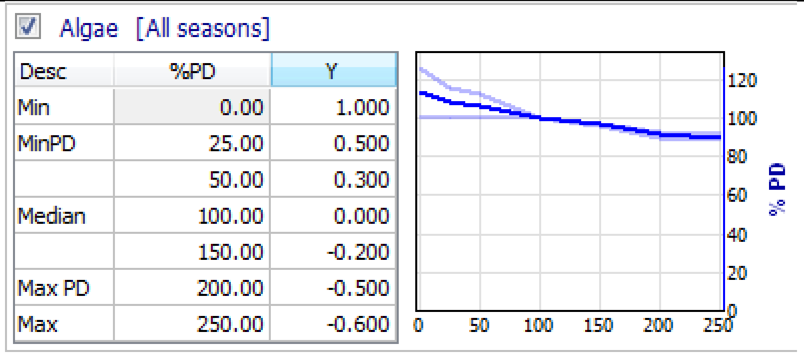
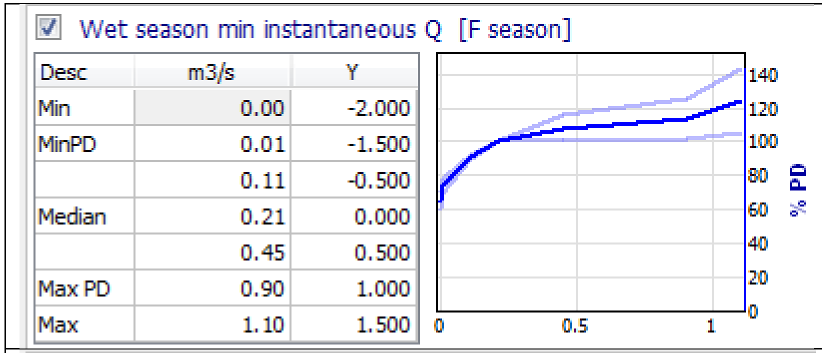
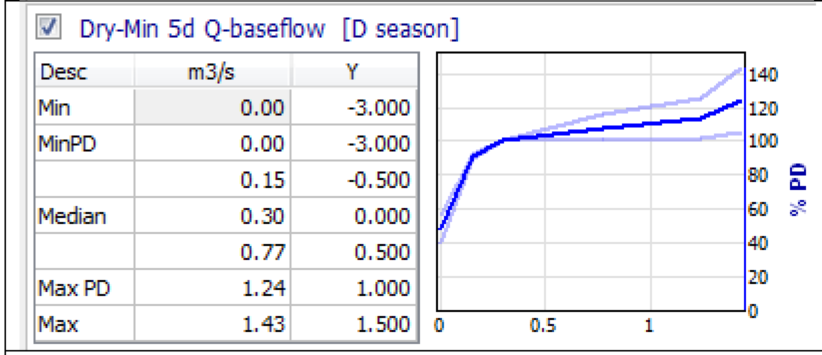
</td>
</tr>
</table>

6.9.12 Indicator 12: Elmidae

<table>
<tr><td>Elmidae</td><td></td><td></td></tr>
<tr><td>Response Curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.200</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>0.300</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>-0.100</td></tr>
</table>
</td><td>Elmidae show a strong preference for the cobble biotope (Thirion 2007 2014) as well as some preference for GSM.</td><td>High</td></tr>
<tr><td>
☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.300</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>-0.600</td></tr>
</table>
</td><td>An increase in algae will have a negative impact on the Elmidae and vice versa.</td><td>High</td></tr>
</table>

<table>
<tr>
<td>

☑ Wet season min instantaneous 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>-2.000</td></tr>
<tr><td>MinPD</td><td>0.01</td><td>-1.500</td></tr>
<tr><td></td><td>0.11</td><td>-0.500</td></tr>
<tr><td>Median</td><td>0.21</td><td>0.000</td></tr>
<tr><td></td><td>0.45</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>0.90</td><td>1.000</td></tr>
<tr><td>Max</td><td>1.10</td><td>1.500</td></tr>
</table>

</td>
<td>Elmidae show preference for velocities between 0.3 - 0.6 m/s (Thirion 2007 2014).</td>
<td>High</td>
</tr>
<tr>
<td>

☑ Dry-Min 5d Q-baseflow [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>0.00</td><td>-3.000</td></tr>
<tr><td></td><td>0.15</td><td>-0.500</td></tr>
<tr><td>Median</td><td>0.30</td><td>0.000</td></tr>
<tr><td></td><td>0.77</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>1.24</td><td>1.000</td></tr>
<tr><td>Max</td><td>1.43</td><td>1.500</td></tr>
</table>

</td>
<td>A decrease in discharge will have a resultant decrease in velocities, which will have a resultant negative impact on Elmidae which show preference for velocities between 0.3 - 0.6 m/s.</td>
<td>High</td>
</tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report.
Thirion, C. 2014. The Determination of Flow and Habitat Requirements for Riverine Macroinvertebrates with Particular Emphasis on the Ephemeroptera, Coleoptera, Trichoptera and Diptera. Draft PhD thesis, University of North West.</td></tr>
</table>

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7 FISH: SPECIALIST REPORT

7.1 Introduction

7.1.1 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 EWR assessment, 34 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 Tlou Consulting:

- A description of the extent of the study area, including:
    - The character of the fish communities in the study rivers;
    - delineation of homogenous areas;
    - the character of the fish communities in the reaches encompassing the proposed sites.
- Provide a record at each site, where relevant, of (i) the fish species, (ii) the arrangement of the fish relative to flow velocities, (iii) the nature and extent of instream or overhead habitat.
    - Identify fish specimens collected, to species level and provide information about length, weight and fecundity.
    - Select key species as indicators for the EWR assessment, and provide information on: descriptions, distribution and abundance of the species (in particular, flow-related limitations to spatial distribution); habitat and microhabitat requirements in terms of water depth, water velocity and substratum type; life histories (e.g. spawning).
    - Provide fish information on anticipated sensitivity to change in the flow regime and additional relevant information on the species characteristic of each site, from the scientific literature or from data collections.
- Provide detailed information for eight EWR sites.
- Select key species as indicators for use in the DRIFT DSS, and provide/develop information on:
    - descriptions of the species;
    - distribution and abundance (in particular, flow-related limitations to spatial distribution);
    - habitat and microhabitat requirements in terms of water depth, water velocity and substratum type;
    - life histories (e.g. emergence);
    - anticipated sensitivity to change in the flow regime;

  - any additional relevant information on the species characteristic of each site, from the scientific literature or from data collections;
  - any other available information relevant to flow assessments;
  - provide relevant scientific references.
- Select linked indicators that can be used to explain flow-related changes for each of your indicators (as selected in 5 above).
- Prepare data files for use at the DRIFT Workshop and populate the DRIFT response curves for fish.
- Prepare response curve motivation tables and include statements about the confidence level of your outputs.

7.1.1 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 EWR sites:
  - Ecoclassification assessments for fish, with supporting evidence;
  - the DRIFT indicators chosen, and reasons therefore;
  - the relationships between your chosen indicators and flow or other drivers (described in the DRIFT DSS), with referenced, supporting motivations (see Table below- the figures will be available once the DRIFT DSS has been populated).
- Data and the details of analyses performed.
- Ecospecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to fish.

7.2 Description of the Study Area

7.2.1 Bioregional Context

Three ecoregional classification systems[2] are relevant to the fish communities of the Usuthu-Mhlatuze WMA. These include: (1) the World Wildlife Fund's (WWF) global freshwater ecoregional classification (Freshwater Ecoregions of the World, FEOW; Thieme et al. 2005); (2) Kleynhans et al.'s (2005) Level I ecoregional classification for South Africa and Skelton's (1993) aquatic ecoregions for freshwater fish, both of which correspond to broadly with the FEOW classification. All three classifications are used here to provide an overview of the study area from a bioregional perspective. The FEOW and Skelton's aquatic ecoregion classifications are the strongest predictors of fish community composition at a broad scale, whereas Level I ecoregions provide an indication of environmental variables (e.g. temperature, topography, hydrology) controlling community composition and structure at more local scales. The bulk of the catchments in the Usuthu-Mhlatuze WMA fall within the

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[2] See Glossary for an explanation of these terms

Zambezian Lowveld or Southern Temperate Highveld ecoregions (Thieme et al. 2005). The boundary between these the two ecoregions runs north-south roughly through the centre of the WMA (Figure 7-1).

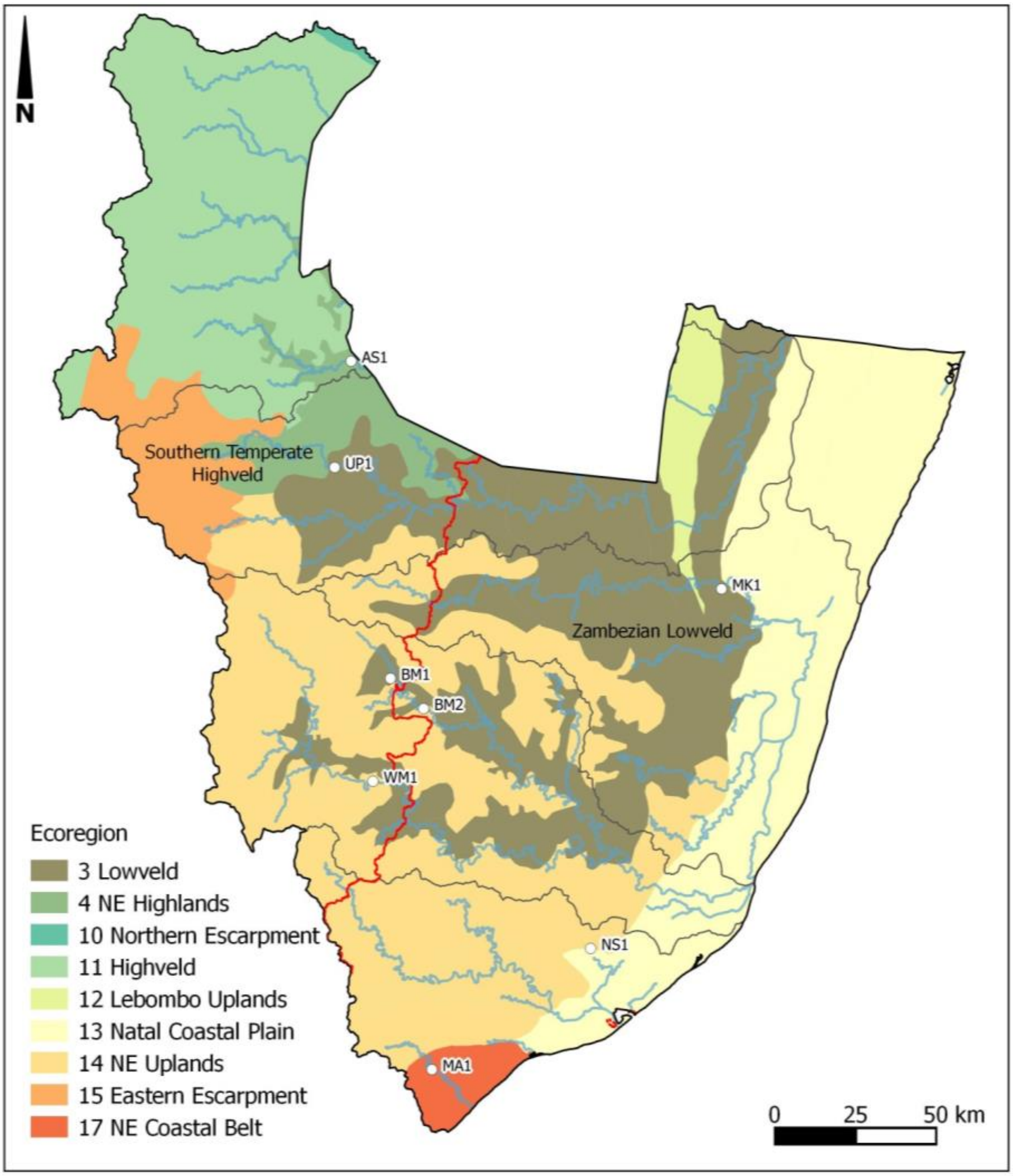


Figure 7-1 Usuthu-Mhlatuze WMA showing the location of the EWR Sites, Level I Ecoregions and the boundary between the Southern Temperate Highveld and the Zambezian Lowveld FEOW represented by the red line.

The Zambezian Lowveld ecoregion extends as far as the mouth of the Mzimvubu River in the Eastern Cape, South Africa and as far north as the Zambezi Delta in Mozambique. The fauna of this ecoregion is considered to form a part of the broader Zambezi bioregion because the fish communities found here are thought to have had historical links with the aforementioned river. The Zambezian Loweveld ecoregion where it intersects with the Usuthu-Mhlatuze WMA is characterised by coastal lakes and low-gradient rivers with floodplains, swamp forests and seasonally inundated pans. It includes important coastal lake systems such as St. Lucia and Lake Sibaya. The lower reaches of all the rivers in the study reach – except for the Usuthu River – drain through the Zambezian Lowveld ecoregion. South of St Lucia, fish communites are increasingly dominated by temperate species, in particular cyprinids, cichlids and siluroid catfishes (Skelton et al. 1995).

The upper reaches of the Usuthu-Mhlatuze WMA fall within the Southern Temperate Highveld freshwater ecoregion - Skelton's 'Highveld' aquatic ecoregion (Skelton 1993), which comprises the greater portion of South Africa's eastern interior freshwater ecosystems. The Southern Temperate Highveld fish fauna is less diverse than the Zambezian fauna, with 33 species – the majority being cyprinids.

In terms of Kleynhans et. al's (2005) Level I ecoregions, the majority of the Usuthu-Mhlatuze's surface area is comprised of Natal Coastal Plain, Lowveld and North Eastern Uplands. As already noted, these ecoregions are likely to control fish community structure through their influence on biophysical factors at a local scale rather than indicate broader biogeographical groupings.

7.2.2 The fishes of the Usuthu-Mhlatuze WMA

For the purposes of this study, historical fish distributions for the six catchments were obtained from records held by the South African Institute for Biodiversity (SAIAB) and from Ezemvelo Kwazulu Natal Wildlife. The two datasets were combined, cleaned and sorted and all ambiguous species records (designated *sp.*) were removed. Marine and estuarine species that were not considered freshwater dependant were excluded from the dataset. The primary freshwater fish dataset was overlayed on a secondary catchment layer and a spatial join in QGIS used to produce a list of species per secondary catchment (Table 7-1).

On the basis of the above records, a total of 83 fish species in 19 different families have been recorded from the Usuthu Mhlatuze WMA. Of these, seven are Alien Invasive and seven are semi-anadromous euryhaline species (gobies). In total, therefore, 69 primary freshwater indigenous fish species have been recorded from the WMA. The Pongola catchment has the highest species richness, while the Mhlatuze and the Kosi catchments had the lowest with 37 and 34 species respectively.

Table 7-1 List of species primary freshwater fish species occurring in the Usuthu Mhlatuze WMA (some amphidromous/brakish water species have been included). NA = Not Assessed, LC = Least Concern, En = Endangered, NT = Near Threatened, AI = Alien Invasive, DD = Data Deficient (SAIAB, KZN Wildlife databases combined).

FAMILY	SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS	SECONDARY CATCHMENT					
				Mhlatuze	Umfolozi	Mkuze	Phongola	Usuthu	Kosi
Amphiliidae	*Amphilius natalensis*	Natal mountain catfish	LC		▨	▨		▨	
	Amphilius uranoscopus	Stargazer mountain catfish	LC		▨	▨	▨	▨	
Anabantidae	*Ctenopoma multispine*	Manyspined climbing perch	LC	▨		▨			▨
	Microctenopoma intermedium	Blackspot climbing perch	LC			▨			
Anguillidae	*Anguilla bengalensis labiata*	African mottled eel	NA	▨	▨	▨	▨		
	Anguilla bicolor	Shortfin eel	LC	▨					▨
	Anguilla marmorata	Giant mottled eel	LC	▨	▨	▨	▨	▨	▨
	Anguilla mossambica	Longfin eel	NA	▨	▨	▨	▨		▨
Aplocheilidae	*Nothobranchius orthonotus*	Spotted killifish	LC			▨	▨	▨	
Centrarchidae	*Lepomis macrochirus*	Bluegill sunfish	**AI**		▨	▨		▨	
	Micropterus punctulatus	Spotted bass	**AI**		▨				
	Micropterus salmoides	Largemouth bass	**AI**	▨	▨	▨	▨		▨
Characidae	*Brycinus imberi*	Imberi	LC				▨	▨	
	Brycinus lateralis	Striped robber	LC		▨	▨			
	Hydrocynus vittatus	Tigerfish	LC			▨	▨	▨	▨
	Micralestes acutidens	Silver robber	LC		▨		▨	▨	
Cichilidae	*Oreochromis mossambicus*	Mozambique tilapia	**NT**	▨	▨	▨	▨	▨	▨
	Oreochromis placidus	Black tilapia	LC			▨	▨		▨
	Pseudocrenilabrus philander	Southern mouthbrooder	NA	▨	▨	▨	▨	▨	▨
	Serranochromis meridianus	Lowveld largemouth	**En B2ab(iii,v)**						▨
	Serranochromis robustus	Yellowbelly bream	LC	▨					
	Serranochromis thumbergi	Brownspot largemouth	LC	▨					
	Tilapia rendalli	Redbreast tilapia	LC	▨	▨	▨	▨	▨	▨
	Tilapia sparrmanii	Banded tilapia	LC	▨	▨	▨	▨	▨	▨
Clariidae	*Clarias gariepinus*	Sharptooth catfish	NA	▨	▨	▨	▨	▨	▨
	Clarias ngamensis	Blunttooth catfish	LC				▨		▨
	Clarias theodorae	Snake catfish	LC	▨	▨	▨	▨		▨

Table 7-1 (cont'd)

FAMILY	SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS	CATCHMENT					
				Mhlatuze	Umfolozi	Mkuze	Phongola	Usuthu	Kosi
Cyprinidae	*Barbus afrohamiltoni*	Plump barb	LC				■	■	
(Small barbs)	*Barbus annectens*	Broadstriped barb	LC			■	■	■	
	Barbus anoplus	Chubbyhead barb	LC		■	■	■	■	■
	Barbus argenteus	Rosefin barb	LC		■	■	■	■	
	Barbus bifrenatus	Hyphen barb	LC			■	■		■
	Barbus eutaenia	Orangefin barb	DD		■				
	Barbus gurneyi	Redtail barb	LC	■					
	Barbus lineomaculatus	Line-spotted barb	LC		■	■	■	■	
	Barbus neefi	Sidespot barg	LC					■	
	Barbus pallidus	Goldie barb	LC		■		■	■	
	Barbus paludinosus	Straightfin barb	LC	■	■	■	■	■	■
	Barbus radiatus	Beira barb	LC				■	■	
	Barbus toppini	East coast barb	LC			■	■	■	■
	Barbus trimaculatus	Threespot barb	LC	■	■	■	■	■	
	Barbus unitaeniatus	Longbeard barb	LC		■	■	■	■	
	Barbus viviparus	Bowstripe barb	LC	■	■	■	■	■	■
(Alien Invasive)	*Carassius auratus*	Goldfish	AI	■					
	Cyprinus carpio	Carp	AI		■	■	■		
(Labeos)	*Labeo congoro*	Purple labeo	LC				■	■	
	Labeo cylindricus	Redeye labeo	LC	■	■	■	■	■	
	Labeo molybdinus	Leaden labeo	LC	■	■	■	■		■
	Labeo rosae	Rednose labeo	LC			■	■	■	
(Yellowfishes)	*Labeobarbus aeneus*	Smallmouth yellowfish	LC					■	
	Labeobarbus marequensis	Lowveld largescale yellowfish	LC		■		■	■	
	Labeobarbus natalensis	KwaZulu-Natal yellowfish	LC	■	■	■	■		
	Labeobarbus polylepis	Bushveld smallscale yellowfish	LC		■		■	■	
	Mesobola brevianalis	River Sardine	LC		■	■	■	■	
	Opsaridium peringueyi	Southern barred minnow	LC				■	■	
	Varicorhinus nelspruitensis	Incomati chiselmouth	**NT**				■	■	

Table 7-1 (cont'd)

FAMILY	SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS	CATCHMENT					
				Mhlatuze	**Umfolozi**	**Mkuze**	**Phongola**	**Usuthu**	**Kosi**
Cyprinodontidae	*Aplocheilichthys johnstoni*	Johnston's topminnow	LC	▨	▨	▨			▨
	Aplocheilichthys katangae	Striped topminnow	LC	▨		▨			▨
	Aplocheilichthys myaposae	Natal topminnow	LC	▨	▨	▨			▨
Gobiidae	*Awaous aeneofuscus*	Freshwater goby	NA	▨	▨	▨	▨	▨	▨
	Croilia mossambica	Burrowing goby	LC	▨					▨
	Glossogobius callidus	River goby	LC	▨	▨	▨	▨	▨	▨
	Glossogobius giuris	Tank goby	LC	▨	▨	▨	▨	▨	▨
	Redigobius dewaali	Checked goby	LC	▨	▨	▨	▨	▨	▨
	Silhouettea sibayi	Sibayi gobi	**En B1ab(iii), 2ab(iii)**	▨		▨			▨
	Stenogobius kenyae	African rivergoby	LC	▨					
Loricariidae	*Pterygoplichtys disjunctivus*	Vermiculated sailfin catfish	**AI**	▨					
Megalopidae	*Megalops cyprinoides*	Oxeye tarpon, Indo-Pacific tarpon	LC	▨	▨	▨	▨		▨
Mochokidae	*Chiloglanis anoterus*	Pennant-tailed suckermouth	LC		▨		▨	▨	
	Chiloglanis emarginatus	Phongolo suckermouth	LC				▨	▨	
	Chiloglanis paratus	Sawfin suckermouth	LC				▨	▨	
	Chiloglanis pretoriae	Shortspine suckermouth	LC				▨	▨	
	Chiloglanis swierstrai	Lowveld suckermouth	LC			▨	▨	▨	
	Synodontis zambezensis	Brown squeaker	LC				▨	▨	▨
Mormyridae	*Marcusenius macrolepidotus*	Bulldog	LC	▨		▨	▨	▨	▨
	Petrocephalus catostoma	Churchill	NA				▨	▨	
Poeciliidae	*Poecilia reticulata*	Guppy	**AI**	▨		▨			
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	**AI**		▨		▨		
	Salmo trutta	Brown trout	**AI**		▨				
Schilbeidae	*Schilbe intermedius*	Silver catfish	LC				▨	▨	▨
Sygnathidae	*Microphis fluviatilis*	Freshwater pipefish	NA		▨			▨	
		Total No. of species per Secondary catchment		**37**	**43**	**47**	**58**	**49**	**34**

The species compliment of the Usuthu-Mhlatuze WMA is made up primarily of small (18) and large (10) Cyprinids, the latter including a number of yellowfish and labeo species. The remainder of the species complement comprises Cichlids (second most numerous after the cyprinids), Amphiliid and Mochokid rock catfish and several Characids, including the tigerfish (*Hydrocynus vittatus*) which is restricted to the lower reaches of the Pongola River floodplains. Four Anguillid eel species have also been recorded from the Usuthu-Mhlatuze WMA. Species that occur in the catchment and which have specialised adaptations include the Mormyridae which are capable of detecting prey by means of an electric field, the Killifish (*Nothobranchius orthonotus*) which has eggs capable of aestivation and the Anabantids (the climbing perches) which have an auxiliary breathing apparatus enabling them to metabolise atmospheric oxygen.

The Lowveld largemouth (*Serranochromis meridianus*) and the Sibaya goby (*Silhouettea sibayi*) are considered endangered, and the Mozambique tilapia (*Oreochromis mossambicus*), the Incomati chiselmouth (Varicorhinus nelspruitensis) are listed as Near Threatened (the latter by possible hybridisation with *Oreochromis niloticus*) (D'Amato et al. 2007). Although listed currently listed as 'Least Concern', populations of the southern barred minnow (*Opsaridium peringueyi*) are considered at risk as a result of a number of anthropogenic factors (Venter et al. 2010).

7.3 Literature review

The approach used in this study to assessing the response of fish populations in the Usuthu-Mhlatuze WMA to flow change has been undertaken on two fronts: (1) hydraulic habitat models, which are based on instantaneous approximations of flow, depth and substratum combinations deemed to be of importance to fish populations and (2) conceptual hydrological models which focus on biologically relevant components of the hydrograph. Both approaches have strengths and weaknesses which are explained in the sections that follow. They are here used in combination. Section 7.3.1 explains the approach used to describe and assess hydraulic habitat characteristics of fish, while 7.3.3 explains accepted biologically important components of the flow hydrograph. Section 7.3.3 describes the ecological fish guilds relevant to this study and Section 7.3.4 describes the approach used to assign the fishes of the Usuthu-Mhlatuze WMA to ecological guilds.

7.3.1 Habitat preference criteria and flow classes for fish

The estimation of Ecological Water Requirements (EWRs) for fish is premised on the notion that river flow plays a central role in regulating river ecosystem processes and therefore the persistence and resilience of the fish populations that inhabit them. (Poff and Allan 1995; Bunn and Arthington 2002; Murchie et al. 2008). River flow acts on fish either directly by providing the medium in which they live and through which they move, or indirectly by shaping the aquatic habitats they depend on for cover, to avoid predation, migrate, or reproduce.

The most widely applied method for describing aquatic habitat for fish is by means of habitat preference curves which represent the range of a species occurrence across a gradient of various abiotic variables. Habitat preference curves (or Habitat Suitability Criteria, HSC) (Bovee 1982; 1986) are univariate response curves which translate the hydraulic and geomorphological conditions in rivers into indices of habitat quality for fish and aquatic invertebrates. These response curves are then used to make predictions with regard to how habitat quality and quantity will change under any given flow scenario when linked to a hydraulic model.

South African environmental flow practitioners have nominated to use ‘Habitat’ or ‘Flow-Depth’ classes rather than preference curves (Kleynhans 1999; Jordanova et al. 2004). Flow-Depth classes represent hydraulic bands or ‘envelopes’ which define depth and velocity combinations deemed to be of importance to aquatic biota (fish and aquatic invertebrates). They can be thought of as generic upper and lower hydraulic tolerances that can be applied across a range of different species. From an original four categories (Kleynhans 1999), they have been expanded to include seven classes (Table 7-2) (Kleynhans et al. 2008).

Table 7-2 Flow-Depth Classes for fish (Kleynhans et al. 2008)

Flow-Depth Class	Abbreviation	Velocity	Depth	Description
Slow Very Shallow	SVS	<0.3 $m.s^{-1}$	<0.1 m	Backwaters and slackwaters
Slow Shallow	SS	<0.3 $m.s^{-1}$	0.1-0.5 m	Backwaters and shallow pools
Slow Deep	SD	<0.3 $m.s^{-1}$	>0.5 m	Deep pools and backwaters
Fast Very Shallow	FVS	>0.3 $m.s^{-1}$	<0.1 m	Very shallow riffles and runs
Fast Shallow	FS	>0.3 $m.s^{-1}$	0.1-0.2 m	Shallow riffles and runs
Fast Intermediate	FI	>0.3 $m.s^{-1}$	0.2-0.3 m	Intermediate depth riffles and runs
Fast Deep	FD	>0.3 $m.s^{-1}$	>0.3 m	Deep riffles, runs and rapids

The original Fast-Shallow class (0-0.3 m) has been split into Fast-Shallow (0.1-0.2 m) and Fast-Intermediate (0.2-0.3 m), since depths <0.1 m are not considered adequate for small rheophilic fish guilds (Kleynhans et al. 2008). In addition to velocity and depth classes, Habitat Classes include other non-flow dependent habitat characteristic such as substratum, vegetation or woody debris – all features which are used by fish as refuge from predation, high velocity flow, or high/low temperatures (Jordanova et al. 2004; Hirschowitz et al. 2007). Non-flow dependent habitat classes are shown in Table 7-3. It is important to note the certain flow and non-flow dependent habitat classes need to occur concurrently, e.g. Fast Shallow flow needs to occur over cobble substratum to be suitable maintenance habitat for rheophilic fish, or spawning habitat for semi-rheophilic fish species.

Table 7-3 Non-flow dependent Habitat Classes for fish (Jordanova et al. 2004)

Habitat Class	Description
Overhanging vegetation	Thick vegetation overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface. This includes marginal vegetation
Undercut banks and root wads	Banks overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface
Stream substrate	Various substrate components (rocks, boulders, cobbles, gravel, sand, fine sediment and woody debris “snags”) that provide cover for fish
Aquatic macrophytes	Submerged and emergent water plants
Water column	Used to assess depth in relation to the size of fish

It is important note that the requirement for a particular set of habitat conditions, e.g. Fast Intermediate or Fast Deep, may not be continuous, but may be required during certain times of the year when fish are reproducing and even during these times, there may be periods when these conditions may not be met under natural conditions.

7.3.2 Fish responses to the flow regime

There are limitations to the sole use of habitat use or preference criteria for assessing the response of fish communities to flow change. Habitat preference criteria provide static ‘snapshot’ representations of fish habitat which fail to account for the complex interplay of a number of other hydraulic and hydrological factors that affect fish populations through the year. Chief among the limitations of habitat preference criteria, or flow classes, is the difficulty of using them to predict the response of fish populations to changes in the high flow components of the flow regime. These may be in response to the timing of flows of certain magnitudes that trigger physiological or behavioural (e.g. migration) responses; continuity (flood interruption) which may cause fish strandings; the smoothness or flashiness of floods, and/or; the speed of change, amplitude or duration. A change in the timing and duration of the flood may result in a more prolonged dry season with delayed spawning and a mismatch with other biological cues such as suitable temperatures or photoperiods. Together with the FRAI Flow Classes, these considerations provide conceptual basis of all deliberations regarding the response of fish populations in the Usuthu-Mhlatuze WMA to the range of flow scenarios.

7.3.3 Fish guild identification

In diverse river systems, it is not feasible or necessary to assess the response of every fish species present in the river to flow change. The ecological guild concept has therefore been used extensively for evaluating the effects of flow changes on diverse river fish communities (Leonard and Orth 1988; Aadland 1993; Welcomme et al. 2006; Baumgartner et al. 2013). Ecological guilds group species according to similar morphological, physiological, behavioural and life history adaptations rather than by taxonomic relatedness – the assumption being that species with similar adaptations will respond to environmental change and variability in similar ways.

Kleynhans et al. (2008) identifies three indicator guilds based on their requirement for flowing water during all (rheophilics) or part (semi-rheophilics) or no (limnophilics) phases of their life cycle (Table 7-4). Both rheophilic and semi-rheophilic groups are further subdivided into 'fast' and 'slow' groups depending on if they are considered to require flows of great or less than 0.3 $m.s^{-1}$.

Table 7-4 Indicator guilds suggested by Kleynhans (2008).

Indicator guild	Description
Rheophilics	Require flowing water during all phases of their life cycle *Fast rheophilics*: >0.3 $m.s^{-1}$ *Slow rheophilics*: <0.3 $m.s^{-1}$
Semi-rheophilics	Require flowing water during certain phases of their life cycle *Fast semi-rheophilics*: >0.3 $m.s^{-1}$ *Slow semi-rheophilics*: <0.3 $m.s^{-1}$
Limnophilics	No particular flow requirements during any phases of their life cycle. Water level may be required to provide cover features during certain phases of the life cycle

Kleynhans et al. (2008) suggest further classifying guilds into (1) small (<15 cm), (2) intermediate (15-25 cm) and large (> 25 cm) body sizes. This provides an indication of the absolute dimensions of the habitat required when considering the range of flow classes relevant to the species. Welcomme et al. (2006) devised an ecological guild classification system particularly relevant to environmental flow assessment and river rehabilitation (Table 7-5). The principal groupings of this classification take into account: (1) whether a fish species depends on lotic (flowing water) or lentic (standing water) conditions, (2) whether the species occurs in the upper (rhithronic) or lower (potamonic) parts of a rivers system and (3) whether they are predominantly a main channel or floodplain dependent species, or both. Table 7-5 provides a list of the guilds proposed by Welcomme et al. (2006) together with a description of typical habitat requirements, key life history features and some Southern African examples (where these are known). In addition to ecological fish guilds, reproductive guilds (adapted from Balon 1975; Balon 1990; Welcomme et al. 2006) are listed in Table 7-6.

Table 7-5 Ecological fish guilds suggested by Welcomme et al. (2006) adapted for local fish species (where these are known) and modified to be consistent with the terminology used in this chapter. Only the obligate freshwater guilds are included: estuarine and coastal lagoon guilds are not considered. Reproductive guilds are from Balon (1975).

	Ecological Guild	Guild Characteristics	Response to change	Examples
RHITHRONIC	*Upper reaches of rivers, fast flowing, turbulent, rheophilic main channel residents, longitudinal pool-riffle-pool sequence*			
	Riffle guild	*Characteristics*: small size, equipped with suckers, spines to grip rocks, elongated or flattened morphology *Reproduction*: guarding and non-guarding lithophilic, eggs between gravel and rocks, riffles for spawning, pools for nurseries *Feeding*: insectivorous, algal scrapers, filter feeders	*Sensitive to*: catastrophic flows, disturbances to pool-riffle structure, seasonal desiccation, sedimentation, loss of interstitial spaces, wash-out, submergence of gravel reaches, loss of connectivity	Rock and mountain catfishes: *Chiloglanis* spp., *Austroglanis* spp., *Amphilius* spp. Rheophilics (Kleynhans et al. 2008)
	Pool guild	*Characteristics*: more limnophilic than riffle community. Pools and slackwaters with aquatic vegetation, well defined home ranges *Reproduction*: lithophilic or phytophilic *Feeding*: insectivorous drift feeders	*Sensitive to*: pool-rifle structure, pool desiccation or extended periods without flow, changes in water level, loss of connectivity	Minnows, *Barbus* and *Pseudobarbus* spp. Semi-rheophilics (Kleynhans et al. 2008)
POTAMONIC – LENTIC	*Lower reaches of rivers, non-migratory floodplain residents, move between floodplain pools, swamps, backwaters, breed during high and low hydrograph phases, strategies to cope with low Dissolved Oxygen (DO), 'black fish' (dark colouration)*			
	Plesiopotamonic guild (Floodplain pans seasonally connected to the main river by flooding)	*Characteristics*: tolerant of low DO, but not anoxia, lateral migrants between backwaters and floodplains, dominant in wetlands *Reproduction*: guarding and non-guarding phytophilic and nest-building	*Sensitive to*: descending limb of the annual hydrological cycle, amplitude of flooding regulating connectivity between river and floodplain, channelization, berms and levees disconnecting floodplain from main channel	*Aplocheilichthys* spp., Mosquitofish (*Gambusia affinis*) (introduced), *Schilbe intermedius* Limnophilics (Kleynhans et al. 2008)
	Paleopotamonic guild (Floodplain pools and lakes disconnected from the main river, fed by groundwater)	*Characteristics*: tolerant of complete anoxia, usually non-migratory, sedentary, xerophils resist complete desiccation, high population densities *Reproduction*: parental care, nest building,	*Sensitive to*: the descending limb of the annual hydrological cycle, residual floodplain water bodies, land reclamation.	African lungfishes (*Protopterus*), Vundu (*Heterobranchus longifilis*) Limnophilics (Kleynhans et al. 2008)

		viviparity		

Table 7-5 (cont’d)

	Ecological Guild	Guild Characteristics	Response to change	Southern African examples
POTAMONIC – LENTIC (cont’d)	**Annual guild**	*Characteristics:* seasonal isolated water bodies, completely dry during part of the year, outermost limits of the floodplain. *Reproduction*: aestivating eggs with diapause, complete life cycle in one season.	*Sensitive to*: the descending limb of the annual hydrological cycle, residual floodplain water bodies, land reclamation. *Rehabilitation*: restoration of floodplain, elimination of levees and berms, seasonal floodplain flooding reinstated.	Killifishes, Spotted killifish (*Nothobranchius orthonotus*) Limnophilics (Kleynhans et al. 2008)
	Longitudinal migration over long distances, complex migration patterns, one breeding season per year linked to peak flows, flow cues for migration require high DO, ‘white fish’ (reflective scales)			
POTAMONIC – LOTIC	**Eupotamonic pelagophilic guild** (Main channel – pelagic)	*Characteristics:* main channel residents not entering floodplain, longitudinal migrations between downstream feeding site and upstream spawning. *Reproduction:* lithopelagophils and pelagophils, drifting eggs and larvae, fry may be resident at upstream spawning sites, downstream point bars as nurseries, bred in a single event. *Feeding:* for piscivorous species - movements linked to prey.	*Sensitive to*: dams block migration, timing and velocity of flow for spawning and needs of drifting larvae, temperature of dam releases, degradation of spawning substratum, removal of instream structure such as wood debris. *Rehabilitation*: respond positively to fish passes, correct timing and magnitudes of flow for spawning and migration cues and for drifting larvae.	No known South African examples Barramundi, Asian barbs, Panagsiid catfishes Semi-rheophilics (Kleynhans et al. 2008)
	Eupotamonic lithophilic guild (Main channel – rock and sand substratum)	*Characteristics:* main channel, longitudinal migrations between upstream spawning and downstream feeding sites. *Reproduction*: lithophils and psammophils, single breeding season, some semelparous, fry may be resident in upstream reaches.	*Sensitive to*: dams block migration, timing and velocity of flow for spawning, changes in quality of upstream habitat, temperature of dam releases, degradation of spawning substratum, removal of instream structure such as wood debris. *Rehabilitation*: respond positively to fish passes, correct timing and magnitudes of flow for spawning and migration cues and development of eggs – aerating flows in gravels.	Large cyprinids: *Labeobarbus* spp., *Onchorhynchus* spp. (introduced) Semi-rheophilics (Kleynhans et al. 2008)

Table 7-5 (cont’d)

	Ecological Guild	Guild Characteristics	Response to change	Southern African examples
POTAMONIC – LOTIC (cont'd)	**Eupotamonic phytophilic guild** (Main channel - vegetation)	*Characteristics*: long or short distance longitudinal migrants. Lateral migration onto floodplain for breeding, nursery and feeding by juvenile and adult fish. *Reproduction*: predominantly phytophils, phytolithophils spawning on floodplain margins in flowing channels or floodplain. Some eggs semi-pelagic, carried onto floodplain by rising flood.	*Sensitive to*: dams block migration, lateral connectivity between main channel and floodplain reduced, amplitude and duration of floods, berms, levees, channelization.	Alestidae (*Brycinus* spp.), Tigerfish (*Hydrocynus* spp.), *Labeos* spp.
	Parapotamonic guild (Backwaters and slackwaters formed by remains of old anabranches, disconnected from main channel during low flow)	*Characteristics*: generalist species, resistant to change. Semi-lotic, intermediate between long distance lotic and lentic guilds. Semi-migratory or sedentary. Short distance non-obligate migrants. *Reproduction*: backwaters, slackwaters and point bars for breeding. Prefer anabranches, backwaters and tributary creeks with low seasonal flows. Lithophils, psammophils, phytophils.	*Sensitive to*: river straightening and bank revetments that reduce main channel diversity and bank structure, stress flows habitat flows for resetting the system.	European species: Northern Pike *Esox lucius*, roaches *Rutilus rutilus*, wild carp, Bream *Abramis brama*
EURYTOPIC	Adaptive generalists with flexible behaviour, tolerant of low DO, repeat breeders, short distance migrants or sedentary local populations, rheophilic or limnophilic			
	Eupotamonic benthic guild (Main channel – bottom dwelling)	*Characteristics*: centre of the main channel, benthic sites. Tolerant of low DO for short periods over dry season. Increase in numbers as others decline. *Reproduction*: pasmmophils and lithophils	*Sensitive to*: Sedimentary processes that alter the bed of the river. Deoxygenation in deeper areas during dry season.	Some mormyrids, some *Synodontis*
	Eupotamonic riparian guild (main channel – riparian vegetation)	*Characteristics*: riparian zone and vegetation of main channel and floodplain. May use floodplain. Tolerant of low DO. Semi-migratory. Tolerant of modified hydrograph. Behaviourally adaptable, increase in numbers as others decline. Very common. Increase to pest levels in regulated systems. Reproduction: wide range, but predominantly phytophils. Some nest building and parental care	*Sensitive to*: degradation of the riparian zone and vegetation structure	Tilapia and *Oreochromis* spp., Common carp (*Cyprinus carpio*), Sharptooth catfish (*Clarius garipeinus*), *Lepomis* spp. (introduced) Limnophilics (Kleynhans et al. 2008)

Table 7-6 Summary of common reproductive styles in fishes (adapted from Balon 1975; Balon 1990; Welcomme et al. 2006). Examples of South African and African indigenous or introduced species are given if known. Exclusively marine and less common reproductive styles have been omitted.

	Ecological Group	Guild	Spawning type	Description	Key features
A. NON-GAURDERS	A.1 Open substratum	Pelagic spawners	1. *Pelagohils*	Pelagic	Release buoyant pelagic eggs and larvae. Mostly marine origin (e.g. Anguillid eels).
			2. *Lithopelagophils*	Rock/gravel – pelagic	Spawn on rock and gravel, eggs become buoyant, pelagic eggs and larvae or active movement.
		Benthic spawners	3. *Lithophils*	Rock/gravel – benthic	Rock and gravel spawners with benthic larvae, early hatch embryos photophobic, hide in rock crevices (e.g. South African yellowfishes).
			4. *Phytolithophils*	Non-obligatory – plant	Non-obligatory plant spawners, adhesive eggs on submerged material, cement glands in free embryos, photophobic.
			5. *Phytophils*	Obligatory – plant	Obligatory plant spawners, adhesive eggs adhere to submerged live or dead plant material, larvae cement glands (e.g. common carp).
			6. *Psammophils*	Sand	Adhesive eggs in running water on sand or fine roots over sand, free embryos with cement glands.
	A.2 Brood hiders	Prepare nests, but abandon immediately	*3. Lithophils*	Rock/gravel	Eggs and embryos buried in gravel depressions (redds) or rock interstices, large dense yolk, early hatched embryos photophobic.
			5. *Xerophils*	Annual fishes	Embryos survive without water in intermittent pools for months (e.g. killifishes).
B. GAURDERS	B.1 Clutch tenders	Don't build nests but clean and select a substratum and tend eggs/embryos	1. *Pelagophils*	Pelagic	Non-adhesive, positively buoyant eggs guarded at the surface of hypoxic waters.
			3. *Lithophils*	Rock	Choose rock, strongly adhesive eggs attached at one pole by fibres, most with pelagic free embryos and larvae.
			4. *Phytohils*	Plant	Scatter or attach adhesive eggs attach to aquatic plants, free embryos without cement glands (e.g. bichir).
	B.2 Nesters	Build nests	1. *Aphrophils*	Froth nesters	Eggs deposited in a cluster of mucous bubbles (e.g. African pike)
			2. *Polyphils*	Miscellaneous substratum	Adhesive eggs attached singly in clusters to any available substratum.
			3. *Lithophils*	Rock/gravel nesters	Eggs in spherical or elliptical envelopes always adhesive, free embryos photophobic or with cement glands (e.g. bluegill sunfish).
C. BEARERS	C.1 External brooders	Eggs/larvae held in buccal cavity	3. Mouth brooders	No buccal feeding	Eggs incubated in buccal cavity of either male of female or both, embryos do not feed (e.g. Mozambique tilapia)
			4. Mouth brooders	Buccal feeding	Eggs incubated in buccal cavity of either male of female or both, embryos feed on inhaled particles
	C.2 Internal livebearers	Eggs fertilised internally	2. Obligate livebearers	Obligate lecithotrophic livebearers	Eggs fertilised internally, undergo development in reproductive system of female until end of embryonic phase or beyond, yolk sole source of nutrients (e.g. mosquitofish)

There are three main categories based on whether the species is found only in the upper (rhithron) or lower (potamon) reaches of the river, or whether it is a generalist and occurs in both (eurytopic). The guilds are then further distinguished on the basis of their preference for particular morphological or hydro-geomorphic units within the catchment, i.e. riffles or pools, pans seasonally connected to (plesiopotamon) or permanently disconnected from (paleopotamon) the main channel, the main channel itself (eupotamon) or backwaters and slackwaters (parapotamon). Fish species may fall into different combinations of these categories, and many may share characteristics between groupings.

7.3.4 Fish guild selection and assignment of indicators for the Usuthu-Mhlatuze WMA

The correct identification of fish guilds and the assignment of indicators to each guild is a critical step in the process of assessing the response of fish populations to flow change in rivers with diverse fish assemblages.

For this assessment, habitat requirements for fish species were obtained from the Fish Response Assessment Index (FRAI) (Kleynhans 2008), combined with a thorough review of the literature on each species occurring in the Usuthu-Mhlatuze WMA. The FRAI contains a database that includes the Flow-Depth classes, flow/no flow tolerance indices, together with vegetation and migration requirements for each fish species in the South Africa.

Using the FRAI database, different combinations of each of these indices were selected for each guild. For example, the Rhithronic riffle assemblage was selected on the basis of small body size and a requirement for Fast Shallow and/or Fast Deep flow over a rocky substratum. The Eupotamonic phytophilic guild was selected using the criteria of large-bodied migratory fish with a requirement for Fast Shallow and/or Fast Deep that were intolerant of no flow and required aquatic macrophytes.

The list of guilds produced directly from the FRAI database was then carefully reviewed and species added or replaced on the basis of expert knowledge and additional information gleaned from the literature. For the smaller eurytopic barbs, Rogers and O'Keefe's (2003) groupings of marginal, pool and rapid assemblages for the Sabie River aided guild identification.

A total of eleven fish guilds in the Usuthu-Mhlatuze WMA were identified in this way. However, not all the guilds were used in the EWR assessment – those guilds not considered to exhibit significant responses to flow change, or where flow-response factor is duplicate – for instance, any of the requirements of anguillid eels (Catadromous guild) will be met if the requirements for the Eupotamonic lithophilic guild has been met. Following the selection of appropriate guilds for the Usuthu-Mhlatuze WMA, indicator species were selected and assigned to each guild. The role of the indicator species is to provide an early warning for change while at the same time being relatively abundant. It is no use therefore selecting a species that occupies a specialised flow-sensitive niche when it is exceedingly rare. Indicator species were therefore selected using the following criteria:

- Fairly widely distributed and relatively common
- Flow sensitive larval, juvenile and/adult stages
- Taxonomic and/or ecological representivity
- Keystone species (e.g. prey for a larger predator)
- High vs low motility (migratory species)
- Economic importance (subsistence, commercial or recreational)
- Well studied

If an indicator species did not occur in a particular secondary catchment, an alternative was selected based on the same criteria listed above. Indicator species may warn of change either by decreasing or increasing in abundance. The increase in abundance of highly tolerant species e.g. *Oreochromis mossambicus* may indicate an absence of large floods (Pollard et al. 1996). In total, ten indicator species were selected. The final list of fish indicators and guilds for the Usuthu-Mhlatuze EWR assessment can be found in Section 7.8.1.

7.4 Description of the EWR sites

See

Figure 1-1 for a map showing the location of the study sites.

7.4.1 EWR Site MA1

EWR Site MA1 on the Matigulu River falls within the North East Coastal Belt ecoregion type roughly 22 km from the estuary at the southern limit of the Zambezian Lowveld ichthyofaunal region. The river here flows in a confined channel surrounded by low-lying, undulating topography with the surrounding landscape not exceeding 300 *amsl* (Figure 7-2). The instream habitat is characterised by bedrock-boulder, step-pool sequence with relatively large bed elements and a low proportion of fines and sand.

Figure 7-2 **EWR Site MA1 on the Matigulu River viewed from the left bank, flow direction from right to left.**

The channel width was roughly 20 m at the site, the mean depth sampled was 0.5 m and the maximum was 0.8 m. The dominant flow type at the site was Slow Shallow (SS: 55%) with progressively decreasing proportions in each flow class to the most uncommon class at the site: Fast Deep (FD: 5%). The substratum size class was dominated by boulders (B: 66%) (Figure 7-3).

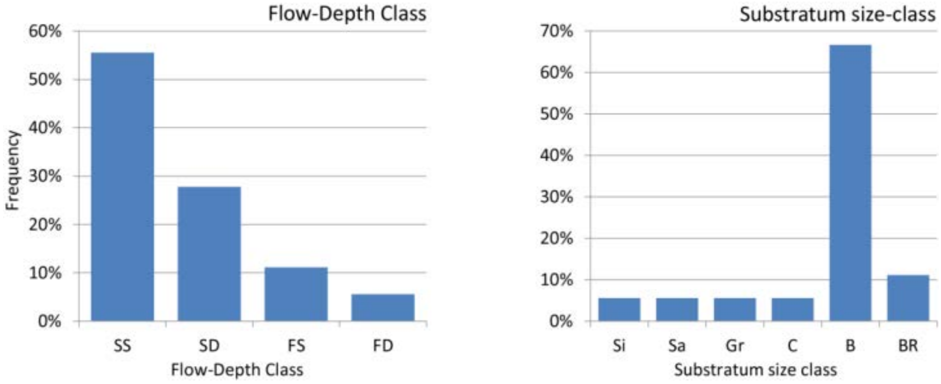


Figure 7-3 **Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD=Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site MA1 on the Matigulu River.**

7.4.2 EWR Site NS1

EWR Site NS1 on the Nseleni River falls on the border of the North Eastern Uplands and Natal Coastal plain and completely within the Zambezian Lowveld ichthyofaunal region at an altitude of roughly 400 *amsl*. The river here is approximately 10 m wide and shaded by riparian forest. The site itself consisted of a downstream pool and a shallow, relatively slow-flowing small-cobble and gravel-bed riffle (Figure 7-4).

Figure 7-4 EWR Site NS1 on the Nseleni River viewed from the left bank, flow direction from right to left.

The mean depth sampled at this site was 0.2 m and the maximum was 0.4 m. Flow-Depth classes were dominated by Slow Shallow (FS: 90%). Substratum size-classes at the site were well sorted, showing a mix of Silt (Si: 10%), Sand (Sa: 35%), Gravel (Gr: 35%) and Cobble (C: 20%). Boulder and bedrock substratum size classes were absent (Figure 7-5).

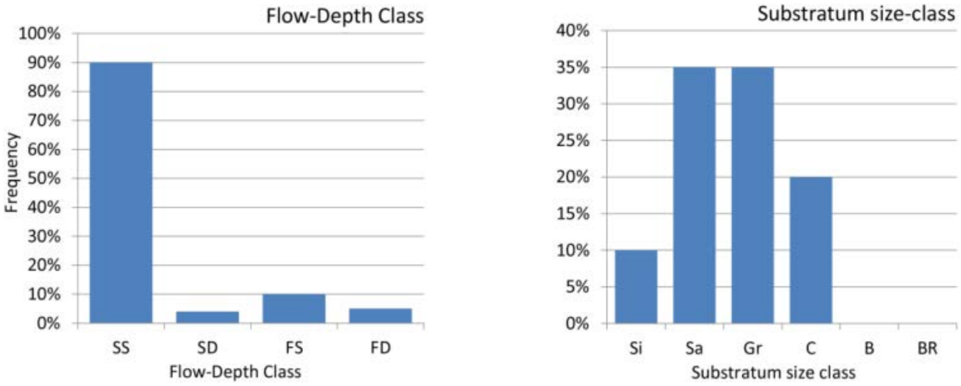


Figure 7-5 Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD=Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site NS1 on the Nseleni River.

7.4.3 EWR Site WM1

EWR Site WM1 on the White Mflolozi River falls on the border of the North Eastern Uplands and Southern Temperate Highveld ichthyofaunal region at an altitude of roughly 650 *amsl*. The river here is approximately 20-30 m wide and braids through series of sand, gravel and cobble-bed bars. The site itself consisted of boulder-cobble rapid and run (Figure 7-6).

Figure 7-6 EWR Site WM1 on the White Mfolozi River viewed from the left bank, flow direction from right to left.

Flow-Depth classes were dominated by Fast Deep (FD: 78%) and Fast Shallow (FS: 21%), with comparatively lower proportions of SS and SD. Substratum size-classes at the site were dominated by Boulder (C: 78%) with much smaller proportions of Cobble and Sand (Figure 7-7).

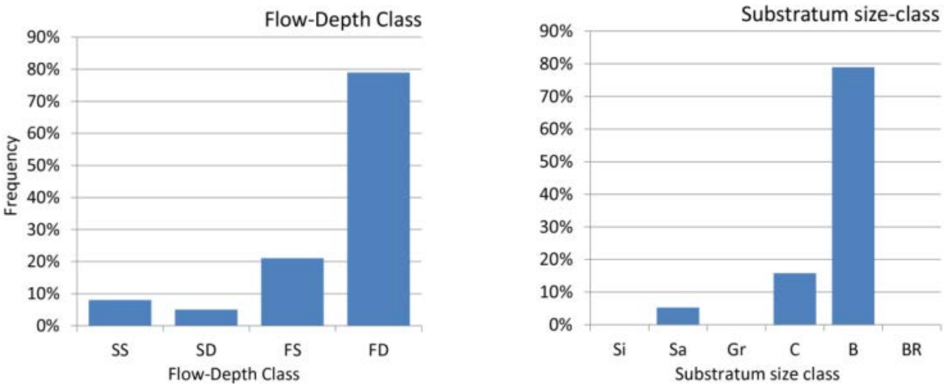


Figure 7-7 Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD=Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site WM1 on the White Mfolozi River.

7.4.4 EWR Site BM1

EWR Site BM1 on the Black Mfolozi River is the most upstream of the two sites on this river. It falls within the Lowveld ecoregion and the Zambezian Lowveld ichthyofaunal region at roughly 600 *amsl*. The site is bedrock dominated, with some cobble and boulder bed elements present and a pool immediately downstream (Figure 7-8).

Figure 7-8 EWR Site BM1 on the Black Mfolozi River viewed from the right bank, flow direction from left to right.

Depths sampled at this site averaged at 0.5 m, with a maximum depth sampled at 0.9 m. Flow-Depth classes were dominated by Slow Shallow (SS: 70%), with comparatively smaller proportions of Slow Deep (SD: 14%) and Fast Shallow (FS: 11%) and no Fast Deep (FD). Substratum size-classes at the site were dominated by Cobble (C: 53%), Bedrock (BR: 21%) and Sand (S: 18%) (Figure 7-9).

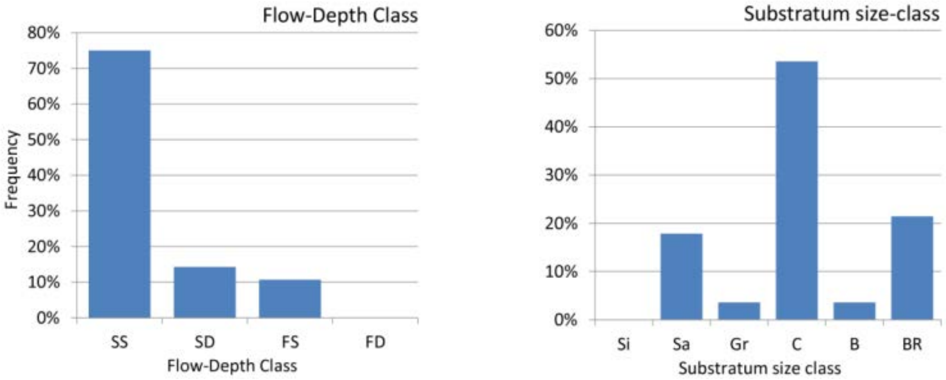


Figure 7-9 Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD= Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site BM1 on the Black Mfolozi River.

7.4.5 EWR Site BM2

EWR Site BM2 on the Black Mfolozi River is the downstream of the two sites located on this river. It is situated at an approximate altitude of 500 *amsl* on the boundary of the Lowveld and North Eastern Uplands ecoregions and it falls completely within the Southern Temperate Highveld ichthyofaunal region. The site is characterised by a sequence bedrock runs and small-cobble and gravel riffles and channel width varies between roughly 3-15 m (Figure 7-10).

Figure 7-10 **EWR Site BM2 on the Black Mfolozi River viewed from the right bank, flow direction from left to right.**

The mean depth sampled at this site was 0.5 m and the maximum 0.9 m. Flow-Depth classes were dominated by Slow Deep (SS: 50%), with equal proportions of Slow Deep (SS: 15%) and Fast Shallow (FS: 17%) and Fast Deep (FD: 17%). Substratum size-classes at the site were dominated by Bedrock (C: 58%), Boulder (BR: 21%) and Gravel (S: 14%) (Figure 7-11).

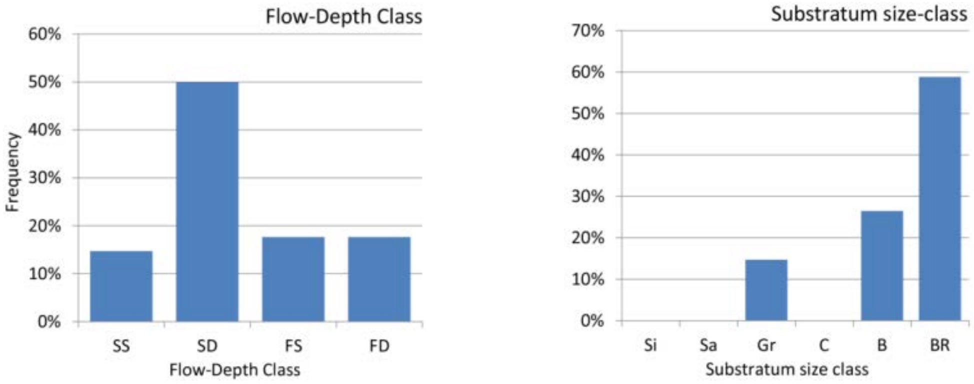


Figure 7-11 **Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD= Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site BM2 on the Black Mfolozi River.**

7.4.6 EWR Site MK1

EWR Site MK1 on the Mkuze River is situated at the boundary of the Lowveld and the low-lying Natal Coastal plain ecoregions (but within the former), at an elevation of ~70 *amsl* and ~50 km from the estuary. The Mkuze is a predominantly sand bed river at the site with riparian floodplain forest bordering its banks. The site is situated on the outside bend of a meander with a sandbar located on the inside bend (Figure 7-12).

Figure 7-12 EWR Site MK1 on Mkuze River viewed from the right bank, flow direction from left to right.

Mean depths sampled at this site varied between 0.3 m and maximum 0.8 m. Flow depth classes at the site were predominantly Slow Shallow (SS: 83%) and 100% of the substrate was sand (Figure 7-13).

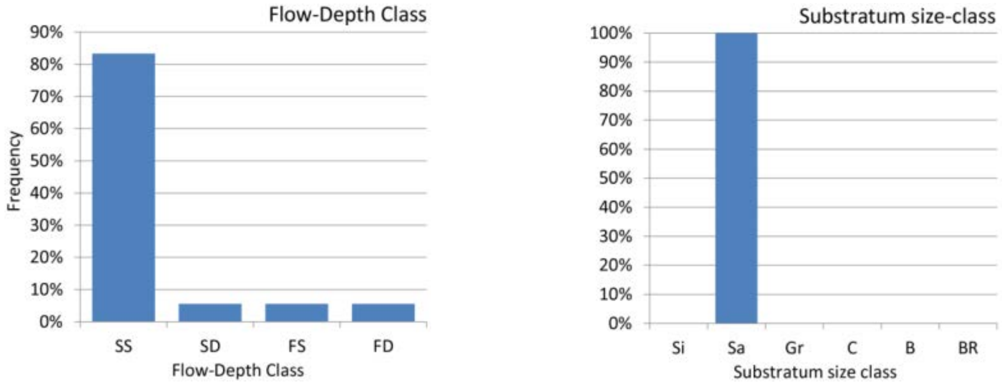


Figure 7-13 Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD= Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site MK1 on the Mkuze River.

7.4.7 EWR Site UP1

EWR Site UP1 on the upper Pongola River is located in the Lowveld ecoregion on the boundar of the North Eastern Highlands at an altitude of ~800 *amsl*. The river channel here is roughly 20-30 m wide and consists of a series of boulder-steps with riffle and rapid morphological units at the upstream end of the site and pool-run sequence immediately downstream (Figure 7-14).

Figure 7-14 **EWR Site UP1 on upper Pongola River viewed from the right bank, flow direction from left to right.**

Mean depths sampled were 0.4 m and maximum sampled depths were 0.55 m. Flow-Depth classes on the upper Pongola were dominated by Fast Deep (FD: 57%) with the remaining classes made up of Fast Shallow (FS: 22%), Slow Deep (SD: 12%) and Slow Shallow (SS: 9%). Substratum size classes comprised mainly Cobble (50%) and Boulder (B: 35%) (Figure 7-15).

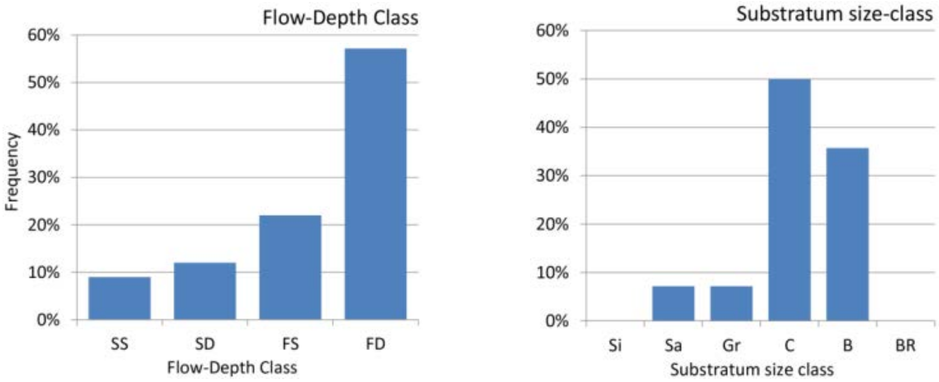


Figure 7-15 **Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD= Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site UP1 on the Pongola River.**

7.4.8 EWR Site AS1

EW Site AS1 on the Assegai River is situated in the Lowveld ecoregion near to the boundary with the North East Highlands in the Southern Temperate Highveld ichthyofaunal region at an elevation of ~1000 m. Instream habitat comprises predominantly riffle over a cobble and boulder substratum with a pool at the downstream end of the site (Figure 7-16).

Figure 7-16 EWR Site AS1 on Assegai River viewed from the right bank, flow direction from left to right.

Depths sampled at this site varied between 0.5 m and 0.78 m. The substratum in the sampled reach comprised predominantly cobble and boulder (35 and 50 % respectively). Flow-Depth classes included Slow Shallow (SS: 9%), Slow Deep (SD: 12%), but with the highest proportion of habitat falling within the Fast Shallow (FS: 22) and Fast Deep (FS: 23) classes (Figure 7-17).

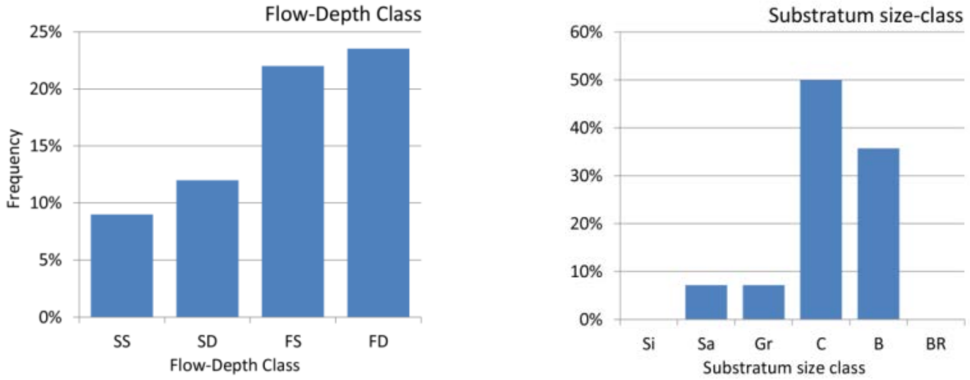


Figure 7-17 Flow-Depth classes (SS=Slow Shallow, SD=Slow Deep, FS=Fast Shallow, FD= Fast Deep) and Substratum size classes (Si=Silt, Sa=Sand, Gr=Gravel, C=Cobble, B=Boulder, BR=Bedrock) at EWR Site AS1 on the Assegai River.

7.5 Ecoclassification of river reaches represented by the EWR sites

In all instances below, there is a large discrepancy between the species expected at the site and those recorded during the course of the survey. However, this is considered attributable to the limited fishing effort of the survey (manpower, time, geographical extent and sampling gear) and the rarity of some species throughout the catchment, e.g. Anguillid eels, the bulldog (*Marcusenius macrolepidotus*). There are, as a consequence, often large discrepancies between the automated and adjusted FRAI scores. The adjusted FRAI score was therefore based on an assessment of available habitat classes that would be expected under reference conditions and those measured at the site (see Section 7.4).

7.5.1 EWR Site MA1

Of the 23 fish species expected at the EWR Site MA1 on the Matigulu River under reference conditions (Kleynhans et al. 2007; Department of Water Affairs 2013, National database records SAIAB and KZN Wildlife), five species were collected during the course of the survey (Table 7-7).

Table 7-7 Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site MA1.

SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Micropterus salmoides	1	1
Oreochromis mossambicus	1	0
Labeobarbus natalensis	1	1
Awaous aeneofuscus	1	2
Glossogobius giuris	1	1
Aplocheilichthys katangae	1	0
Anguilla bengalensis labiata	1	0
Anguilla marmorata	1	1
Anguilla mossambica	1	0
Aplocheilichthys myaposae	1	0
Barbus gurneyi günther	1	0
Barbus paludinosus	1	0
Barbus trimaculatus	1	0
Barbus viviparus	1	0
Clarias gariepinus	1	0
Clarias theodorae	1	0
Gilchristella aestuaria	1	0
Glossogobius callidus	1	0
Labeo molybdinus	1	0
Mesobola brevianalis	1	0
Marcusenius macrolepidotus	1	0
Pseudocrenilabrus philander	1	0
Tilapia sparrmanii	1	0

The fish species compliment at the site was found to have a strongly euryhaline component with a lower proportion of freshwater species being present.

The automated and adjusted PES scores for EWR Site MA1 are shown in Table 7-8. The reason for the divergent scores is attributable to the low number of species recorded from the site during surveys as explained in the introduction to this section. The adjusted FRAI scores were therefore based on an assessment of habitat at the site, i.e. the frequency and diversity of flow habitat classes. These were considered adequate to support the fish species in a near-reference condition. Three species at the site are considered to have a preference of FS and FD habitat classes, one of which (*L. natalensis*) was found to be present at the site.

Table 7-8 The automated and adjusted ECs for EWR Site MA1 for the FRAI assessment showing the % and score.

AUTOMATED	
FRAI (%)	42.3
EC: FRAI	D
ADJUSTED	
FRAI (%)	86.7
EC: FRAI	B

One species with migratory requirement for catchment scale migrations (>100 km) was present at the site (*A. marmorata*). Four species expected to occur under reference conditions are considered moderately intolerant of modified physico-chemical conditions and none of these were present at the; suggesting impaired water quality conditions could be contributing to the B Ecological Category. The trend at this site is considered to be stable.

7.5.2 EWR Site NS1

Based on Kleynhans et al. (2007), National database records (SAIAB and KZN Wildlife) and the Department of Water Affairs (2013), 20 fish species were expected at EWR Site NS1 on the Nseleni River under reference conditions. Of these, only two were collected during the course of the survey (Table 7-9). The low number of species recorded is believed attributable to the reasons outlined at the beginning of this section.

Table 7-9 **Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site NS1.**

SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Pseudocrenilabrus philander	3	2
Glossogobius callidus	3	5
Oreochromis mossambicus	3	0
Labeobarbus natalensis	3	0
Glossogobius giuris	3	0
Awaous aeneofuscus	3	0
Aplocheilichthys katangae	3	0
Anguilla bengalensis labiata	3	0
Anguilla marmorata	3	0
Anguilla mossambica	3	0
Aplocheilichthys myaposae	3	0
Barbus viviparus	3	0
Clarias gariepinus	3	0
Clarias theodorae	3	0
Gilchristella aestuaria	3	0
Glossogobius callidus	3	0
Labeo molybdinus	3	0
Mesobola brevianalis	3	0
Marcusenius macrolepidotus	3	0
Tilapia sparrmanii	3	0

The automated and adjusted PES scores for EWR Site NS1 are shown in Table 7-10. The reason for the divergent scores is attributable to the low number of species recorded from the site during surveys. The adjusted FRAI scores were therefore based on an assessment of habitat at the site, i.e. the frequency and diversity of flow habitat classes. Conditions observed at the site were considered inadequate to support fish species with a preference for Fast Shallow, Fast Deep habitat classes. However these conditions are not expected to be substantially different from reference.

Table 7-10 **The automated and adjusted ECs for EWR Site NS1 for the FRAI assessment showing the % and score.**

AUTOMATED	
FRAI (%)	23.7
EC: FRAI	E
ADJUSTED	
FRAI (%)	68.1
EC: FRAI	C

Three fish species which would be expected at the site under reference conditions are considered moderately intolerant of modified physico-chemical conditions and none of these were found to be present during surveys. Fish cover in the form of overhanging vegetation, woody debris, as well as undercut banks and root wads were abundant and one species with a preference for cover was found to be present (*P. philander*). No species with a strong requirement for migration were present. The trend at this site is considered to be stable.

7.5.3 EWR Site WM1

Of the 19 fish species expected under reference conditions at the EWR Site WM1 on the White Mflolozi River (Kleynhans et al. 2007; Department of Water Affairs 2013, National database records SAIAB and KZN Wildlife), four species were collected during the course of the survey (Table 7-11).

Table 7-11 Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site WM1.

SCIENTIFIC NAMES: REFERENCE SPECIE (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Amphilius uranoscopus	2	2
Clarias gariepinus	2	2
Labeo molybdinus	4	5
Labeobarbus natalensis	4	5
Anguilla bengalensis labiata	2	0
Anguilla marmorata	2	0
Anguilla mossambica	2	0
Barbus anoplus	2	0
Barbus paludinosus	2	0
Barbus trimaculatus	2	0
Barbus unitaeniatus	2	0
Barbus viviparus	2	0
Clarias gariepinus	2	0
Labeo cylindricus	2	0
Labeo molybdinus	4	0
Micralestes acutidens	2	0
Marcusenius macrolepidotus	2	0
Oreochromis mossambicus	2	0
Tilapia sparrmanii	4	0

The automated and adjusted PES scores for EWR Site WM1 are shown in Table 7-12. The FRAI scores are largely congruent compared to the other sites. The adjusted scores were based on an assessment of habitat at the site, i.e. the frequency and diversity of flow habitat classes. Habitat conditions observed at the site were considered adequate to support fish species with a preference for Fast Shallow and Fast Deep habitat classes and the conditions are not expected to be substantially different from reference.

Table 7-12 The automated and adjusted ECs for EWR Site WM1 for the FRAI assessment showing the % and score.

AUTOMATED	
FRAI (%)	58.8
EC: FRAI	C/D
ADJUSTED	
FRAI (%)	72.6
EC: FRAI	C

Three fish species with strong preferences for faster flow-depth classes (FS and FD) and intolerant to moderately intolerant of no-flow conditions were found at this site. One of these species (*A. uranoscopus*) is considered intolerant of modified physico-chemical conditions. Fish cover (overhanging vegetation etc.) and Slow Deep habitat types were scarce at this site, possibly contributing to the C Ecological Category. Two species with a strong requirement for migration between reaches were present. The trend at this site is considered to be stable.

7.5.4 EWR Site BM1

Of the 15 fish species expected under reference conditions at the EWR Site BM1 on the Black Mflolozi River (Kleynhans et al. 2007; Department of Water Affairs 2013, National database records SAIAB and KZN Wildlife), five species were collected during the course of the survey (Table 7-13).

Table 7-13 Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site BM1.

SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Amphilius uranoscopus	2	3
Barbus trimaculatus	3	1
Tilapia sparrmanii	4	2
Barbus eutaenia	2	4
Labeobarbus natalensis	2	3
Anguilla bengalensis labiata	2	0
Anguilla mossambica	2	0
Barbus anoplus	3	0
Barbus unitaeniatus	3	0
Barbus viviparus	3	0
Clarias gariepinus	3	0
Clarias theodorae	2	0
Labeo molybdinus	4	0
Oreochromis mossambicus	4	0
Pseudocrenilabrus philander	4	0

The automated and adjusted PES values for EWR Site BM1 are shown in Table 7-14. The adjusted FRAI scores were based on an assessment of habitat available at the site, i.e. the frequency and diversity of flow habitat classes. Habitat conditions observed at the site were considered adequate to support fish species with a preference for Fast Shallow and Fast Deep, as well as Slow Deep habitat classes and the conditions are not expected to be substantially different from reference.

Table 7-14 The automated and adjusted ECs for EWR Site BM1 for the FRAI assessment showing the % and score.

AUTOMATED	
FRAI (%)	45.5
EC: FRAI	D
ADJUSTED	
FRAI (%)	75.9
EC: FRAI	C

Two fish species with strong preferences for faster flow-depth classes (FS and FD) and intolerant to moderately-intolerant of no-flow conditions were found at this site (*L. natalensis* and *A. uranoscopus*). One of these species (*A. uranoscopus*) is considered intolerant of modified physico-chemical conditions, suggesting that water quality conditions at the site were relatively good. One species with a requirement for overhanging marginal vegetation (*B. trimaculatus*) and one species with a strong requirement for migration between reaches were present (*L. natalensis*). The trend at this site is considered to be stable.

7.5.5 EWR Site BM2

Based on Kleynhans et al. (2007), National database records (SAIAB and KZN Wildlife) and the Department of Water Affairs (2013), 18 fish species were expected under reference conditions at EWR Site BM2 on the Black Mfolozi River. Of these, seven were collected during the course of the survey (Table 7-15).

Table 7-15 Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site BM2.

SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Barbus eutaenia	2	0
Anguilla bengalensis labiata	2	0
Anguilla mossambica	2	0
Amphilius natalensis	2	0
Amphilius uranoscopus	2	1
Barbus anoplus	3	0
Labeobarbus natalensis	4	5
Barbus trimaculatus	4	4
Barbus unitaeniatus	3	2
Barbus viviparus	3	0
Clarias gariepinus	3	0
Clarias theodorae	3	0
Labeo molybdinus	4	2
Oreochromis mossambicus	3	0
Pseudocrenilabrus philander	3	0
Tilapia rendalli	3	0
Tilapia sparrmanii	3	2
Barbus paludinosus	1	2

The automated and adjusted PES scores for EWR Site BM2 are shown in Table 7-16. The scores are roughly congruent compared to the other sites. The adjusted FRAI scores were based on weighting of habitat at the site, i.e. the frequency and diversity of flow habitat classes. Conditions observed at the site were considered adequate to support fish species with a for preference for Fast Shallow, Fast Deep as well as Slow Deep habitat classes.

Table 7-16 The automated and adjusted ECs for EWR Site BM2 for the FRAI assessment showing the % and score.

AUTOMATED	
FRAI (%)	54.0
EC: FRAI	D
ADJUSTED	
FRAI (%)	75.2
EC: FRAI	C

Three fish species with strong preferences for faster flow-depth classes (FS and FD) and intolerant to moderately intolerant of no-flow conditions were found at this site (*L. natalensis, L. molybdinus* and *A. uranoscopus*). One of these species (*A. uranoscopus*) is considered intolerant of modified physico-chemical conditions. One species with a requirement for overhanging marginal vegetation (*B. trimaculatus*) and two species with a strong requirement for migration between reaches were present (*L. natalensis* and *L. molybdinus*). The FROC of many of the species were similar or higher than expected (Table 7-15). The trend at this site is considered to be stable.

7.5.6 EWR Site MK1

Of the 31 fish species expected at the EWR Site MK1 on the Matigulu River under reference conditions (Kleynhans et al. 2007; Department of Water Affairs 2013, National database records SAIAB and KZN Wildlife), four species were collected during the course of the survey at FROCs higher than expected (Table 7-17).

Table 7-17 Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site MK1.

SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Oreochromis mossambicus	1	5
Clarias gariepinus	1	2
Barbus paludinosus	1	3
Barbus viviparus	1	4
Barbus argenteus	1	0
Awaous aeneofuscus	1	0
Acanthopagrus berda	1	0
Aplocheilichthys katangae	1	0
Anguilla bengalensis labiata	1	0
Anguilla marmorata	1	0
Anguilla mossambica	1	0
Barbus annectens	1	0
Brycinus lateralis	1	0
Barbus natalensis	1	0
Barbus toppini	1	0
Barbus unitaeniatus	1	0
Clarias theodorae	1	0
Glossogobius callidus	1	0
Glossogobius giuris	1	0
Labeo cylindricus	1	0
Labeo molybdinus	1	0
Labeo rosae	1	0
Micralestes acutidens	1	0
Mesobola brevianalis	1	0
Marcusenius macrolepidotus	1	0
Nothobranchius orthonotus	1	0
Redigobius dewaali	1	0
Schilbe intermedius	1	0
Synodontis zambezensis	1	0
Tilapia rendalli	1	0
Tilapia sparrmanii	1	0

The automated and adjusted PES scores for EWR Site MK1 are shown in Table 7-18. The adjusted FRAI scores (C) are much higher than the automated scores (D), primarily due to the limited scope of the surveys as already discussed, as well as the fact that the site is located in a sand-bed reach with limited availability of cobble-bed riffle, rapid or pool habitats. The adjusted FRAI scores were based on weighting of habitat at the site, i.e. the frequency and diversity of flow habitat classes, rather than on solely the presence or absence of species. Although the diversity of habitats at the site were low (primarily FS and SS) with no exposed cobble, the site is located in a sand-bed reach and this condition is not expected to be different from reference.

Table 7-18 The automated and adjusted ECs for EWR Site MK1 for the FRAI assessment showing the % and score.

AUTOMATED	
FRAI (%)	43.0
EC: FRAI	D
ADJUSTED	
FRAI (%)	78.5
EC: FRAI	C

As expected from the habitat conditions at the site, no fish species with strong preferences for faster flow-depth classes (FS and FD) and a requirement for cobble-boulder substratum conditions were found. No species with an intolerance for modified physic-chemical conditions were recorded. Two species were present that had a preference for overhanging vegetation or aquatic macrophytes (*B. paludinosus* and *B. viviparus*). Most species present were fairly tolerant species, however, this is considered more a reflection of natural habitat conditions at the site, rather than the presence of any external stressors. The FROC of many of the species were similar or higher than expected (Table 7-17). The trend at this site is considered to be stable.

7.5.7 EWR Site UP1

Of the 29 fish species expected at the EWR Site UP1 on the Pongola River under reference conditions (Kleynhans et al. 2007; Department of Water Affairs 2013, National database records SAIAB and KZN Wildlife), four species were collected during the course of the survey at FROCs equal to or lower than expected (Table 7-19).

Table 7-19 Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site UP1.

SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Anguilla marmorata	3	0
Anguilla mossambica	3	0
Amphilius uranoscopus	3	0
Barbus anoplus	3	0
Anguilla marmorata	3	0
Anguilla mossambica	3	0
Amphilius uranoscopus	3	0
Barbus anoplus	3	0
Barbus argenteus	3	0
Labeobarbus marequensis	3	0
Barbus paludinosus	3	0
Labeobarbus polylepis	3	3
Barbus trimaculatus	3	0
Barbus unitaeniatus	3	0
Chiloglanis anoterus	3	1
Chiloglanis emarginatus	3	0
Clarias gariepinus	3	0
Labeo cylindricus	3	0
Labeo molybdinus	3	1
Labeo rosae,	3	0
Mesobola brevianalis	3	0
Marcusenius macrolepidotus	3	0
Oreochromis mossambicus	3	0
Petrocephalus wesselsi	3	0
Pseudocrenilabrus philander	3	0
Tilapia rendalli	3	0
Tilapia sparrmanii	3	1
Varicorhinus nelspruitensis	3	0
Chiloglanis swierstrai	3	0

The automated and adjusted PES scores for EWR Site UP1 are shown in Table 7-18. The adjusted FRAI scores (C) are much higher than the automated scores (E). The adjusted FRAI scores were therefore based on weighting of habitat at the site, i.e. the frequency and diversity of flow habitat classes, rather than on solely the presence or absence of species. EWR Site UP1 exhibited a wide diversity of habitat types including Fast Deep, Fast Shallow and Slow Deep as well as a diversity of cover types including large bed structure (boulders), and marginal vegetation. It is presumed therefore that the site is capable of supporting all the species expected to be present under reference conditions.

Table 7-20 The automated and adjusted ECs for EWR Site UP1 for the FRAI assessment showing the % and score.

AUTOMATED	
FRAI (%)	27.9
EC: FRAI	E
ADJUSTED	
FRAI (%)	70.1
EC: FRAI	C

Three fish species with strong preferences for faster flow-depth classes (FS and FD) and a requirement for cobble-boulder substratum for all or part of their life cycle were found at this site (*L. polylepis*, *C. anoterus* and *L. molybdinus*). One of these species (*C. anoterus*) is considered to be intolerant of modified physico-chemical conditions, suggesting that water quality at this site is relatively unimpaired. One species was present that is considered to have a preference for overhanging vegetation or aquatic macrophytes (*T. sparrmanii*). The trend at this site is considered to be stable.

7.5.8 EWR Site AS1

Based on Kleynhans et al. (2007), National database records (SAIAB and KZN Wildlife) and the Department of Water Affairs (2013), 18 fish species were expected at EWR Site AS1 on the Assegai River under reference conditions. Of these, four were collected during the course of the survey (Table 7-21).

Table 7-21 Reference species (excluding introduced species) together with their expected and observed Frequency of Occurrence (FROC) at EWR Site AS1.

SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)	REFERENCE FREQUENCY OF OCCURRENCE	FREQUENCY OF OCCURRENCE: EC
Anguilla mossambica	2	0
Amphilius uranoscopus	2	1
Barbus anoplus	3	0
Barbus argenteus	3	0
Labeobarbus marequensis	4	5
Labeobarbus polylepis	4	0
Barbus trimaculatus	4	1
Barbus unitaeniatus	3	0
Barbus viviparus	3	0
Chiloglanis anoterus	2	0
Chiloglanis emarginatus	2	1
Chiloglanis swierstrai	2	0
Labeo cylindricus	2	0
Labeo molybdinus	4	0
Opsaridium peringueyi	2	0
Pseudocrenilabrus philander	4	0
Tilapia sparrmanii	4	0
Varicorhinus nelspruitensis	2	0

The automated and adjusted PES scores for EWR Site AS1 are shown in Table 7-22. The adjusted FRAI scores were based on an assessment of habitat at the site, i.e. the frequency and diversity of flow habitat classes. The flow habitat conditions observed at the site were considered adequate to support fish species with a preference for Fast Shallow, Fast Deep habitat classes and the conditions are not expected to be substantially different from reference, although some impacts are expected from the Heyshope Dam upstream.

Table 7-22 The automated and adjusted ECs for EWR Site AS1 for the FRAI assessment showing the % and score.

AUTOMATED	
FRAI (%)	34.6
EC: FRAI	E
ADJUSTED	
FRAI (%)	81.8
EC: FRAI	B/C

Five fish species which are expected at the site under reference conditions are considered intolerant of modified physico-chemical conditions and tow of these were found to be present during survey (*C. anoterus* and *C. emarginatus*). Water quality at the site is not therefore expected to be significantly impaired. Fish cover in the form of overhanging vegetation, woody debris, as well as undercut banks and root wads were abundant and one species with a preference for cover was found to be present (*B. trimaculatus*). One species with a strong requirement for migration (*L. marequensis*) were present and two with an intolerance for no-flow as well as FD and FS flow conditions were also found to be present (*C. anoterus* and *C. emarginatus*). The trend at this site is considered to be stable.

7.6 Field data collection and analysis

7.6.1 Electrofishing methodology

A SAMUS 725G backpack electrofisher with a maximum output power of 650 Watts and an output voltage of up to 1000 V was used to capture fish to a depth of around one meter in pools, riffles, runs and rapids. Pulse frequency was set at 50 Hz and pulse duration at 0.05 seconds. Electrofishing was conducted at each site along the margins and thalweg of the active channel and side channels. The electrofishing team consisted of two people – the electrofisher and netter – who began at the downstream end of the site and proceeded in an upstream direction for a distance of 100 – 150 m and electrofished for a period of between 45 and 60 minutes.

7.6.2 Habitat measurement

During the course of electrofishing, visually assessed breaks in habitat composition and structure were identified on the basis of the Flow-Depth classes described in Table 7-2. Electrofishing would then commence in a pre-selected habitat unit. Once the unit had been electrofished, the effort (time in minutes) would be recorded and the fish caught would be transferred to polyethylene ‘zip-lock’ packets held in an inflatable raft. The depth, substratum, velocity and cover characteristics of the habitat unit would then be measured, recorded on waterproof paper and placed within the polyethylene sample bag with the fish. The depth and velocity was recorded by means of a Transparent Velocity-Head Rod (TFHR) as described Fonstad et al. (2005). Substratum was classified according to the size classed defined by Rowntree and Wadeson (1999). In this way, individual fish species could be associated with specific habitat conditions.

7.6.3 Fish sample processing

At the end of the electrofishing transect, the captured fish were taken to the bank where following information was recorded for each fish:

- The habitat characteristics of the sample (depth, velocity, substratum and cover)
- Species name
- Fork Length (FL, mm)
- Total Length (TL, mm)
- Weight (grams)

- Reproductive stage (i.e. whether it was ripe-and-running – note that no dissections were carried out)
- Fish health and condition (i.e. the presence of any externally visible anomalies such as parasites and lesions)

Where the taxon could not be confirmed on-site, the sample was fixed in a 40 % solution of formaldehyde and transferred to the laboratory for further examination. The remaining fish were returned to the river.

7.6.4 Habitat characterisation

The habitat in which each species was found to occur was described in terms of Depth, Velocity ($m.s^{-1}$), Substratum (silt, sand, gravel, cobble, boulder), Flow-Depth classes (Table 7-2) and Fish Cover criteria (overhanging vegetation, aquatic macrophytes, marginal vegetation, woody debris and undercut banks) for all indicator species across all sites. The data linking fish species to a habitat conditions – collected in the manner described in Section 7.6.2 – was transcribed and individual fish species were linked to specific habitat conditions by means of a sample code with its associated habitat criteria. Because of low sample sizes and high variability, habitat data were first smoothed using a two-point running mean and represented as frequencies of occurrence histograms which were normalised, i.e. represented as a value between 0 and 1. These histograms were then used in conjunction with the Habitat-Flow Simulation Model (HABFLO) to create DRIFT response curves.

7.7 Results

A total of 319 individual fish belonging to 21 species and nine families were collected from the eight EWR Sites across the Usuthu-Mhlatuze WMA during the low-flow survey between the 7th and 12th of July 2014. This represents 25 % of the species compliment in the WMA. the Kwazulu-Natal yellowfish (*Labeobarbus natalensis*) was the most abundant fish caught (N = 66) and this species was caught at four of the eight sites. The second most abundant species was the leaden labeo (*Labeo molybdinus*) (N = 36) and it was caught at three of the sampled sites. Size frequency distributions are included for the three most abundant species caught at each site.

7.7.1 EWR Site MA1

A total of 31 fish belonging to six species were collected from EWR Site MA1 on the Matigulu River. This site was the second most diverse site in the survey ($H' = 1.47; E = 0.82$) with most of the species present being euryhaline – a direct consequence of the site's proximity to the Matigulu River estuary. The oval moony (*Monodactylus falciformis*) was the most abundant species at the site ($N = 13$, *CPUE* = *11.14 fish/hr*) (Table 7-23). Individual fish ranged between 57 and 73 mm*TL* is size ($\bar{x}$ = 64.1 mm*TL*) (Figure 7-18). This species is a common euryhaline estuarine resident, but juveniles are believed to enter estuary headwaters and lower river reaches to feed on aquatic invertebrates (Wasserman and Strydom 2011). The second most abundant species was the freshwater goby (*Awaous aeneofuscus*) (*Abun = 8, CPUE = 6.86 fish/hr*) (Table 7-23). This is another euryhaline species which may be able to breed in both fresh and brackish waters. The third euryhaline species recorded at EWR Site MA1 was one the tank goby (*Glossogobius giuris*) which is reported to breed in freshwaters during summer (Skelton 2001a). Only two indigenous primary freshwater fish species were recorded from the site: two Mozambique tilapia (*Oreochromis mossambicus*) and five sub-adult Kwazulu-Natal yellowfish (*Labeobarbus natalensis*) ranging size from 100-200 mm*TL* ($\bar{x}$ = 146.6 mm*TL*) (Figure 7-18).

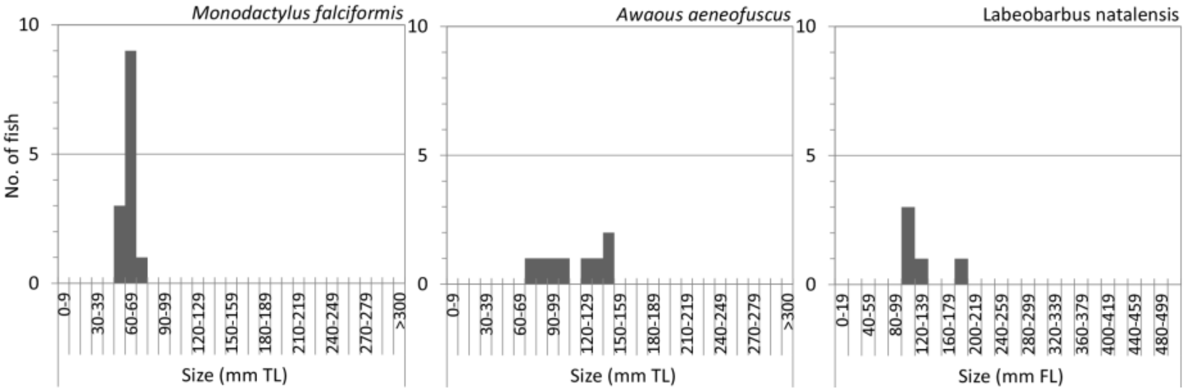


Figure 7-18 Size class frequencies (mm TL) for *M. falciformis*, *A. aeneofuscus* and *L. natalensis* at EWR Site MA1.

7.7.2 EWR Site NS1

Only two fish species were recorded from EWR Site NS1 on the Nseleni River – these were the southern mouthbrooder (*Pseudocrenilabris philander*) and the river goby (*Glossogobius calidus*) (Table 7-23). The southern mouthbrooder is distributed through the Orange-Vaal River system and northwards to the southern Congo tributaries and is commonly associated with aquatic or marginal vegetation. It breeds from early spring to late summer and eggs are laid in cleared nests constructed in slow-flowing river reaches. River gobies, a widely distributed species, occurring in the eastern coastal rivers of southern Africa from Swartvlei in the Western Cape to Mozambique (Skelton 2001a), were the most abundant species at the site (*N = 20, CPUE 24 fish/hr*). This species was collected from shallow riffle habitats with moderately-fast flowing water over cobbles and gravel. The ranged in size from 30 – 90 mm TL (Figure 7-19).

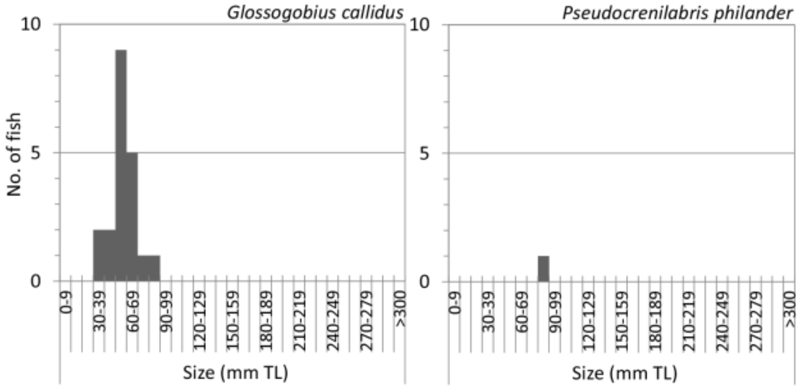


Figure 7-19 Size class frequencies (mm TL) for *G. callidus* and *P. philander* at EWR Site NS1.

7.7.3 EWR Site WM1

A total of four species were collected from EWR Site WM1 (*H′ = 0.87; E = 0.63*) (Table 7-23). The most abundant species at this site was the Kwazulu-Natal yellowfish (*N = 23, CPUE = 27.6 fish/hr*) followed by the leaden labeo (*N = 18, CPUE = 21.6 fish/hr*). Kwazulu-Natal yellowfish comprised mostly young-of-the-year juveniles, ranging in size from 60 – 220 mm TL, with the median size range between 100 -110 mm TL (Figure 7-20). Median size ranges for leaden labeos fell between 150 – 220 mm TL, suggesting most were sub-adult. Both the Kwazulu-Natal yellowfish and leaden labeos were selected as indicator species and their ecology. Also collected from this site was a single Stargazer mountain catfish (*Amphilius uranoscopus*) and the sharptooth catfish (*Clarius gariepinus*).

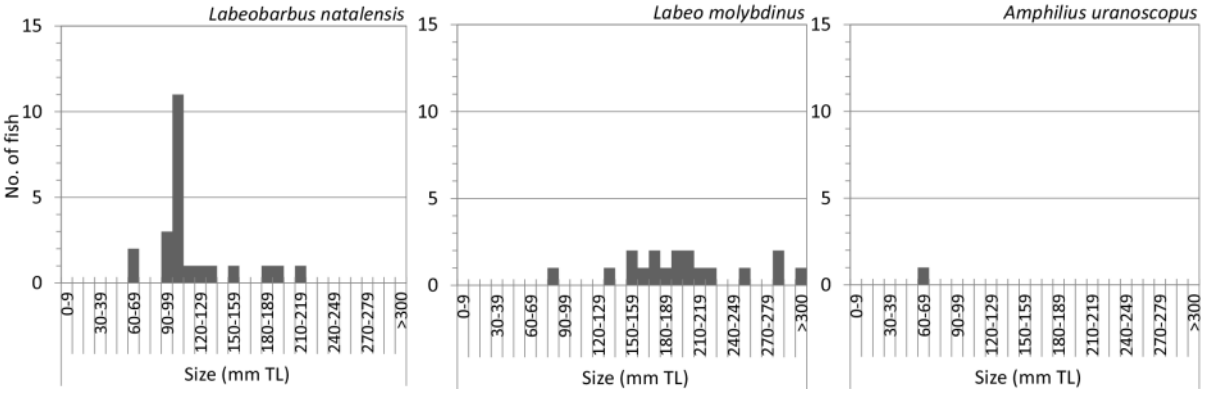


Figure 7-20 Size class (mm TL) frequencies for *L. natalensis*, *L. molybdinus* and *A. uranoscopus* at EWR Site WM1.

7.7.4 EWR Site BM1

EWR Site BM1 – the most upstream of the two sites on the Black Mfolozi River was the third most diverse site in the survey with five species being recorded here (*H′ = 1.13; E = 0.70*) (Table 7-23). The most abundant species at this site was the orangefin barb (*Barbus eutaenia*) (*N = 32, CPUE = 42.67 fish/hr*) (Table 7-23). The orangefin barb prefers rivers with rocky habitats (Skelton 2001a) and is one of the three sawfin barbs present in the WMA. Historical records (SAIAB and KZN Wildife) suggest that the orangefin barb are not common in the catchment and that they are restricted to the immediate vicinity of EWR Sites BM1 and BM2. Young-of-the-year Kwazulu-Natal yellowfish between 30 and 50 mm TL (Figure 7-21) were the second most abundant species present at the site (*N = 13, CPUE = 42.60 fish/hr*). Six stargazer mountain catfish in two size classes (40-50 and 90-100 mm TL) also occurred here (*N = 8, CPUE = 8 fish/hr*) (Figure 7-21). Other species present at EWR Site BM1 in lower numbers included: the threespot barb (*Barbus trimaculatus*) (*N = 1, CPUE = 1.33 fish/hr*) and banded tilapia (*Tilapia sparrmanii*) (*N = 3, CPUE = 4 fish/hr*).

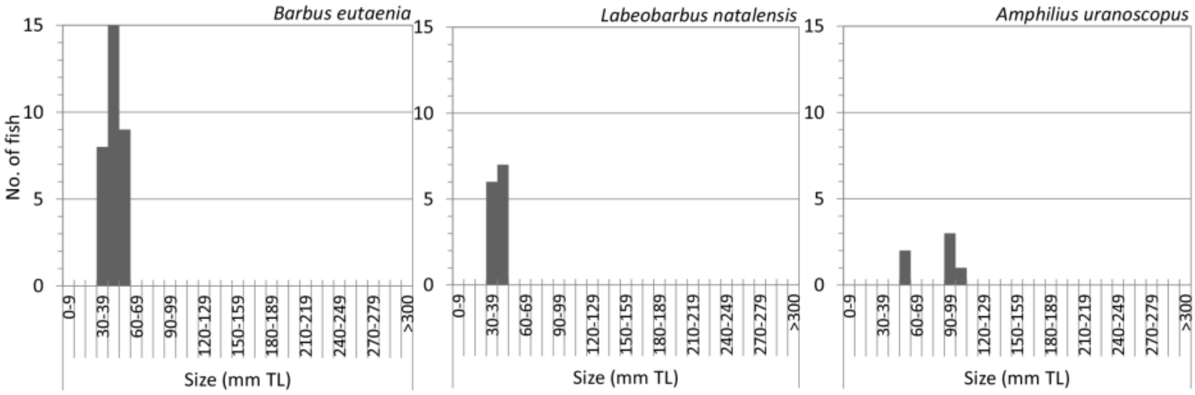


Figure 7-21 Size class frequencies (mm TL) for *B. eutaenia*, *L. natalensis* and *A. uranoscopus* at EWR Site BM1.

7.7.5 EWR Site BM2

A total of seven species were collected from EWR Site BM2 (*H = 0.53; E = 0.79*) – with EWR MA1, this was the highest number of species recorded at a site (Table 7-1). The three most abundant species at EWR Site BM2 were the Kwazulu-Natal yellowfish (*N = 25, CPUE = 31.91 fish/hr*), the threespot barb (*N = 18, CPUE = 22.98 fish/hr*) and the leaden labeo (*N = 17, CPUE = 21.7 fish/hr*) (Table 7-24). Kwazulu-Natal yellowfish comprised mostly juveniles, ranging in size from 30 – 140 mm TL, with four potential cohorts being present at median lengths of: 30-39, 40-49, 80-89 and >100 mm TL (Figure 7-22). Median size ranges of the threespot barb fell between 30-59 and 70-79 mm TL. Leaden labeos were present in a wide range of size classes ranging from 60-270 mm TL. Also collected from this site were Stargazer mountain catfish and the banded tilapia, straightfin barb and longbeard barb.

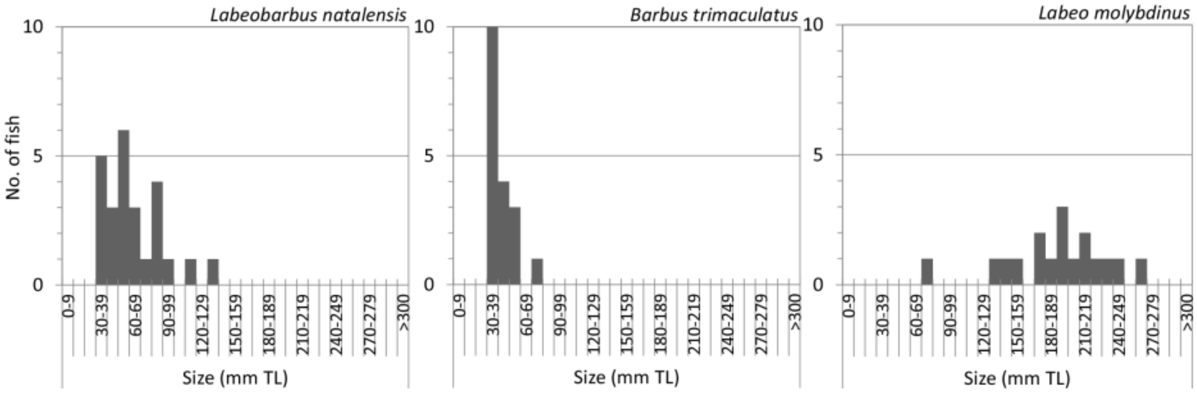


Figure 7-22 Size class frequencies (mm TL) for *L. natalensis*, *B. trimaculatus* and *L. molybdinus* at EWR Site BM2.

7.7.6 EWR Site MK1

Four species were collected from EWR Site MK1 (*H = 0.89; E = 0.64*). The three most abundant species at EWR Site BM2 were the bowstripe barb (*N = 31, CPUE = 31 fish/hr*), the Mozambique tilapia (*N = 16, CPUE = 16 fish/hr*) and the straightfin barb (*N = 14, CPUE = 14 fish/hr*) (Table 7-24). Bowstripe barbs ranged in size between 10-50 mm TL, with most fish in the 30-39 mm TL size class (Figure 7-23). Median sizes of Mozambique tilapia ranged between 50-100 mm TL and straightfin barbs between 30-80 mm TL.

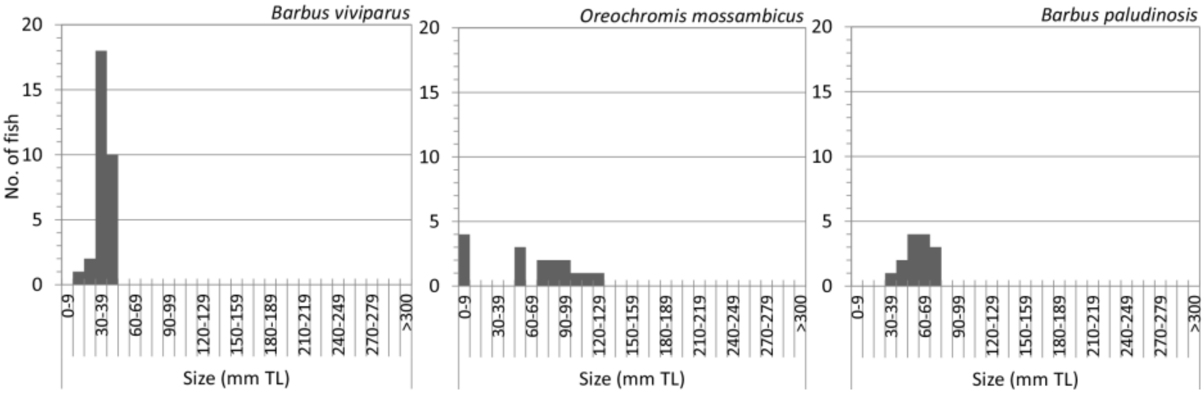


Figure 7-23 Size class frequencies (mm TL) for *B. viviparus*, *O. mossambicus* and *B. paludinosus* at EWR Site MK1.

7.7.7 EWR Site UP1

Four fish species were collected from EWR Site UP1 (*H = 1.21; E = 0.88*) (Table 7-23). These included the penant-tailed suckermouth (*Chiloglanis anoterus*) (*N = 4, CPUE = 4.8 fish/hr*), two juvenile Bushveld smallscale yellowfish (*Labeobarbus polylepis*) (*N = 2, CPUE = 2.4 fish/hr*), banded tilapia (*N = 1, CPUE = 1.2 fish/hr*) and the leaden labeo (*N = 1, CPUE =*

Table 7-23 Results of the fish survey undertaken on the Matigulu, Nseleni, White Mfolozi and Black Mfolozi Rivers (EWR Sites MA1, NS1, WM1 and BM1 respectively). Results are reported in abundance (Abun.) and CPUE (fish/hr). Species Richness (*S*), Shannon Weiner diversity index (*H’*) and Species Evenness (*E*) are reported.

		Site Name	**EWR Site MA1**		**EWR Site NS1**		**EWR Site WM1**		**EWR Site BM1**	
Family	**Common Name**	**Species Name**	**Abun**	***CPUE***	**Abun**	***CPUE***	**Abun**	***CPUE***	**Abun**	***CPUE***
Amphiliidae	Stargazer mountain catfish	*Amphilius uranoscopus*	0	*0.00*	0	*0.00*	1	*1.20*	6	*8.00*
Centrarchidae	Largemouth bass	*Micropterus salmoides*	1	*0.86*	0	*0.00*	0	*0.00*	0	*0.00*
Cichlidae	Mozambique tilapia	*Oreochromis mossambicus*	2	*1.71*	0	*0.00*	0	*0.00*	0	*0.00*
	Southern mouthbrooder	*Pseudocrenilabrus philander*	0	*0.00*	1	*1.20*	0	*0.00*	0	*0.00*
	Banded tilapia	*Tilapia sparrmanii*	0	*0.00*	0	*0.00*	0	*0.00*	3	*4.00*
Clariidae	Sharptooth catfish	*Clarias gariepinus*	0	*0.00*	0	*0.00*	1	*1.20*	0	*0.00*
Cyprinidae	Threespot barb	*Barbus trimaculatus*	0	*0.00*	0	*0.00*	0	*0.00*	1	*1.33*
	Orangefin barb	*Barbus eutaenia*	0	*0.00*	0	*0.00*	0	*0.00*	32	*42.67*
	Longbeard barb	*Barbus unitaeniatus*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*
	Straightfin barb	*Barbus paludinosis*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*
	Bowstripe barb	*Barbus viviparus*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*
	Leaden labeo	*Labeo molybdinus*	0	*0.00*	0	*0.00*	18	*21.60*	0	*21.60*
	Lowveld largescale yellowfish	*Labeobarbus marequensis*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*
	Kwazulu-Natal yellowfish	*Labeobarbus natalensis*	5	*4.29*	0	*0.00*	23	*27.60*	13	*27.60*
	Bushveld smallscale yellowfish	*Labeobarbus polylepis*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*
Gobiidae	Freshwater goby	*Awaous aeneofuscus*	8	*6.86*	0	*0.00*	0	*0.00*	0	*0.00*
	River goby	*Glossogobius callidus*	0	*0.00*	20	*24.00*	0	*0.00*	0	*0.00*
	Tank goby	*Glossogobius giuris*	2	*1.71*	0	*0.00*	0	*0.00*	0	*0.00*
Mochokidae	Penant-tailed suckermouth	*Chiloglanis anoterus*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*
	Phongolo suckermouth	*Chiloglanis emarginatus*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*
Monodactyliidae	Oval moony	*Monodactylus falciformis*	13	*11.14*	0	*0.00*	0	*0.00*	0	*0.00*
Anguiliidae	Anguila mossambica	*Anguila mossambica*	1	*1.7*	0	*0.00*	0	*0.00*	0	*0.00*
		Total	**32**	***26.57***	**21**	***25.20***	**43**	***51.60***	**55**	***101.07***
	Diversity Indices:	*Species Richness (S)*	*7*		*2*		*4*		*5*	
		Shannon-Weiner (H')	*1.47*		*0.19*		*0.87*		*1.13*	
		Species Evenness (E)	*0.82*		*0.28*		*0.63*		*0.70*	

Table 7-24 Results of the fish survey undertaken on the Black Mfolozi, Mkuze Upper Pongola and Assegai Rivers (EWR Sites BM2, MK1, UP1 and AS1 respectively). Results are reported in abundance (Abun.) and CPUE (fish/hr). Species Richness (*S*), Shannon Weiner diversity index (*H’*) and Species Eveness (*E*) are reported together with the totals for all sites.

		Site Name	**EWR Site BM2**		**EWR Site MK1**		**EWR Site UP1**		**EWR Site AS1**		**Total**	
Family	**Common Name**	**Species Name**	**Abun**	***CPUE***	**Abun**	***CPUE***	**Abun**	***CPUE***	**Abun**	***CPUE***	**Abun**	***CPUE***
Amphiliidae	Natal mountain catfish	*Amphilius uranoscopus*	4	*5.11*	0	*0.00*	0	*0.00*	5	*5.00*	**16**	***19.31***
Centrarchidae	Largemouth bass	*Micropterus salmoides*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	**1**	***0.86***
Cichlidae	Mozambique tilapia	*Oreochromis mossambicus*	0	*0.00*	16	*16.00*	0	*0.00*	0	*0.00*	**18**	***17.71***
	Southern mouthbrooder	*Pseudocrenilabrus philander*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	**1**	***1.20***
	Banded tilapia	*Tilapia sparrmanii*	6	*7.66*	0	*0.00*	1	*1.20*	0	*0.00*	**10**	***8.86***
Clariidae	Sharptooth catfish	*Clarias gariepinus*	0	*0.00*	5	*5.00*	0	*0.00*	0	*0.00*	**6**	***7.40***
Cyprinidae	Threespot barb	*Barbus trimaculatus*	18	*22.98*	0	*0.00*	0	*0.00*	1	*1.00*	**20**	***23.98***
	Orangefin barb	*Barbus eutaenia*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	**32**	***42.67***
	Longbeard barb	*Barbus unitaeniatus*	3	*3.83*	0	*0.00*	0	*0.00*	0	*0.00*	**3**	***3.83***
	Straightfin barb	*Barbus paludinosis*	2	*2.55*	14	*14.00*	0	*0.00*	0	*0.00*	**16**	***2.55***
	Bowstripe barb	*Barbus viviparus*	0	*0.00*	31	*31.00*	0	*0.00*	0	*0.00*	**31**	***31.00***
	Leaden labeo	*Labeo molybdinus*	17	*21.70*	0	*0.00*	1	*1.20*	0	*0.00*	**36**	***66.10***
	Lowveld largescale yellowfish	*Labeobarbus marequensis*	0	*0.00*	0	*0.00*	0	*0.00*	9	*9.00*	**9**	***9.00***
	Kwazulu-Natal yellowfish	*Labeobarbus natalensis*	25	*31.91*	0	*0.00*	0	*0.00*	0	*0.00*	**66**	***91.40***
	Bushveld smallscale yellowfish	*Labeobarbus polylepis*	0	*0.00*	0	*0.00*	2	*2.4*	0	*0.00*	**2**	***91.40***
Gobiidae	Freshwater goby	*Awaous aeneofuscus*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	**8**	***6.86***
	River goby	*Glossogobius callidus*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	**20**	***24.00***
	Tank goby	*Glossogobius giuris*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	**2**	***1.71***
Mochokidae	Penant-tailed suckermouth	*Chiloglanis anoterus*	0	*0.00*	0	*0.00*	4	*4.80*	0	*0.00*	**4**	***4.80***
	Phongolo suckermouth	*Chiloglanis emarginatus*	0	*0.00*	0	*0.00*	0	*0.00*	5	*5.00*	**5**	***5.00***
Monodactyliidae	Oval moony	*Monodactylus falciformis*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	**13**	***11.14***
		Total	**75**	***95.74***	**66**	***52.00***	**6**	***7.20***	**20**	***20.00***	**319**	**364.32**
	Diversity Indices:	*Species Richness (S)*	*7*		*4*		*4*		*4*		***S***	***21***
		Shannon-Weiner (H')	*1.53*		*0.89*		*1.21*		*1.20*		***H'***	***0.00***
		Species Evenness (E)	*0.79*		*0.64*		*0.88*		*0.87*		***E***	***0.00***

1.2 fish/hr) (Table 7-24). Penant-tailed suckermouths ranged in size from 30-60 mm TL (Figure 7-24). The banded tilapia was 90 mm TL, the leaden labeo was 199 mm TL and the Bushveld smallscale yellowfish were 41 and 62 mm TL respectively.

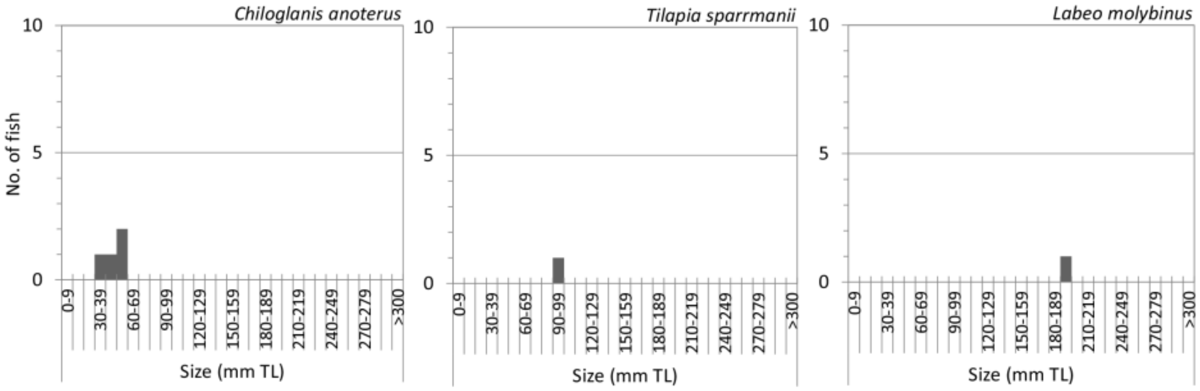


Figure 7-24 Size class frequencies (mm TL) for *C. anoterus*, *T. sparrmanii* and *L. molybdinus* at EWR Site UP1.

7.7.8 EWR Site AS1

Four fish species were collected from EWR Site AS1 on the Assegai River (*H = 1.2; E = 0.87*) (Table 7-24). These included the stargazer catfish (*Amphilius uranoscopus*) (*N = 5, CPUE = 5 fish/hr*) and the Phongolo suckermouth (*Chiloglanis emerginatus*) (*N = 2, CPUE = 2.4 fish/hr*), the lowveld largescale yellowfish (*N = 9, CPUE = 9 fish/hr*) and a single threespot barb (*N = 1, CPUE = 1 fish/hr*) (Table 7-23). Stargazer catfish and Phongolo suckermouths ranged in size from 30-120 mm TL and from 30-60 mm TL respectively. (Figure 7-25), whereas the nine lowveld largescale yellowfish caught were all juvenile (<150 mm TL).

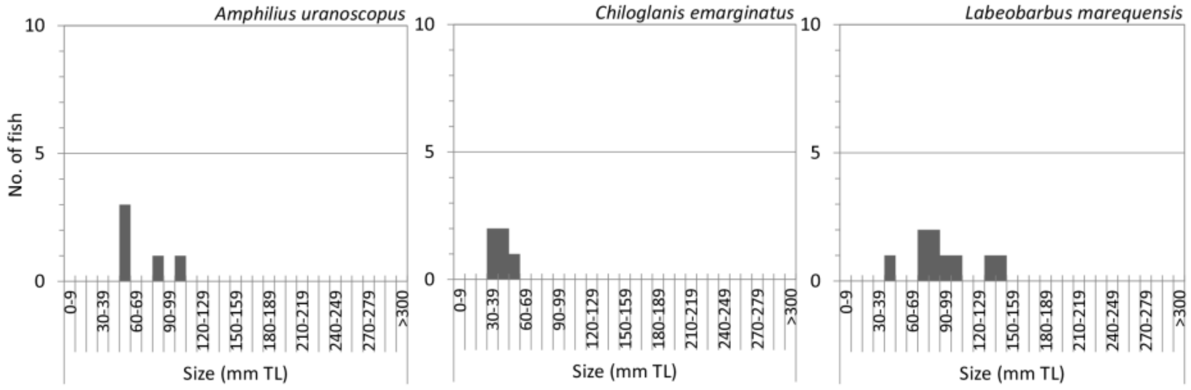


Figure 7-25 Size class frequencies (mm TL) for *A. uranoscopus*, *C. emarginatus* and *L. marequensis* at EWR Site AS1.

7.7.9 Habitat suitability criteria for indicator taxa

Habitat suitability criteria including depth (m), velocity (m.s^{-1}), substratum (classes), flow-depth (classes) and cover types were calculated for indicator taxa collected during the course of the survey using the methods outlined in Sections 7.6 (Figure 7-26). The results of the habitat characterisation for these taxa are presented below. Habitat suitability criteria were pooled for each species across all sites. These habitat criteria were used for inputs to DRIFT when evaluating the response of each species and habitat criterion to flow change.

A. uranoscopus exhibited and narrow depth preference (0.2-0.4 m), a relatively wide velocity preference – but including some of the highest velocities recorded for any species during the course of the survey – and a strong preference for cobble substratum (Figure 7-26 a).

These conditions are typical of cobble-bed riffles for which this species is well adapted. The Flow-Depth classes selected by *A. uranoscopus* is bi-modal with a peak in the Slow-Shallow (SS) habitat class, as well as the faster habitat (FS, FI, FD) classes. This is consistent with the understanding that juveniles select slower, shallower habitats. No particular preference was shown for any particular cover types and any associations are considered spurious.

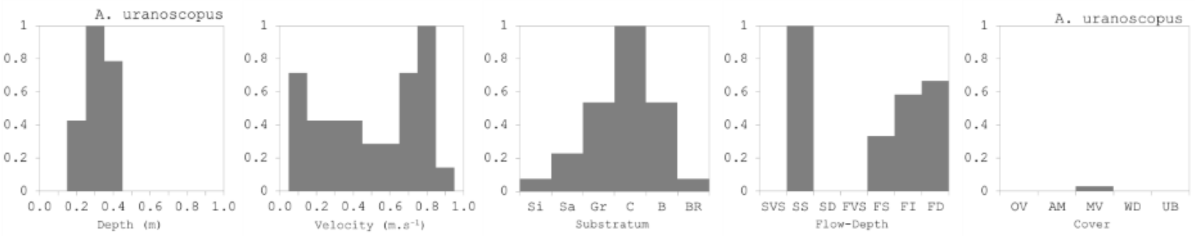
B. eutaenia was found in both shallow (0.2-0.4 m) and depth (>0.6 m) habitats and slower current velocities (<0.2 m.s^{-1}) (Figure 7-26 b). It was found associated with a range of substratum types, but most commonly among boulders and bedrock – although this may reflect the bias towards these conditions at EWR Site BM1 where this species was found.

B. paludinosus was found associated with shallow depths (<0.6 m) and most commonly slower velocities (0.4 m.s^{-1}), although the upper limit of these velocities were higher than those recorded for *B. eutaenia* (Figure 7-26 c). *B. paludinosus* was most commonly associated with a sand substratum – consistent with its preference for marginal vegetation (MV). Flow-Depth classes indicate a preference for Slow-Shallow and Slow-Deep.

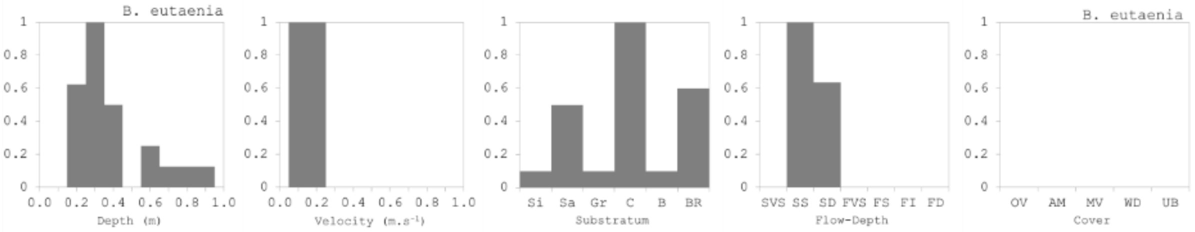
B. trimaculatus was found associated with a range of depths, but most commonly in the deeper areas (>0.4 m)(Figure 7-26 d). It was found over a wider range of velocities than *B. eutaenia* or *B. paludinosus* and most commonly among bedrock or boulder areas. It showed a strong preference for Slow Deep areas, but could be found in most other Flow-Depth classes.

G. callidus occurred most often at moderate velocities (0.2 m.s.$^{-1}$) and very shallow depths (<0.2 m) which was reflected in the Flow-Depth classes where it was found most frequently in Slow-Very-Shallow (SVS), Slow-Shallow (SS) and Fast-Very-Shallow habitats (Figure 7-26 e). A strong association was displayed for sand, gravel and cobble substratum.

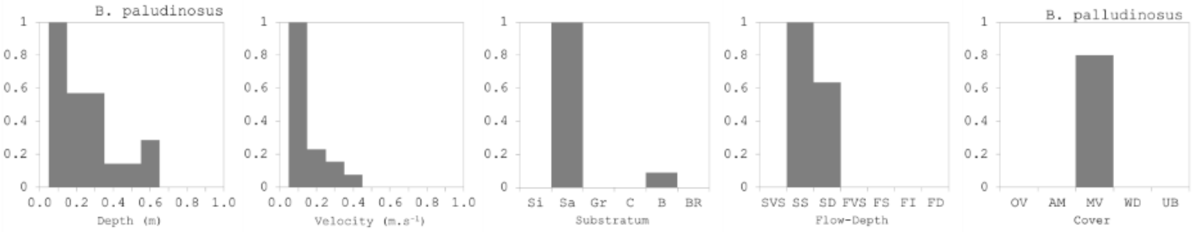
(a) *A. uranoscopus*



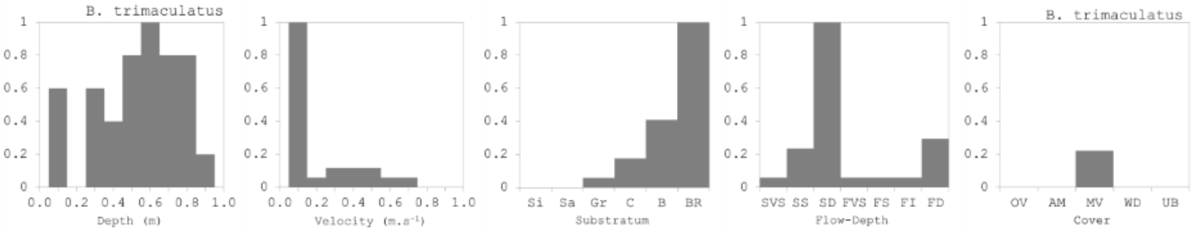
(b) *B. eutaenia*



(c) *B. paludinosus*



(d) *B. trimaculatus*



(e) *G. callidus*

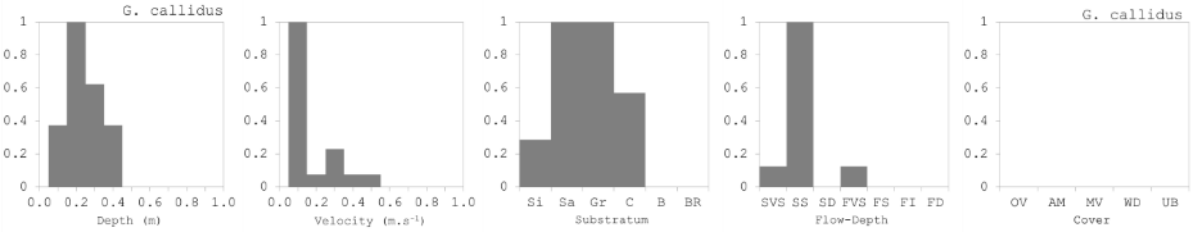
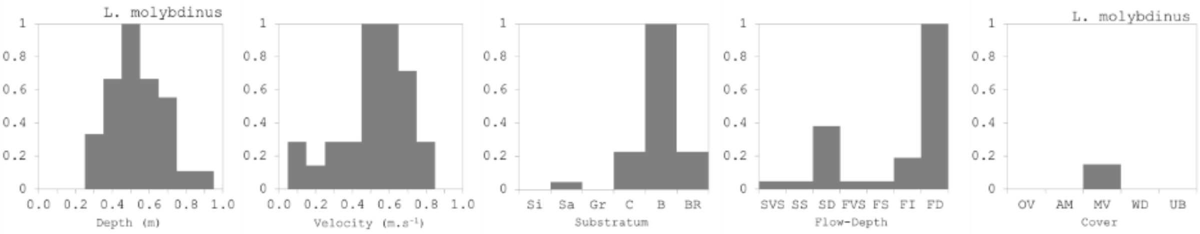


Figure 7-26 Habitat selection by selected indicator species for the Usuthu-Mhlatuze Reserve. Normalised (0-1) frequency charts of habitat selection criteria: Depth (m), Velocity (m.s^{-1}), Substratum (Si = Silt, Sa = Sand, Gr = Gravel, C = Cobble, B = Boulder, BR = Bedrock), Flow-Depth (SVS = Slow Very Shallow, SS = Slow Shallow, SD = Slow Deep, FVS = Fast Very Shallow, FS = Fast Shallow, FI = Fast Intermediate, FD = Fast Deep) and Cover (OV = Overhanging Vegetation, AM = Aquatic Macrophytes, MV = Marginal Vegetation, UB = Undercut Banks).

L. molybdinus was found in moderately deep habitats (0.4 m) with strong flow (0.6-0.8 m.s^{-1}) showing a strong selection of Fast-Deep Flow-Depth classes (Figure 7-26 f). A strong preference for boulder habitat was also evident.

It should be noted at the outset that all the *L. natalensis* caught during the survey were either young-of-the-year or one- or two-year-old juveniles. Thus the habitat described for this species is restricted to these age groups. Juvenile *L. natalensis* showed wide preference for depths ranging between 0.2 to 0.8 m, but were most commonly found in depths over around 0.4 m. Similarly, they inhabited velocity ranges from the slowest (0.1 m.s^{-1}) to the fastest flow (1 m.s^{-1}) and displayed an affinity for boulder cover.

(a) *L. molybdinus*



(b) *L. natalensis*

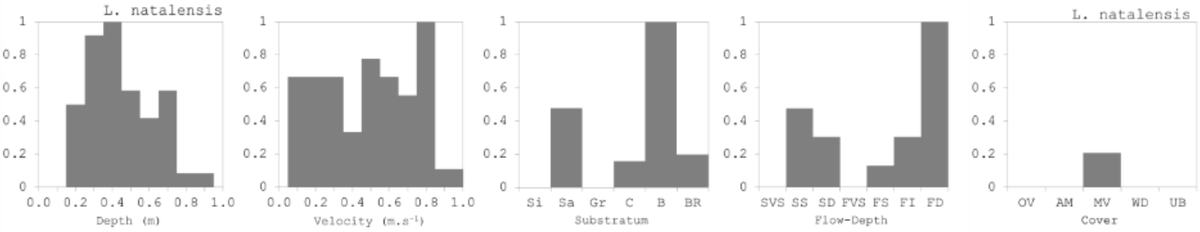


Figure 7-27 Habitat selection by selected indicator species for the Usuthu-Mhlatuze Reserve. Normalised (0-1) frequency charts of habitat selection criteria: Depth (m), Velocity (m.s^{-1}), Substratum (Si = Silt, Sa = Sand, Gr = Gravel, C = Cobble, B = Boulder, BR = Bedrock), Flow-Depth (SVS = Slow Very Shallow, SS = Slow Shallow, SD = Slow Deep, FVS = Fast Very Shallow, FS = Fast Shallow, FI = Fast Intermediate, FD = Fast Deep) and Cover (OV = Overhanging Vegetation, AM = Aquatic Macrophytes, MV = Marginal Vegetation, UB = Undercut Banks).

7.7.10 Expected but not sampled fish species

The total contingent of species collected during the course of the survey (21 species) represented 25 % of the total number of freshwater, or freshwater dependent euryhaline fish species found in the Usuthu-Mhlatuze WMA. The low number of species caught during the course of the survey is attributable to the following factors:

(1) *Gear selectivity*: time constraints limited the sampling gear to electrofishing which limits sampling to wadeable depths (Max 1.5 m). Larger fish in deeper waters are not therefore susceptible to capture.

(2) *Seasonality*: sampling was only undertaken once-off during the low-flow season when temperatures and flow are low. Fish are inactive over this period and seek cover in deeper areas, making them unavailable for capture – the field survey coincided with some of the lowest temperatures recorded for the 2014 winter period over the sub-continent.

(3) *Sites*: none of the EWR sites were located on the Pongola River floodplain where the greatest number of species in the WMA is to be found.

7.8 Identification of Indicators

7.8.1 Indicator list for fish

The motivations for selecting fish guilds and indicators, together with a detailed description of each guild have been provided in Sections 7.3.3 and 7.3.4. A total of twelve fish indicator species were selected for the Usuthu-Mhlatuze WMA (Table 7-25). The indicator list includes species representative of the full range of flow-habitat and physic-chemical conditions in rivers, as well as those species with migratory requirements at different times of the year. A list of guilds with their associated indicator species appears in Table 7-26. No indicator species have been selected for Guild B.3, E.1 and E.2 since the requirements these species are already met through meeting the requirements of the other guilds.

Table 7-25 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Amphilius uranoscopus	Widely distributed through the WMA, juveniles and adults flow sensitive throughout the year, good indicator of benthic riffle habitat quality. Taxonomic/ecological representivity.
Anguilla mossambica	Widely distributed through the lower reaches of rivers throughout the catchment. Present in the upper reaches in lower abundances. High motility. Although it breeds at sea, young elvers require upstream and adults downstream passage during summer high flows. Taxonomic/ecological representivity.
Barbus eutaenia	Widely distributed through the WMA. Representative of the soft-rayed barbs at EWT Site BM1, intermediate between limno- and rheophilic conditions.

Indicator	Reasons for selection as indicator
Barbus paludinosus	Widely distributed through the WMA. Indicative of limnophilic conditions and requiring cover in the form of marginal aquatic/riparian vegetation.
Barbus trimaculatus	Widely distributed through the WMA. Representative of the soft-rayed barbs, intermediate between limno- and rheophilic conditions.
Brycinus lateralis	Sensitive to descending limb of the flood period. Amplitude of flooding. Connectivity between river and floodplain. Inundation of shallow floodplains and floodplain vegetation nursery early life phases. Taxonomic representivity.
Glossogobius callidus	In the lower reaches of the rivers at EWR MA1 and NS1. Indicator of moderate flows and benthic riffle habitat condition. Taxonomic/ecological representivity.
Labeo molybdinus	Widely distributed through the WMA. High motility. Good indicator for Fast Deep flow conditions in riffles and rapids.
Labeobarbus marequensis	Replaces *L. natalensis* as an indicator species at EWR Sites UP1 and AS1. High motility Large rheophilic species, indicator of adequate spring flows, fish passage requirements and riffle habitat quality.
Labeobarbus natalensis	Widely distributed through the WMA. High motility. Large rheophilic species, indicator of adequate spring flows, fish passage requirements and riffle habitat quality.
Oreochromis mossambicus	Widely distributed through the WMA. Generalist species, indicator of increased lentic conditions. Numbers expected to increase under drought scenarios.
Varicorhinus nelspruitensis	Specialist feeding on algae in riffles and rapids. Strong requirement for Fast Deep habitat conditions during all stages of its life cycle and times of the year. Good indicator of riffle and rapid habitat conditions. Only at EWT Sites UP1 and AS1.s

Table 7-26 **The ten fish guilds selected for the EWR assessment (A.1 – E.2) with species and secondary catchment occurrences indicated by shaded cells (light grey = historical record, dark grey = historical record and collected in July 2014). The indicators are indicated with an asterisk and a check box. Where two indicators were used for a guild it was because they have different life history strategies. No indicators were used for A.1 because their requirements are met by A2 indicators.**

	RIVER HABITAT	GUILD	FLOW PREFERENCE	DESCRIPTION	SPECIES	MA1	NS1	WM1	BM1	BM2	MK1	UP1	AS1
A.1	Rhithronic	Riffle	Rheophilic	Small rheophlics with a requirement for substrate and intolerant of no flow	*Amphilius natalensis*					░			░
					*Amphilius uranoscopus**			☑	☑	☑	░	☑	☑
					Chiloglanis anoterus				░			▓	░
					Chiloglanis emarginatus							░	▓
					Chiloglanis paratus							░	
					Chiloglanis swierstrai							░	░
A.2	Rhithronic	Pool	Semi-rheophilic	Small semi-rheophlics with a requirement for substrate and intolerant of no flow	*Barbus argenteus*			░	░	░	░	░	░
					Barbus eutaenia				☑				
					Barbus gurneyi	░							
					Opsaridium peringueyi							░	░
B.1	Potamonic-Lentic	Plesiopotamonic	Limnophilic	Low DO tolerant, floodplain migrants	*Oreochromis mossambicus**	☑	☑	☑	☑	☑	☑	☑	
					Oreochromis placidus						░		
C.1	Potamonic-Lotic	Eupotamonic lithophilic	Rheophilic	Large migratory rheophilics with a requirement for substrate. One or two spawning events per year	*Labeo cylindricus*						░	░	
					*Labeo molybdinus**		▓	☑	☑	☑	░	▓	
					*Labeobarbus marequensis**							☑	☑
					*Labeobarbus natalensis**	☑	☑	☑	☑	☑	☑		
					Labeobarbus polylepis							░	░
					*Varicorhinus nelspruitensis**							☑	☑
C.2		Eupotamonic phytophilic	Rheophilic	Large migratory rheophilics with a requirement for vegetation, obligate flood dependency, floodplain for feeding and nursery	*Labeo rosae*						░	░	░
					Clarias gariepinus	░	▓	░	░	░	▓	░	
					Clarias theodorae		░				░		
C.3		Parapotamonic	Semi-lotic	Intermediate between limno and rheophilic, medium to long migrations, backwaters and slackwaters, most of these require marginal vegetation	*Barbus anoplus*			░	░	░	░	░	░
					Barbus bifrenatus						░		
					Barbus neefi								
					Barbus pallidus			░	░		░	░	░
					Barbus toppini								
					Barbus afrohamiltoni								
					Barbus lineomaculatus			░	░		░	░	
					*Barbus trimaculatus**	░	░	░	▓	☑		☑	☑
					*Brycinus lateralis**			░		░	☑		
					Micralestes acutidens							░	
D.1	Eurytopic	Eupotamonic benthic	Limnophilic	Benthic limnophilics	*Marcusenius macrolepidotus*		░				░	░	

Table 7-26 (cont'd)

	RIVER HABITAT	GUILD	FLOW PREFERENCE	DESCRIPTION	SPECIES	MA1	NS1	WM1	BM1	BM2	MK1	UP1	AS1
D.2		Eupotamonic riparian	Limnophilic	Main channel riparian vegetation, semi-migratory eurytopic	*Tilapia sparrmanii*	░	░	░	▓	▓	░	▓	
					Aplocheilichthys johnstoni						░		
					Aplocheilichthys katangae		░				░		
					Aplocheilichthys myaposae		░				░		
					*Barbus paludinosus**	░ ☑	░ ☑	░		▓	▓ ☑	░	░
					Pseudocrenilabrus philander	░	▓	░	░	░	░		░
					Tilapia rendalli	░	░				░	░	
					Barbus annectens						░		
					Barbus unitaeniatus			░	░	▓		░	
					Barbus viviparus	░	░	░	░	░	▓	░	
E.1	Semi-anadromous estuarine guild	Semi-anadromous estuarine guild	NA	Semi-anadromous estuarine guild	*Awaous aeneofuscus*	▓			░	░	░		
					*Glossogobius callidus**	▓ ☑	▓ ☑	░		░	░		
					Glossogobius giuris	▓				░	░		
					Redigobius dewaali		░				░		
E.2	Catadromous guild	Catadromous guild	NA	Catadromous guild	*Anguilla bengalensis*			░	░				
					Anguilla bicolor		░						
					Anguilla marmorata		░			░			
					*Anguilla mossambica**	▓ ☑	░ ☑		░	░	░	░	

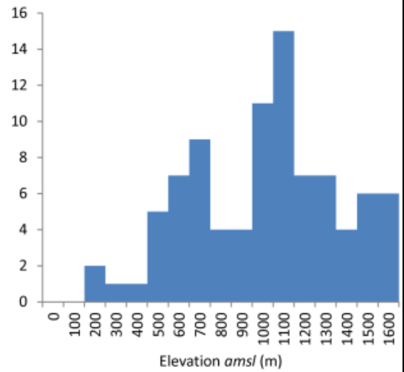
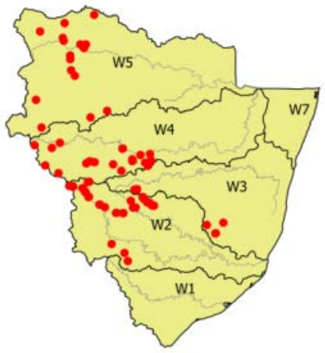
7.8.2 Description and location of indicators

The following tables provide a description of the fish indicators used for the EWR assessment. Distributions and elevations were obtained by overlaying fish distribution records held by the South African Institute for Biodiversity (SAIAB) and the Ezemvelo Kwazulu-Natal Wildlife on 90 × 90 m SRTM Digital Elevations Model (DEM) and querying the GIS with respect to fish species occurrences and associated elevations.

7.8.2.1 Indicator 1: Stargazer mountain catfish *(Amphilius uranoscopus)*

Scientific name:	*Amphilius uranoscopus*
Family:	Amphiliidae
Conservation status:	Least Concern (LC)
Ecological significance:	Regulates benthic invertebrate community structure in riffles and rapids.
Social significance:	Scientific and conservation value
Representative species:	Rhithronic Riffle guild: *Amphilius natalensis, Chiloglanis swierstrai*

Geographic Range

Widespread central, eastern and southern Africa. Upper reaches and tributaries of the Usuthu, Pongola, Mkuze and upper Mfolozi systems. Not found in the Mhlatuze. **Elevation range**: Restricted to upper (rhithronic) reaches, but found lower than *C. anoterus*. Min: 188 *amsl*; Max: 1675 *amsl*; Median: 1007 *amsl*.		

Guild characteristics

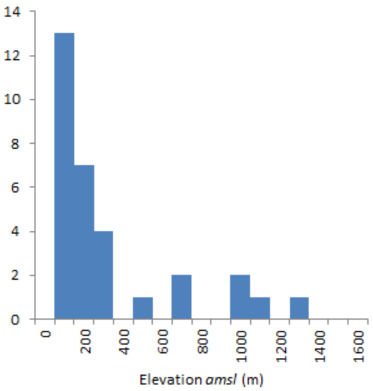
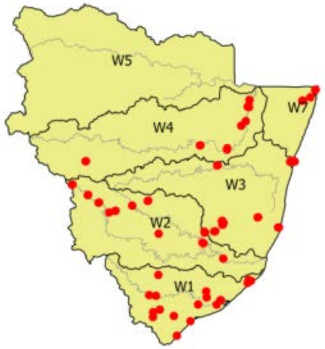
Habitat Guild:	*Rhithronic riffle guild*	Clear, fast-flowing headwater streams, cobble-bed substratum, riffles, rapids. Velocities >0.3 $m.s^{-1}$, Depths <0.3 m.
Feeding Guild:	*Zoobenthivorous*	Nocturnal. Benthic invertebrates
Reproductive Guild:	*A.1.3 Non-guarding, open-substratum benthic lithophils*	Unguarded eggs deposited beneath rocks. Extended breeding season.
Migration:	Local	
Flow related issues:	Sedimentation of cobble-bed riffles, drying of riffles. Turbidity interferes with feeding.	
Population notes:	Population doubling time 1.4-4.4 years. Age = 5 years.	
References	(Crass 1964; Balon 1975; Skelton 2001a; Ngugi et al. 2009; Froese and Pauly 2011; IUCN 2012)	

7.8.2.2 Indicator 2: Longfin eel (*Anguilla mossambica*)

Description

Scientific name:	*Anguilla mossambica*
Family:	Anguillidae
Conservation status:	Least concern
Ecological significance:	Large piscivorous catadromous fish, secondary consumers
Social significance:	Potential fishery
Reason for selection:	Indicator for catadromous guild
Represents:	Catadromous eels: Shortfin eel (*A. bicolor bicolor*), African mottled eel (*Anguilla bengalensis*), Giant mottled eel (*Anguilla marmorata*)

Geographic Range

East coast rivers on African coast from Kenya to Cape Agulhas **Elevation**: Min: 0 *amsl*; Max: 1300 *amsl*; Median: 100 *amsl*. Occur throughout river systems, but mostly at altitudes <300 *amsl*.		

Guild Characteristics

Habitat:	*Catadromous*	Marine and freshwater. Adults found in deep pools with structure (large boulders, woody debris).
Feeding:	*Carnivorous*	Juveniles feed on invertebrates (e.g. blackfly larvae). Adults feed on crabs, frogs and fish.
Reproduction:	*Marine*	Reproduction occurs at sea off the east coast of Madagascar.
Migration	Obligate catadromous species which requires a freshwater phase in its development. Long distance migration – catchment scale >50 km. Adults migrating downstream to breed in the sea and juveniles migrate back into freshwater reaches of rivers. Peak migrations in mid-summer when flows are high.	
Flow-related issues:	Depth >1 m Velocity 0.3-0.5 mud and sand. Substratum requirement. Migratory requirement: juveniles mgrate from estuary during summer at night under high flow conditions. Mature adults return to sea to breed also during high flows.	
Population notes:	Males remain in freshwater 8-10 years, females for 15-20 years. Population doubling time >14 years.	
References	(Skelton 1993; Harris and Cyrus 1997; Bok et al. 2007; Jiang et al. 2010; Froese and Pauly 2011)	

7.8.2.3 Indicator 3: Orangefin barb (*Barbus eutaenia*)

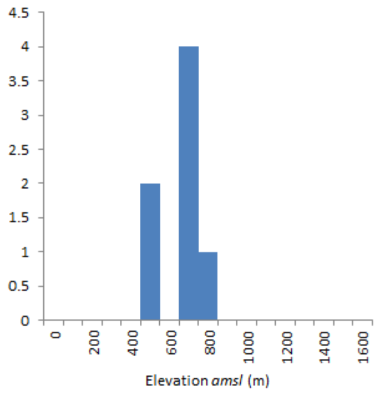
Description

Scientific name:	*Barbus eutaenia*
Family:	Cyprinidae
Conservation status:	Least Concern
Ecological significance:	Prey for piscivorous species
Social significance:	Not known
Reason for selection:	Transitional habitat requirements intermediate between pool and riffle guilds. One of the few barbs with a moderate requirements for flow.
Represents:	Represents small barbs with moderate requirements for flow

Geographic Range

Cunene, Okavango, Zambezi River systems. East coast systems.

Elevation: Min: 500 *amsl*; Max: 800 *amsl*; Median:700 *amsl*.



Guild Characteristics

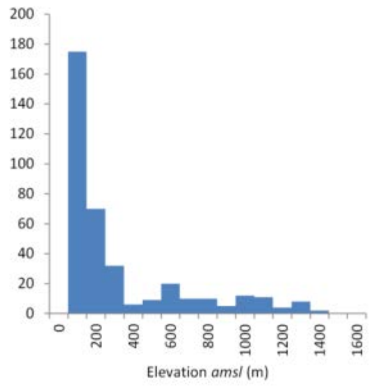
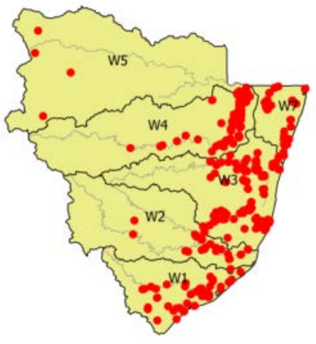
Habitat:	*Rhithronic pool guild*	Rheophilic Moderate flow with rocky habitat, upper reaches.
Feeding:	*Invertivorous*	Feeds on invertebrates
Reproduction:	Not known	Not known
Migration	Moderate requirement for movement between reaches.	
Flow-related issues:	Non-flood dependent multiple spawner. Require moderate flows. Lost from rivers with zero flow for periods of time.	
Population notes:	Population doubling time <15 months	
References	(Skelton 1993; River Health Programme 2006; Golder Associates 2009; Froese and Pauly 2011)	

7.8.2.4 Indicator 4: Straightfin barb (*Barbus paludinosus*)

Description

Scientific name:	*Barbus paludinosus*
Family:	Cyprinidae
Conservation status:	Least Concern
Ecological significance:	Important prey species for larger predators e.g. tigerfish
Social significance:	Bait for tigerfish
Reason for selection:	Flood-independent species, increased proportions may indicate reduced flow. Dependent on marginal vegetation. Abundant throughout catchment.
Represents:	Marginal vegetation community including in the lower reaches *inter alia*: broadstriped barb *(Barbus annectens),* line-spotted barb *(Barbus lineomaculatus),* straightfin barb *(Barbus paludinosus),* east coast barb *(Barbus toppini*)

Geographic Range

Widespread through Africa from Ethiopia south. Lower reaches of Rivers in the Usuthu-Mhlatuze WMA **Elevation**: Min: 2 *amsl*; Max: 1675 *amsl*; Median: 40 *amsl*. Recorded as high as 1600 m, but most populations restricted to altitudes <200 m *amsl*.		

Guild Characteristics

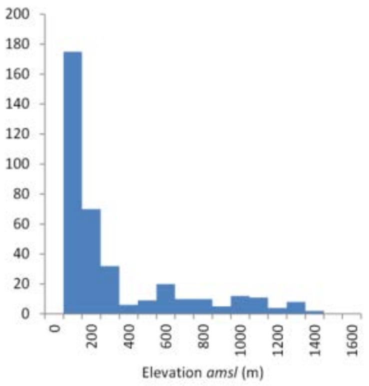
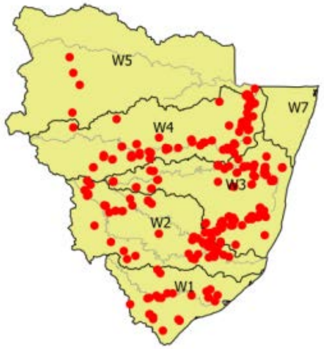
Habitat:	*Potamonic lentic*	Inhabits main channel pools and slackwaters, wide habitat tolerance for slower reaches. Marginal vegetation.
Feeding:	*Facultative omnivore*	Feeds on insects, snails, crustaceans, diatoms, detritus.
Reproduction:	*A.1.1 Open substratum benthic lithophils*	Flood-independent spawner. Two spawning events per year during rainy season (Mar/Apr and Oct/Jan). Spawns in vegetation.
Migration	Low requirement for migration <10 km, over spawning season	
Flow-related issues:	Associated with slow flow classes and deeper waters with vegetation. Sensitive to above average elevated flows. Access to marginal vegetation at all times of the year, but especially over spawning season.	
Population notes:	High fecundity and resilience, population time <15 months	
References	(Skelton 1993; Macuiane et al. 2009; Froese and Pauly 2011)	

7.8.2.5 Indicator 5: Threespot barb *(Barbus trimaculatus)*

Description

Scientific name:	*Barbus trimaculatus*
Family:	Cyprinidae
Conservation status:	Least concern
Ecological significance:	Important prey species for larger predators e.g. tigerfish
Social significance:	Bait for tigerfish
Reason for selection:	Flood-independent species, increased proportions may indicate reduced flow. Abundant throughout catchment.
Represents:	Small barb community inhabiting pools including *inter-alia*: *Barbus viviparus*, *Barbus toppini, Barbs argenteus*

Geographic Range

Widely distributed through the Southern African region, as well as the Usuthu/Pongola systems. **Elevation**: Min: 297 *amsl*; Max: 1400 *amsl*; Median: 100 *amsl*. Although it is a broad elevation distribution it is most frequently found at elevations <400 m.		

Guild Characteristics

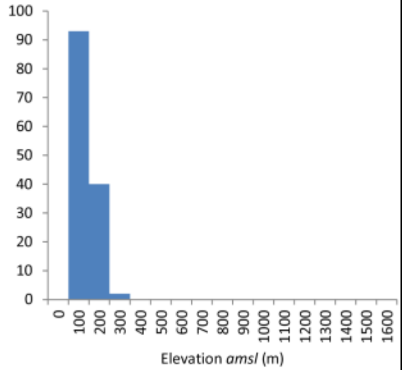
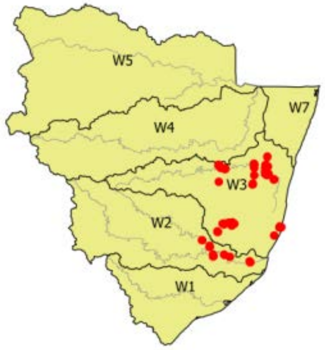
Habitat:	*Potamonic lentic*	Inhabits main channel pools and slackwaters, wide habitat tolerance for slower reaches
Feeding:	*Invertivore*	Feeds on insects and other small organisms
Reproduction:	*A.1.1 Open substratum benthic lithophils*	Flood-independent spawner. Two spawning events per year during rainy season (Mar/Apr and Oct/Jan). Spawns in vegetation.
Migration	Evidence for migration after rains. Oct/Nov and Mar/Apr	
Flow-related issues:	Associated with slow flow classes and deeper waters with vegetation. Sensitive to above average elevated flows. Access to marginal vegetation over spawning season.	
Population notes:	High fecundity. Minimum population doubling time <15 months	
References	(Skelton 1993; Macuiane et al. 2009; Froese and Pauly 2011; Fouché and Heath 2013)	

7.8.2.6 Indicator 6: Striped robber (*Brycinus lateralis*)

Description

Scientific name:	*Brycinus lateralis*
Family:	Characidae
Conservation status:	Least Concern (LC)
Ecological significance:	Prey items for top predators, e.g. tigerfish. Important for aquatic-terrestrial nutrient exchange
Social significance:	Harvested by subsistence fishers
Reason for selection:	Keystone species, availability of published literature
Represents:	Spot-tailed robber *Brycinus imberi,* Silver robber *Micralestes acutidens*

Geographic Range

Abundant and widespread upper Zambezi basin. Lower reaches of the Mkuze and Mfolozi River systems. Not present in Pongola. **Elevation**: Min: 9 *amsl*; Max: 295 *amsl*; Median: 40 *amsl*.		

Guild Characteristics

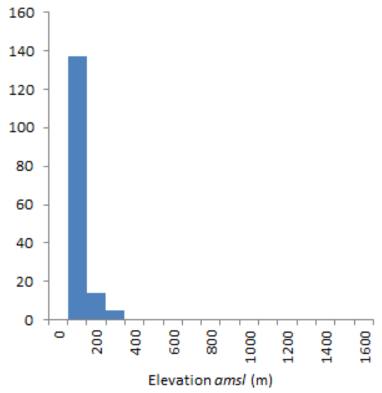
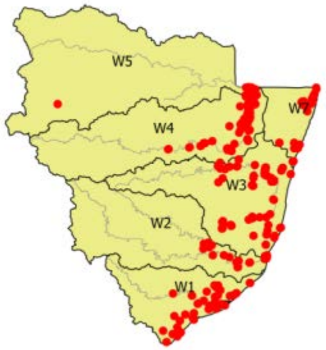
Habitat:	Potamonic – lentic. Plesiopotamonic.	Lower reaches of floodplain rivers. Clear, shallow, slow-flowing, sandy/marshy, well-vegetated. Floodplain channels, pans and lagoons. *B. imberi* migrates onto floodplain lakes after flooding.
Feeding:	*Zooplanktivorous* *Opportunistic*	Open water insectivores. Will take terrestrial insects from the surface.. Prey from a wide spectrum of habitats, but *Daphnia* most important prey item – 'micro-carnivore'. Benefits from increased allochthonous input during floods.
Reproduction:	A.1.6 Non-guarding open substratum benthic psammophil	Protracted 5 month spawning: Oct-Mar (*B. lateralis*). Facultative floodplain-dependent spawners. Increased temperature and photoperiod trigger. Will move onto floodplain over high flow season but spawning not synchronised to flooding.
Migration	Upstream breeding migrations Oct-Nov (high flow) and Mar (low flow) (*M. acutidens*).	
Flow-related issues:	Sensitive to descending limb of the flood period. Amplitude of flooding. Connectivity between river and floodplain. Inundation of shallow floodplains and floodplain vegetation nursery for developmental phases (larvae and juveniles).	
Population notes:	Small size, early maturity (L_{max} 140-190 mm. Maturity = 1 year, 55 mmSL). High population doubling rate.	
References	(Crass 1964; Merron et al. 1993; Booth and McKinlay 2001; Skelton 2001b; Welcomme et al. 2006; Froese and Pauly 2011; Fouché and Heath 2013)	

Indicator 7: River goby (*Glossogobius callidus*)

Description

Scientific name: *Glossogobius callidus*
Family: Gobiidae
Conservation status: Least concern
Ecological significance: Euryhaline species depends on access to freshwater and estuarine habitats.
Social significance: Not known
Reason for selection: Indicator for euryhaline gobies. Feeds in flow-sensitive habitats.
Represents: Euryhaline gobies: tank goby (*Glossogobius giuris*), freshwater goby (*Awaous aeneofuscus*), checked goby (*Redigobius dewaali*)

Geographic Range

East coast rivers of southern Africa from Mozambique to Swartvlei in the Western Cape. **Elevation**: Min: 0 *amsl*; Max: 500 *amsl*; Median: 100 *amsl*.		

Guild Characteristics

Habitat:	*Euryhaline estuarine*	A benthopelagic euryhaline species inhabiting esturies and lower reaches of rivers. During the survey for this study, often found in flowing where it was assumed to be feeding.
Feeding:	*Invertivorous*	Feed on benthic invertebrates in rivers.
Reproduction:	*Estuarine*	Breeds during summer (Oct/Nov). Larval gobiidae form important compontent of the zooplankton of estuaries.
Migration	Movement between estuaries and lower reaches of rivers.	
Flow-related issues:	During the course of this study, found in riffles with moderate velocity where it was assumed to be feeding. Sensitive to reduced flow and hypersalinity in estuaries. Freshwater pulses into estuaries may trigger spawning.	
Population notes:	Not known	
References	(Skelton 1993; Strydom and Neira 2006)	

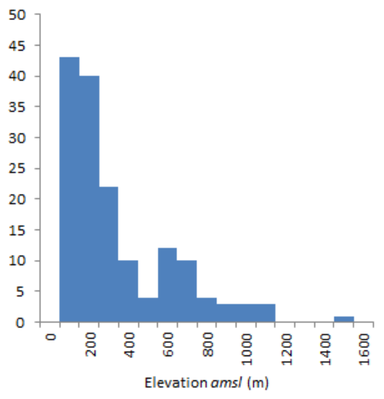
7.8.2.7 Indicator8: Leaden labeo (*Labeo molybdinus*)

Description

Scientific name:	*Labeo molybdinus*
Family:	Cyprinidae
Conservation status:	Least concern
Ecological significance:	Large migratory detritivore
Social significance:	Occasional recreational and subsistence species
Reason for selection:	Large migratory detritivore depends on access to riffles and rapids for feeding. Represents large labeo species
Represents:	Large labeos: purple labeo (*Labeo congoro*), redeye labeo (*Labeo cylindriucs*), rednose labeo (*Labeo rosae*)

Geographic Range

Elevation: Min: 19 *amsl*; Max: 383 *amsl*; Median: 40 *amsl*.



Guild Characteristics

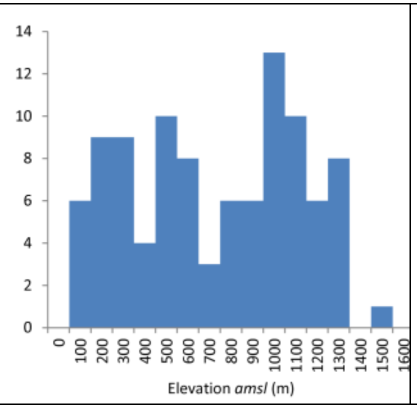
Habitat:	*Eupotamonic lithophilic*	Broad range of habitats: pools and rapids in upland and lowland rivers, as well as impoundments. In this study occurences were stongly associated with fast deep habitats among cobble and boulder. Also occur in flooded pans in lowland rivers and may not be strongly rheophilic.
Feeding:	*Detritivorous*	Specialised feeding on algae and 'aufwachs' on the surfaces of rocks.
Reproduction:	*A.1.3 Non-guarding open substratum benthic spawner*	Reproductive behaviour of this species is not documented, but like other labeos, it is likely to spawn during summer in cobble-bed riffles or inundated vegetation after spates.
Migration	Strong swimmers requiring upstream migrations after the first summer rains (Oct/Nov) to spawn.	
Flow-related issues:	In this study associations were recorded with fast deep habitats among cobbles and boulders. Likely to spawn after flooding in inundated vegetation or cobble riffles.	
Population notes:	Population doubling time 1.4-4.4 years.	
References	(Gaigher 1973; Froese and Pauly 2011; Fouché and Heath 2013)	

7.8.2.8 Indicator 9: Lowveld largescale yellowfish *(Labeobarbus marequensis)*

Description

Scientific name:	*Labeobarbus marequensis*
Family:	Cyprinidae
Conservation status:	Least Concern (LC)
Ecological significance:	Large omnivorous secondary consumers
Social significance:	Important recreational angling species
Representative species:	Eupotamonic lithophilic guild: *Labeo congoro, Labeo cylindricus, Labeobarbus aeneus, Labeobarbus polylepis, Varicorhinus nelspruitensis*
Representative catchments:	Upper reaches – Usuthu, Pongola
Reason for selection:	Represents eupotamonic lithophilic guild. Widely distributed in the Usuthu/Pongola systems. Important recreational angling and subsistence harvested species. Sensitive to reduced flows and sedimentation especially in spawning areas.

Geographic Range

Widely distributed through the middle Zambezi, Limpopo, as well as the Usuthu/Pongola systems. **Elevation**: Broad altitudinal range: Min:35 *amsl*; Max:1409 *amsl*; Median: 716 *amsl*.		

Guild Characteristics

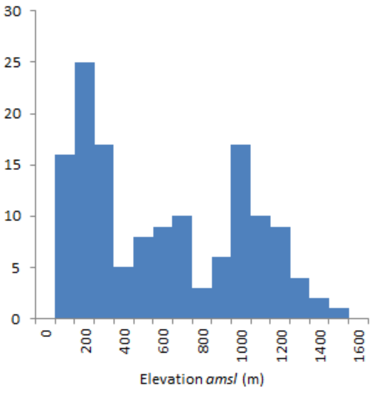
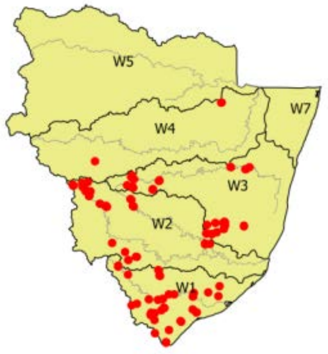
Habitat:	*Eupotamonic lithophilic*	Shows a preference for fast deep and fast shallow habitats, but will occupy pools. Young fish seek hydraulic cover in slow shallow habitats with course substratum.
Feeding:	*Facultative omnivore*	Unspecialised factulative omnivore, mostly plant material, algae and detritus, but will ingest invertebrates.
Reproduction:	*A.1.1 Open substratum benthic spawners - lithophilic*	Flow dependent rock and gravel spawners with benthic larvae, early hatch embryos photophobic, hide in rock crevices. Reproduction correlated with onset of spring flows - ↑ temperature and discharge. Gonadal index Aug-Oct with peaks in Sep. Two spawning events per annum.
Migration	Long distance migration >10 km	
Flow-related issues:	Requires fast flow over cobbles and gravels for spawning. Sufficient depths to migrate over the Transitional period. Requires floods to trigger migration and/or spawning	
Population notes:	Long-lived. High fecundity. Population doubling time 4.5-14 years. L_{max}=700 mmTL	
References	(Merron et al. 1993; Skelton 1993; Fouché 2009)	

7.8.2.10 Indicator 10: Kwazulu-Natal yellowfish *(Labeobarbus natalensis)*

Description

Scientific name:	*Labeobarbus natalensis*
Family:	Cyprinidae
Conservation status:	Least concern
Ecological significance:	Large migratory omnivorous primary consumers
Social significance:	Sought after angling species
Reason for selection:	Flagship yellowfish species requiring access to flow-sensitive habitats over the spawning and juvenile development periods.
Represents:	Only yellowfish species present in Kwazulu-Natal

Geographic Range

Widespread in Kwazulu-Natal from Mkuze River south to the Umtamvuna River. **Elevation**: Min: 100 *amsl*; Max: 1500 *amsl*; Median: 40 *amsl*. Wide altitudinal range with multi-modal occurrences at: 200 m, 700 m and 1000 m.		

Guild Characteristics

Habitat:	*Eupotamonic lithophilic*	Broad range of habitats: pools and rapids in upland and lowland rivers, as well as impoundments. Seek cover from aerial predators.
Feeding:	*Omnivorous*	Algae, detritus invertebrates
Reproduction:	*A.1.3 Non-guarding open substratum benthic spawner*	Breeds in Oct/Nov when temperatures reache 22°C after good rains among algae-free cobble-bed riffles.
Migration	Stongly migratory over the Aug/Sep spawning season – mainly at night – to upstream spawning sites from overwintering sites downstream.	
Flow-related issues:	Flagship yellowfish species requiring access to flow-sensitive habitats over the spawning and juvenile development periods. Requires access to clean cobbles with low embeddedness for successful spawning and recruitment.	
Population notes:	High fecundity (20 000 eggs), males mature 100 mm FL, females at two years (~150 mm FL). Population doubling time 4.5 to 14 years.	
References	(Skelton 1993; Karssing 2008; Froese and Pauly 2011)	

7.8.2.11 Indicator 11: Mozambique tilapia (*Oreochromis mossambicus*)

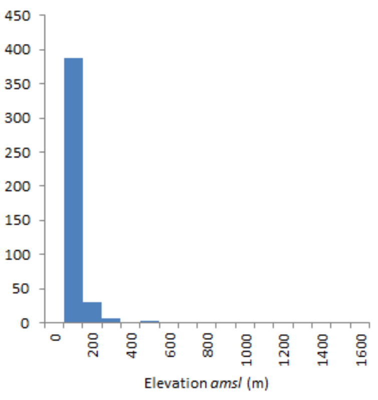
Description

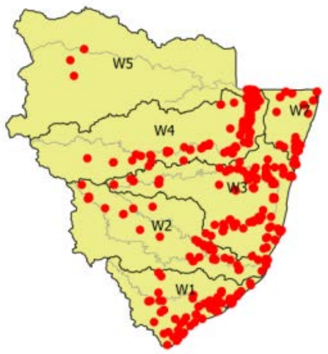
Scientific name:	*Oreochromis mossambicus*
Family:	Cichlidae
Conservation status:	Near threatened (possible hybridization with introduced *O. niloticus*)
Ecological significance:	-
Social significance:	Important subsistence and aquaculture species
Reason for selection:	Flood-independent species, wide tolerance, flexible phenotype – increased relative proportions may indicate reduced flooding. Abundant in the catchment
Represents:	Widely tolerant species: e.g. banded tilapia (*Tilapia sparrmanii*)

Geographic Range

Lower Zambezi River system south to the Bushman's River in the Eastern Cape.

Elevation: Min:2 *amsl*; Max: 1440 *amsl*; Median: 100 *amsl*. Broad range of altitudes between 0 and 1400 m, but most occur below 200 m.





Guild Characteristics

Habitat:	*Eupotamonic riparian guild*	Wide tolerance range for all but the fastest flowing waters. Tolerant of fresh, brackish and marine systems. Lowland rivers and river margins, well-vegetated areas.
Feeding:	*Omnivorous*	Algae, diatoms, detritus, invertebrates.
Reproduction:	*C.1.3 External brooders: mouth brooders*	Flood-independent spawner. Males construct nests on sandy river beds, female mouth broods the eggs. 3-4 batches per season.
Migration	Not dependent on extensive migrations.	
Flow-related issues:	Non-flood dependent multiple spawner. Dominates drought pools.	
Population notes:	Reproduces at a small size (>65 mm TL) in confied conditions. Wide reproductive tolerance and multiple spawning events. Population doubling time 1.4-4.4 years	
References	(Bruton and Boltt 1975; Merron et al. 1993; Skelton 1993; Pollard et al. 1996)	

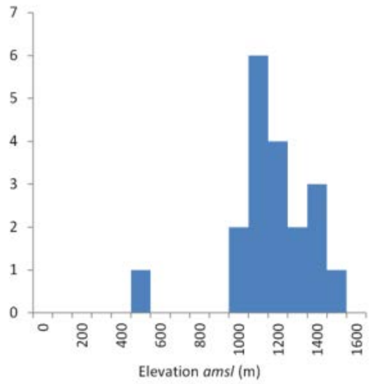
7.8.2.12 Indicator 12: Incomati chiselmouth: (*Varicorhinus nelspruitensis*)

Description

Scientific name:	*Varicorhinus nelspruitensis*
Family:	Cyprinidae
Conservation status:	Near threatened
Ecological significance:	Large schools may control algal biomass on rocks
Social significance:	Occasional angling species
Reason for selection:	Indicator of riffle habitat quality throughout the year. Taxonomic uniqueness, threatened status and sensitivity to flow
Represents:	Only member of this group

Geographic Range

<table>
<tr>
<td>Escarpment rivers of the Incomati and Pongola River systems, South Africa

Elevation: Min: 500 <i>amsl</i>; Max: 1600 <i>amsl</i>; Median: 1100 <i>amsl</i>. Occurs in the upper reaches of the catchments</td>
<td>
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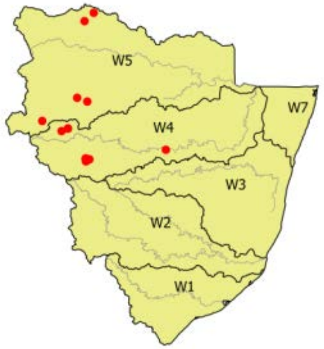
<td>
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Guild Characteristics

Habitat:	*Rhithronic Riffle Guild*	Rocky pools, flowing water. Benthopelagic.
Feeding:	*Benthic algivore/detritivore*	Scrapes aufwachs (algae and detritus) from rocks.
Reproduction:	Not known	Not known
Migration	Believed to undertake migrations over the spawning season.	
Flow-related issues:	Highly dependent on good quality riffle habitat and algal biomass for feeding throughout the year.	
Population notes:	Little available published literature on this species	
References	(Skelton 1993; Froese and Pauly 2011)	

7.8.3 Linked indicators

Table 7-27 Linked indicators and motivation

Indicator	Linked indicator	Motivation
Indicator 1: Stargazer mountain catfish (*Amphilius uranoscopus*)	Nutrients: phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on A. uranoscopus. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible to moderate effect on populations. A. uranoscopus is intolerant of impaired water quality conditions (DWA 2013).
	Summer Water Temp	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). Increasing temperature effects are compounded by concomitant reduced oxygen concentrations. A. uranoscopus inhabits shallow riffles and is vulnerable to acute temperature changes particularly over the spring (T1) when flows are still relatively low and temperature is increasing.
	Chironimidae	Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids) (from Natalensis: Marriott 1997), (Ngugi 2009).
	Beatidae	Reduced beatid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g. to chironimids) (from A. natalensis: Marriott 1997), (Ngugi 2009).
	Dry Season Duration	A. uranoscopus favours faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (from Survey data, Ngugi et al. 2009). A. uranoscopus has protracted spawning period (Aug-Feb) (from A. natalensis: Marriott 1997). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce: the spawning period and annual recruitment and increase the duration of physiological stress and intra-specific competition. An extended Wet Season is expected to benefit A. uranoscopus populations. However Dry Season thresholds of 1.68 and 3.16 m3/s would provide adequate habitat over the extended duration of the season - population declines would therefore be mitigated.
	Wet Season Max Instantaneous Q	Larger floods (>1:5 years: 70 m3/s): Juvenile A. uranoscopus are able to seek hydraulic cover in marginal slackwaters and backwaters and adults seek cover in the benthos. However, feeding and spawning will be interupted.
	Dry-daily ave vol-baseflow	A. uranoscopus favours faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (from EWR Survey data, Ngugi et al. 2009). Reduced availability of these habitat conditions increases physiological stress and intra-specific competition and reduces individual fitness and condition. The proportion of suitable Flow Depth classes in the reach is reduced below the Dry Ave daily Q baseflow of 0.6 m3/s.
	Wet Daily Ave Vol - baseflow	A. uranoscopus favours faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (from EWR Survey data, Ngugi et al. 2009). Reduced availability of these habitat conditions increases physiological stress and intra-specific competition reduces individual fitness and condition. Habitat quality for A. uranoscopus during the Wet Season is not expected to become impaired unless flows fall below the MinPD values (0.8 m3/s). (Q was calculated from Mm3).
	T1 Daily Ave Vol-baseflow	A. uranoscopus favours faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (from EWR Survey data, Ngugi et al. 2009). Reduced availability of these habitat conditions increases physiological stress and intra-specific competition and reduces individual fitness and condition. The proportion of suitable Flow Depth classes in the reach is significantly reduced below the median T1 daily average MinPD baseflow discharge (0.8 m3/s). Reduced flows over T1 will also increase temperature stress. (Q was calculated from Mm3).
	Bed Sediment Conditions	A. uranoscopus is a benthic cobble-bed riffle specialist, living in interstices between bed elements. Increased sedimentation of riffles reduces the total amount and quality of this habitat.

Indicator	Linked indicator	Motivation
Indicator 2: Longfin eel (*Anguilla mossambica*)	Pool depth	O. mossambicus require deep pools >1 m for hydraulic cover and foraging. Reduced pool depth reduces habitat, particularly for large adults.
	Bed sediment conditions	Sufficient hydraulic and predation cover during upstream migration of young elvers. Effects apparent only if there is a severe change from natural, i.e. if all bed sediments are dominated by silt and sand.
	Wet Class 3	A. mossambicus is a catadromous species. Wet season Class 3 intra-annual floods required to trigger upstream summer migration of elvers from estuaries and downstream migration of adults to the sea. Reduced frequency of intra-annual floods expected to reduce passage to and from the sea for this species.
	Wet Class 4	A. mossambicus is a catadromous species. Wet season Class 3 intra-annual floods required to trigger upstream summer migration of elvers from estuaries and downstream migration of adults to the sea. Reduced frequency of intra-annual floods expected to reduce passage to and from the sea for this species.
	Dry daily ave vol baseflow	Continuous flow over the Dry season with maximum depths not < 20 cm to facilitate adult and juvenile movements between habitat units. Effects not expected until discharges fall below 0.1 m3/s (0.01 Mm3/d).
	Wet daily ave vol baseflow	Continuous flow over the Dry season with maximum depths not < 20 cm to facilitate adult and juvenile movements between habitat units. Effects not expected until discharges fall below 0.1 m3/s (0.01 Mm3/d).
Indicator 3: Orangefin barb (*Barbus eutaenia*)	Chironimidae	B. eutaenia is an invertivore (Golder Associates 2009). Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids).
	Baetidae	B. eutaenia is an invertivore (Golder Associates 2009). Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids).
	Dry season duration	B. eutaenia inhabits transitional habitats between riffles and pools and requires well-oxygenated flowing water to maintain fitness and condition (River Health Programme 2006, Golder Associates 2009). An extended dry season would reduce the quality and availability of fast-shallow and fast-intermediate depth-velocity conditions in the river and increase the frequency of no-flow.
	Wet season max instantaneous Q	Increased frequency of larger floods (>1:5 years): juvenile and adult fishare able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.
	Bed sediment conditions	B. eutaenia adults and juveniles use cobbles and boulders for cover (Survey data, (River Health Programme 2006, Golder Associates 2009). Increased sedimentation of riffles and runs reduces the total amount and quality of hydraulic and predation cover for this species.
	Pool depth	B. eutaenia uses pools as cover during periods of low flow and high temperatures (Golder Associates 2009). Pool depth would reduce the available habitat for this species which will translate to increased competition reduced fish condition, growth and survival particularly over the dry season.
	Nutrients phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. B. eutaenia is considered intolerant of impaired water quality conditions (DWA 2013).
	Summer water temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate and oxygen demand (Hellawell 1986). B. eutaenia is more common in the upper reaches of rivers in cooler waters and may be more sensitive to higher temperatures than low (River Health Programme 2006, Golder Associates 2009).
	Dry ave daily vol baseflow	B. eutaenia requires moderate flow conditions, it is considered intolerant of no flow and is lost from rivers with zero flow for periods of time (River Health Programme 2006, Golder Associates 2009). Flow volumes less than medianPD over the dry season will reduce the availability and quality of aquatic habitat, increasing competition and reducing individual fitness and condition.

Indicator	Linked indicator	Motivation
	Wet daily ave vol baseflow	B. eutaenia requires moderate flow conditions, it is considered intolerant of no flow and is lost from rivers with zero flow for periods of time (River Health Programme 2006, Golder Associates 2009). Flow volumes less than medianPD. over the wet season will reduce the availability and quality of aquatic habitat, increasing competition and reducing individual fitness and condition.
Indicator 4: Straightfin barb (*Barbus paludinosus*)	Nutrients: phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. B. paludinosus is tolerant of impaired water quality conditions and its response is expected to be minimal (DWA 2013).
	Summer Water Temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate and oxygen demand (Hellawell 1986). B.paludinosus is more common in the lowlands and may be more sensitive to lower temperatures than high.
	Pool Depth	B. paludinosus is a predominantly limnophilic species, strongly associated with Slow Deep flow classes and pools (Velocities <0.1 m/s) (Survey data, Skelton 1993). A reduction in pool depth would reduce the available habitat for this species.
	Chironimidae	Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids)
	Beatidae	Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids)
	Dry Season Duration	B. paludinosus is a predominantly limnophilic species, strongly associated with Slow Deep (Velocities <0.1 m/s) (Survey data, Skelton 1993). An extended Wet Season (i.e. a shortened Dry Season) would increase the duration of the faster flow classes, reducing the availability of habitat for this species. Conversely B. paludinosus would benefit from a longer dry season.
	Dry Season Min 5D Q	B. paludinosus uses marginal vegetation for hydraulic and predation cover (data from this Survey, Skelton 1993). If dry season flows fall below 0.9 m3/s, the marginal vegetation is not inundated. Reduced cover for adults and juveniles and increased predation pressure. Positive effects are mitigated by increased competition over extended dry season conditions.
	Dry Season Ave Daily Vol-baseflow	B. paludinosus depends on access to marginal vegetation cover. The wetted edge will withdraw from marginal vegetation at discharges <1 m/s increasing vulnerability to predation. Higher than medianPD discharges
	Wet Season Ave Daily Vol-baseflow	B. paludinosus spawns in vegetation (Skelton 1993; Macuiane et al. 2009), reduced inundation of this habitat type will reduce recruitment over the wet season.
	Wet Season Max Instantaneous	Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted and the amount of pool habitat for B. paludinosus will be reduced
	Pool Depth	B. paludinosus is a predominantly limnophilic species, strongly associated with Slow Deep flow classes and pools (Velocities <0.1 m/s) (Survey data, Skelton 1993). A reduction in pool depth would reduce the available habitat for this species.
	Marginal Zone Graminoids	B. paludinosus uses marginal vegetation for hydraulic and predation cover (data from this Survey, Skelton 1993). Large floods remove marginal vegetation and this zone is not indundated by subsequent normal flows. Reduced marginal zone translates to reduced cover for adults and juveniles and increased predation pressure.

Indicator	Linked indicator	Motivation
Indicator 5: Threespot barb (*Barbus trimaculatus*)	Nutrients: phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. B. trimaculatus is tolerant of impaired water quality conditions and its response is expected to be minimal (DWA 2013).
	Summer Water Temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate and oxygen demand (Hellawell 1986). B.trimaculatus is more common in the lowlands and may be more sensitive to lower temperatures than high.
	Chironimidae	Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids).
	Baetidae	Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids)
	Dry Season Duration	B. trimaculatus is a predominantly limnophilic species, strongly associated with Slow Deep (Velocities <0.1 m/s) (Survey data, Skelton 1993). An extended Wet Season (i.e. a shortened Dry Season) would increase the duration of the faster flow classes, reducing the availability of habitat for this species. Conversely B. trimaculatus would benefit from a longer dry season. Positive effects are mitigated by increased competition over extended dry season conditions.
	Dry Season Ave Daily Vol	B. trimaculatus is a predominantly limnophilic species, strongly associated with Slow Deep habitats (Velocities <0.1 m/s) (Survey data, Skelton 1993). High flows will increase velocities and drown out pool habitats in the river reducing habitat quality and fish condition: >7 m3/s Av Pool Vel = 0.4 m/s (Q calculated from Mm3).
	Wet Season Max Instantaneous	Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted and the amount of pool habitat for B. trimaculatus will be reduced which will reduce habitat quality and fish condition.
	Pool Depth	B. trimaculatus is a predominantly limnophilic species, strongly associated with Slow Deep flow classes and pools (Velocities <0.1 m/s) (Survey data, Skelton 1993). A reduction in pool depth would reduce the available habitat for this species which will translate to reduced fish condition.
	Wet Season Ave Daily Vol	B. trimaculatus is a predominantly limnophilic species, strongly associated with Slow Deep habitats (Velocities <0.1 m/s) (Survey data, Skelton 1993). High flows will increase velocities and drown out pool habitats in the river reducing habitat quality and fish condition: >7 m3/s Av Pool Vel = 0.4 m/s. (Q calculated from Mm3).
Indicator 6: Striped robber (*Brycinus lateralis*)	Summer water temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). Lower than medianPD temperatures are likely to delay spawning and slow embryonic development. Higher than medianPD temperatures are likely to promote growth and development to a point where they cause physiological stress to B. paludinosus individuals.
	Channel width	Reduced channel width reduces habitat complexity and the availability of secondary channels and hydraulic cover for B. lateralis.
	Pool depth	B. lateralis is a predominantly limnophilic species, strongly associated with Slow Deep flow classes and pools (Velocities <0.1 m/s) (Skelton 1993). A reduction in pool depth would reduce the available habitat for this species.
	Bed sediment conditions	B. lateralis prefers sand-bed conditions (Skelton 1993). Increased predominance of courser sediments will reduce the suitability of habitat for this species
	Dry season duration	A prolonged dry season would reduce access to secondary channels and floodplain habitats for B.lateralis increasing competition and predation in the main channel.

Indicator	Linked indicator	Motivation
	Wet season max instantaneous Q	Larger floods (>1:5 years) will inundate a greater proportion of floodplain habitats and secondary channels used by B. lateralis for feeding and spawning.
	Wet Class 4	B. lateralis migrates onto floodplains during the wet season for feeding and spawning. Class 4 and 1:2 year floods are required to overtop banks.
	1:2 Class 5	B. lateralis migrates onto floodplains during the wet season for feeding and spawning. Class 4 and 1:2 year floods are required to overtop banks.
	Nutrients phosphates	Phosphates are here used as an indicator of wate quality conditions. B. lateratlis is considered moderately intolerant of impaired water quality conditions (from Brycinus imberi: DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.
	Marginal zone graminoids	B. lateralis favours slow flowing, well vegetated pools (Skelton 1993). The loss of marginal zone graminoids would reduce the availability of predation cover for this species.
	Dry daily ave vol baseflow	B. lateralis depends on access to marginal vegetation cover. The wetted edge will withdraw from marginal vegetation at discharges <1 m/s increasing vulnerability to predation.
	Wet daily ave vol baseflow	B. lateralis depends on access to marginal vegetation cover. The wetted edge will withdraw from marginal vegetation at discharges <1 m/s increasing vulnerability to predation.
Indicator 7: River goby (*Glossogobius callidus*)	Nutrients - phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on G. callidus adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. G. callidus is moderately tolerant of impaired water quality conditions (DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.
	Summer water temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). Increasing temperature effects are compounded by concomitant reduced oxygen concentrations. During surveys, G. callidus was found predominantly in shallow riffles (Survey data) and is vulnerable to acute temperature changes particularly over the spring (T1) when flows are still relatively low and temperature is increasing.
	Bed sediment conditions	G. callidus was found predominantly in shallow riffles, using bed elements for hydraulic cover. Increased sedimentation of riffles reduces the total amount and quality of this habitat - but only if there is a severe change from natural, i.e. if all bed sediments are dominated by silt and sand.
	Baetidae	Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids)
	Chironimidae	Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids)
	Dry daily ave vol baseflow	G. callidus was found feeding in shallow riffles with velocities ranging between 0.1 - 0.5 m/s (median: 0.1 m/s). Their presence in these areas are considered to be primarily a result of foraging rather than physiological requirements - the former accounted for in the invertebrate response curves. Some minor physiological and predation effects may effect survival at lower than Dry medianPD flows. Flows much higher than medianPD with increased velocities may result in greater energetic costs during feeding and reduce individual survival.
	Wet daily ave vol baseflow	G. callidus was found feeding in shallow riffles with velocities ranging between 0.1 - 0.5 m/s (median: 0.1 m/s). Their presence in these areas are considered to be primarily a result of foraging rather than physiological requirements - the former accounted for in the invertebrate response curves. Some minor physiological and predation effects may effect survival at lower than Wet medianPD flows. Flows much higher than medianPD with increased velocities may result in greater energetic costs during feeding and reduce individual survival.

Indicator	Linked indicator	Motivation
Indicator 8: Leaden labeo (*Labeo molybdinus*)	Wet Class 4	L. molybdinus likely spawn between October and February (from L. rosae: Weyl 1999). Intra-annual floods (Class 3 and 4) over the early Wet Season trigger spawning migrations. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.
	Wet Class 3	L. molybdinus likely spawn between October and February (from L. rosae: Weyl 1999). Intra-annual floods (Class 3 and 4) over the early Wet Season trigger spawning migrations. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.
	T1 daily ave vol baseflow	L. molybdinus likely to undertake migration over the spring transitional period (T1) (from L. rosae: Weyl 1999) fish passage, minimum depths. At discharges lower than MinPD fish passage will be constrained by maximum depths.
	Wet daily ave vol baseflow	L. molybdinus likely spawn between October and February in Fast Deep habitats (from L. rosae: Weyl 1999). Reduced wet daily ave baseflow reduces spawning and feeding habitat quality over this period. Higher than Median PD reduces the amount of slow very shallow habitat for larvae and juveniles.
	Wet max instantaneous Q	Larger floods (>1:5 years): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.
	Dry daily ave vol baseflow	L. molybdinus juveniles feed in faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s through the Dry Season (Survey data). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce the availability of this class of habitat and reduce individual growth, fitness and condition.
	Algae	Labeo molyibdinus feed primarily on auwachs and algae. Reduced availability will affect adult fish fecundity and condition. Effects will not be mitigated by an ability fish food sources.
	Summer water temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. molybinus is tolerant of a wide temperature range that enables it to colonise mountain streams and lowland rivers. Adults and juveniles are mobile and will be able to seek out temperature refugia. Reproductive cycles, however, will be affected by temperature changes. L. molbydinus spawns October and April, possibly multiple times. Lower than normal temperatures are likely to delay spawning and slow embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality, lower than normal tempertures would slow development and growth and increase egg and larval mortality.
	Dry season duration	L. molybdinus juveniles feed in faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (Survey data). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce: the spawning period and annual recruitment and increase the duration of physiological stress and intra-specific competition.
	Bed sediment conditions	L. molybinus adults and juveniles occupy cobble and boulder habitat in areas of high flow (Fast Deep) (Survey data). Increased sedimentation of riffles reduces the total amount and quality of this habitat.
	Nutrients phosphates	L. molybinus adults and juveniles occupy cobble and boulder habitat in areas of high flow (Fast Deep) (Survey data). Increased sedimentation of riffles reduces the total amount and quality of this habitat.

Indicator	Linked indicator	Motivation
Indicator 9: Lowveld largescale yellowfish (*Labeobarbus marequensis*)	Nutrients: phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on L. marequensis adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. L. marequensis is moderately tolerant of impaired water quality conditions (DWA 2013).
	Summer Water Temperatures	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. marequensis is tolerant of a wide temperature range that enables it to colonise mountain streams and lowland rivers. Adults and juveniles are mobile and will be able to seek out temperature refugia. Reproductive cycles, however, will be affected by temperature changes. L. marequensis spawns twice a year (September and January) (Fouche 2009). Lower than normal temperatures are likely to delay spawning and slow embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality. Temperatures over the Wet Season are not expected to vary by more than 10% under PD conditions.
	Chironimidae	Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Larval and juvenile L. marequensis are expected to be affected since invertebrates form an important component of the diet of younger age classes (Fouche 2009). Effects will be mitigated to a large degree by ability to switch prey species.
	Baetidae	Reduced beatid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by switching prey species (e.g. to chironimids) (from A. natalensis: Marriott 1997), (Ngugi 2009). Population growth is constrained by absolute availability of riffle habitat and density-dependent factors beyond a certain point of increased prey density.
	Dry Season Duration	L. marequensis spawns and feeds in faster Flow Depth classes (FS, FI, FD). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce the Wet Season duration and therefore the spawning period. An extended Wet Season is not expected to benefit L. marequensis populations. However Dry Season thresholds of 1.68 and 3.16 m3/s would provide suitable habitat for spawning over the duration of the extended Dry Season - population declines would therefore be mitigated.
	Wet Season onset	L. marequensis spawning is timed to coincide with increased temperatures during in September (weeks: 36-40), just before the median Wet Season onset (week 45). Delayed onset by 7 weeks would result in sub-optimal hydraulic conditions at the spawning sites. The effect would be mitigated by the fact that Dry Season thresholds of 1.68 and 3.16 m3/s would provide suitable habitat for spawning even if Wet Season onset was delayed.
	Wet Class 3	L. marequensis spawn twice a year (September and January) (Fouche 2009). Intra-annual floods over the early Wet Season trigger spawning migrations. L. marequensis migrations peak in September and October (Fouche 2013). Too many floods may wash larvae from nursery habitat.
	Wet Class 4	Two spawning events per year (September and January) (Fouche 2009). Intra-annual floods over the early Wet Season trigger spawning migrations. L. marequensis migrations peak in September and October (Fouche 2013).Two spawning events per year (September and January) (Fouche 2009). Small intra-annual floods later in the Wet Season may trigger a second spawning event. L. marequensis migrations peak in September and October (Fouche 2013).
	Wet Season Max instantaneous	Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.
	Dry Daily ave vol-baseflow	Through the Dry Season, Juvenile L. marequensis are rheophilic and feed in FS, FI and FD Flow Depth classes (EWR survey data, Fouche 2009). However, it is assumed that their presence here is a consequence of their feeding rather than physiological requirements - these requirements are already accounted for through links to macro-invertebrate indacors. Some fish passage and dispersal by juveniles between pools is required. At discharges <0.6 m3/s fish passage will be constrained by maximum depths <0.3 m.
	Wet Daily Ave Vol - baseflow	South African yellwofishes are known to select faster Flow Depth classes (FS, FI, FD) and higher velocities for spawning (Fouche 2009, Paxton and King 2009, O'Brien and de Villiers 2011). Reduced availability of these habitat conditions impair water flow around eggs in spawning gravels and increase embryo mortality. The proportion of suitable Flow Depth classes in the reach is reduced below the median MinPD Wet-daily average

Indicator	Linked indicator	Motivation
		baseflow discharge (0.8 m3/s). Increases over this value will improve spawning habitat to a point where Slow Shallow habitat for larval and early juvenile life stages become limiting (Q calculated from Mm3).
	T1-Daily Ave Vol baseflow	L. marequensis undertakes migration over the spring transitional period (T1) (Fouche 2009) fish passage, minimum depths. At discharges <0.4 m3/s (0.04 Mm3) fish passage will be constrained by maximum depths <0.3 m (Q calculated from Mm3)
	Bed Sediment Conditions	L. marequensis is a benthic rheophilic spawner and depends on good quality cobble-bed riffles for successful recruitment. Increased sedimentation of riffles reduces the total amount and quality of this habitat.
	Algae	Algae form an important component of the diet of L. marequensis (Fouche 2009). Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources.
	Marginal Tree Zones	Large South African yellowfishes use woody debris for adult and juvenile predation and hydraulic cover. Loss of woody debris and root wads would marginally increase predation. Effects will be mitigated by being able to utilise bank structure or boulders for cover.
Indicator 10: Kwazulu-Natal yellowfish (*Labeobarbus natalensis*)	Nutrients phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on L. natalensis adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. L. natalensis s is moderately tolerant of impaired water quality conditions (DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.
	Summer water temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. marequensis is tolerant of a wide temperature range that enables it to colonise mountain streams and lowland rivers. Adults and juveniles are mobile and will be able to seek out temperature refugia. Reproductive cycles, however, will be affected by temperature changes. L. marequensis spawns twice a year (September and January) (Fouche 2009). Lower than normal temperatures are likely to delay spawning and slow embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality. Temperatures over the Wet Season are not expected to vary by more than 10% under PD conditions.
	Bed sediment conditions	L. natalensis is a benthic rheophilic spawner and depends on good quality cobble-bed riffles for successful recruitment. Increased sedimentation of riffles reduces the total amount and quality of this habitat increasing embronyic and larval mortality.
	Algae	Algae form an important component of the diet of L. natalensis. Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources (e.g. to invertebrates).
	Marginal zone trees	Large South African yellowfishes use woody debris for adult and juvenile predation and hydraulic cover. Loss of woody debris and root wads would marginally increase predation. Effects will be mitigated by being able to utilise bank structure or boulders for cover.
	Dry season duration	L. natalensis juveniles feed in faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s over the dry season (Survey data; Karssing 2008). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce: the spawning period and annual recruitment and increase the duration of physiological stress and intra-specific competition over the dry season.
	Wet season onset	L. marequensis spawning is timed to coincide with increased temperatures during in September (weeks: 36-40), just before the median Wet Season onset (week 45). Delayed onset by 7 weeks would result in sub-optimal hydraulic conditions at the spawning sites. The effect would be mitigated by the fact that Dry Season thresholds of 1.68 and 3.16 m3/s would provide suitable habitat for spawning even if Wet Season onset was delayed.
	Wet season max instantaneous Q	Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.
	T1 Class1	Intra-annual floods (Class 1 or Class 2) over the early Wet Season (Sep/Oct) trigger spawning migrations. Minor reductions in recruitment success if migrations are delayed.

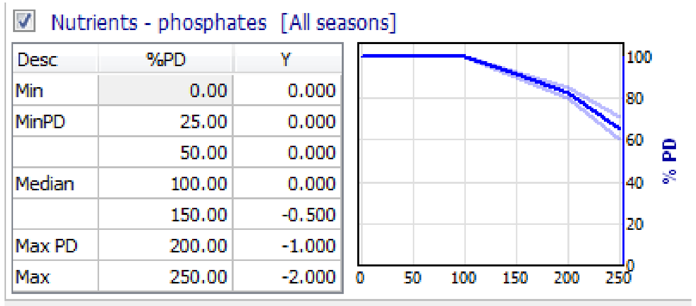
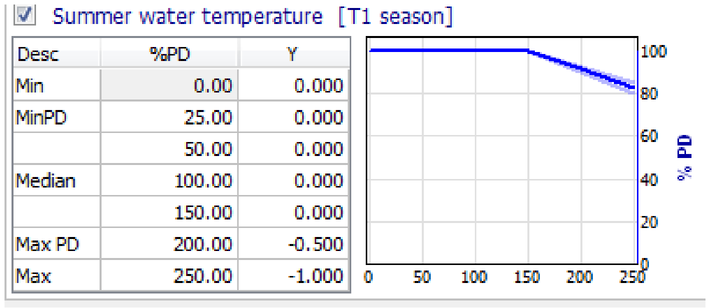
Indicator	Linked indicator	Motivation
	T1 Class 2	Intra-annual floods (Class 1 or Class 2) over the early Wet Season (Sep/Oct) trigger spawning migrations. Minor reductions in recruitment success if migrations are delayed.
	Wet Class 3	L. natalensis spawn between October and April, possibly on multiple occassions (Karssing 2008, Bell-Cross and Minshull 1998). Intra-annual floods over the early Wet Season trigger spawning migrations. L. natalensis migrations peak in September and October. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.
	Wet Class 4	L. natalensis spawn between October and April, possibly on multiple occasions (Karssing 2008, Bell-Cross and Minshull 1998). Intra-annual floods over the early Wet Season trigger spawning migrations. Small intra-annual floods later in the Wet Season may trigger a second spawning event. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.
	Baetidae	Reduced beatid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by switching prey species (e.g. to chironimids) (from A. natalensis: Marriott 1997), (Ngugi 2009). Population growth is constrained by absolute availability of riffle habitat and density-dependent factors beyond a certain point of increased prey density.
	Chironimidae	Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Larval and juvenile L. marequensis are expected to be affected since invertebrates form an important component of the diet of younger age classes (Fouche 2009). Effects will be mitigated to a large degree by ability to switch prey species.
	Dry daily ave vol baseflow	Through the Dry Season, juvenile L. natalensis are rheophilic and feed in FS, FI and FD Flow Depth classes (EWR survey data). However, it is assumed that their presence here is a consequence of their feeding rather than physiological requirements - these requirements are already accounted for through links to macro-invertebrate indacors. Some fish passage and dispersal by juveniles between pools is required.
	Wet daily ave vol baseflow	South African yellwofishes are known to select faster Flow Depth classes (FS, FI, FD) and higher velocities for spawning (Karrsing 2008, Paxton and King 2009, O'Brien and de Villiers 2011). Reduced availability of these habitat conditions impair water flow around eggs in spawning gravels and increase embryo and larval mortality. The proportion of suitable Flow Depth classes in the reach is reduced below the median MinPD Wet-daily average baseflow discharge (0.6 m3/s). Increases over this value are at NS1 not expected to be limiting, but will benefit L. natalensis.
	T1 daily ave vol baseflow	L. natalensis undertakes migration over the spring transitional period (T1) Karrsing 2009). Fish passage is required. At discharges <0.4 m3/s fish passage will be constrained by maximum depths <0.3 m (Q calculated from Mm3).
Indicator 11: Mozambique tilapia (*Oreochromis mossambicus*)	Nutrients phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible to moderate effect on populations. However, O. mossambicus is very tolerant of impaired water quality conditions, negative response will be minor (DWA 2013).
	Algae	Algae form an important component of the diet of O. mossambicus. Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources.
	Marginal zone graminoids	Juvenile and adult O. mossambicus make use of marginal zone vegetation for hydrualic and predation cover. Reduced availablity of this type of cover will increase predation and hydraulic stress on individuals.
	Dry season duration	O. mossambicus favours slower Flow-Depth Classes and tolerates longer dry seasons. Numbers increase in pools over the dry season (Merron 1993). Minor negative response to a curtailed dry season expected, but a flexible life history strategy means that responses will not be as pronounced.
	Wet season max instantaneous Q	O. mossambicus males construct nests in slower flowing areas on sandy beds (Skelton 1993). Larger floods (>1:5 years) disrupt nests and reduce recruitment.
	Dry ave vol baseflow	O. mossambicus favours slow flow classes, the reduced availability of these at base flows over the MedianPD levels for the Dry Season (5 m3/s) would increase hydraulic stress on inividuals and negatively impact their growth and survival.

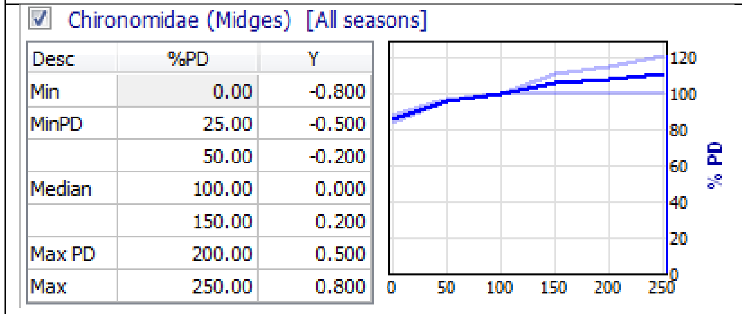
Indicator	Linked indicator	Motivation
	Wet ave vol baseflow	O. mossambicus favours slow flow classes, the reduced availability of these at base flows over the MedianPD levels for the Wet Season (10 m3/s) would increase hydraulic stress on inividuals and negatively impact their growth and survival.
Indicator 12: Incomati chiselmouth (*Varicorhinus nelspruitensis*)	Nutrients: phosphates	Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on V. nelspruitensis adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. V. nelspruitensis is considered moderately intolerant of impaired water quality conditions (DWA 2013).
	Summer Water Temperature	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. marequensis is tolerant of a wide temperature range that enables it to colonise mountain streams and lowland rivers. Adults and juveniles are mobile and will be able to seek out temperature refugia. Reproductive cycles, however, will be affected by temperature changes. Lower than normal temperatures are likely to delay spawning and slow embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality. Temperatures over the Wet Season are not expected to vary by more than 10% under PD conditions. Temperature requirements inferred on the basis of L. marequensis requirements.
	Dry Season Duration	V. nelspruitensis permanently occupies and feeds in fast Flow Depth classes (FS, FI, FD). Limited availability of optimal habitat conditions under extended Dry Season conditions is expected to increase intra-specific competition and reduce fish growth and condition. Conversely, an extended Wet Season is expected to benefit V. nelspruitensis populations. However Dry Season thresholds of 1.68 and 3.16 m3/s would provide suitable habitat for spawning over the duration of the extended Dry Season - population declines would therefore be mitigated.
	Wet Class 3	Intra-annual floods over the early Wet Season trigger spawning and migration. V. nelspruitensis populations assumed to spawn and migrate at the same time as L. marequensis (September and October: Fouche 2013). Too many floods may wash larvae from nursery habitat.
	Wet Class 4	Intra-annual floods over the early Wet Season trigger spawning migrations. V. nelspruitensis populations assumed to spawn and migrate at the same time as L. marequensis (September and October: Fouche 2013). Too many floods may wash larvae from nursery habitat.
	Wet Season Max Instantaneous	Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.
	Dry Min 5D Q - baseflow	V. nelspruitensis favours faster Flow Depth classes (FS, FI, FD) (N.Kleynhans pers. comm.). Reduced availability of these habitat conditions increases physiological stress and intra-specific competition reduces individual fitness and condition. The proportion of suitable Flow Depth classes in the reach is significantly reduced below the median Dry-Min 5d Q baseflow (0.86 m3/s). Baseflows 1 m3/s will benefit V. nelspruitensis populations.
	Bed sediment conditions	V. nelspruitensis is a benthic rheophilic spawner and depends on good quality cobble-bed riffles for successful recruitment (N. Kleynhans pers. comm.). Increased sedimentation of riffles reduces the total amount and quality of this habitat.
	Algae	Algae in the form of aufwuchs form an important component of the diet of L. marequensis (N. Kleynhans pers. comm.). Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources.

7.9 Motivations for Response Curves

Response curves provided below and those in the DSS MAY differ very slightly as a result of final calibration, but the overall shape and reasoning remains the same.

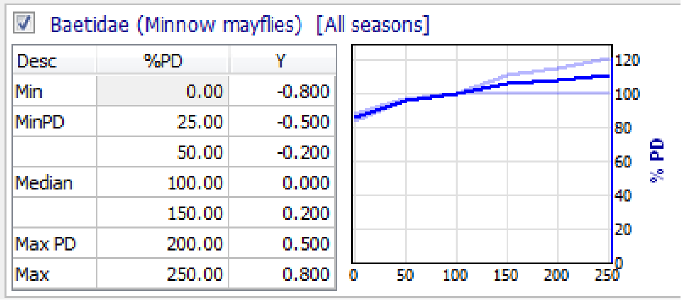
7.9.1 Indicator 1: Stargazer mountain catfish

<table>
<tr><td colspan="3">A. uranoscopus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Nutrients - phosphates [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-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>A. uranoscopus is intolerant of impaired water quality conditions (DWA 2013). Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which causes physiological stress on A. uranoscopus. Some of these nutrients may be bound to sediments which would mitigate negative impacts. Any value over current median values are expected to have a negligible to moderate effect on A. uranoscopus populations.</td><td>Medium</td></tr>
<tr><td>
☑ Summer water temperature [T1 season]
<table>
<tr><th>Desc</th><th>%PD</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>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>
</table>
</td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). Increasing temperature effects are compounded by concomitant reduced oxygen concentrations. A. uranoscopus inhabits shallow riffles and is vulnerable to acute temperature changes particularly over the spring (T1) when flows are still relatively low and temperature is increasing.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">A. uranoscopus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


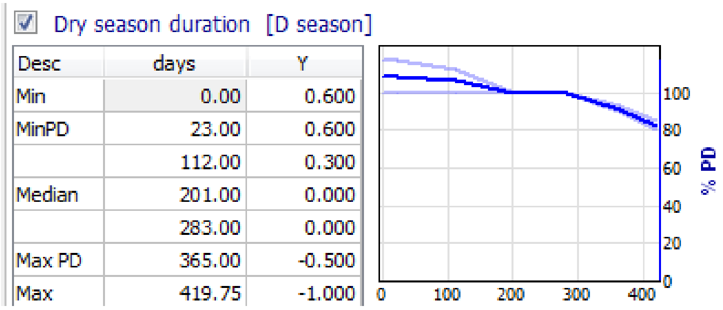
☑ Chironomidae (Midges) [All seasons]

<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.800</td></tr>
</table>

</td><td>Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids) (from Natalensis: Marriott 1997), (Ngugi 2009).</td><td>Medium</td></tr>
<tr><td>


☑ Baetidae (Minnow mayflies) [All seasons]

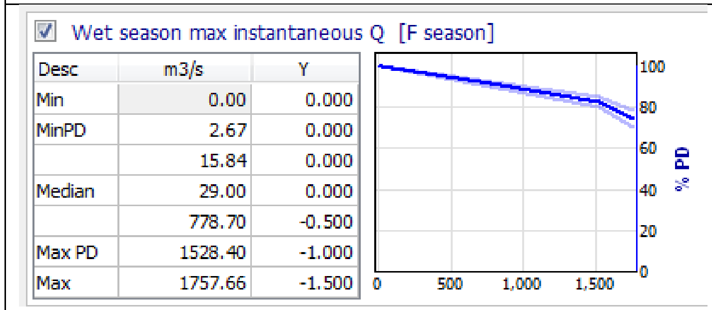
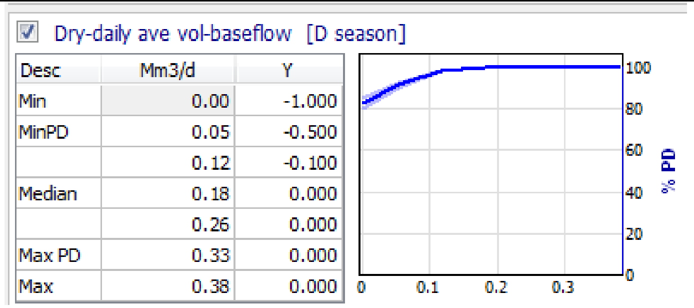
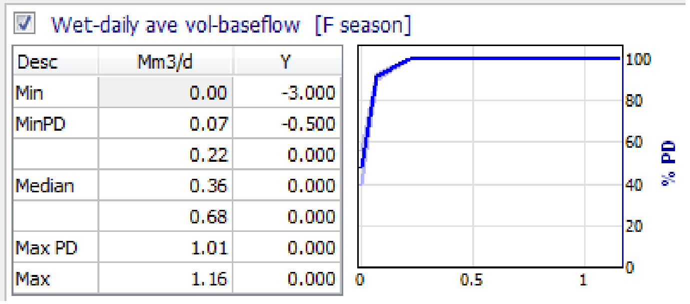
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.800</td></tr>
</table>

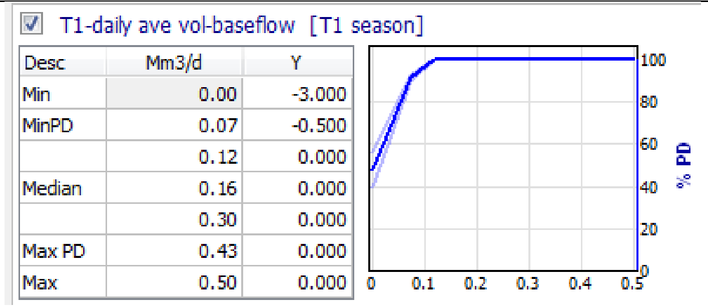
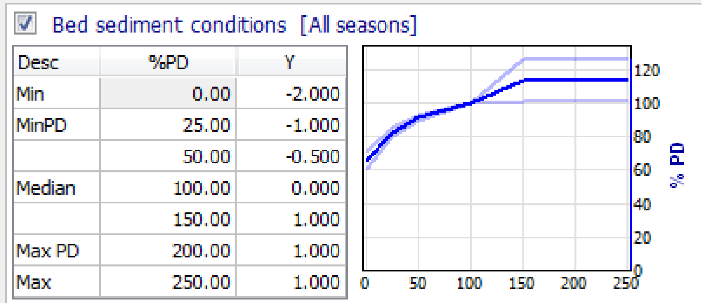
</td><td>Reduced beatid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g. to chironimids) (from A. natalensis: Marriott 1997), (Ngugi 2009).</td><td>Medium</td></tr>
<tr><td>


☑ Dry season duration [D season]

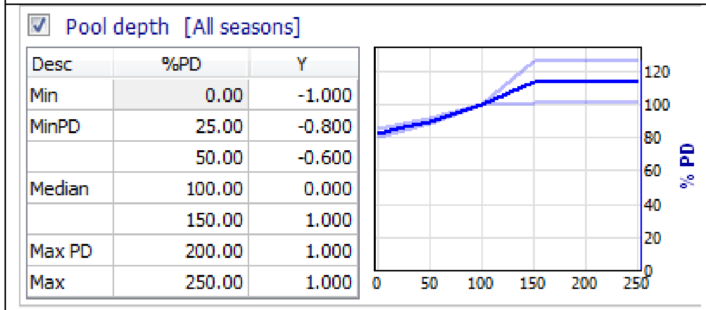
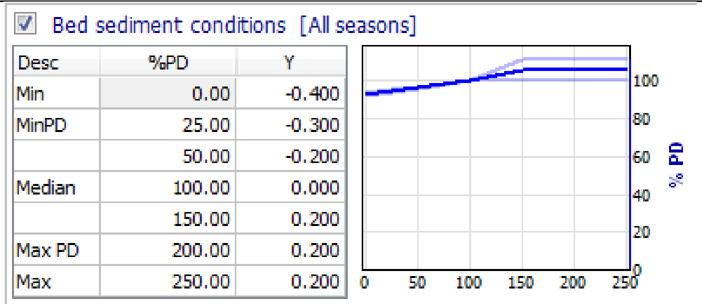
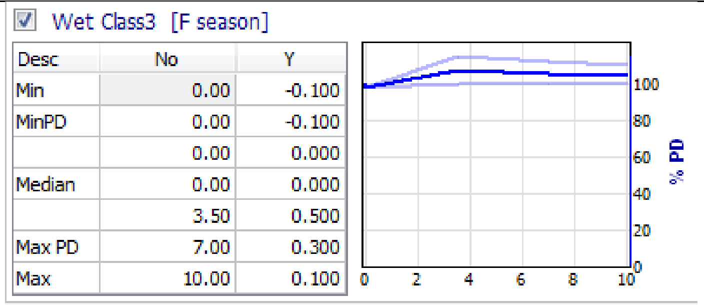
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.600</td></tr>
<tr><td>MinPD</td><td>23.00</td><td>0.600</td></tr>
<tr><td></td><td>112.00</td><td>0.300</td></tr>
<tr><td>Median</td><td>201.00</td><td>0.000</td></tr>
<tr><td></td><td>283.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.000</td></tr>
</table>

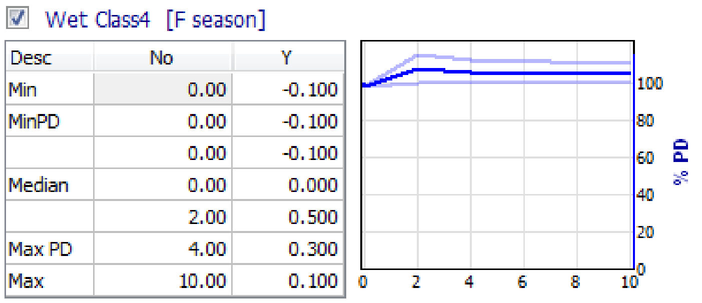
</td><td>A. uranoscopus favours faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s Survey data, Ngugi et al. 2009). A. uranoscopus has protracted spawning period (Aug-Feb) (from A. natalensis: Marriott 1997). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce: the spawning period and annual recruitment and increase the duration of physiological stress and intra-specific competition. An extended Wet Season is expected to benefit A. uranoscopus populations. However Dry Season thresholds of 1.68 and 3.16 m3/s at this site would provide adequate habitat</td><td>High</td></tr>
</table>

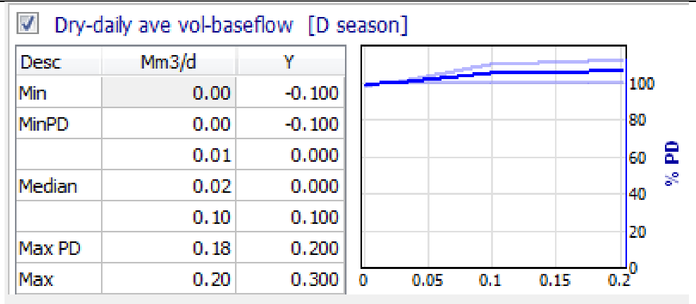
<table>
<tr><th colspan="3">A. uranoscopus</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td></td><td>over the extended duration of the season - population declines would therefore be mitigated.</td><td></td></tr>
<tr><td>
☑ Wet season max instantaneous Q [F season]
<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>2.67</td><td>0.000</td></tr>
<tr><td></td><td>15.84</td><td>0.000</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>778.70</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>1528.40</td><td>-1.000</td></tr>
<tr><td>Max</td><td>1757.66</td><td>-1.500</td></tr>
</table>
</td><td>Larger floods (>1:5 years: 70 m3/s): Juvenile A. uranoscopus are able to seek hydraulic cover in marginal slackwaters and backwaters and adults seek cover in the benthos. However, feeding and spawning will be interupted.</td><td>Medium</td></tr>
<tr><td>
☑ Dry-daily ave vol-baseflow [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>0.05</td><td>-0.500</td></tr>
<tr><td></td><td>0.12</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.18</td><td>0.000</td></tr>
<tr><td></td><td>0.26</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.33</td><td>0.000</td></tr>
<tr><td>Max</td><td>0.38</td><td>0.000</td></tr>
</table>
</td><td>A. uranoscopus permanently inhabits faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (EWR Survey data, Ngugi et al. 2009). Reduced availability of these habitat conditions increases physiological stress and intra-specific competition and reduces individual fitness and condition. The proportion of suitable Flow Depth classes in the reach is reduced below the Dry Ave daily Volume baseflow of 1.5 m3/s.</td><td>High</td></tr>
<tr><td>
☑ Wet-daily ave vol-baseflow [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>0.07</td><td>-0.500</td></tr>
<tr><td></td><td>0.22</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.36</td><td>0.000</td></tr>
<tr><td></td><td>0.68</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.01</td><td>0.000</td></tr>
<tr><td>Max</td><td>1.16</td><td>0.000</td></tr>
</table>
</td><td>A. uranoscopus favours faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (from EWR Survey data, Ngugi et al. 2009). Reduced availability of these habitat conditions</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="3">A. uranoscopus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ T1-daily ave vol-baseflow [T1 season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>0.07</td><td>-0.500</td></tr>
<tr><td></td><td>0.12</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.16</td><td>0.000</td></tr>
<tr><td></td><td>0.30</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.43</td><td>0.000</td></tr>
<tr><td>Max</td><td>0.50</td><td>0.000</td></tr>
</table>
</td><td>A. uranoscopus favours faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (from EWR Survey data, Ngugi et al. 2009). Reduced availability of these habitat conditions</td><td>High</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>1.000</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>
</table>
</td><td>A. uranoscopus is a benthic cobble-bed riffle specialist, living in interstices between bed elements. Increased sedimentation of riffles reduces the total amount and quality of this habitat.</td><td>High</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Clarkson, R.W. and Childs, M.R. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia, 2000: 402-412.
Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London.
Marriott, M.S.; Booth, A.J. and Skelton, P.H. 1997. Reproductive and feeding biology of the Natal mountain catfish, Amphilius natalensis (Siluriformes: Amphiliidae). Environmental Biology of Fishes, 49: 461-470.
Ngugi, C.C.; Manyala, J.O.; Njiru, M. and Mlewa, C.M. 2009. Some aspects of the biology of the stargazer mountain catfish, Amphilius uranoscopus (Pfeffer);(Siluriformes: Amphiliidae) indigenous to Kenya streams. African Journal of Ecology, 47: 606-613.</td></tr>
</table>

7.9.2 Indicator 2: Longfin eel

<table>
<tr><td colspan="3">O. mossambicus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Pool depth [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.800</td></tr>
<tr><td></td><td>50.00</td><td>-0.600</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>1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.000</td></tr>
</table>
</td><td>O. mossambicus require deep pools >1 m for hydraulic cover and foraging. Reduced pool depth reduces habitat, particularly for large adults.</td><td>Medium</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.400</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.300</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.200</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.200</td></tr>
</table>
</td><td>Sufficient hydraulic and predation cover during upstream migration of young elvers. Effects apparent only if there is a severe change from natural, i.e. if all bed sediments are dominated by silt and sand.</td><td>Low</td></tr>
<tr><td>
☑ Wet Class3 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.100</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>3.50</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>7.00</td><td>0.300</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.100</td></tr>
</table>
</td><td>A. mossambicus is catadromous (Skelton 1993). Wet season Class 3 intra-annual floods required to trigger upstream summer migration of elvers from estuaries and downstream migration of adults to the sea. Reduced frequency of intra-annual floods expected to reduce passage to and from the sea for this species.</td><td>Medium</td></tr>
</table>

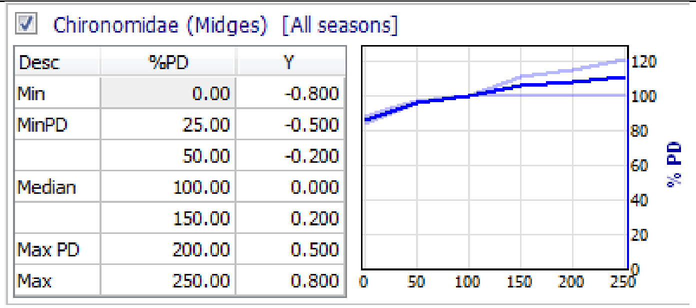
<table>
<tr><td colspan="3">O. mossambicus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.100</td></tr>
<tr><td></td><td>0.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>2.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>0.300</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.100</td></tr>
</table>

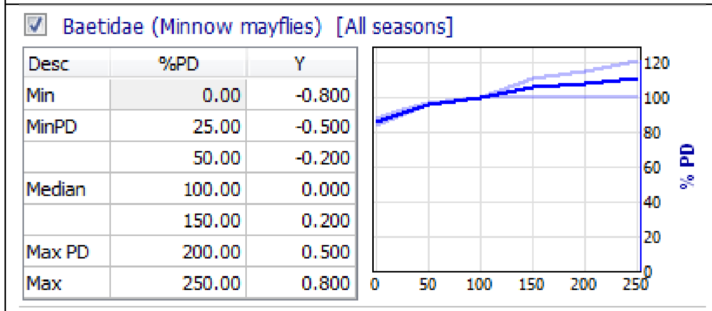
</td><td>A. mossambicus is catadromous (Skelton 1993). Wet season Class 3 intra-annual floods required to trigger upstream summer migration of elvers from estuaries and downstream migration of adults to the sea. Reduced frequency of intra-annual floods expected to reduce passage to and from the sea for this species.</td><td>Medium</td></tr>
<tr><td>

☑ Dry-daily ave vol-baseflow [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>0.00</td><td>-0.100</td></tr>
<tr><td></td><td>0.01</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.02</td><td>0.000</td></tr>
<tr><td></td><td>0.10</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>0.18</td><td>0.200</td></tr>
<tr><td>Max</td><td>0.20</td><td>0.300</td></tr>
</table>

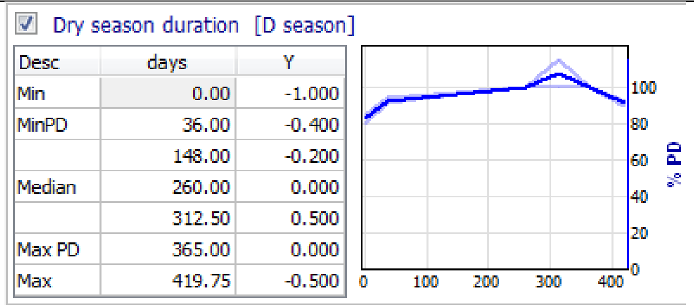
</td><td>Continuous flow over the Dry season with maximum depths not < 20 cm to facilitate adult and juvenile movements between habitat units. Effects not expected until discharges fall below 0.1 m3/s (0.01 Mm3/d).</td><td>Medium</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Jiang, X.; Arthington, A. and Changming, L. 2010. Environmental flow requirements of fish in the lower reach of the Yellow River. Water International, 35: 381-396.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.</td></tr>
</table>

7.9.3 Indicator 3: Orangefin barb

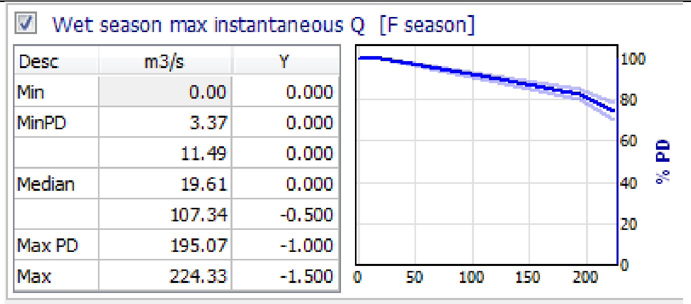
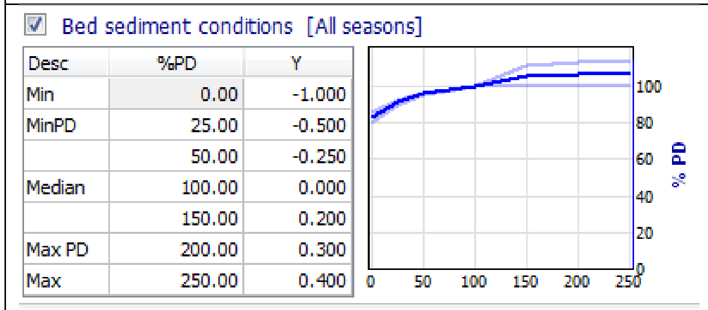
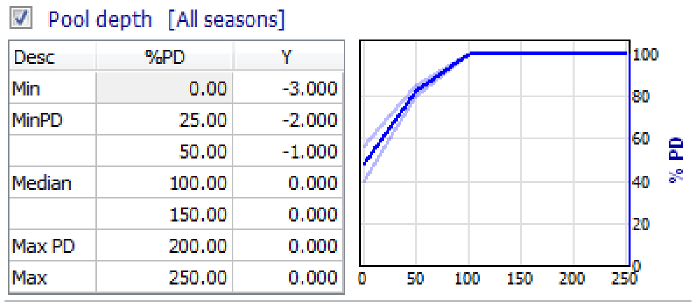
<table>
<tr><td colspan="3">B. eutaenia</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
</table>

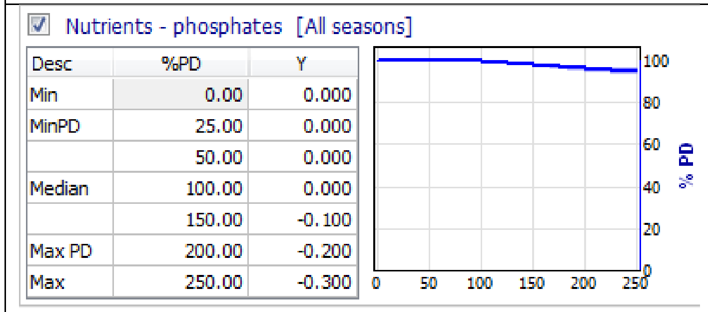
<table>
<tr><th colspan="3">B. eutaenia</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Chironomidae (Midges) [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.800</td></tr>
</table>

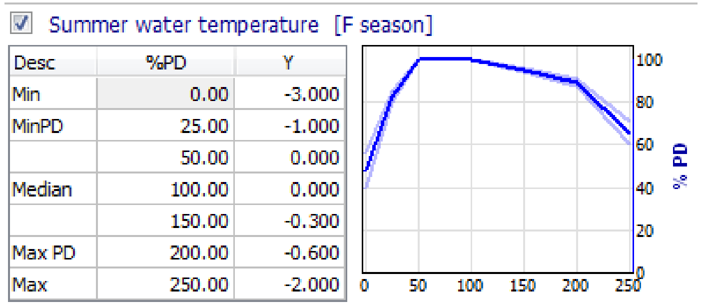
</td><td>B. eutaenia is an invertivore (Golder Associates 2009). Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids).</td><td>Medium</td></tr>
<tr><td>

☑ Baetidae (Minnow mayflies) [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.800</td></tr>
</table>

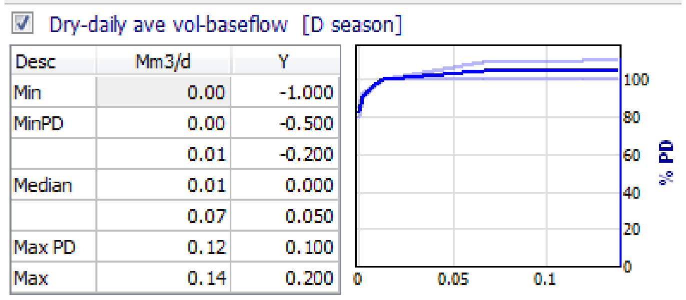
</td><td>B. eutaenia is an invertivore (Golder Associates 2009). Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids).</td><td>Medium</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>36.00</td><td>-0.400</td></tr>
<tr><td></td><td>148.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>260.00</td><td>0.000</td></tr>
<tr><td></td><td>312.50</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>419.75</td><td>-0.500</td></tr>
</table>

</td><td>B. eutaenia inhabits transitional habitats between riffles and pools and requires well-oxygenated flowing water to maintain fitness and condition (River Health Programme 2006, Golder Associates 2009). An extended dry season would reduce the quality and availability of fast-shallow and fast-intermediate depth-velocity conditions in the river and increase the frequency of no-flow.</td><td>Medium</td></tr>
</table>

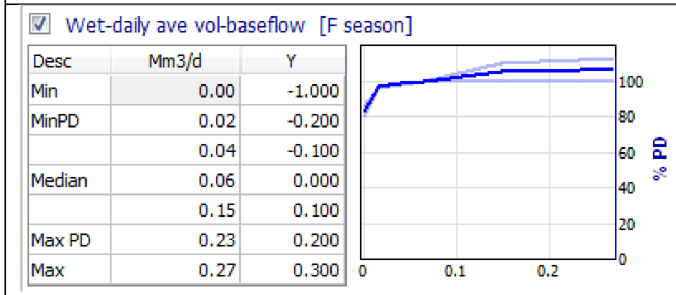
<table>
<tr><th colspan="3">B. eutaenia</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Wet season max instantaneous Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>3.37</td><td>0.000</td></tr>
<tr><td></td><td>11.49</td><td>0.000</td></tr>
<tr><td>Median</td><td>19.61</td><td>0.000</td></tr>
<tr><td></td><td>107.34</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>195.07</td><td>-1.000</td></tr>
<tr><td>Max</td><td>224.33</td><td>-1.500</td></tr>
</table>
</td><td>Increased frequency of larger floods (>1:5 years): juvenile and adult fishare able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.</td><td>Medium</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.250</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>0.300</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.400</td></tr>
</table>
</td><td>B. eutaenia adults and juveniles use cobbles and boulders for cover (Survey data, (River Health Programme 2006, Golder Associates 2009). Increased sedimentation of riffles and runs reduces the total amount and quality of hydraulic and predation cover for this species.</td><td>Medium</td></tr>
<tr><td>
☑ Pool depth [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.000</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>B. eutaenia uses pools as cover during periods of low flow and high temperatures (Golder Associates 2009). Pool depth would reduce the available habitat for this species which will translate to increased competition reduced fish condition, growth and survival particularly over the dry season.</td><td>Medium</td></tr>
</table>

<table>
<tr><th colspan="3">B. eutaenia</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Nutrients - phosphates [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-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>-0.300</td></tr>
</table>

</td><td>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. B. eutaenia is considered intolerant of impaired water quality conditions (DWA 2013).</td><td>Medium</td></tr>
<tr><td>

☑ Summer water temperature [F season]
<table>
<tr><th>Desc</th><th>%PD</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>-1.000</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>-0.300</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>250.00</td><td>-2.000</td></tr>
</table>

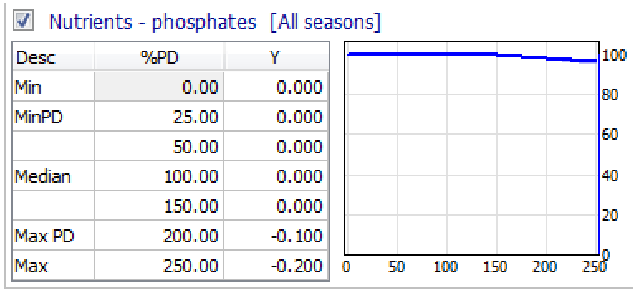
</td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate and oxygen demand (Hellawell 1986). B. eutaenia is more common in the upper reaches of rivers in cooler waters and may be more sensitive to higher temperatures than low (River Health Programme 2006, Golder Associates 2009).</td><td>Medium</td></tr>
<tr><td>

☑ Dry-daily ave vol-baseflow [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>0.00</td><td>-0.500</td></tr>
<tr><td></td><td>0.01</td><td>-0.200</td></tr>
<tr><td>Median</td><td>0.01</td><td>0.000</td></tr>
<tr><td></td><td>0.07</td><td>0.050</td></tr>
<tr><td>Max PD</td><td>0.12</td><td>0.100</td></tr>
<tr><td>Max</td><td>0.14</td><td>0.200</td></tr>
</table>

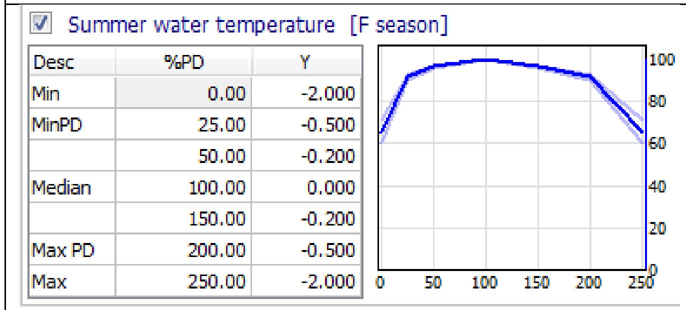
</td><td>B. eutaenia requires moderate flow conditions, it is considered intolerant of no flow and is lost from rivers with zero flow for periods of time (River Health Programme 2006, Golder Associates 2009). Flow volumes less than medianPD over the dry season will reduce the availability and quality of aquatic habitat, increasing competition and reducing individual fitness and condition.</td><td>Medium</td></tr>
</table>

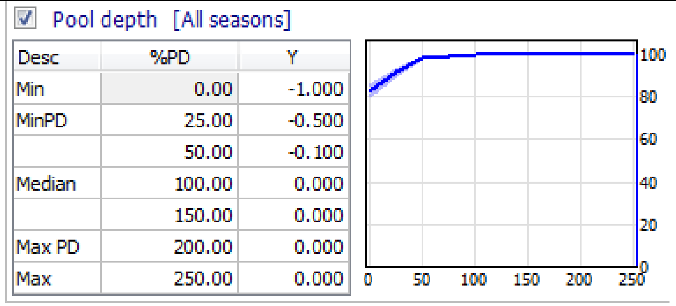
<table>
<tr><td colspan="3">B. eutaenia</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Wet-daily ave vol-baseflow [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>0.02</td><td>-0.200</td></tr>
<tr><td></td><td>0.04</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.06</td><td>0.000</td></tr>
<tr><td></td><td>0.15</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>0.23</td><td>0.200</td></tr>
<tr><td>Max</td><td>0.27</td><td>0.300</td></tr>
</table>
</td><td>B. eutaenia requires moderate flow conditions, it is considered intolerant of no flow and is lost from rivers with zero flow for periods of time (River Health Programme 2006, Golder Associates 2009). Flow volumes less than medianPD. over the wet season will reduce the availability and quality of aquatic habitat, increasing competition and reducing individual fitness and condition.</td><td>Medium</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Clarkson, R.W. and Childs, M.R. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia, 2000: 402-412.
Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa: FRAI reference data. Draft. Compiled by RQS-RDM.
Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London.
Golder Associates. 2009. Groot Letaba River water development project (GLeWaP). Environmental Impact Assessment. Annexure H2: Report No. 10647-8819-2.
River Health Programme. 2006. State-of-Rivers Report: the Moloko River system. Department of Environmental Affairs and Tourism, Pretoria. 37 pp</td></tr>
</table>

7.9.4 Indicator 4: Straightfin barb

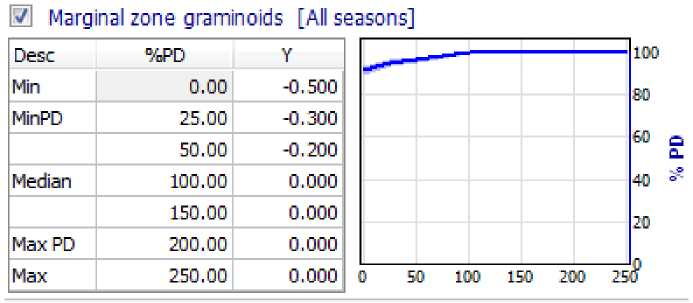
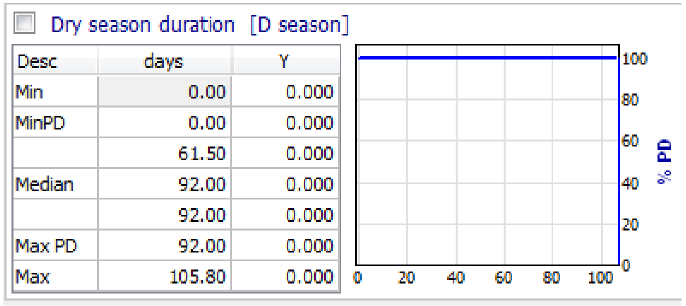
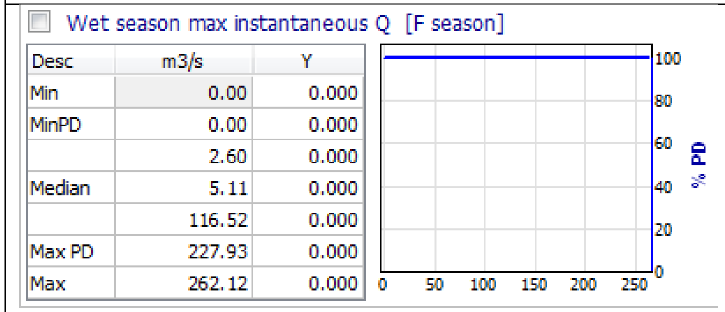
B. paludinosus		
Response curve	Explanation	Confidence

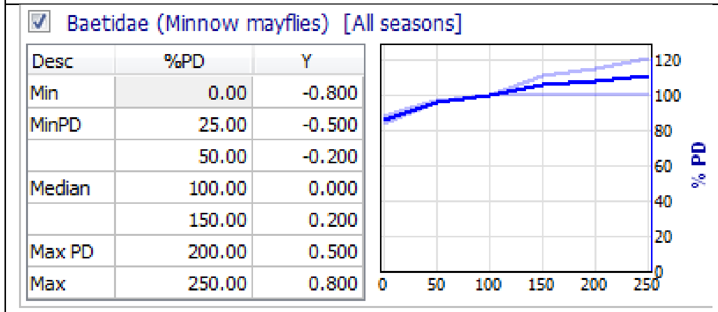
<table>
<tr><th colspan="3">B. paludinosus</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Nutrients - phosphates [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>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>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on B. paludinosus adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. B. paludinosus is moderately tolerant of impaired water quality conditions (DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.</td><td>Medium</td></tr>
<tr><td>

☑ Summer water temperature [F season]
<table>
<tr><th>Desc</th><th>%PD</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>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>-2.000</td></tr>
</table></td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate and oxygen demand (Hellawell 1986). B.paludinosus is more common in the lowlands and may be more sensitive to lower temperatures than high.</td><td>Medium</td></tr>
<tr><td>

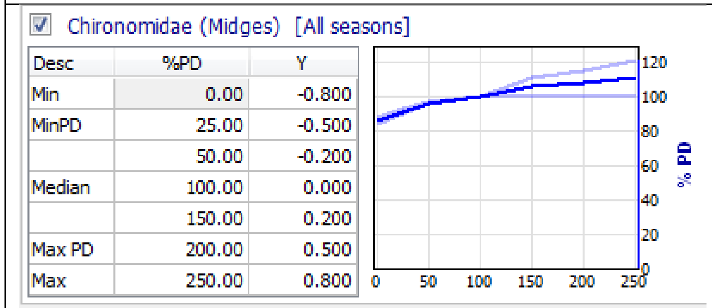
☑ Pool depth [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</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>B. paludinosus is a predominantly limnophilic species, strongly associated with Slow Deep flow classes and pools (Velocities <0.1 m/s) (Survey data, Skelton 1993). A reduction in pool depth would reduce the available habitat for this species.</td><td>High</td></tr>
</table>

B. paludinosus		
Response curve	Explanation	Confidence
 ☑ Marginal zone graminoids [All seasons] Desc | %PD | Y Min | 0.00 | -0.500 MinPD | 25.00 | -0.300 | 50.00 | -0.200 Median | 100.00 | 0.000 | 150.00 | 0.000 Max PD | 200.00 | 0.000 Max | 250.00 | 0.000 	B. paludinosus uses marginal vegetation for hydraulic and predation cover (data from this Survey, Skelton 1993). Large floods remove marginal vegetation and this zone is not indundated by subsequent normal flows. Reduced marginal zone translates to reduced cover for adults and juveniles and increased predation pressure.	Medium
 ☐ Dry season duration [D season] Desc | days | Y Min | 0.00 | 0.000 MinPD | 0.00 | 0.000 | 61.50 | 0.000 Median | 92.00 | 0.000 | 92.00 | 0.000 Max PD | 92.00 | 0.000 Max | 105.80 | 0.000 	B. paludinosus is a predominantly limnophilic species, strongly associated with Slow B. paludinosus is a predominantly limnophilic species, strongly associated with Slow Deep (Velocities <0.1 m/s) (Survey data, Skelton 1993). An extended Wet Season (i.e. a shortened Dry Season) would increase the duration of the faster flow classes, reducing the availability of habitat for this species. Conversely B. paludinosus would benefit from a longer dry season up to a point where the benefits of a low flow are outweighed by increased competition and predation. TURNED OFF< WILL BE DELETED>	Medium
 ☐ Wet season max instantaneous Q [F season] Desc | m3/s | Y Min | 0.00 | 0.000 MinPD | 0.00 | 0.000 | 2.60 | 0.000 Median | 5.11 | 0.000 | 116.52 | 0.000 Max PD | 227.93 | 0.000 Max | 262.12 | 0.000 	Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted and the amount of pool habitat for B. paludinosus will be reduced.	Low

<table>
<tr><td colspan="3">B. paludinosus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


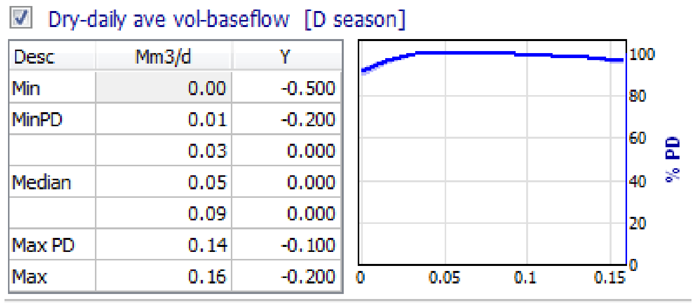
☑ Baetidae (Minnow mayflies) [All seasons]

<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.800</td></tr>
</table>

</td><td>Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids)</td><td>Medium</td></tr>
<tr><td>


☑ Chironomidae (Midges) [All seasons]

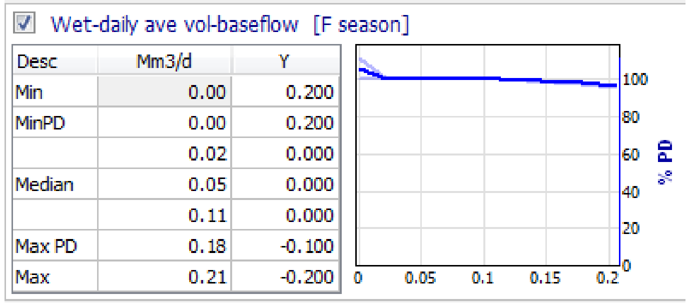
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.800</td></tr>
</table>

</td><td>Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids)</td><td>Medium</td></tr>
<tr><td>


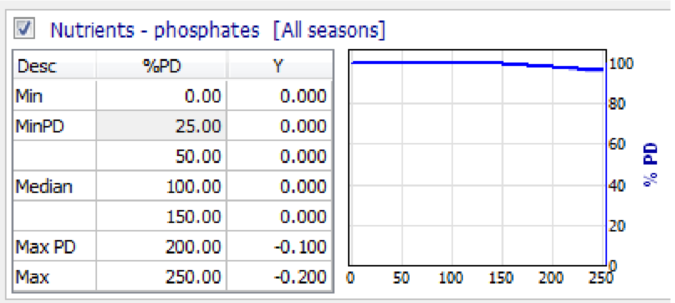
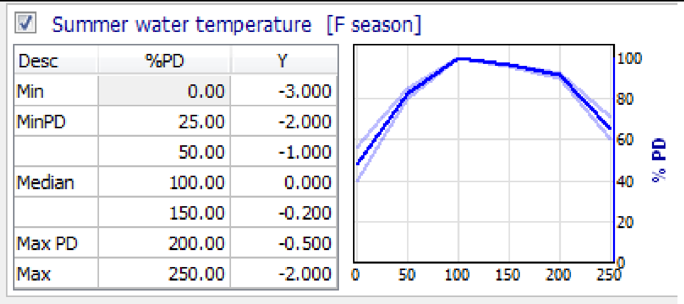
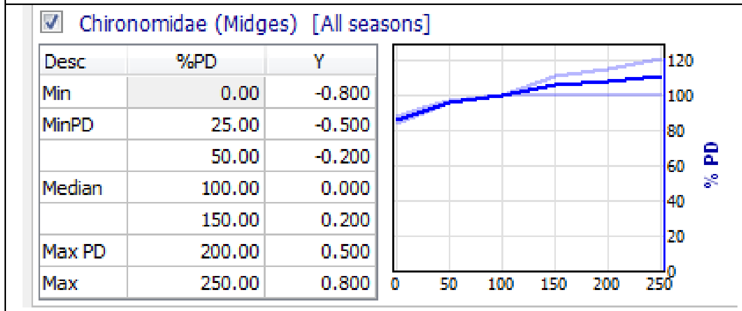
☑ Dry-daily ave vol-baseflow [D season]

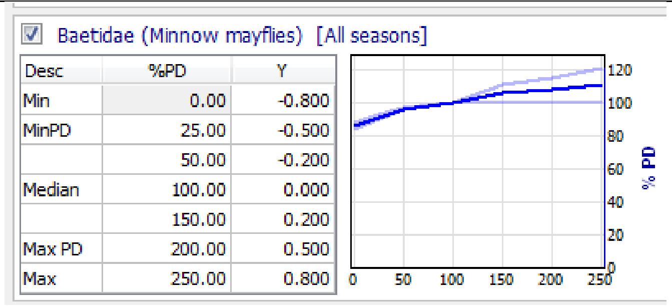
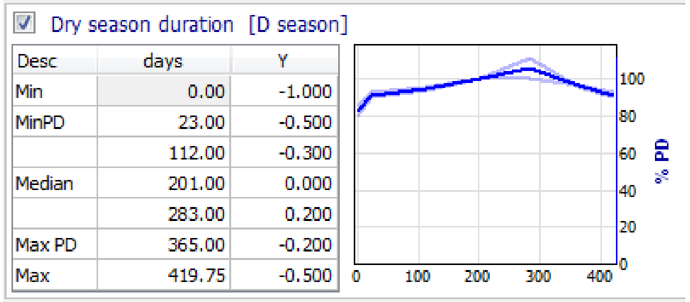
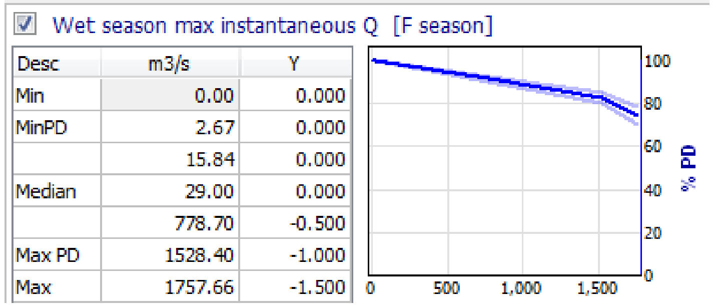
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>0.01</td><td>-0.200</td></tr>
<tr><td></td><td>0.03</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.09</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.14</td><td>-0.100</td></tr>
<tr><td>Max</td><td>0.16</td><td>-0.200</td></tr>
</table>

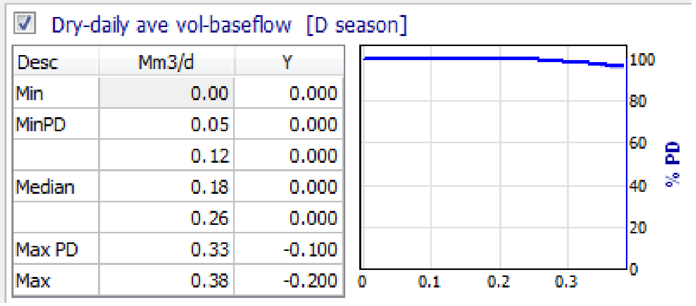
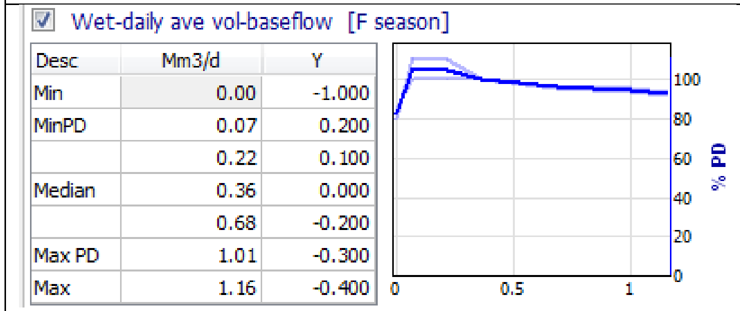
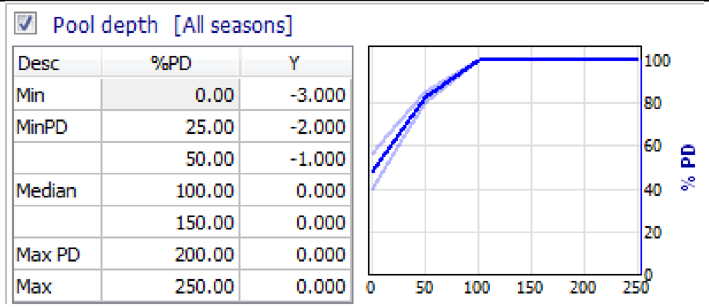
</td><td>B. paludinosus depends on access to marginal vegetation cover. The wetted edge will withdraw from marginal vegetation at discharges <1 m/s increasing vulnerability to predation. This will be mitigated to some degree by the availability of substratum cover. Median discharges rising to >7 m/s would increase velocities and reduce availability of Slow Deep habitats for this species over the Dry Season.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">B. paludinosus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Wet-daily ave vol-baseflow [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.200</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.200</td></tr>
<tr><td></td><td>0.02</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.11</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.18</td><td>-0.100</td></tr>
<tr><td>Max</td><td>0.21</td><td>-0.200</td></tr>
</table>
</td><td>B. paludinosus is a predominantly limnophilic species, strongly associated with Slow Deep habitats (Velocities <0.1 m/s) (Survey data, Skelton 1993). High flows will increase velocities and drown out pool habitats in the river reducing habitat quality and fish condition. Reduced wet baseflows would be beneficial to a point where at very low flows, competition and predation increases and reduced habitat volume is reduced.</td><td>Medium</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Clarkson, R.W. and Childs, M.R. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia, 2000: 402-412.
Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London.
Macuiane, M.A.; Kaunda, E.K.; Jamu, D.M. and Kanyerere, G.Z. 2009. Reproductive biology and breeding of Barbus paludinosus and B. trimaculatus (Teleostei: Cyprinidae) in Lake Chilwa, Malawi: implications for fisheries management. African Journal of Aquatic Science, 34: 123-130.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.</td></tr>
</table>

7.9.5 Indicator 5: Threespot barb

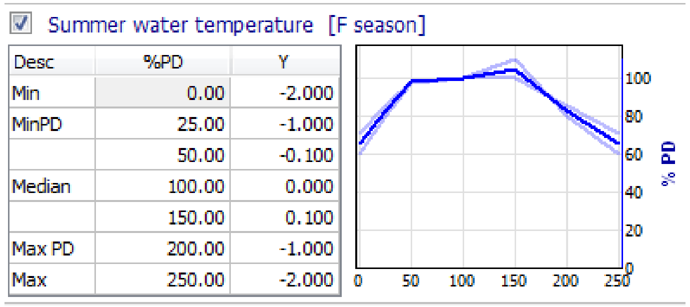
<table>
<tr><td colspan="3">B. trimaculatus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Nutrients - phosphates [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>25.00</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>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>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. B. trimaculatus is tolerant of impaired water quality conditions and its response is expected to be minimal (DWA 2013).</td><td>Medium</td></tr>
<tr><td>
☑ Summer water temperature [F season]
<table>
<tr><th>Desc</th><th>%PD</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>-0.200</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>-2.000</td></tr>
</table>
</td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate and oxygen demand (Hellawell 1986). B.trimaculatus is more common in the lowlands and may be more sensitive to lower temperatures than high.</td><td>High</td></tr>
<tr><td>
☑ Chironomidae (Midges) [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.800</td></tr>
</table>
</td><td>Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids).</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="3">B. trimaculatus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Baetidae (Minnow mayflies) [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.800</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.800</td></tr>
</table>
</td><td>Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids).</td><td>High</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>23.00</td><td>-0.500</td></tr>
<tr><td></td><td>112.00</td><td>-0.300</td></tr>
<tr><td>Median</td><td>201.00</td><td>0.000</td></tr>
<tr><td></td><td>283.00</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.200</td></tr>
<tr><td>Max</td><td>419.75</td><td>-0.500</td></tr>
</table>
</td><td>B. trimaculatus is a predominantly limnophilic species, strongly associated with Slow Deep (Velocities <0.1 m/s) (Survey data, Skelton 1993). An extended Wet Season (i.e. a shortened Dry Season) would increase the duration of the faster flow classes, reducing the availability of habitat for this species. Conversely B. trimaculatus would benefit from a longer dry season. Positive effects are mitigated by increased competition over extended dry season conditions.</td><td>Medium</td></tr>
<tr><td>
☑ Wet season max instantaneous 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>2.67</td><td>0.000</td></tr>
<tr><td></td><td>15.84</td><td>0.000</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>778.70</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>1528.40</td><td>-1.000</td></tr>
<tr><td>Max</td><td>1757.66</td><td>-1.500</td></tr>
</table>
</td><td>Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.</td><td>Low</td></tr>
</table>

<table>
<tr><td colspan="3">B. trimaculatus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry-daily ave vol-baseflow [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>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.12</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.18</td><td>0.000</td></tr>
<tr><td></td><td>0.26</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.33</td><td>-0.100</td></tr>
<tr><td>Max</td><td>0.38</td><td>-0.200</td></tr>
</table>
</td><td>B. trimaculatus depends on access to marginal vegetation cover. The wetted edge will withdraw from marginal vegetation at discharges <1 m/s increasing vulnerability to predation. This will be mitigated to some degree by the availablity of substratum cover.</td><td>Medium</td></tr>
<tr><td>
☑ Wet-daily ave vol-baseflow [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>0.07</td><td>0.200</td></tr>
<tr><td></td><td>0.22</td><td>0.100</td></tr>
<tr><td>Median</td><td>0.36</td><td>0.000</td></tr>
<tr><td></td><td>0.68</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>1.01</td><td>-0.300</td></tr>
<tr><td>Max</td><td>1.16</td><td>-0.400</td></tr>
</table>
</td><td>B. trimaculatus is a predominantly limnophilic species, strongly associated with Slow Deep habitats (Velocities <0.1 m/s) (Survey data, Skelton 1993). High flows will increase velocities and drown out pool habitats in the river reducing habitat quality and fish condition. Reduced wet baseflows would be beneficial to a point where at very low flows, competition and predation increases and reduced habitat volume is reduced.</td><td>Medium</td></tr>
<tr><td>
☑ Pool depth [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.000</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>B. trimaculatus is a predominantly limnophilic species, strongly associated with Slow Deep flow classes and pools (Survey data, Skelton 1993). A reduction in pool depth would reduce the available habitat for this species which will translate to increased competition reduced fish condition, growth and survival, particularly over the dry season.</td><td>High</td></tr>
<tr><td colspan="3">Clarkson, R.W. and Childs, M.R. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia, 2000: 402-412.</td></tr>
</table>

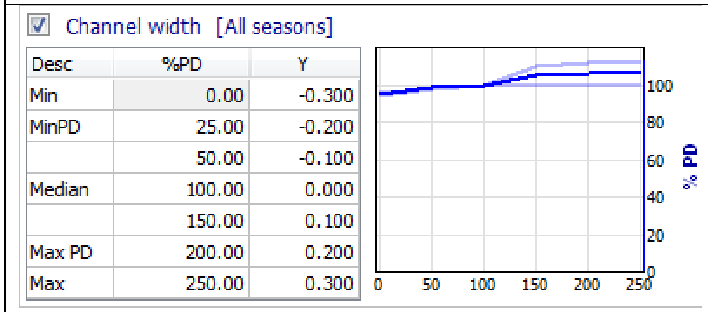
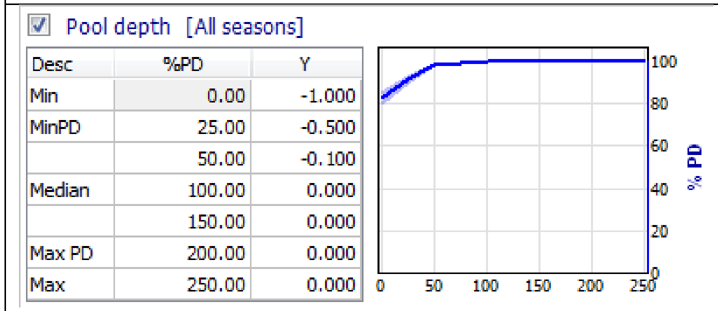
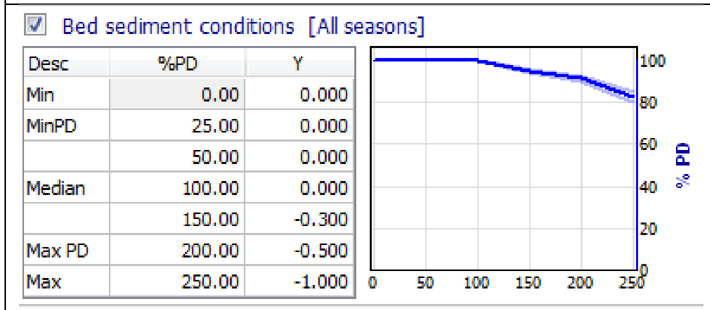
B. trimaculatus		
Response curve	Explanation	Confidence
Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. FRAI reference data. Draft. Compiled by RQS-RDM. Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London. Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.		

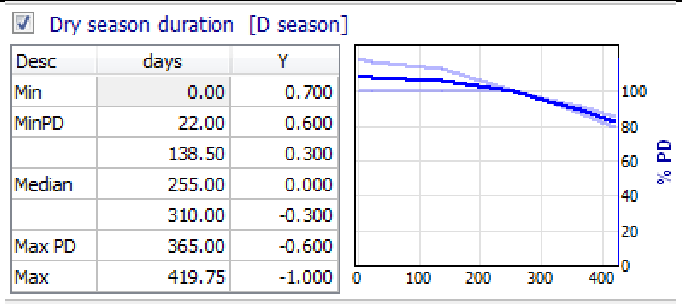
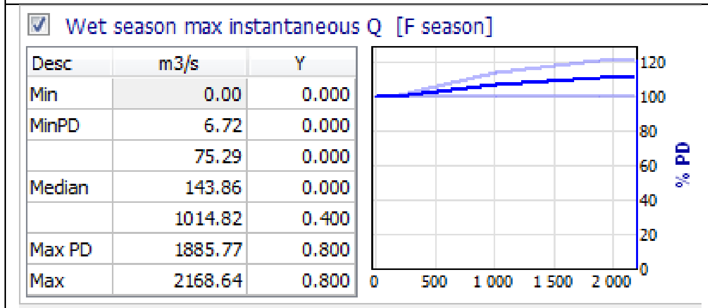
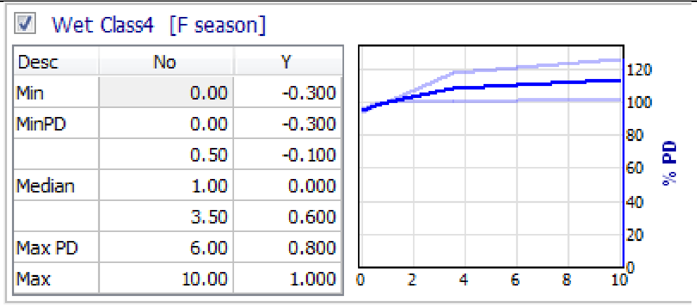
7.9.6 Indicator 6: Striped robber

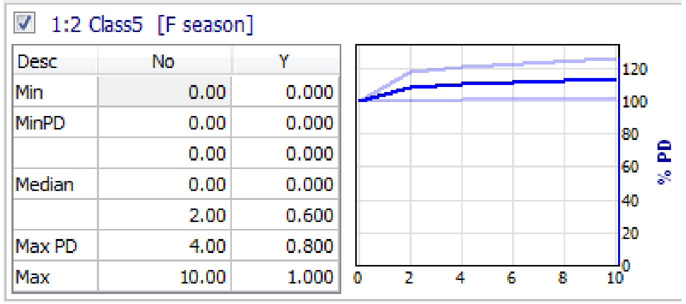
B. lateralis		
Response curve	Explanation	Confidence
	Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). Lower than medianPD temperatures are likely to delay spawning and slow embryonic development. Higher than medianPD temperatures are likely to promote growth and development to a point where they cause physiological stress to B. paludinosus individuals.	Medium

☑ Summer water temperature [F season]

Desc	%PD	Y
Min	0.00	-2.000
MinPD	25.00	-1.000
	50.00	-0.100
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	-1.000
Max	250.00	-2.000

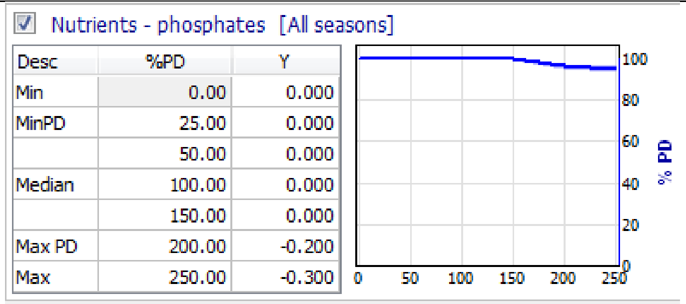
<table>
<tr><td colspan="3">B. lateralis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Channel width [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.200</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>0.100</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>0.300</td></tr>
</table>
</td><td>Reduced channel width reduces habitat complexity and the availability of secondary channels and hydraulic cover for B. lateralis.</td><td>Medium</td></tr>
<tr><td>
☑ Pool depth [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.000</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>B. lateralis is a predominantly limnophilic species, strongly associated with Slow Deep flow classes and pools (Velocities <0.1 m/s) (Skelton 1993). A reduction in pool depth would reduce the available habitat for this species.</td><td>Low</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.300</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>B. lateralis prefers sand-bed conditions (Skelton 1993). Increased predominance of courser sediments will reduce the suitability of habitat for this species</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">B. lateralis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry season duration [D season]
<table>
<tr><td>Desc</td><td>days</td><td>Y</td></tr>
<tr><td>Min</td><td>0.00</td><td>0.700</td></tr>
<tr><td>MinPD</td><td>22.00</td><td>0.600</td></tr>
<tr><td></td><td>138.50</td><td>0.300</td></tr>
<tr><td>Median</td><td>255.00</td><td>0.000</td></tr>
<tr><td></td><td>310.00</td><td>-0.300</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.000</td></tr>
</table>
</td><td>A prolonged dry season would reduce access to secondary channels and floodplain habitats for B.lateralis increasing competition and predation in the main channel.</td><td>High</td></tr>
<tr><td>
☑ Wet season max instantaneous 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>0.000</td></tr>
<tr><td>MinPD</td><td>6.72</td><td>0.000</td></tr>
<tr><td></td><td>75.29</td><td>0.000</td></tr>
<tr><td>Median</td><td>143.86</td><td>0.000</td></tr>
<tr><td></td><td>1014.82</td><td>0.400</td></tr>
<tr><td>Max PD</td><td>1885.77</td><td>0.800</td></tr>
<tr><td>Max</td><td>2168.64</td><td>0.800</td></tr>
</table>
</td><td>Larger floods (>1:5 years) will inundate a greater proportion of floodplain habitats and secondary channels used by B. lateralis for feeding and spawning.</td><td>Medium</td></tr>
<tr><td>
☑ Wet Class4 [F season]
<table>
<tr><td>Desc</td><td>No</td><td>Y</td></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.300</td></tr>
<tr><td></td><td>0.50</td><td>-0.100</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.000</td></tr>
<tr><td></td><td>3.50</td><td>0.600</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>1.000</td></tr>
</table>
</td><td>B. lateralis migrates onto floodplains during the wet season for feeding and spawning. Class 4 and 1:2 year floods are required to overtop banks.</td><td>Medium</td></tr>
</table>

<table>
<tr><th colspan="3">B. lateralis</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>


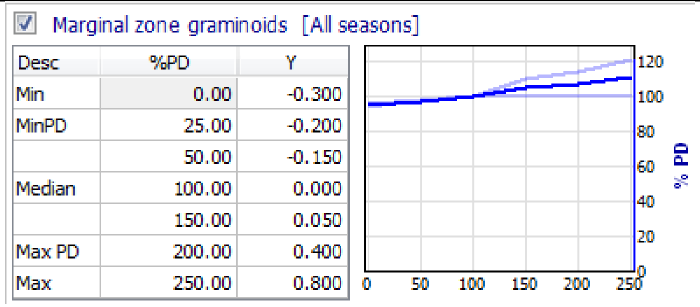
☑ 1:2 Class5 [F season]

<table>
<tr><th>Desc</th><th>No</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>2.00</td><td>0.600</td></tr>
<tr><td>Max PD</td><td>4.00</td><td>0.800</td></tr>
<tr><td>Max</td><td>10.00</td><td>1.000</td></tr>
</table>

</td><td>B. lateralis migrates onto floodplains during the wet season for feeding and spawning. Class 4 and 1:2 year floods are required to overtop banks.</td><td>High</td></tr>
<tr><td>


☑ Nutrients - phosphates [All seasons]

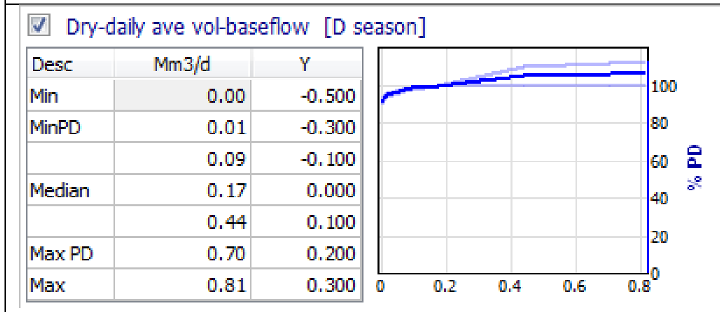
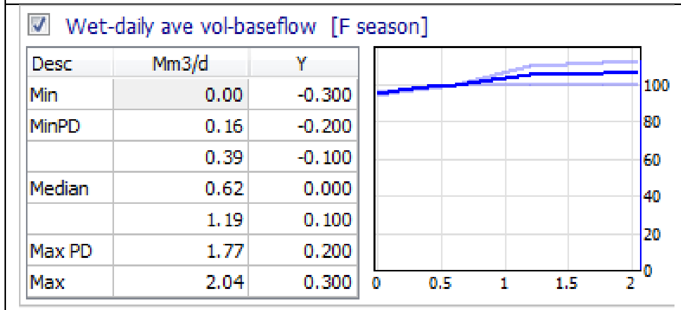
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.000</td></tr>
<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>Phosphates are here used as an indicator of water quality conditions. B. lateralis is considered moderately intolerant of impaired water quality conditions (from Brycinus imberi: DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.</td><td>Low</td></tr>
<tr><td>


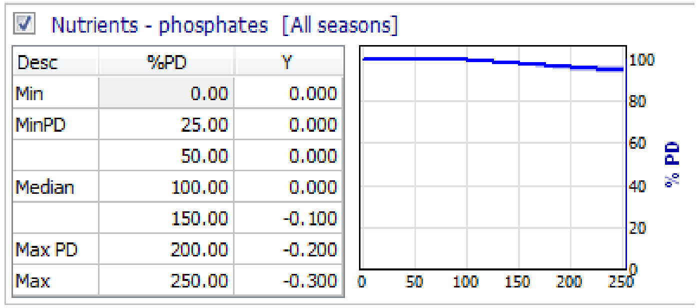
☑ Marginal zone graminoids [All seasons]

<table>
<tr><th>Desc</th><th>%PD</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>-0.200</td></tr>
<tr><td></td><td>50.00</td><td>-0.150</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>0.400</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.800</td></tr>
</table>

</td><td>B. lateralis favours slow flowing, well vegetated pools (Skelton 1993). The loss of marginal zone graminoids would reduce the availability of predation cover for this species.</td><td>High</td></tr>
</table>

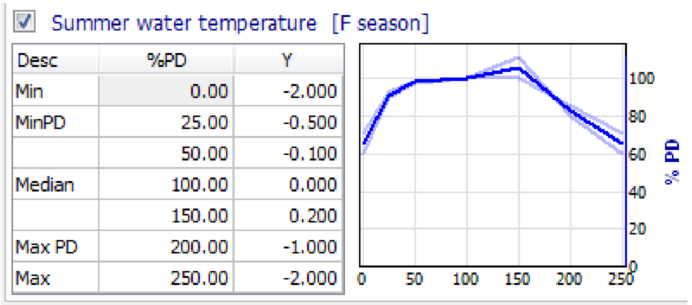
<table>
<tr><td colspan="3">B. lateralis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry-daily ave vol-baseflow [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>0.01</td><td>-0.300</td></tr>
<tr><td></td><td>0.09</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.17</td><td>0.000</td></tr>
<tr><td></td><td>0.44</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>0.70</td><td>0.200</td></tr>
<tr><td>Max</td><td>0.81</td><td>0.300</td></tr>
</table>
</td><td>B. lateralis depends on access to marginal vegetation cover. The wetted edge will withdraw from marginal vegetation at discharges <1 m/s increasing vulnerability to predation.</td><td>High</td></tr>
<tr><td>
☑ Wet-daily ave vol-baseflow [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.16</td><td>-0.200</td></tr>
<tr><td></td><td>0.39</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.62</td><td>0.000</td></tr>
<tr><td></td><td>1.19</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>1.77</td><td>0.200</td></tr>
<tr><td>Max</td><td>2.04</td><td>0.300</td></tr>
</table>
</td><td>B. lateralis depends on access to marginal vegetation cover and floodplain habitats over the wet season. Reduced wet medianPD volumes will reduce access to these habitats over the wet season. The wetted edge will withdraw from marginal vegetation at discharges <1 m/s increasing vulnerability to predation.</td><td>High</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa FRAI reference data. Draft. Compiled by RQS-RDM.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.
Clarkson, R.W. and Childs, M.R. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia, 2000: 402-412.</td></tr>
</table>

7.9.7 Indicator 7: River goby

<table>
<tr><th colspan="3">G. callidus</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Nutrients - phosphates [All seasons]

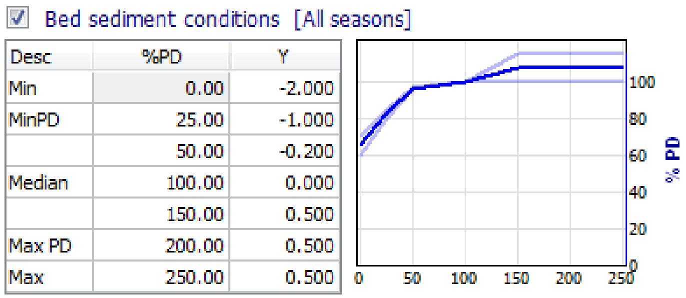
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.200</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.300</td></tr>
</table>

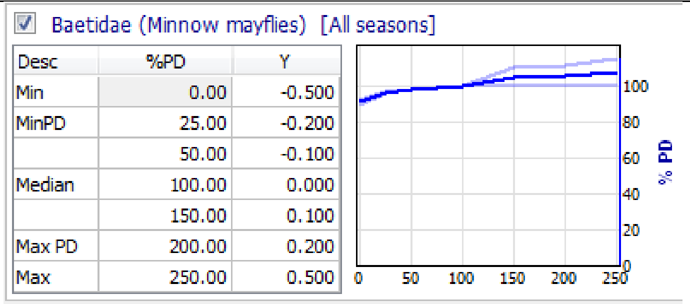
</td><td>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on G. callidus adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. G. callidus is moderately tolerant of impaired water quality conditions (DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.</td><td>Medium</td></tr>
<tr><td>

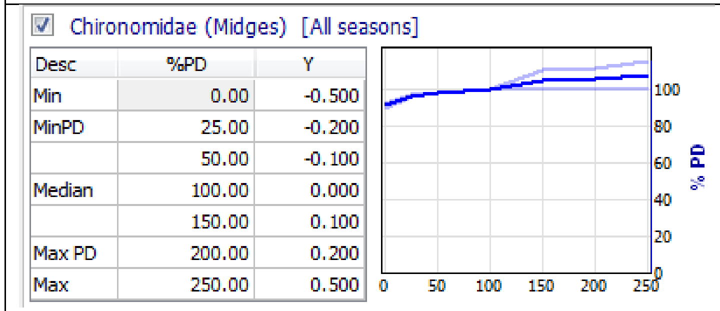
☑ Summer water temperature [F season]

<table>
<tr><th>Desc</th><th>%PD</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>-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>0.200</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>

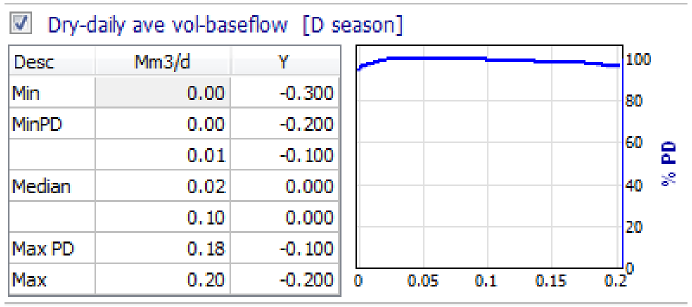
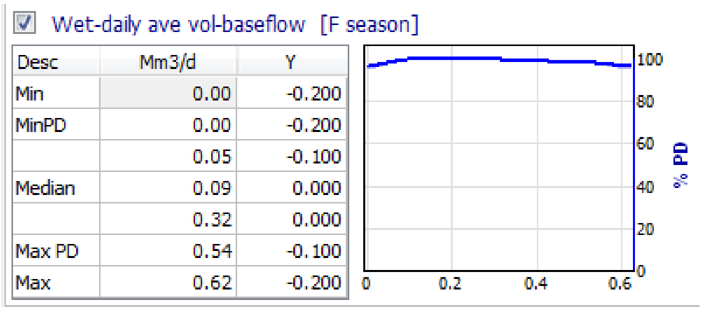
</td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). Increasing temperature effects are compounded by concomitant reduced oxygen concentrations. During surveys, G. callidus was found predominantly in shallow riffles (Survey data) and is vulnerable to acute temperature changes particularly over the spring (T1) when flows are still relatively low and temperature is increasing.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">G. callidus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.200</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>0.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.500</td></tr>
</table>

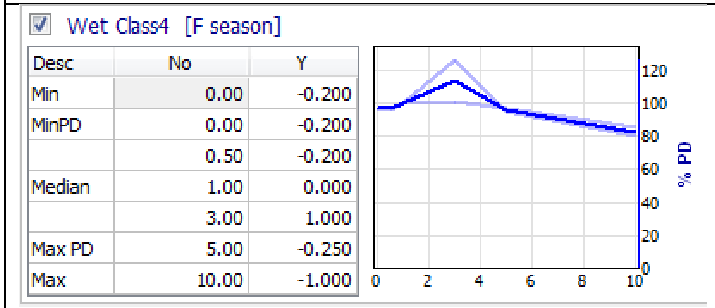
</td><td>G. callidus was found predominantly in shallow riffles, using bed elements for hydraulic cover. Increased sedimentation of riffles reduces the total amount and quality of this habitat - but only if there is a severe change from natural, i.e. if all bed sediments are dominated by silt and sand.</td><td>High</td></tr>
<tr><td>

☑ Baetidae (Minnow mayflies) [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.100</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>0.500</td></tr>
</table>

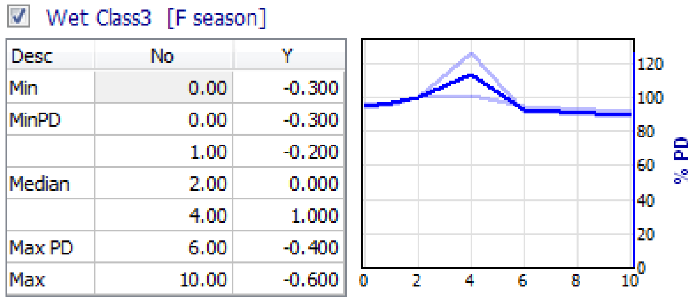
</td><td>Reduced baetid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to chironimids)</td><td>High</td></tr>
<tr><td>

☑ Chironomidae (Midges) [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.100</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>0.500</td></tr>
</table>

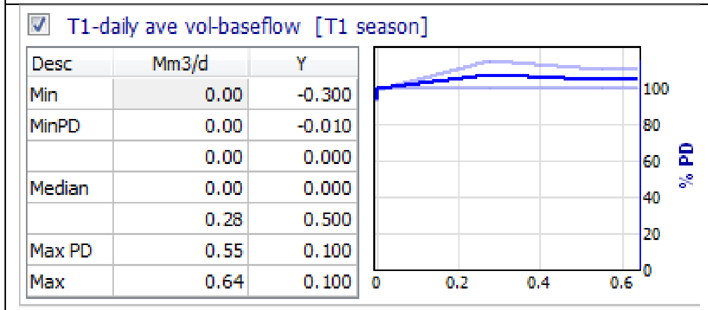
</td><td>Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by ability to switch prey species (e.g.to beatids)</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="3">G. callidus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry-daily ave vol-baseflow [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.200</td></tr>
<tr><td></td><td>0.01</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.02</td><td>0.000</td></tr>
<tr><td></td><td>0.10</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.18</td><td>-0.100</td></tr>
<tr><td>Max</td><td>0.20</td><td>-0.200</td></tr>
</table>
</td><td>G. callidus was found feeding in shallow riffles with velocities ranging between 0.1 - 0.5 m/s (median: 0.1 m/s). Their presence in these areas are considered to be primarily a result of foraging rather than physiological requirements - the former accounted for in the invertebrate response curves. Some minor physiological and predation effects may effect survival at lower than Dry medianPD flows. Flows much higher than medianPD with increased velocities may result in greater energetic costs during feeding and reduce individual survival.</td><td>Medium</td></tr>
<tr><td>
☑ Wet-daily ave vol-baseflow [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.200</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.200</td></tr>
<tr><td></td><td>0.05</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.09</td><td>0.000</td></tr>
<tr><td></td><td>0.32</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.54</td><td>-0.100</td></tr>
<tr><td>Max</td><td>0.62</td><td>-0.200</td></tr>
</table>
</td><td>G. callidus was found feeding in shallow riffles with velocities ranging between 0.1 - 0.5 m/s (median: 0.1 m/s). Their presence in these areas are considered to be primarily a result of foraging rather than physiological requirements - the former accounted for in the invertebrate response curves. Some minor physiological and predation effects may effect survival at lower than Wet medianPD flows. Flows much higher than medianPD with increased velocities may result in greater energetic costs during feeding and reduce individual survival.</td><td>Medium</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa FRAI reference data. Draft. Compiled by RQS-RDM.
Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.</td></tr>
</table>

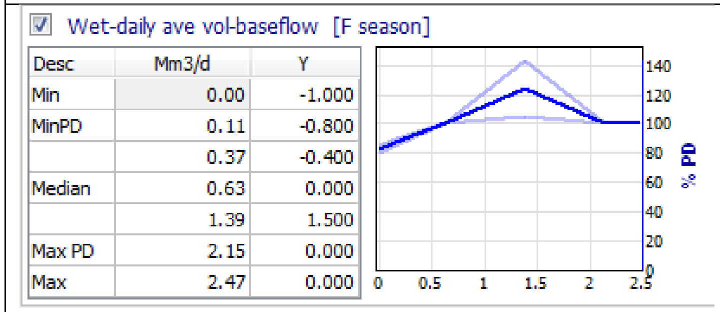
7.9.8 Indicator 8: Leaden labeo

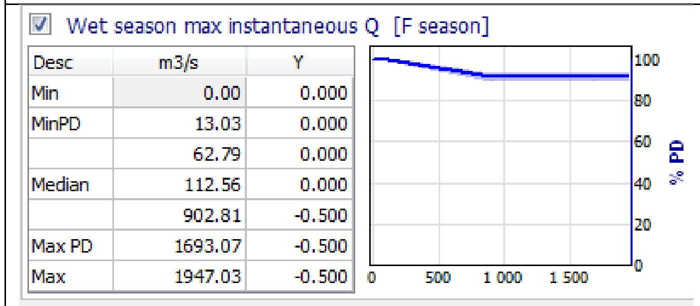
<table>
<tr><th colspan="3">L. molybdinus</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.200</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.200</td></tr>
<tr><td></td><td>0.50</td><td>-0.200</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.000</td></tr>
<tr><td></td><td>3.00</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>5.00</td><td>-0.250</td></tr>
<tr><td>Max</td><td>10.00</td><td>-1.000</td></tr>
</table>

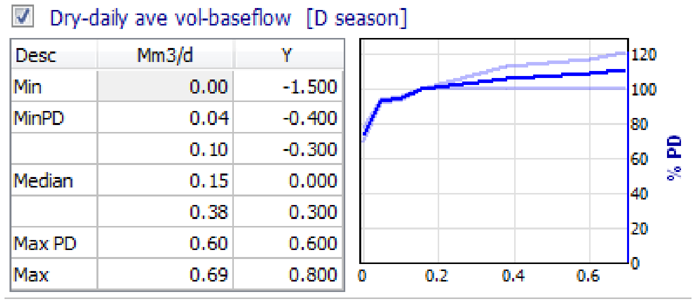
</td><td>L. molybdinus likely spawn between October and February (from L. rosae: Weyl 1999). Intra-annual floods (Class 3 and 4) over the early Wet Season trigger spawning migrations. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.</td><td>Medium</td></tr>
<tr><td>

☑ Wet Class3 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.300</td></tr>
<tr><td></td><td>1.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>2.00</td><td>0.000</td></tr>
<tr><td></td><td>4.00</td><td>1.000</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>-0.400</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.600</td></tr>
</table>

</td><td>L. molybdinus likely spawn between October and February (from L. rosae: Weyl 1999). Intra-annual floods (Class 3 and 4) over the early Wet Season trigger spawning migrations. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.</td><td>Medium</td></tr>
<tr><td>

☑ T1-daily ave vol-baseflow [T1 season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.010</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>0.28</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>0.55</td><td>0.100</td></tr>
<tr><td>Max</td><td>0.64</td><td>0.100</td></tr>
</table>

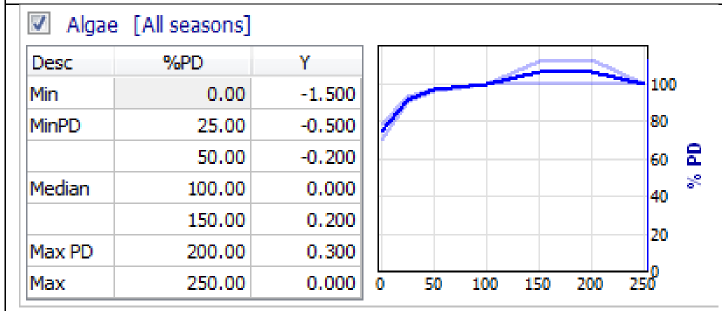
</td><td>L. molybdinus likely to undertake migration over the spring transitional period (T1) (from L. rosae: Weyl 1999) fish passage, minimum depths. At discharges lower than MinPD fish passage will be constrained by maximum depths.</td><td>High</td></tr>
</table>

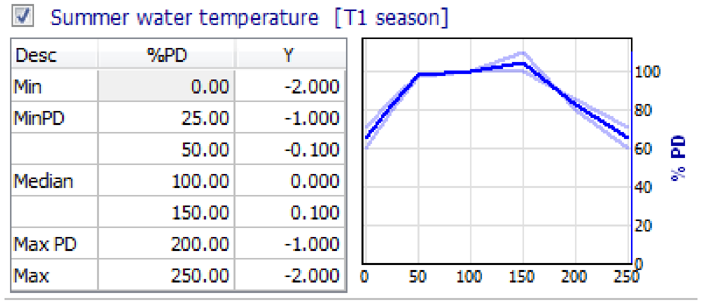
<table>
<tr><td colspan="3">L. molybdinus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Wet-daily ave vol-baseflow [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>0.11</td><td>-0.800</td></tr>
<tr><td></td><td>0.37</td><td>-0.400</td></tr>
<tr><td>Median</td><td>0.63</td><td>0.000</td></tr>
<tr><td></td><td>1.39</td><td>1.500</td></tr>
<tr><td>Max PD</td><td>2.15</td><td>0.000</td></tr>
<tr><td>Max</td><td>2.47</td><td>0.000</td></tr>
</table>
</td><td>L. molybdinus likely spawn between October and February in Fast Deep habitats (from L. rosae: Weyl 1999). Reduced wet daily ave baseflow reduces spawning and feeding habitat quality over this period. Higher than Median PD reduces the amount of slow very shallow habitat for larvae and juveniles.</td><td>High</td></tr>
<tr><td>


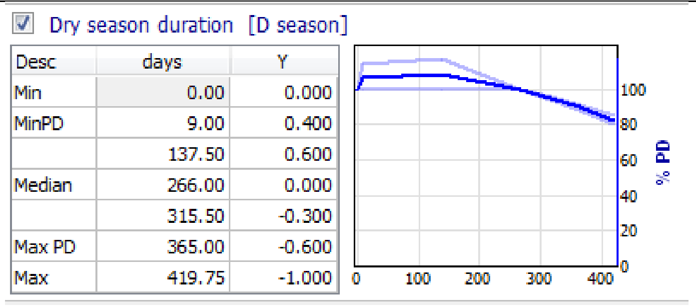
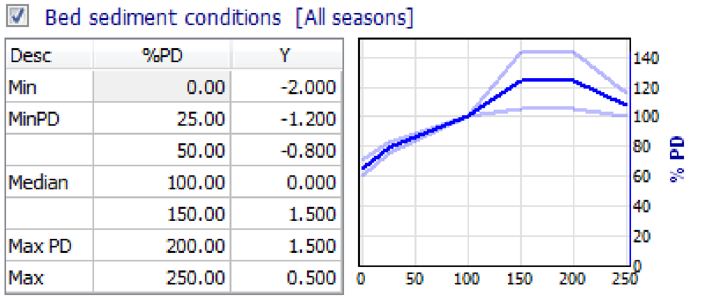
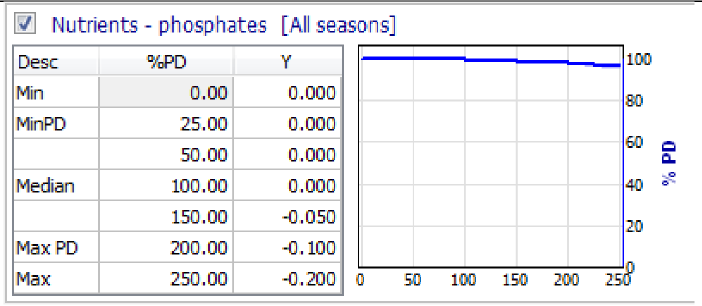
☑ Wet season max instantaneous Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>13.03</td><td>0.000</td></tr>
<tr><td></td><td>62.79</td><td>0.000</td></tr>
<tr><td>Median</td><td>112.56</td><td>0.000</td></tr>
<tr><td></td><td>902.81</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>1693.07</td><td>-0.500</td></tr>
<tr><td>Max</td><td>1947.03</td><td>-0.500</td></tr>
</table>
</td><td>Larger floods (>1:5 years): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.</td><td>Low</td></tr>
<tr><td>


☑ Dry-daily ave vol-baseflow [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>0.04</td><td>-0.400</td></tr>
<tr><td></td><td>0.10</td><td>-0.300</td></tr>
<tr><td>Median</td><td>0.15</td><td>0.000</td></tr>
<tr><td></td><td>0.38</td><td>0.300</td></tr>
<tr><td>Max PD</td><td>0.60</td><td>0.600</td></tr>
<tr><td>Max</td><td>0.69</td><td>0.800</td></tr>
</table>
</td><td>L. molybdinus juveniles feed in faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s through the Dry Season (Survey data). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce the availability of this class of habitat and reduce individual growth, fitness and condition.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">L. molybdinus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


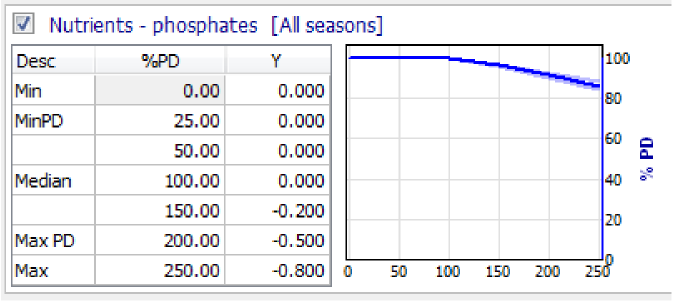
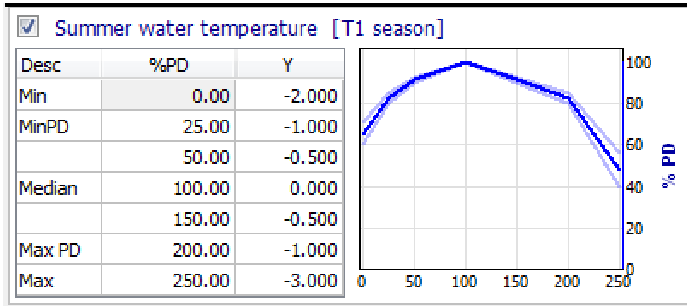
☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.500</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.500</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.300</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.000</td></tr>
</table>
</td><td>Labeo molybidinus feed primarily on auwachs and algae. Reduced availability will affect adult fish fecundity and condition. Effects will not be mitigated by an ability fish food sources.</td><td>High</td></tr>
<tr><td>


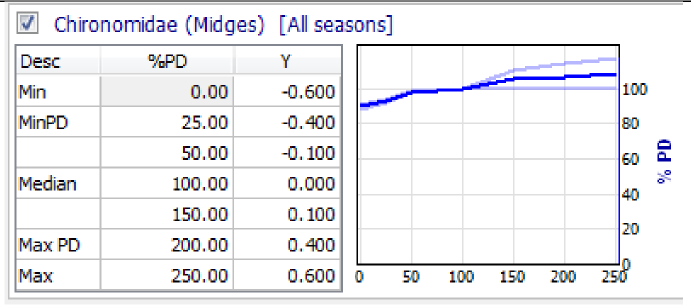
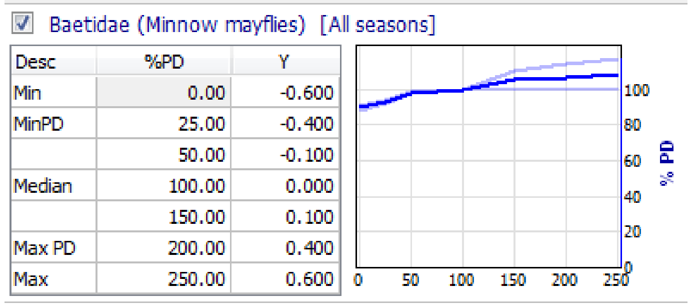
☑ Summer water temperature [T1 season]
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>-2.000</td></tr>
</table>
</td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. molybinus is tolerant of a wide temperature range that enables it to colonise mountain streams and lowland rivers. Adults and juveniles are mobile and will be able to seek out temperature refugia. Reproductive cycles, however, will be affected by temperature changes. L. molbydinus spawns October and April, possibly multiple times. Lower than normal temperatures are likely to delay spawning and slow embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality, lower than normal temperatures would slow development and growth and increase egg and larval mortality.</td><td>Medium</td></tr>
</table>

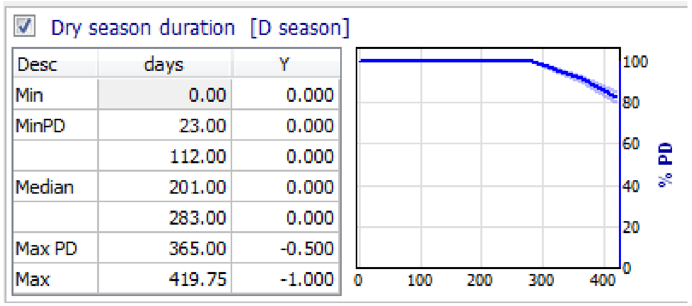
<table>
<tr><td colspan="3">L. molybdinus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>9.00</td><td>0.400</td></tr>
<tr><td></td><td>137.50</td><td>0.600</td></tr>
<tr><td>Median</td><td>266.00</td><td>0.000</td></tr>
<tr><td></td><td>315.50</td><td>-0.300</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.000</td></tr>
</table>
</td><td>L. molybdinus juveniles feed in faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s (Survey data). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce: the spawning period and annual recruitment and increase the duration of physiological stress and intra-specific competition.</td><td>Medium</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-1.200</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>1.500</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>0.500</td></tr>
</table>
</td><td>L. molybinus adults and juveniles occupy cobble and boulder habitat in areas of high flow (Fast Deep) (Survey data). Increased sedimentation of riffles reduces the total amount and quality of this habitat.</td><td>High</td></tr>
<tr><td>
☑ Nutrients - phosphates [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-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>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on L. natalensis adults and juveniles. L. natalensis s is moderately intolerant of impaired water quality conditions (DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.</td><td>Medium</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary</td></tr>
</table>

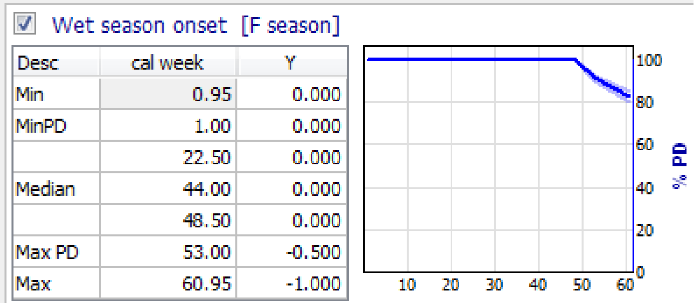
<table>
<tr><td colspan="3">L. molybdinus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td colspan="3">Reaches for Secondary Catchments in South Africa FRAI reference data. Draft. Compiled by RQS-RDM.
Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.</td></tr>
</table>

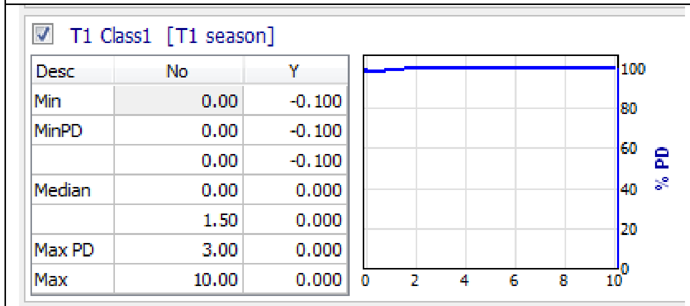
7.9.9 Indicator 9: Lowveld largescale yellowfish

<table>
<tr><td colspan="3">L. marequensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Nutrients - phosphates [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-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>-0.800</td></tr>
</table>
</td><td>L. marequensis is moderately tolerant of impaired water quality conditions (DWA 2013). Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on L. marequensis adults and juveniles. Any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations.</td><td>Medium</td></tr>
<tr><td>
☑ Summer water temperature [T1 season]
<table>
<tr><th>Desc</th><th>%PD</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>-0.500</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>-3.000</td></tr>
</table>
</td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. marequensis is tolerant of a wide temperature range that enables it to colonise mountain streams and lowland rivers. Adults and juveniles are mobile and will be able to seek out temperature refugia. Reproductive cycles, however, will be affected by temperature changes. L.</td><td>High</td></tr>
</table>

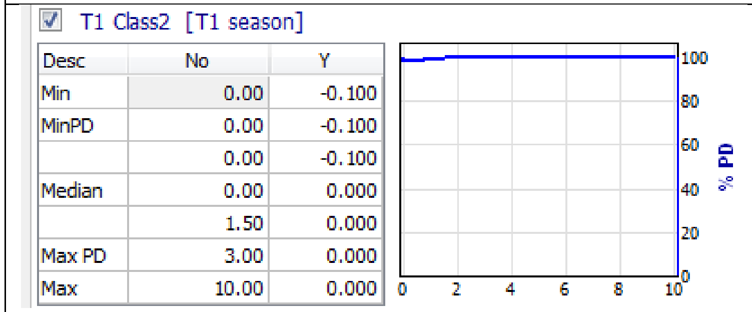
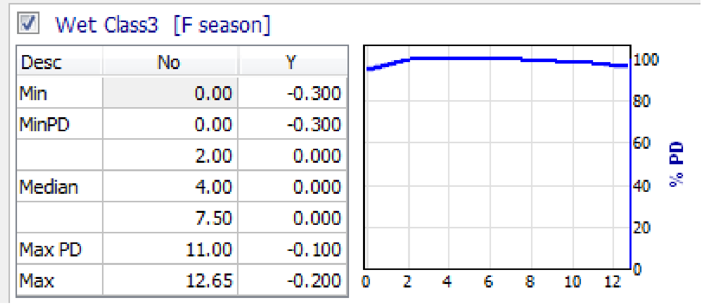
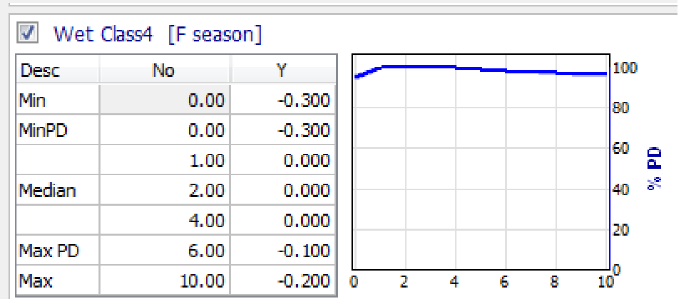
L. marequensis		
Response curve	Explanation	Confidence
	marequensis spawns twice a year (September and January) (Fouche 2009). Lower than normal temperatures are likely to delay spawning and slow embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality. Temperatures over the Wet Season are not expected to vary by more than 10% under PD conditions.	
 ☑ Chironomidae (Midges) [All seasons] Desc %PD Y Min 0.00 -0.600 MinPD 25.00 -0.400 50.00 -0.100 Median 100.00 0.000 150.00 0.100 Max PD 200.00 0.400 Max 250.00 0.600 	Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Larval and juvenile L. marequensis are expected to be affected since invertebrates form an important component of the diet of younger age classes (Fouche 2009). Effects will be mitigated to a large degree by ability to switch prey species.	High
 ☑ Baetidae (Minnow mayflies) [All seasons] Desc %PD Y Min 0.00 -0.600 MinPD 25.00 -0.400 50.00 -0.100 Median 100.00 0.000 150.00 0.100 Max PD 200.00 0.400 Max 250.00 0.600 	Reduced beatid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by switching prey species (e.g. to chironimids) (from A. natalensis: Marriott 1997), (Ngugi 2009). Population growth is constrained by absolute availability of riffle habitat and density-dependent factors beyond a certain point of increased prey density.	High

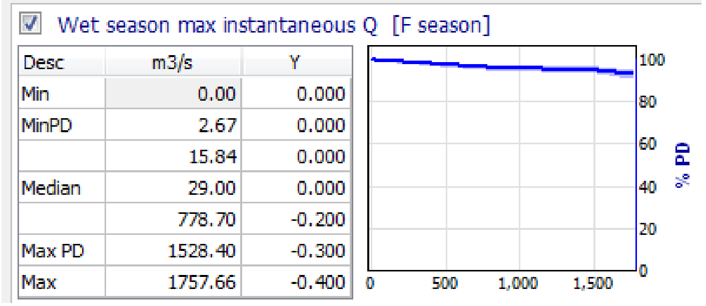
<table>
<tr><td colspan="3">L. marequensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

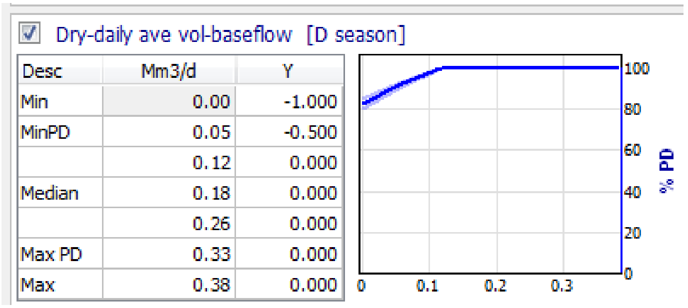
☑ Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>23.00</td><td>0.000</td></tr>
<tr><td></td><td>112.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>201.00</td><td>0.000</td></tr>
<tr><td></td><td>283.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>419.75</td><td>-1.000</td></tr>
</table></td><td>L. marequensis spawns and feeds in faster Flow Depth classes (FS, FI, FD). Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce the Wet Season duration and therefore the spawning period. An extended Wet Season is not expected to benefit L. marequensis populations. However Dry Season thresholds of 1.68 and 3.16 m3/s would provide suitable habitat for spawning over the duration of the extended Dry Season - population declines would therefore be mitigated.</td><td>High</td></tr>
<tr><td>

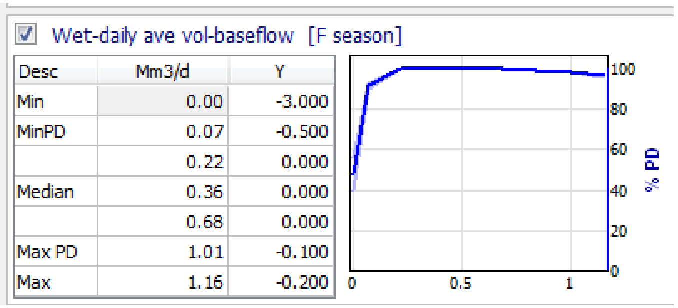
☑ Wet season onset [F season]
<table>
<tr><th>Desc</th><th>cal week</th><th>Y</th></tr>
<tr><td>Min</td><td>0.95</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>1.00</td><td>0.000</td></tr>
<tr><td></td><td>22.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>44.00</td><td>0.000</td></tr>
<tr><td></td><td>48.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>53.00</td><td>-0.500</td></tr>
<tr><td>Max</td><td>60.95</td><td>-1.000</td></tr>
</table></td><td>L. marequensis spawning is timed to coincide with increased temperatures during in September (weeks: 36-40), just before the median Wet Season onset (week 45). Delayed onset by 7 weeks would result in sub-optimal hydraulic conditions at the spawning sites. The effect would be mitigated by the fact that Dry Season thresholds of 1.68 and 3.16 m3/s would provide suitable habitat for spawning even if Wet Season onset was delayed.</td><td>Medium</td></tr>
<tr><td>

☑ T1 Class1 [T1 season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.100</td></tr>
<tr><td></td><td>0.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>1.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>3.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.000</td></tr>
</table></td><td>Intra-annual floods (Class 1 or Class 2) over the early Wet Season (Sep/Oct) trigger spawning migrations. L. marequensis migrations peak in September and October (Fouche 2013). Minor reductions in recruitment success if migrations are delayed.</td><td>Medium</td></tr>
</table>

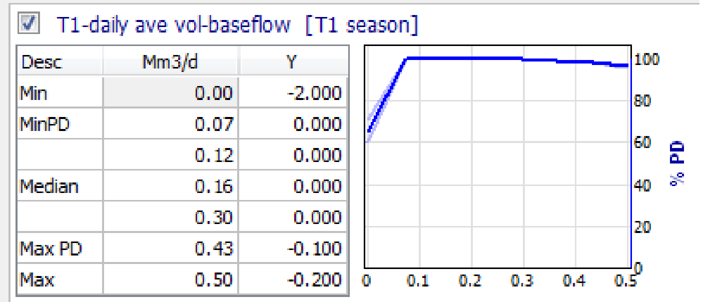
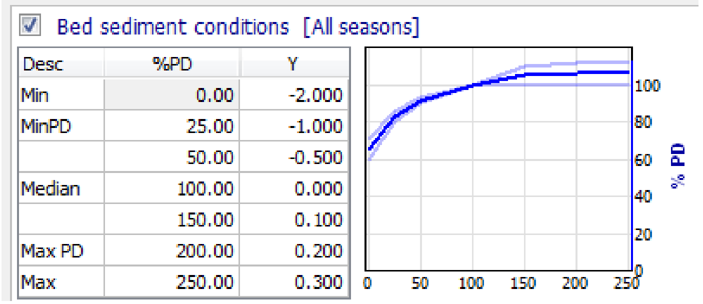
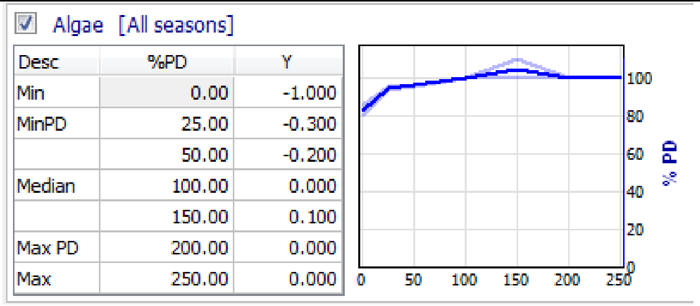
<table>
<tr><td colspan="3">L. marequensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ T1 Class2 [T1 season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.100</td></tr>
<tr><td></td><td>0.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>1.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>3.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.000</td></tr>
</table>
</td><td>L. marequensis spawn twice a year (September and January) (Fouche 2009). Class 3 or 4 floods trigger spawning, but too many floods may wash larvae from nursery habitat.</td><td>Medium</td></tr>
<tr><td>
☑ Wet Class3 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.300</td></tr>
<tr><td></td><td>2.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>4.00</td><td>0.000</td></tr>
<tr><td></td><td>7.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>11.00</td><td>-0.100</td></tr>
<tr><td>Max</td><td>12.65</td><td>-0.200</td></tr>
</table>
</td><td>L. marequensis spawn twice a year (September and January) (Fouche 2009). Class 3 or 4 floods trigger spawning, but too many floods may wash larvae from nursery habitat.</td><td>Medium</td></tr>
<tr><td>
☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.300</td></tr>
<tr><td></td><td>1.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>2.00</td><td>0.000</td></tr>
<tr><td></td><td>4.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>-0.100</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.200</td></tr>
</table>
</td><td>L. marequensis spawn twice a year (September and January) (Fouche 2009). Class 3 or 4 floods trigger spawning, but too many floods may wash larvae from nursery habitat.</td><td>Medium</td></tr>
</table>

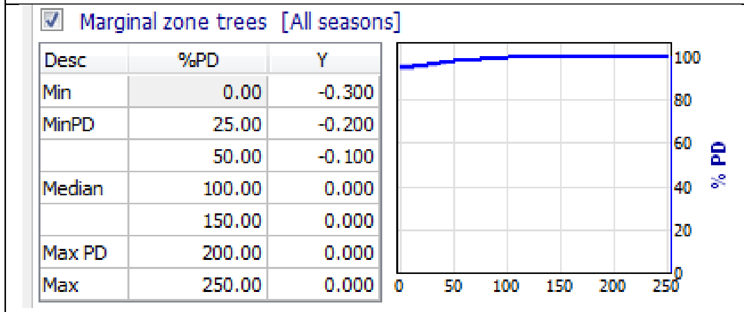
<table>
<tr><th colspan="3">L. marequensis</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Wet season max instantaneous 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>2.67</td><td>0.000</td></tr>
<tr><td></td><td>15.84</td><td>0.000</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>778.70</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>1528.40</td><td>-0.300</td></tr>
<tr><td>Max</td><td>1757.66</td><td>-0.400</td></tr>
</table></td>
<td>Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.</td>
<td>Low</td></tr>
<tr><td>

☑ Dry-daily ave vol-baseflow [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>0.05</td><td>-0.500</td></tr>
<tr><td></td><td>0.12</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.18</td><td>0.000</td></tr>
<tr><td></td><td>0.26</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.33</td><td>0.000</td></tr>
<tr><td>Max</td><td>0.38</td><td>0.000</td></tr>
</table></td>
<td>Through the Dry Season, Juvenile L. marequensis are rheophilic and feed in FS, FI and FD Flow Depth classes (EWR survey data, Fouche 2009). However, it is assumed that their presence here is a consequence of their feeding rather than physiological requirements - these requirements are already accounted for through links to macro-invertebrate indacors. Some fish passage and dispersal by juveniles between pools is required. At discharges <0.6 m3/s fish passage will be constrained by maximum depths <0.3 m.</td>
<td>Medium</td></tr>
<tr><td>

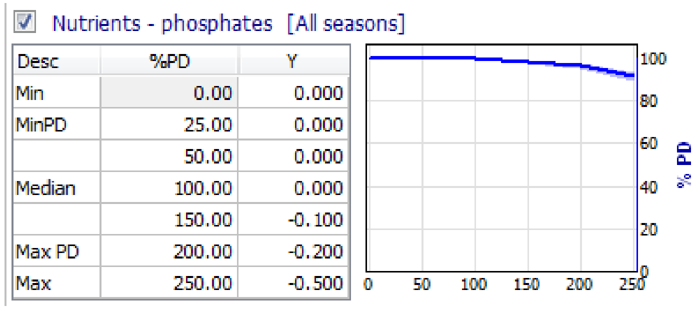
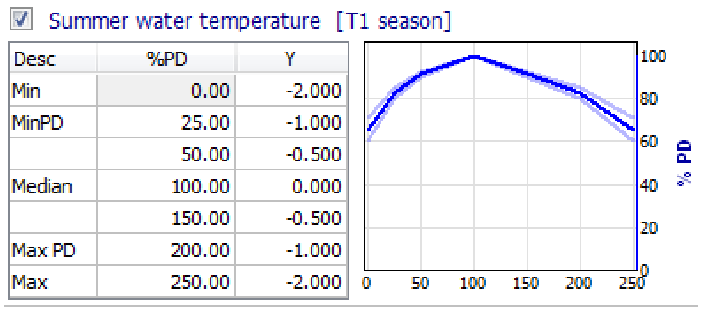
☑ Wet-daily ave vol-baseflow [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>0.07</td><td>-0.500</td></tr>
<tr><td></td><td>0.22</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.36</td><td>0.000</td></tr>
<tr><td></td><td>0.68</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.01</td><td>-0.100</td></tr>
<tr><td>Max</td><td>1.16</td><td>-0.200</td></tr>
</table></td>
<td>South African yellwofishes are known to select faster Flow Depth classes (FS, FI, FD) and higher velocities for spawning (Fouche 2009, Paxton and King 2009, O'Brien and de Villiers 2011). Reduced availability of these habitat conditions impair water flow around eggs in spawning gravels and increase embryo mortality. The proportion of suitable Flow Depth classes in the reach is reduced below the median MinPD Wet-daily average baseflow discharge (0.8 m3/s). Increases over this value will improve spawning habitat to a point where Slow Shallow habitat for larval</td>
<td>High</td></tr>
</table>

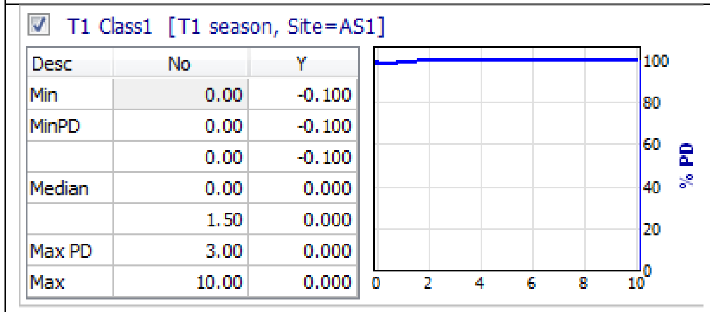
<table>
<tr><td colspan="3">L. marequensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td></td><td>and early juvenile life stages become limiting (Q calculated from Mm3).</td><td></td></tr>
<tr><td>
☑ T1-daily ave vol-baseflow [T1 season]
<table>
<tr><th>Desc</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>0.07</td><td>0.000</td></tr>
<tr><td></td><td>0.12</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.16</td><td>0.000</td></tr>
<tr><td></td><td>0.30</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.43</td><td>-0.100</td></tr>
<tr><td>Max</td><td>0.50</td><td>-0.200</td></tr>
</table>
</td><td>L. marequensis undertakes migration over the spring transitional period (T1) (Fouche 2009) fish passage, minimum depths. At discharges <0.4 m3/s (0.04 Mm3) fish passage will be constrained by maximum depths <0.3 m (Q calculated from Mm3)</td><td>Medium</td></tr>
<tr><td>
☑ Bed sediment conditions [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>0.100</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>0.300</td></tr>
</table>
</td><td>L. marequensis is a benthic rheophilic spawner and depends on good quality cobble-bed riffles for successful recruitment. Increased sedimentation of riffles reduces the total amount and quality of this habitat.</td><td>High</td></tr>
<tr><td>
☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.300</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</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>0.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.000</td></tr>
</table>
</td><td>Algae form an important component of the diet of L. marequensis (Fouche 2009). Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">L. marequensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

<table>
<tr><th>Desc</th><th>%PD</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>-0.200</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>0.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.000</td></tr>
</table></td><td>Large South African yellowfishes use woody debris for adult and juvenile predation and hydraulic cover. Loss of woody debris and root wads would marginally increase predation. Effects will be mitigated by being able to utilise bank structure or boulders for cover.</td><td>Medium</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="2">Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa FRAI reference data. Draft. Compiled by RQS-RDM.
Fouché, P.S.O. (2009). Aspects of the ecology and biology of the Lowveld largescale yellowfish (Labeobarbus marequensis, Smith 1843) in the Luvuvhu River, Limpopo River system, South Africa. PhD Thesis. University of Limpopo, 299 pp.
Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London.
O'Brien, G. and De Villiers, P. 2011. Biology and ecology of the Orange-Vaal largemouth and smallmouth yellowfishes in the Vaal River. Research Report No TT 508/11. Water Research Commission, Pretoria. 245 pp.
Paxton, B.R. and King, J.M. 2009. The influence of hydraulics, hydrology and temperature on the distribution, habitat use and recruitment of threatened cyprinids in a Western Cape river, South Africa. WRC Report No. 1483/1/09. Water Research Commission, Pretoria. 170 pp.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.</td><td></td></tr>
</table>

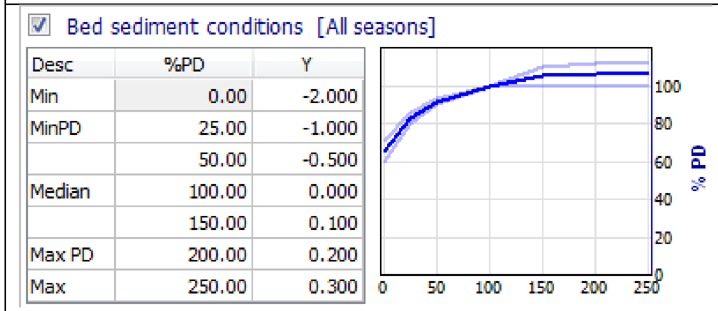
7.9.10 Indicator 10: Kwazulu-Natal yellowfish

<table>
<tr><td colspan="3">L. natalensis NS1</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Nutrients - phosphates [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-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>-0.500</td></tr>
</table>
</td><td>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on L. natalensis adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. L. natalensis s is moderately tolerant of impaired water quality conditions (DWA 2013). Effects will be mitigated by the fact that a proportion of these nutrients will be bound to sediments.</td><td>Medium</td></tr>
<tr><td>
☑ Summer water temperature [T1 season]
<table>
<tr><th>Desc</th><th>%PD</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>-0.500</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>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. natalensis is tolerant of a wide temperature range and colonises mountain streams and lowland rivers. Adults and juveniles are mobile and able to seek out temperature refugia. Reproductive cycles, however, are affected by temperature changes. L. natalensis spawns October and April (Karssing 2008), possibly multiple times. Lower than normal temperatures may delay spawning and slow embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality. Temperatures over the Wet Season are not expected to vary by more than 10% under PD conditions.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="3">L. natalensis NS1</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


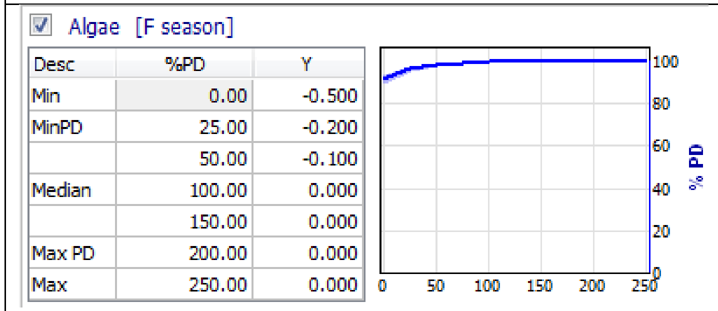
☑ T1 Class1 [T1 season, Site=AS1]

<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.100</td></tr>
<tr><td></td><td>0.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>1.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>3.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.000</td></tr>
</table>

</td><td>Intra-annual floods (Class 1 or Class 2) over the early Wet Season (Sep/Oct) trigger spawning migrations. Minor reductions in recruitment success if migrations are delayed. Too many floods may interupt spawning and/or migration.</td><td>Medium</td></tr>
<tr><td>


☑ Bed sediment conditions [All seasons]

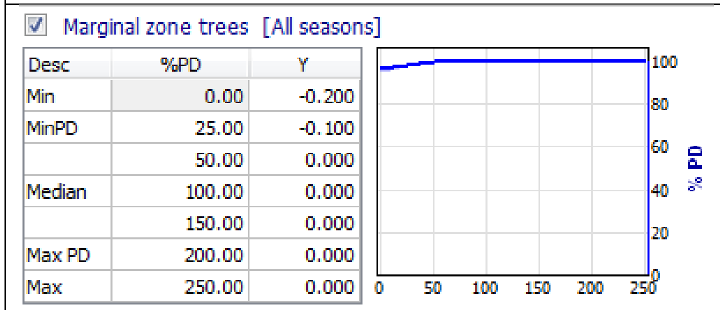
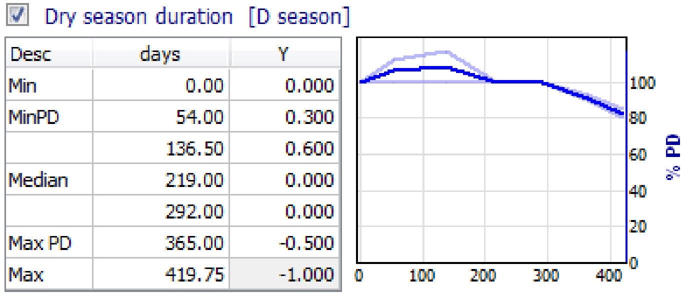
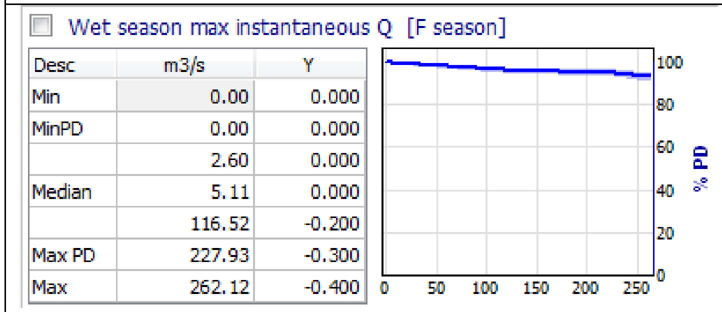
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.200</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.300</td></tr>
</table>

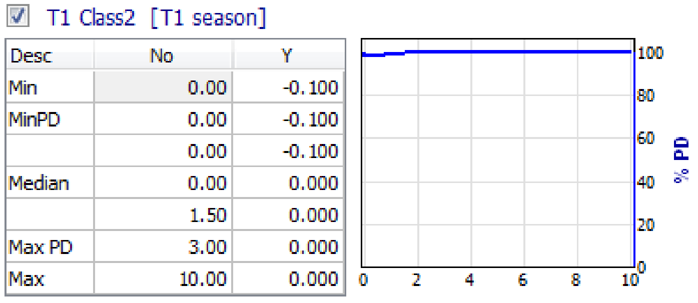
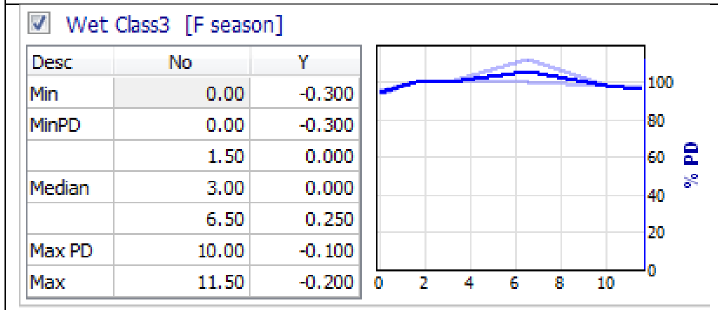
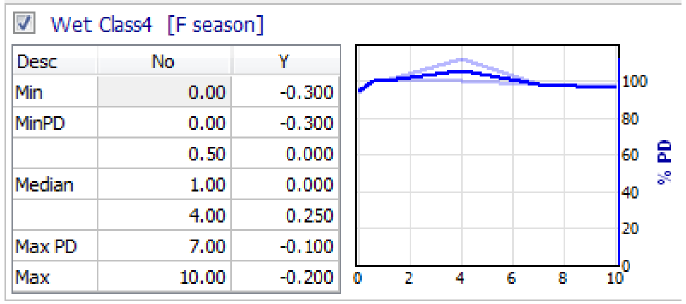
</td><td>L. natalensis is a benthic rheophilic spawner and depends on good quality cobble-bed riffles for successful recruitment. Increased sedimentation of riffles reduces the total amount and quality of this habitat increasing embronyic and larval mortality.</td><td>High</td></tr>
<tr><td>


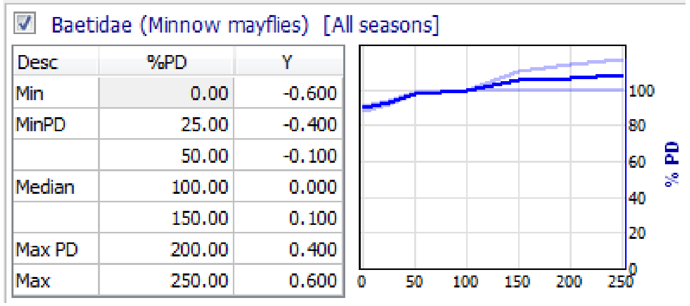
☑ Algae [F season]

<table>
<tr><th>Desc</th><th>%PD</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>0.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.000</td></tr>
</table>

</td><td>Algae form an important component of the diet of L. natalensis. Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources (e.g. to invertebrates).</td><td>Medium</td></tr>
</table>

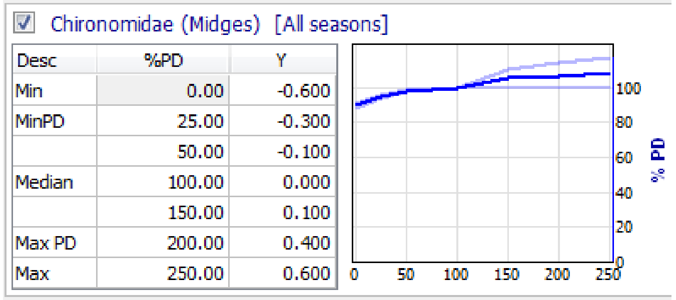
L. natalensis NS1		
Response curve	Explanation	Confidence
☑ Marginal zone trees [All seasons] Desc · %PD · Y Min · 0.00 · -0.200 MinPD · 25.00 · -0.100 · 50.00 · 0.000 Median · 100.00 · 0.000 · 150.00 · 0.000 Max PD · 200.00 · 0.000 Max · 250.00 · 0.000	Large South African yellowfishes use woody debris for adult and juvenile predation and hydraulic cover. Loss of woody debris and root wads would marginally increase predation and reduce hydraulic cover for adults and juveniles. Effects will be mitigated by being able to utilise bank structure or boulders for cover.	Medium
☑ Dry season duration [D season] Desc · days · Y Min · 0.00 · 0.000 MinPD · 54.00 · 0.300 · 136.50 · 0.600 Median · 219.00 · 0.000 · 292.00 · 0.000 Max PD · 365.00 · -0.500 Max · 419.75 · -1.000	L. natalensis juveniles feed in faster Flow Depth classes (FS, FI, FD) and velocities between 0.4 - 0.8 m/s. Limited availability of optimal habitat conditions under extended Dry Season conditions would reduce: the spawning period and annual recruitment and increase the duration of physiological stress and intra-specific competition. Dry Season thresholds of 1.68 and 3.16 m3/s would provide adequate habitat over the extended duration of the season - population declines would therefore be mitigated.	High
☐ Wet season max instantaneous Q [F season] Desc · m3/s · Y Min · 0.00 · 0.000 MinPD · 0.00 · 0.000 · 2.60 · 0.000 Median · 5.11 · 0.000 · 116.52 · -0.200 Max PD · 227.93 · -0.300 Max · 262.12 · -0.400	Larger floods (>1:5 years): Juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.	Low

<table>
<tr><th colspan="3">L. natalensis NS1</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ T1 Class2 [T1 season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.100</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.100</td></tr>
<tr><td></td><td>0.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>0.00</td><td>0.000</td></tr>
<tr><td></td><td>1.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>3.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>10.00</td><td>0.000</td></tr>
</table>
</td><td>Intra-annual floods (Class 1 or Class 2) over the early Wet Season (Sep/Oct) trigger spawning migrations. Minor reductions in recruitment success if migrations are delayed. Too many floods may interupt spawning and/or migration.</td><td>Low</td></tr>
<tr><td>
☑ Wet Class3 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.300</td></tr>
<tr><td></td><td>1.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>3.00</td><td>0.000</td></tr>
<tr><td></td><td>6.50</td><td>0.250</td></tr>
<tr><td>Max PD</td><td>10.00</td><td>-0.100</td></tr>
<tr><td>Max</td><td>11.50</td><td>-0.200</td></tr>
</table>
</td><td>L. natalensis spawn between October and April, possibly on multiple occassions (Karssing 2008, Bell-Cross and Minshull 1998). Intra-annual floods over the early Wet Season trigger spawning migrations. L. natalensis migrations peak in September and October. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.</td><td>Medium</td></tr>
<tr><td>
☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.300</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.300</td></tr>
<tr><td></td><td>0.50</td><td>0.000</td></tr>
<tr><td>Median</td><td>1.00</td><td>0.000</td></tr>
<tr><td></td><td>4.00</td><td>0.250</td></tr>
<tr><td>Max PD</td><td>7.00</td><td>-0.100</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.200</td></tr>
</table>
</td><td>L. natalensis spawn between October and April, possibly on multiple occassions (Karssing 2008, Bell-Cross and Minshull 1998). Intra-annual floods over the early Wet Season trigger spawning migrations. Small intra-annual floods later in the Wet Season may trigger a second spawning event. There will be an optimum frequency, after which too many floods may wash larvae from nursery habitat.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">L. natalensis NS1</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


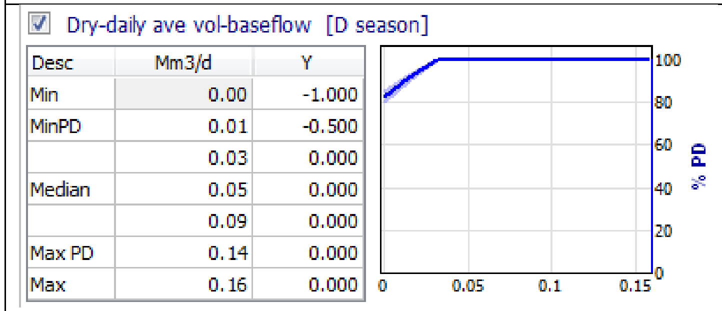
☑ Baetidae (Minnow mayflies) [All seasons]

<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.600</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.400</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>0.400</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.600</td></tr>
</table>

</td><td>Reduced beatid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Effects will be mitigated to a large degree by switching prey species (e.g. to chironimids). Population growth is constrained by absolute availability of riffle habitat and density-dependent factors beyond a certain point of increased prey density.</td><td>High</td></tr>
<tr><td>


☑ Chironomidae (Midges) [All seasons]

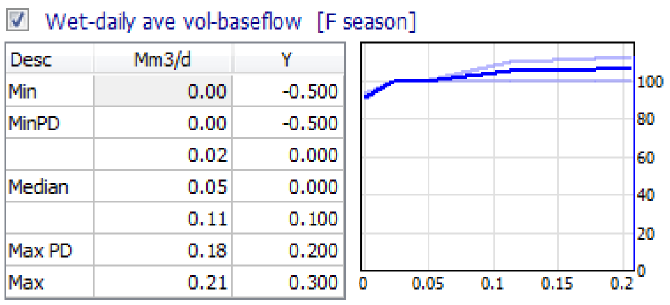
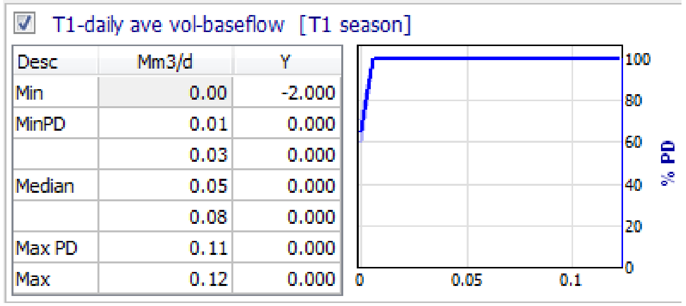
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.600</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.300</td></tr>
<tr><td></td><td>50.00</td><td>-0.100</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.400</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.600</td></tr>
</table>

</td><td>Reduced chironimid abundance reduces prey abundance which negatively impacts the growth, development and survival of individuals. Larval and juvenile L. natalensis are expected to be affected since invertebrates form an important component of the diet of younger age classes. Effects will be mitigated to a large degree by ability to switch prey species.</td><td>High</td></tr>
<tr><td>


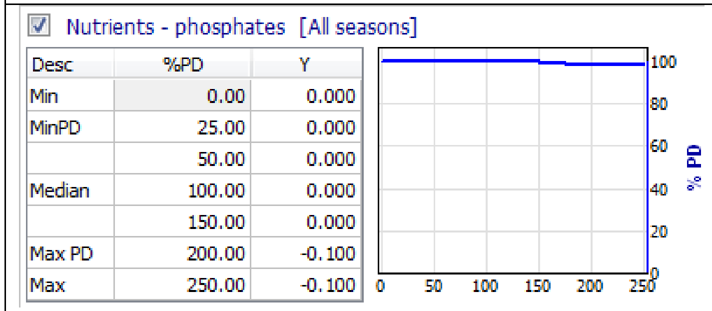
☑ Dry-daily ave vol-baseflow [D season]

<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>0.01</td><td>-0.500</td></tr>
<tr><td></td><td>0.03</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.09</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.14</td><td>0.000</td></tr>
<tr><td>Max</td><td>0.16</td><td>0.000</td></tr>
</table>

</td><td>Through the Dry Season, juvenile L. natalensis are rheophilic and feed in FS, FI and FD Flow Depth classes (EWR survey data). However, it is assumed that their presence here is a consequence of their feeding rather than physiological requirements - these requirements are already accounted for through links to macro-invertebrate indacors. Some fish passage and dispersal by juveniles between pools is required.</td><td>High</td></tr>
</table>

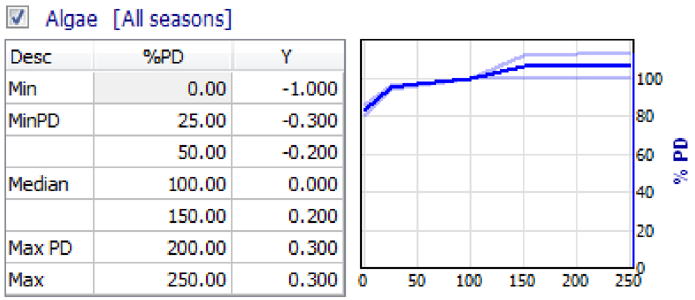
<table>
<tr><td colspan="3">L. natalensis NS1</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Wet-daily ave vol-baseflow [F season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.500</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.500</td></tr>
<tr><td></td><td>0.02</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.11</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>0.18</td><td>0.200</td></tr>
<tr><td>Max</td><td>0.21</td><td>0.300</td></tr>
</table>
</td><td>South African yellwofishes are known to select faster Flow Depth classes (FS, FI, FD) and higher velocities for spawning (Karrsing 2008, Paxton and King 2009, O'Brien and de Villiers 2011). Reduced availability of these habitat conditions impair water flow around eggs in spawning gravels and increase embryo and larval mortality. The proportion of suitable Flow Depth classes in the reach is reduced below the median MinPD Wet-daily average baseflow discharge (0.6 m3/s). Increases over this value are at NS1 not expected to be limiting, but will benefit L. natalensis.</td><td>High</td></tr>
<tr><td>
☑ T1-daily ave vol-baseflow [T1 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>0.01</td><td>0.000</td></tr>
<tr><td></td><td>0.03</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.08</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.11</td><td>0.000</td></tr>
<tr><td>Max</td><td>0.12</td><td>0.000</td></tr>
</table>
</td><td>L. natalensis undertakes migration over the spring transitional period (T1) Karssing 2009) fish passage, minimum depths. At discharges <0.4 m3/s fish passage will be constrained by maximum depths <0.3 m (Q calculated from Mm3).</td><td>Medium</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Clarkson, R.W. and Childs, M.R. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia, 2000: 402-412.
Hellawell, J. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science. London.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.
Karssing, R.J. 2008. Status of the Kwazulu-Natal yellowfish Labeobarbus natalensis (Castelnau 1861). In: Technical report on the state of the yellowfishes in South Afica. Impson, N.D; Bills I.R. and L. Wolhuter (eds). WRC Report No. KV 212/08. Water Research Commission, Pretoria. 186 pp.</td></tr>
</table>

7.9.11 Indicator 11: Mozambique tilapia

<table>
<tr><td colspan="3">O. mossambicus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


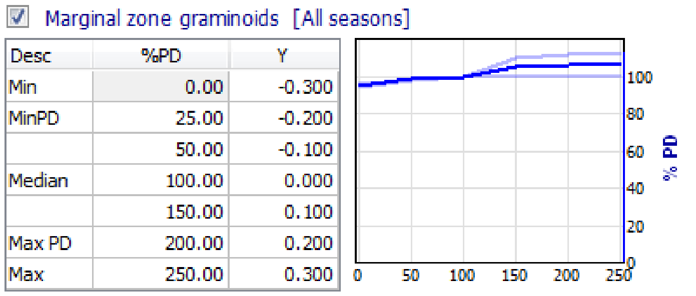
☑ Nutrients - phosphates [All seasons]

<table>
<tr><th>Desc</th><th>%PD</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>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>-0.100</td></tr>
</table>

</td><td>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible to moderate effect on populations. However, O. mossambicus is very tolerant of impaired water quality conditions, negative response will be minor (DWA 2013).</td><td>Medium</td></tr>
<tr><td>


☑ Algae [All seasons]

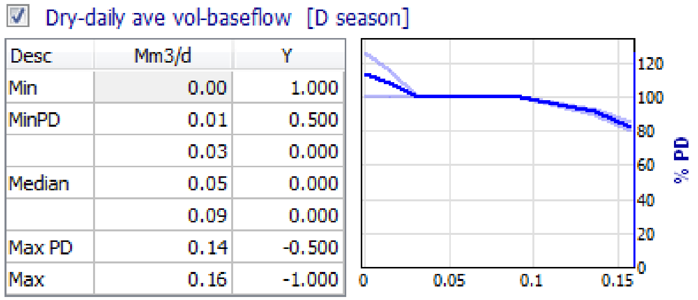
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-1.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-0.300</td></tr>
<tr><td></td><td>50.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.200</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>0.300</td></tr>
<tr><td>Max</td><td>250.00</td><td>0.300</td></tr>
</table>

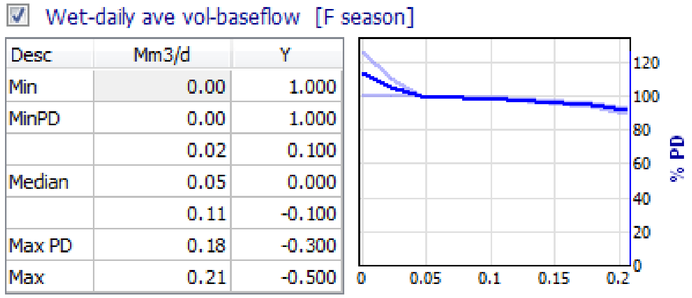
</td><td>Algae form an important component of the diet of O. mossambicus. Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources.</td><td>Medium</td></tr>
<tr><td>


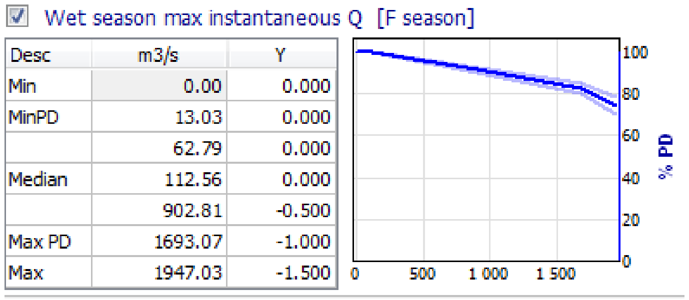
☑ Marginal zone graminoids [All seasons]

<table>
<tr><th>Desc</th><th>%PD</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>-0.200</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>0.100</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>0.300</td></tr>
</table>

</td><td>Juvenile and adult O. mossambicus make use of marginal zone vegetation for hydraulic and predation cover. Reduced availability of this type of cover will increase predation and hydraulic stress on individuals.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="3">O. mossambicus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Dry-daily ave vol-baseflow [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>0.01</td><td>0.500</td></tr>
<tr><td></td><td>0.03</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.09</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.14</td><td>-0.500</td></tr>
<tr><td>Max</td><td>0.16</td><td>-1.000</td></tr>
</table>

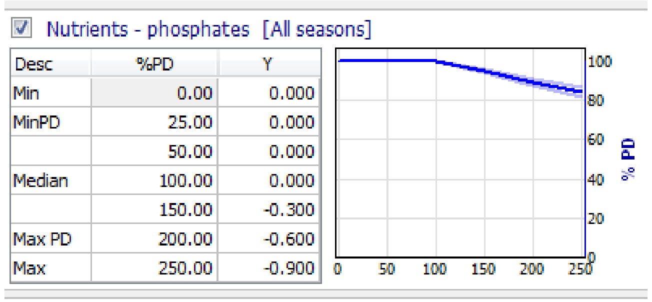
</td><td>O. mossambicus favours slow flow classes, the reduced availability of these at base flows over the MedianPD levels for the Dry Season (5 m3/s) would increase hydraulic stress on inividuals and negatively impact their growth and survival.</td><td>Medium</td></tr>
<tr><td>

☑ Wet-daily ave vol-baseflow [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>0.00</td><td>1.000</td></tr>
<tr><td></td><td>0.02</td><td>0.100</td></tr>
<tr><td>Median</td><td>0.05</td><td>0.000</td></tr>
<tr><td></td><td>0.11</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>0.18</td><td>-0.300</td></tr>
<tr><td>Max</td><td>0.21</td><td>-0.500</td></tr>
</table>

</td><td>O. mossambicus favours slow flow classes, the reduced availability of these at base flows over the MedianPD levels for the Wet Season (10 m3/s) would increase hydraulic stress on inividuals and negatively impact their growth and survival.</td><td>Medium</td></tr>
<tr><td>

☑ Wet season max instantaneous 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>13.03</td><td>0.000</td></tr>
<tr><td></td><td>62.79</td><td>0.000</td></tr>
<tr><td>Median</td><td>112.56</td><td>0.000</td></tr>
<tr><td></td><td>902.81</td><td>-0.500</td></tr>
<tr><td>Max PD</td><td>1693.07</td><td>-1.000</td></tr>
<tr><td>Max</td><td>1947.03</td><td>-1.500</td></tr>
</table>

</td><td>During the larger floods (>1:5 years: 70 m3/s): juvenile and adult fish to seek are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted and the amount of pool habitat in the main channel will be reduced.</td><td>Low</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary</td></tr>
</table>

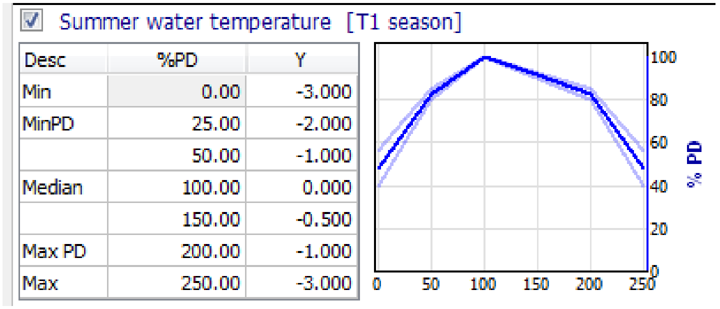
<table>
<tr><td colspan="3">O. mossambicus</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td colspan="3">Reaches for Secondary Catchments in South Africa. FRAI reference data. Draft. Compiled by RQS-RDM.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.</td></tr>
</table>

7.9.12 Indicator 12: Incomati chiselmouth

<table>
<tr><td colspan="3">V. nelspruitensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Nutrients - phosphates [All seasons]

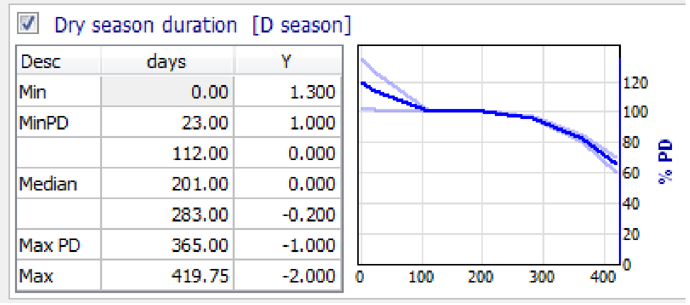
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>0.000</td></tr>
<tr><td></td><td>50.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.300</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>-0.600</td></tr>
<tr><td>Max</td><td>250.00</td><td>-0.900</td></tr>
</table>

</td><td>Excessive nutrients result in eutrophication and increased Biological Oxygen Demand (BOD) which would result in physiological stress on V. nelspruitensis adults and juveniles. Phosphate >0.025 mg/l is considered eutrophic, any value over current median values of 0.05 mg/l is expected to have a negligible effect on populations. V. nelspruitensis is considered moderately intolerant of impaired water quality conditions (DWA 2013).</td><td>Medium</td></tr>
<tr><td>

☑ Summer water temperature [T1 season]

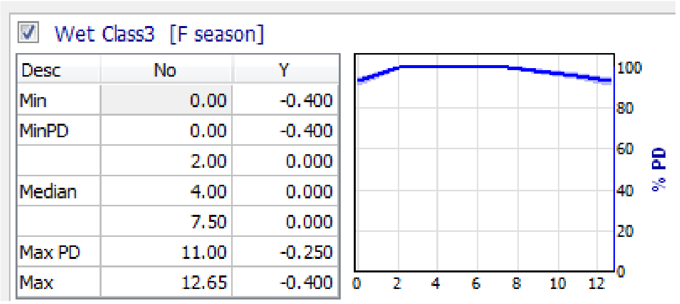
<table>
<tr><th>Desc</th><th>%PD</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-2.000</td></tr>
<tr><td></td><td>50.00</td><td>-1.000</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>-0.500</td>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

</td><td>Low temperatures inhibit gonadal maturation and spawning, slow embryonic development, depress growth and alter behaviour and feeding of fish (Clarkson and Childs 2000). A 10 C increase in temperature doubles an organisms metabolic rate, increased oxygen demand (Hellawell 1986). L. marequensis is tolerant of a wide temperature range that enables it to colonise mountain streams and lowland rivers. Adults and juveniles are mobile and will be able to seek out temperature refugia. Reproductive cycles, however, will be affected by temperature changes. Lower than normal temperatures are likely to delay spawning and slow</td><td>High</td></tr>
</table>

<table>
<tr><th colspan="3">V. nelspruitensis</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td></td><td>embryonic development. Higher than normal temperatures in spawning gravels may increase egg mortality. Temperatures over the Wet Season are not expected to vary by more than 10% under PD</td><td></td></tr>
<tr><td>


☑ Dry season duration [D season]

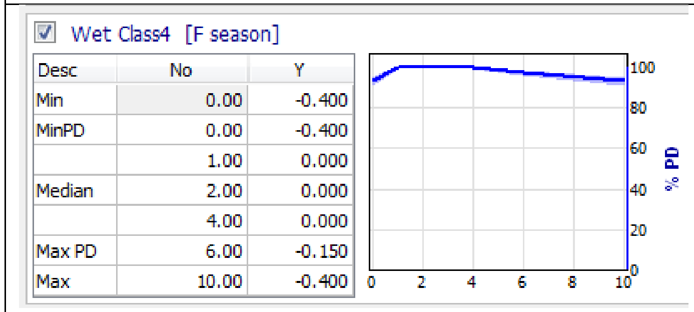
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>1.300</td></tr>
<tr><td>MinPD</td><td>23.00</td><td>1.000</td></tr>
<tr><td></td><td>112.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>201.00</td><td>0.000</td></tr>
<tr><td></td><td>283.00</td><td>-0.200</td></tr>
<tr><td>Max PD</td><td>365.00</td><td>-1.000</td></tr>
<tr><td>Max</td><td>419.75</td><td>-2.000</td></tr>
</table>

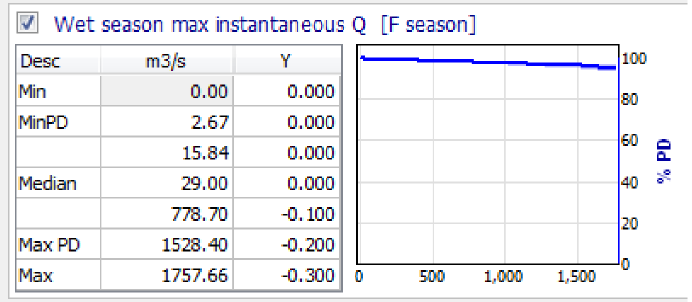
</td><td>V. nelspruitensis permanently occupies and feeds in fast Flow Depth classes (FS, FI, FD). Limited availability of optimal habitat conditions under extended Dry Season conditions is expected to increase intra-specific competition and reduce fish growth and condition. Conversely, an extended Wet Season is expected to benefit V. nelspruitensis populations. However Dry Season thresholds of 1.68 and 3.16 m3/s would provide suitable habitat for spawning over the duration of the extended Dry Season - population declines would therefore be mitigated.</td><td>High</td></tr>
<tr><td>


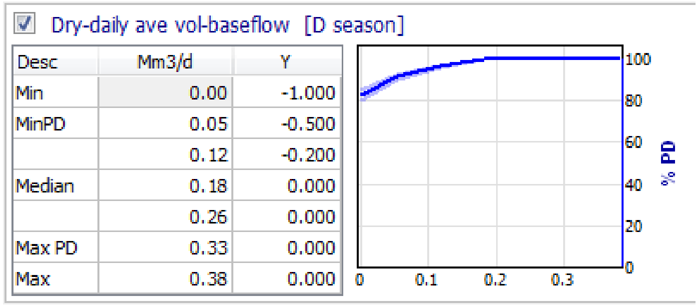
☑ Wet Class3 [F season]

<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.400</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.400</td></tr>
<tr><td></td><td>2.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>4.00</td><td>0.000</td></tr>
<tr><td></td><td>7.50</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>11.00</td><td>-0.250</td></tr>
<tr><td>Max</td><td>12.65</td><td>-0.400</td></tr>
</table>

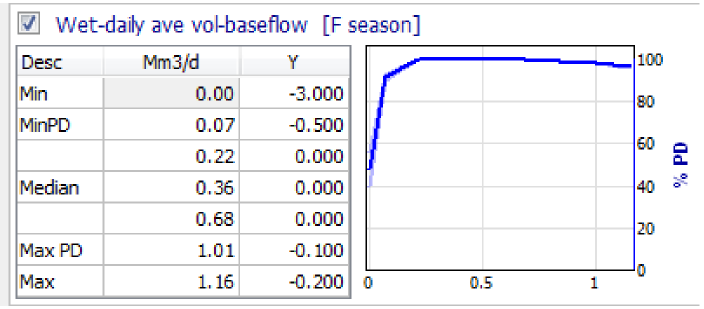
</td><td>Intra-annual floods over the early Wet Season trigger spawning and migration. V. nelspruitensis populations assumed to spawn and migrate at the same time as L. marequensis (September and October: Fouche 2013). Too many floods may wash larvae from nursery habitat.</td><td>Low</td></tr>
</table>

<table>
<tr><td colspan="3">V. nelspruitensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Wet Class4 [F season]
<table>
<tr><th>Desc</th><th>No</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.400</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>-0.400</td></tr>
<tr><td></td><td>1.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>2.00</td><td>0.000</td></tr>
<tr><td></td><td>4.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>6.00</td><td>-0.150</td></tr>
<tr><td>Max</td><td>10.00</td><td>-0.400</td></tr>
</table>

</td><td>Intra-annual floods over the early Wet Season trigger spawning migrations. V. nelspruitensis populations assumed to spawn and migrate at the same time as L. marequensis (September and October: Fouche 2013). Too many floods may wash larvae from nursery habitat.</td><td>Low</td></tr>
<tr><td>

☑ Wet season max instantaneous 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>2.67</td><td>0.000</td></tr>
<tr><td></td><td>15.84</td><td>0.000</td></tr>
<tr><td>Median</td><td>29.00</td><td>0.000</td></tr>
<tr><td></td><td>778.70</td><td>-0.100</td></tr>
<tr><td>Max PD</td><td>1528.40</td><td>-0.200</td></tr>
<tr><td>Max</td><td>1757.66</td><td>-0.300</td></tr>
</table>

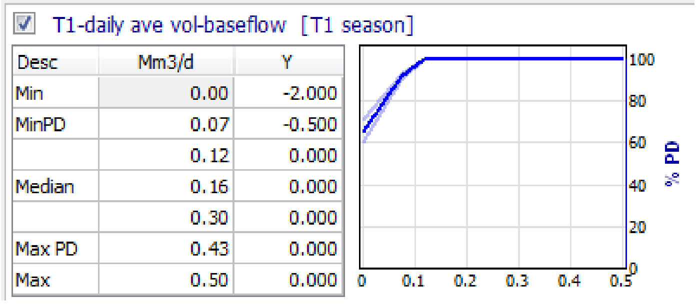
</td><td>Larger floods (>1:5 years: 70 m3/s): Juvenile and adult fish are able to seek hydraulic cover in marginal slackwaters and backwaters. However, feeding and spawning will be interupted.</td><td>Low</td></tr>
<tr><td>

☑ Dry-daily ave vol-baseflow [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>0.05</td><td>-0.500</td></tr>
<tr><td></td><td>0.12</td><td>-0.200</td></tr>
<tr><td>Median</td><td>0.18</td><td>0.000</td></tr>
<tr><td></td><td>0.26</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.33</td><td>0.000</td></tr>
<tr><td>Max</td><td>0.38</td><td>0.000</td></tr>
</table>

</td><td>V. nelspruitensis favours faster Flow Depth classes (FS, FI, FD) (N.Kleynhans pers. V. nelspruitensis favours faster Flow Depth classes (FS, FI, FD) (N.Kleynhans pers. comm.). Reduced availability of these habitat conditions increases physiological stress and intra-specific competition reduces individual fitness and condition. The proportion of suitable Flow Depth classes in the reach is significantly reduced below the median Dry-daily ave vol baseflow (0.86 m3/s). Baseflows 1 m3/s will benefit V. nelspruitensis populations.</td><td>Medium</td></tr>
</table>

<table>
<tr><th colspan="3">V. nelspruitensis</th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>


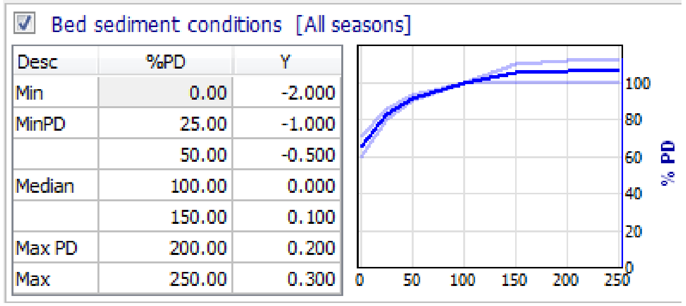
☑ Wet-daily ave vol-baseflow [F season]

<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>0.07</td><td>-0.500</td></tr>
<tr><td></td><td>0.22</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.36</td><td>0.000</td></tr>
<tr><td></td><td>0.68</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>1.01</td><td>-0.100</td></tr>
<tr><td>Max</td><td>1.16</td><td>-0.200</td></tr>
</table>

</td><td>V. nelspruitensis is known to select faster Flow Depth classes (FS, FI, FD) and higher velocities for spawning and feeding (N. Kleynhans pers. comm.). Reduced availability of these habitat conditions impair water flow around eggs in spawning gravels and increase embryo mortality. The proportion of suitable Flow Depth classes in the reach is reduced below the Wet-daily average baseflow discharge (2.5 m3/s). Increases over this value will improve spawning habitat to a point where Slow Shallow habitat for larval and early juvenile life stages become limiting (Q calculated from Mm3).</td><td>Medium</td></tr>
<tr><td>


☑ T1-daily ave vol-baseflow [T1 season]

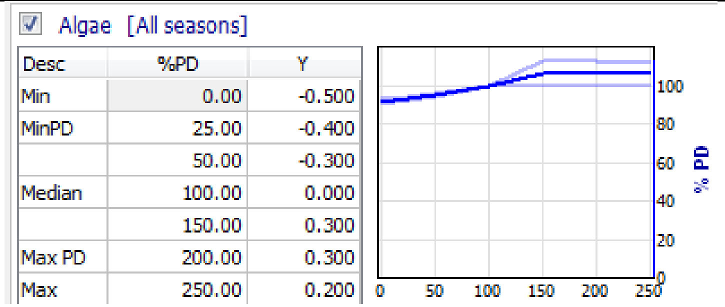
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-2.000</td></tr>
<tr><td>MinPD</td><td>0.07</td><td>-0.500</td></tr>
<tr><td></td><td>0.12</td><td>0.000</td></tr>
<tr><td>Median</td><td>0.16</td><td>0.000</td></tr>
<tr><td></td><td>0.30</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>0.43</td><td>0.000</td></tr>
<tr><td>Max</td><td>0.50</td><td>0.000</td></tr>
</table>

</td><td>V. nelspruitensis undertakes migration over the spring transitional period (T1) . Fish passage and minimum depths >0.3 m. At discharges <0.4 m3/s (0.04 Mm3) fish passage will be constrained by maximum depths <0.3 m (Q calculated from Mm3)</td><td>Medium</td></tr>
<tr><td>


☑ Bed sediment conditions [All seasons]

<table>
<tr><th>Desc</th><th>%PD</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>0.100</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>0.300</td></tr>
</table>

</td><td>V. nelspruitensis is a benthic rheophilic spawner and depends on good quality cobble-bed riffles for successful recruitment (N. Kleynhans pers. comm.). Increased sedimentation of riffles reduces the total amount and quality of this habitat.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="3">V. nelspruitensis</td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Algae [All seasons]
<table>
<tr><th>Desc</th><th>%PD</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>-0.300</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.300</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>0.200</td></tr>
</table></td><td>Algae in the form of aufwuchs form an important component of the diet of L. marequensis (N. Kleynhans pers. comm.). Reduced availability will affect adult fish fecundity and condition. Effects may be mitigated by fish being able to switch food sources.</td><td>High</td></tr>
<tr><td>References</td><td></td><td></td></tr>
<tr><td colspan="3">Department of Water Affairs 2013. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. FRAI reference data. Draft. Compiled by RQS-RDM.
Skelton, P.H. 1993. A complete guide to the freshwater fishes of Southern Africa. Southern Book Publishers. Halfway House. 388 pp.</td></tr>
</table>

7.10 Assumptions and limitations

The responses of species to flow change contained in this document are based on best-available-knowledge therefore subject to the limitations of this type of information. Where information for a species response to any environmental variable has not been available, literature from a related species has been used, or a generic response to a particular habitat change has been based on responses by a particular guild. This is especially the case for species such as the Incomati chiselmouth for which very little published literature is available and information for its responses to flow change has been based on similar responses by yellowfish, as well as through communications with local experts. The species presence/absence at a site is also subject to the limitations of gear selectivity, seasonality and site selection as outlined in Section 7.7.10.

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