

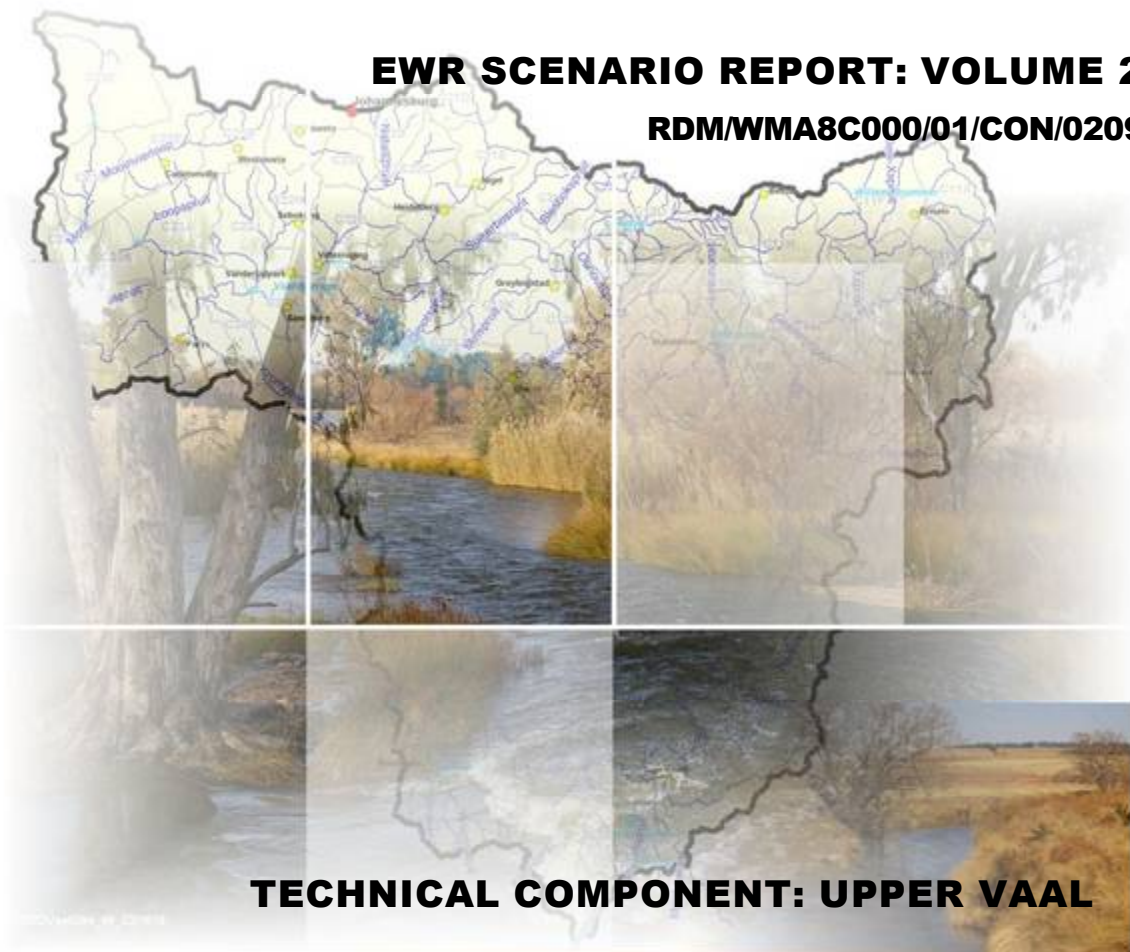
# COMPREHENSIVE RESERVE DETERMINATION

## INTEGRATED VAAL RIVER SYSTEM

### SURFACE WATER

#### EWR SCENARIO REPORT: VOLUME 2

RDM/WMA8C000/01/CON/0209



#### TECHNICAL COMPONENT: UPPER VAAL

NOVEMBER 2009

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**water & forestry**

Department:  
Water Affairs and Forestry  
REPUBLIC OF SOUTH AFRICA

# **COMPREHENSIVE RESERVE DETERMINATION STUDY OF THE INTEGRATED VAAL RIVER SYSTEM**

## **UPPER VAAL WATER MANAGEMENT AREA TECHNICAL COMPONENT: EWR SCENARIO REPORT: VOLUME 2**

**Report number: RDM/WMA8C000/01/CON/00209**

**NOVEMBER 2009**

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## DOCUMENT INDEX

Reports as part of this project:

Index number	RDM Report number	Report title
1.1	RDM/WMA8C000/01/CON/0107	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: Inception Report
1.2	RDM/WMA8C000/01/CON/0207	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: Desktop EcoClassification Report
1.3	RDM/WMA8C000/01/CON/0610	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: Basic Human Needs Reserve. Included in the Main Report.
1.4	RDM/WMA8C000/01/CON/0208	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: Resource Unit Report
1.5	RDM/WMA8C000/01/CON/0109 Volume 1 and 2	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: EcoClassification Report
1.6	<b>RDM/WMA8C000/01/CON/0209</b> <b>Volume 1 and 2</b>	<b>Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: EWR Scenario Report</b>
1.7	RDM/WMA8C000/01/CON/0110	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: Ecological and Goods & Services Consequences of Various Operational Scenarios.
1.8	RDM/WMA8C000/01/CON/0210	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: Socio Economic Consequences of Various Operational Scenarios.
1.9	RDM/WMA8C000/01/CON/0310	Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: EcoSpecs Report
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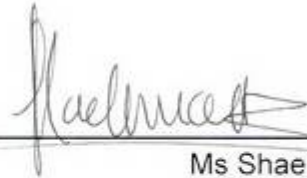
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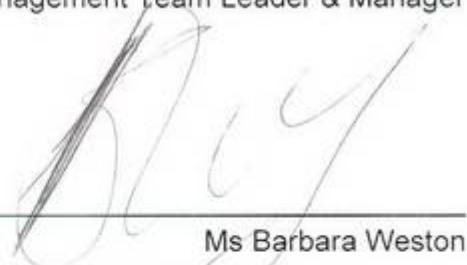


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## ABBREVIATIONS AND ACRONYMS

A/MSL	Above/Mean Sea Level
Ave	Average
BBM	Building Block Methodology
CD: RDM	Chief Directorate: Resource Directed Measures
CSIR	Centre for Scientific and Industrial Research
D:RQS	Directorate: Resource Quality Services
DRM	Desktop Reserve Model
DTM	Digital Terrain Model
DWA	Department of Water Affairs (Name change 2009)
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
EWR/s	Environmental Water Requirement/s
FBR	Fast over Bedrock
FCS	Fast over Coarse Sediment
FD	Fast (velocity > 0.3 m/s) and Deep (depth > 0.3 m)
FDI	Flow dependent macroinvertebrate
FFS	Fast over Fine Sediment
FI	Fast (velocity > 0.3 m/s) and Intermediate depth (0.2 m < depth < 0.3 m)
FS	Fast shallow fish habitat
Geom.	Geomorphology/ical
GPS	Global Positioning System
HFSR	Habitat Flow Stressor Response
Integ	Integrated
Invert's	Macroinvertebrates
LIDAR	Light Detection And Ranging
LIM	Limnophilic fish species
LSR	Large semi-rheophilic fish species
Marg.	Marginal
Max.	Maximum
Meas.	Measured
Min.	Minimum
MS	Microsoft
MVI	Marginal vegetation macroinvertebrate
OWS	Observed water surface
OWS	Observed water surface
PD	Present Day
PES	Present Ecological State
prep.	preparation
Quat	Quaternary catchment
REC	Recommended Ecological Category
REC	Recommended Ecological Category
RU	Resource Unit
SBR	Slow over Bedrock
SCS	Slow over Coarse Sediment
SD	Slow deep fish habitat
SFS	Slow over Fine Sediment
SR	Small rheophilic fish
SS	Slow shallow fish habitat
SSR	Small semi-rheophilic fish species
VEG	Fringing vegetation
Veg.	Vegetation

VFBR	Very Fast over Bedrock
VFCS	Very fast over coarse substrate habitat
VFCS	Very Fast over Coarse Sediment
VFFS	Very Fast over Fine Sediment
VSBR	Very Slow over Bedrock
VSCS	Very Slow over Coarse Sediment
VSFS	Very Slow over Fine Sediment
WL	Water level
WMA	Water Management Area
WRC	Water Research Commission
WS	Water surface
1/2/3/-D	One/Two/Three/-Dimensional

**APPENDIX A: ECOHYDRAULICS OF THE UPPER VAAL RIVER SYSTEM**

Dr AL Birkhead, Streamflow Solutions

## **ACKNOWLEDGEMENTS**

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The contributions to site selection and data collection by Delana Louw (Water for Africa), Mark Rountree (Fluvius Environmental Consultants), James Mackenzie (BioRiver Solutions), Shael Koekemoer (Koekemoer Aquatic Services) and Piet Kotze (Clean Stream Biological Services) are gratefully acknowledged. The Digital Terrain survey of EWR 3 on the Vaal River was assisted by Sean McGee of Underwater Surveys.

## **A1 OBJECTIVES**

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The objectives of the ecohydraulic component of this study are to provide geomorphologically and ecologically relevant hydraulic information (data collection, analysis and results) for assessing the Environmental Water Requirements (EWRs) at thirteen sites along the Upper Vaal River system.

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## **A2 ECOHYDRAULIC INFORMATION FOR ENVIRONMENTAL WATER ASSESSMENT ALONG THE UPPER VAAL RIVER SYSTEM**

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The application of holistic methods for ecological flow determination (refer to Tharme, 1996) requires environmental flow requirements to be expressed as discharge rates (including its temporal characteristics) through assessments of the presence of suitable habitat for certain biota at different flows. The interface between the way in which flow requirements are assessed and expressed is through the results of hydraulic measurements, analyses and modelling at sites along rivers. The primary product of these hydraulic analyses are relationships between discharge and the following determinants, which have been found over the course of numerous flow assessments, to be the most useful: depth (maximum and average), velocity (average), wetted perimeter, and width of the water surface. The discharge-depth (or rating) relationship is fundamental to hydraulic analysis, and is generally derived from a combination of measured and synthesized data (refer to Rowston *et al.* (2000), Birkhead (1999), Jordanova *et al.* (2004), Hirschowitz *et al.* (2007) and Birkhead (in press) for descriptions of procedures for deriving hydraulic information for use in EWRs in South Africa). Once the rating relationship for a river section has been developed, the relationships between discharge and the other hydraulic parameters (listed above) may readily be computed using the cross-sectional geometry, and are generally provided in tabular format using look-up tables (refer to Section A3.2).

The cross-sectional profile plots and look-up tables comprise the “standard hydraulic data” used in EWR determinations in South Africa. Ecologists use these standard hydraulic data with the aid of site assessments and photographs to determine the quantity and quality of hydraulic habitat at different flows. Substantial experience and interpretation are required to provide assessments of site-based and reach-based biological habitats using cross-sectional surveys and the results of one-dimensional hydraulic analyses (biological habitat refers to the integration of the different components defining habitat (e.g. hydraulic, substrate and cover attributes for fish)). Procedures have therefore been developed for using standard hydraulic information as the basis for quantifying hydraulic habitat for fish (refer to Hirschowitz *et al.* (2007) and Birkhead (in press) for an explanation of the method). The method allows the assessment of abundance of different flow classes to be applied more consistently in EWRs, and has been used in this study.

### **A2.1 DATA COLLECTION**

The measured discharge and flow depth data are provided in Table A1, together with the dates when the data were collected.

**Table A1 Hydraulic data collected at EWR sites along the Upper Vaal River System**

Site no.	River (Site)	DWA Gauge no.	Date	Discharge Q (m <sup>3</sup> /s)	Max. flow depth y (m)	Stage AMSL z (m)
EWR 1	Vaal (Uitkoms)	C1H007	21/09/07 <sup>6</sup>	4.8	0.74	n/a
			07/04/08	5.5	0.81	
			08/12/07	17	1.05	
			09/11/07	146	1.68	
EWR 2	Vaal (Grootdraai)	C1H019	18/09/07 <sup>6</sup>	0.30	0.27	n/a
			08/04/08	7.43	0.68	
			09/12/07	29.6	1.10	
			09/11/07	108	2.14	
			08/11/07	200	2.99	
			07/11/07	318	4.30	
EWR 3	Vaal (Gladdedrift) <sup>5</sup>	C1H012	17/09/07 <sup>3, 6</sup>	0.040	1.01	1512.96
			07-10/07/07 <sup>3, 6</sup>	1.36	1.22	1513.17
			08/04/08	14.5	1.63	1513.58
			08/12/07	67	2.90	1514.85
			09/11/07	368	6.03	1517.98
			09/11/07 <sup>4</sup>	398	6.22	1518.17
EWR 4	Vaal (Deneys)	C2H122	07/08/07 <sup>6</sup>	10.0	0.47 <sup>1</sup> - 0.53 <sup>2</sup>	n/a
			11/04/08	14.7	0.50 <sup>1</sup>	
			29/01/08	17.2	0.61 <sup>1</sup>	
EWR 5	Vaal (Scandania)	C2H018	06/08/07 <sup>6</sup>	14.2	0.95	n/a
			11/04/08	19.4	1.09	
			10/01/08	95.5	1.12	
			26/01/08 <sup>4</sup>	110	1.73	
EWR 6	Klip		18/09/07 <sup>6</sup>	0.003	0.16	n/a
			08/04/08	1.0	0.45	
			08/11/07	4.3	0.62	
EWR 7	Wilge (Upper)		09/04/08 <sup>6</sup>	0.33	0.86	n/a
EWR 8	Wilge (Bavaria)	C8H028	19/09/07 <sup>6</sup>	0.003	0.08	n/a
			10/04/08	6.8	0.81 <sup>1</sup> - 1.23 <sup>2</sup>	
			11/12/07	60	1.70	
			09/12/07	152	2.06	
EWR 9	Suikerbos (Upper)		09/08/07 <sup>6</sup>	0.040	0.14 <sup>2</sup> - 0.23 <sup>1</sup>	n/a
			10/04/08	0.110	0.21 <sup>2</sup> - 0.32 <sup>1</sup>	
			10/12/07	0.30	0.29 <sup>2</sup> - 0.53 <sup>1</sup>	
			24/01/08	25	1.60	
EWR 10	Suikerbos (Lower)		09/08/07 <sup>6</sup>	1.9	0.54	n/a
			10/04/08	5.1	0.64	
			10/12/07	6.3	0.73	
			24/01/08	35	1.36	
EWR 11	Blesbokspruit	C2H133	10/08/07 <sup>6</sup>	1.9	0.36	n/a
			14/04/08	3.7	0.46	
			10/12/07	3.6	0.48	
			24/01/08	11.8	1.04	
			20/01/08	25.7	1.48	
RE-EWR 1	Klein Vaal		20/09/07 <sup>6</sup>	0.014	0.12	n/a
			08/11/07	6.9	0.75	
RE-EWR 2	Mooi		08/08/07 <sup>6</sup>	0.050	0.23	n/a
			28/01/08	6.4	1.17	

1: Right channel

2: Left channel

3: DTM Surveys

4: Peak

5: Max. flow depths for cross-section at downstream boundary of modelled rapid area

6: Date/s of topographical survey/s

n/a – not applicable (local datum used)

## **A2.2 MODELLING**

Predicted resistance coefficients, energy slopes and modelled rating relationships are archived electronically in Corel Quattro Pro and MS Excel, and included in the EWR ecohydraulics database (Birkhead *et al.*, in prep.).

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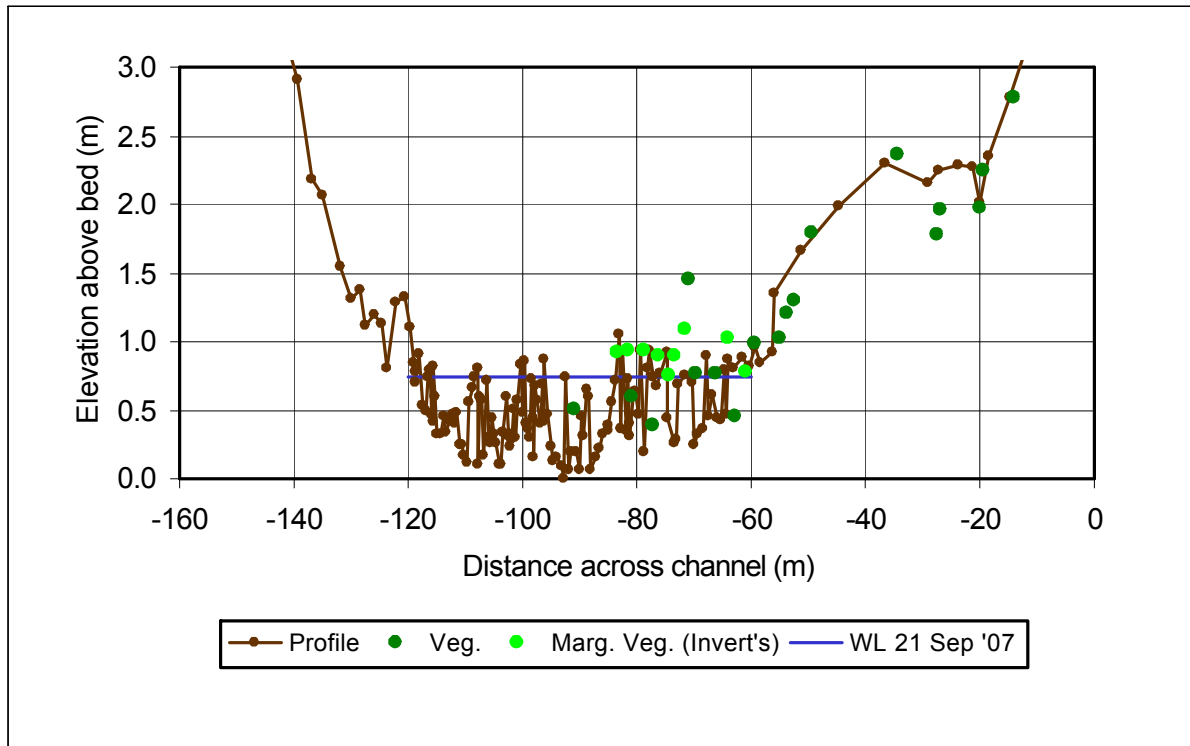
## A3 RESULTS

### A3.1 CROSS-SECTIONAL PROFILES

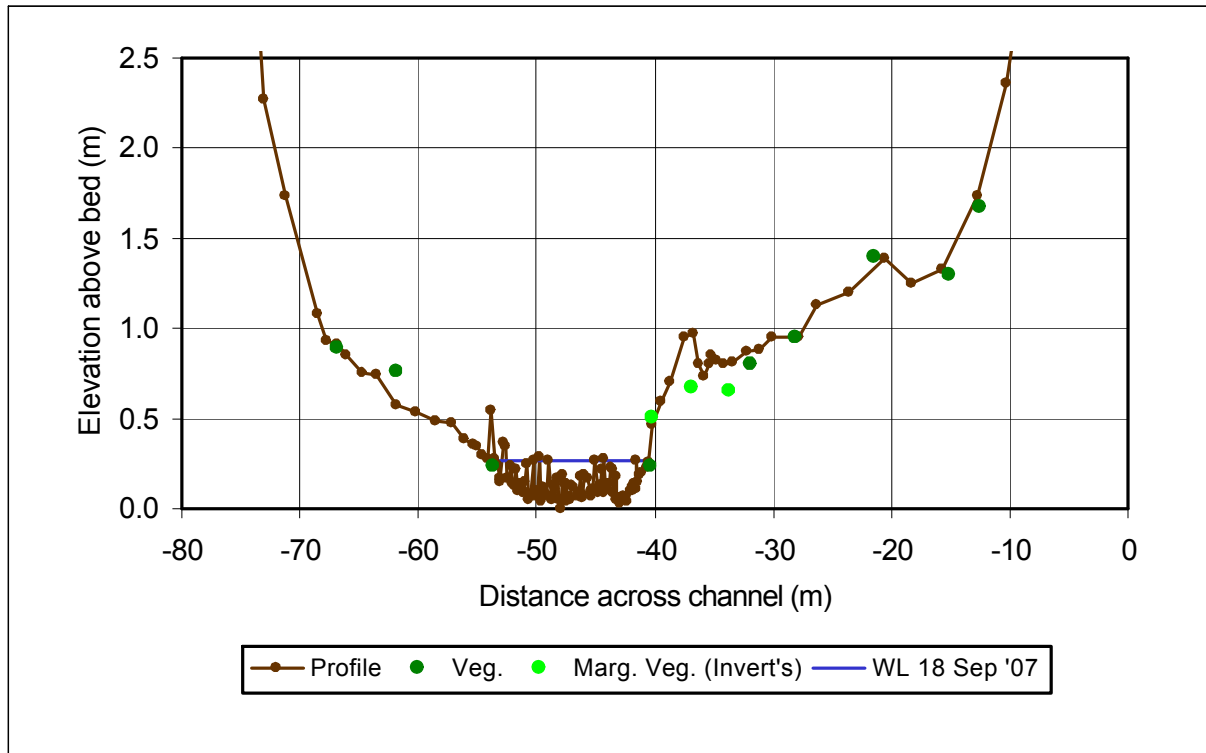
Refer to Figures A1 - A13.

### A3.2 LOOKUP TABLES

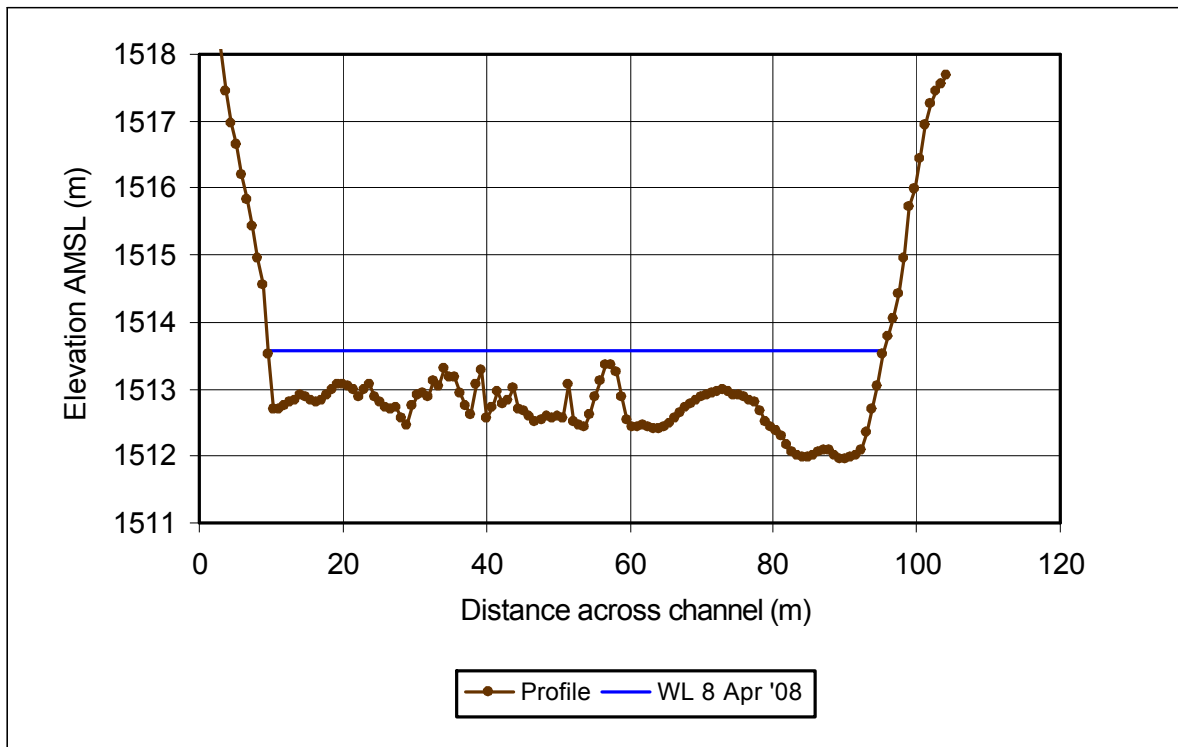
Lookup tables (hydraulic variables and flow-classes) are archived electronically in MS Excel.



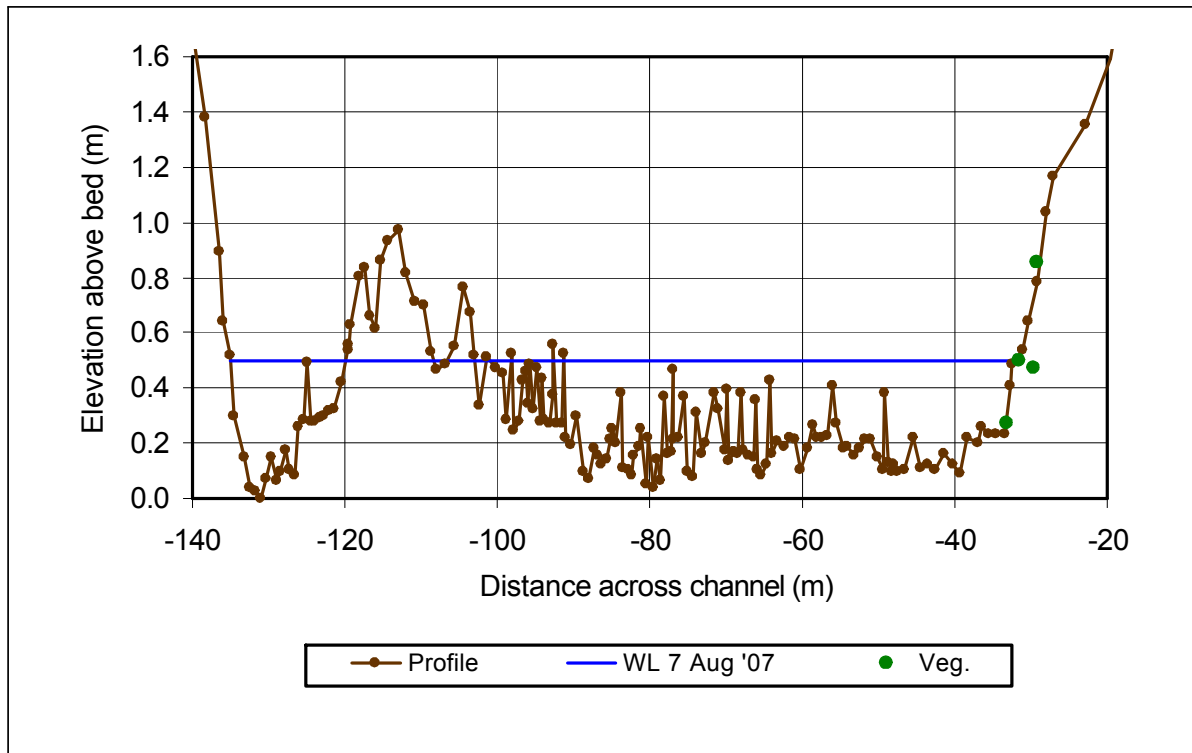
**Figure A1** Cross-sectional profile for EWR 1 (Vaal River), showing the water level (WL) surveyed on 21 Sep 2007 and the position of vegetation (Veg.) markers



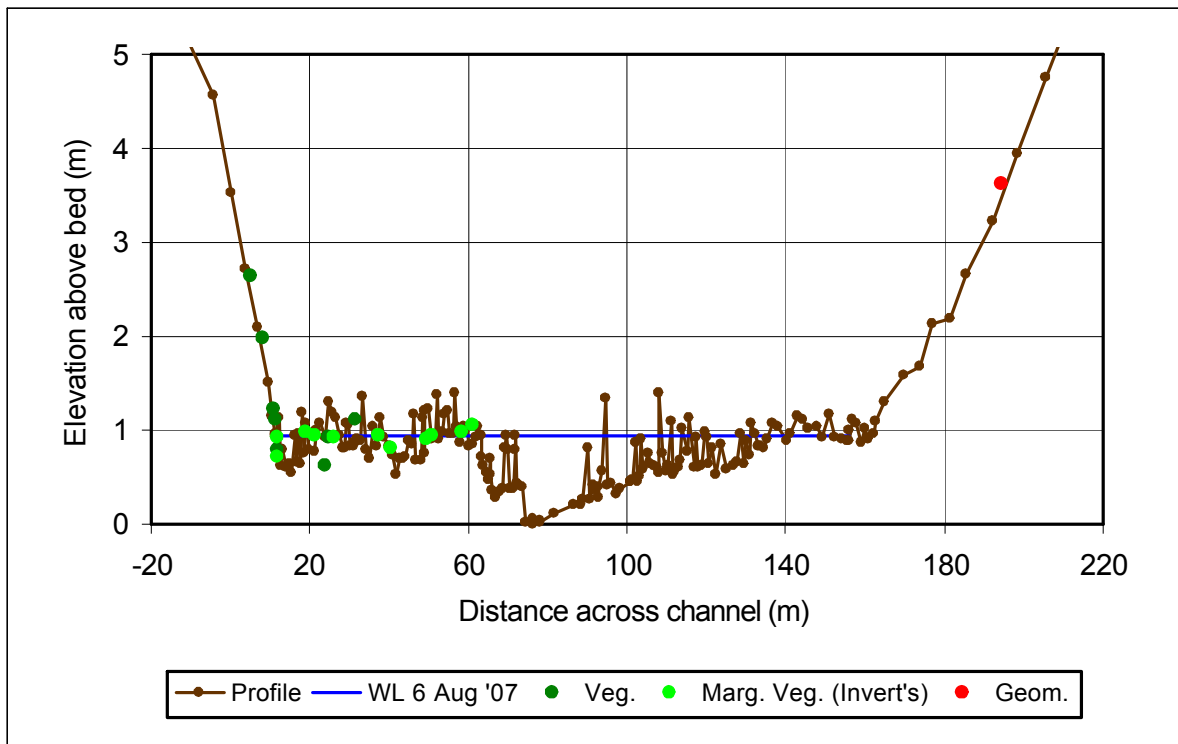
**Figure A2** Cross-sectional profile for EWR 2 (Vaal River), showing the water level (WL) surveyed on 18 Sep 2007 and the position of vegetation (Veg.) markers



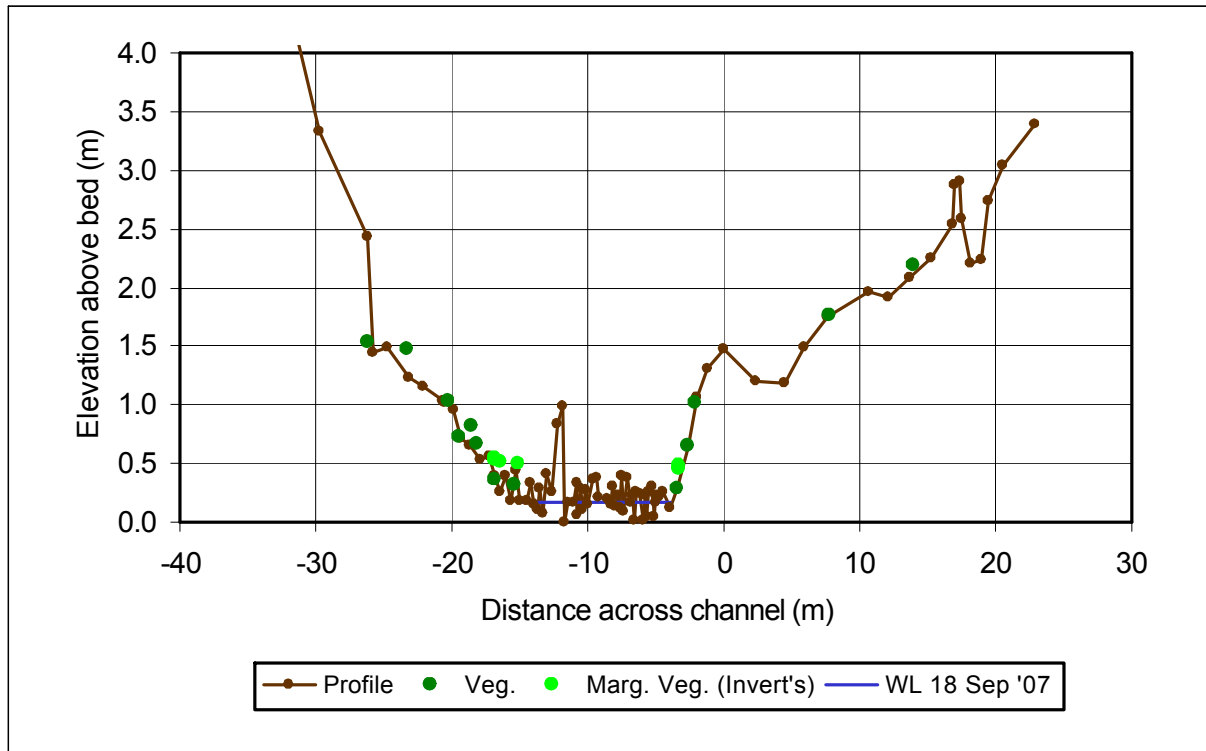
**Figure A3** Cross-sectional profile at the downstream boundary of the modelled rapid area at EWR 3 (Vaal River), showing the water level (WL) surveyed on 8 Apr 2008



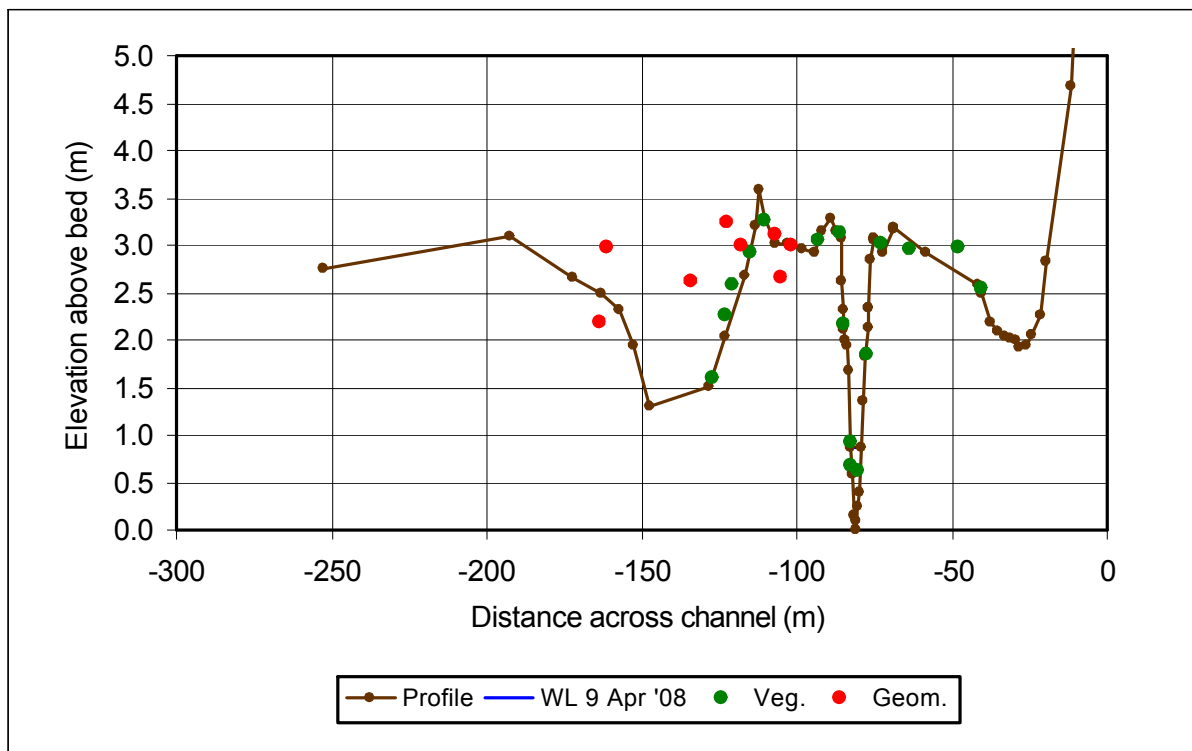
**Figure A4** Cross-sectional profile for EWR 4 (Vaal River), showing the water level (WL) surveyed on 7 Aug 2007 and the position of vegetation (Veg.) markers



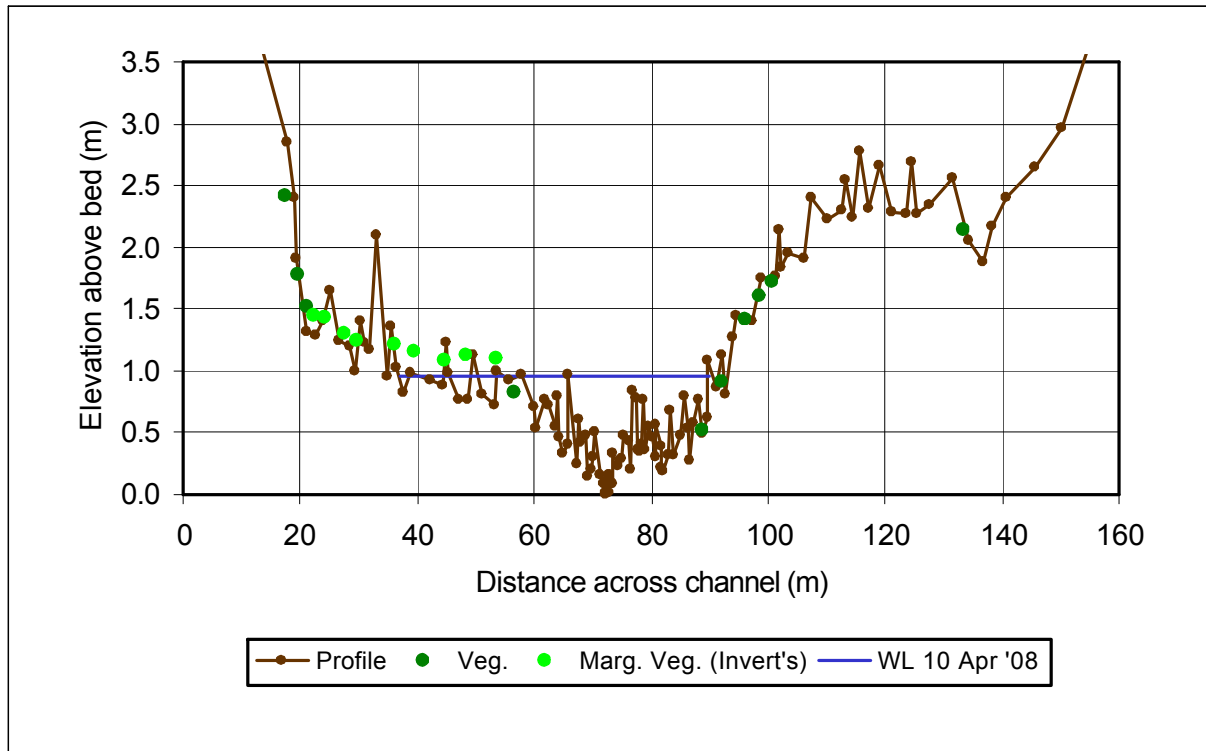
**Figure A5** Cross-sectional profile for EWR 5 (Vaal River), showing the water level (WL) surveyed on 6 Aug 2007 and the position of vegetation (Veg.) and geomorphological (Geom.) markers



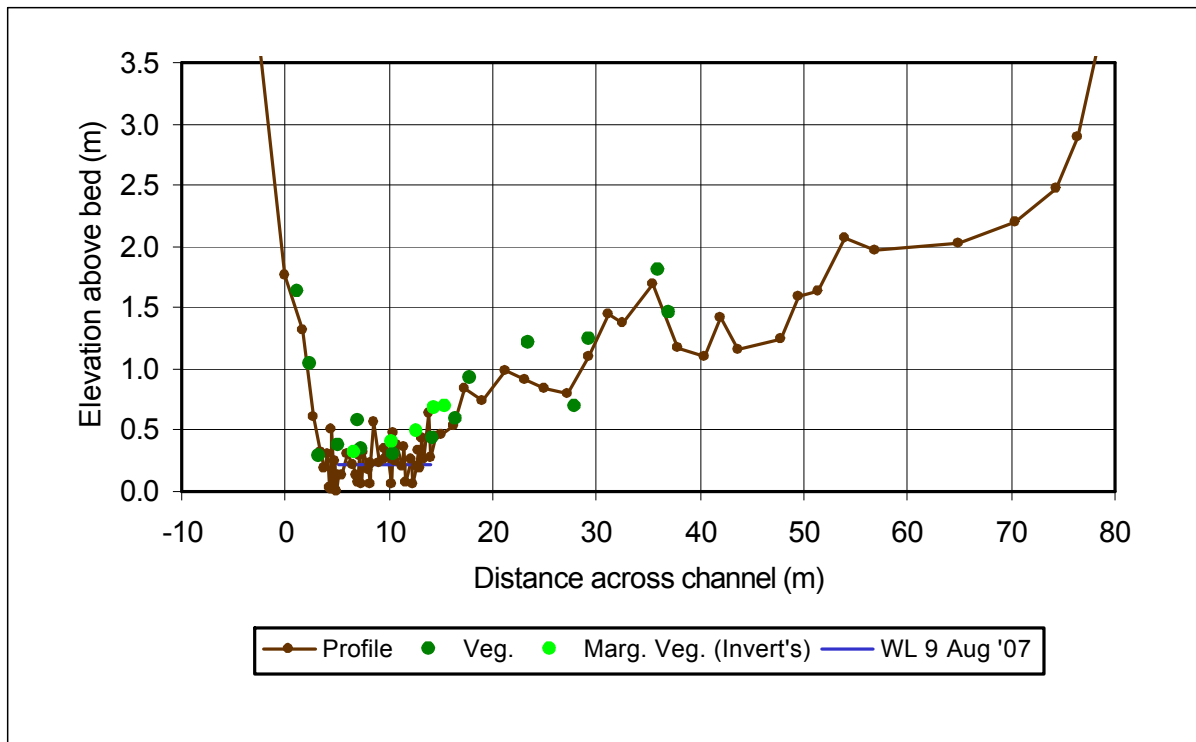
**Figure A6** Cross-sectional profile for EWR 6 (Klip River), showing the water level (WL) surveyed on 18 Sep 2007 and the position of vegetation (Veg.) markers



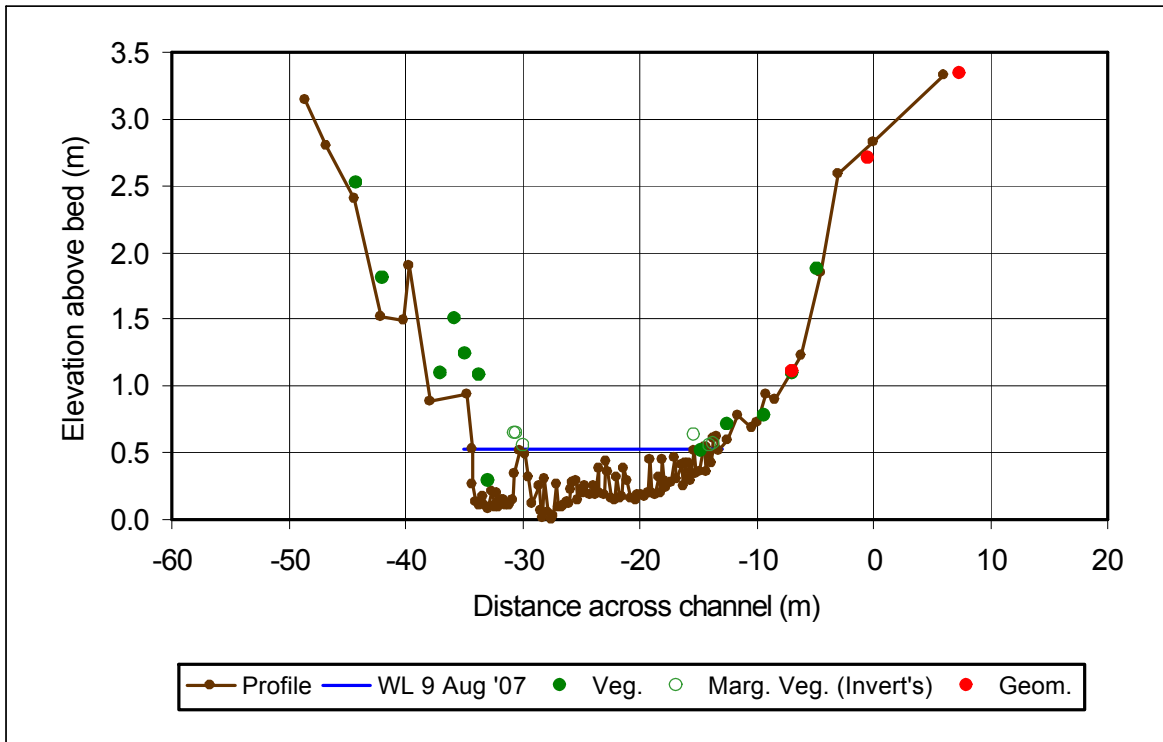
**Figure A7** Cross-sectional profile for EWR 7 (Upper Wilge River), showing the water level (WL) surveyed on 9 Apr 2008 and the position of vegetation (Veg.) and geomorphological (Geom.) markers



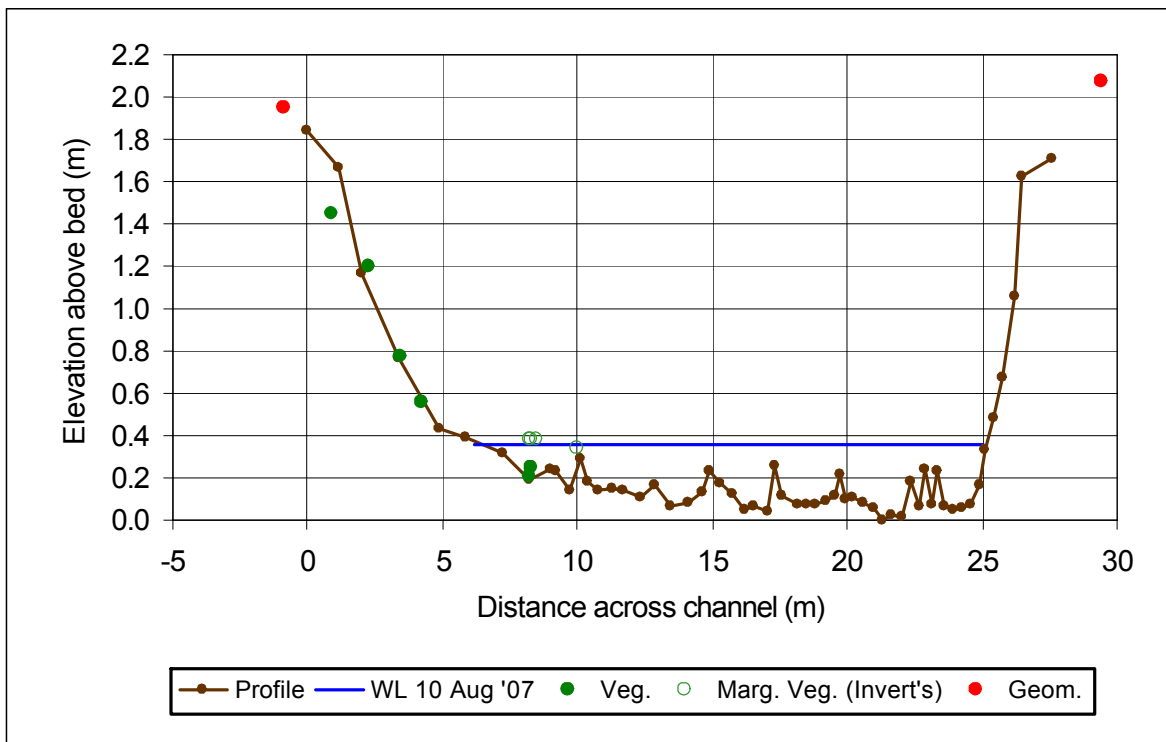
**Figure A8** Cross-sectional profile for EWR 8 (Lower Wilge River), showing the water level (WL) surveyed on 10 Apr 2008 and the position of vegetation (Veg.) markers



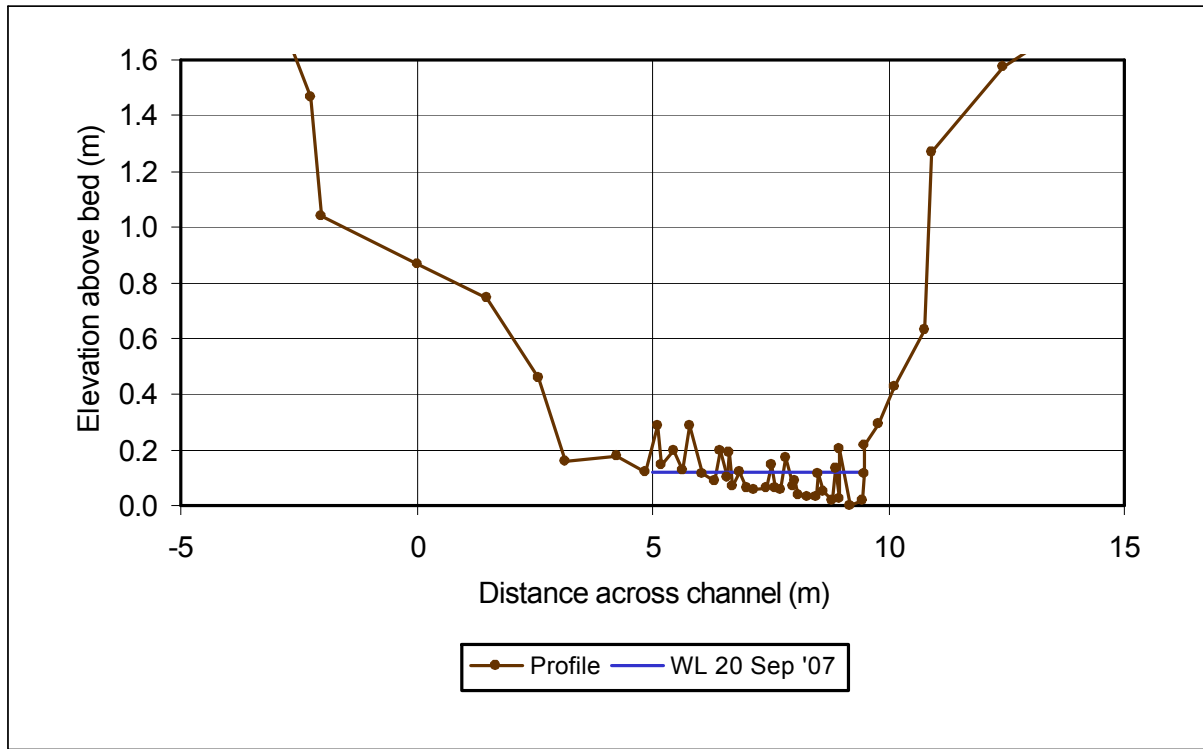
**Figure A9** Cross-sectional profile for EWR 9 (Upper Suikerbos River), showing the water level (WL) surveyed on 9 Aug 2007 and the position of vegetation (Veg.) markers



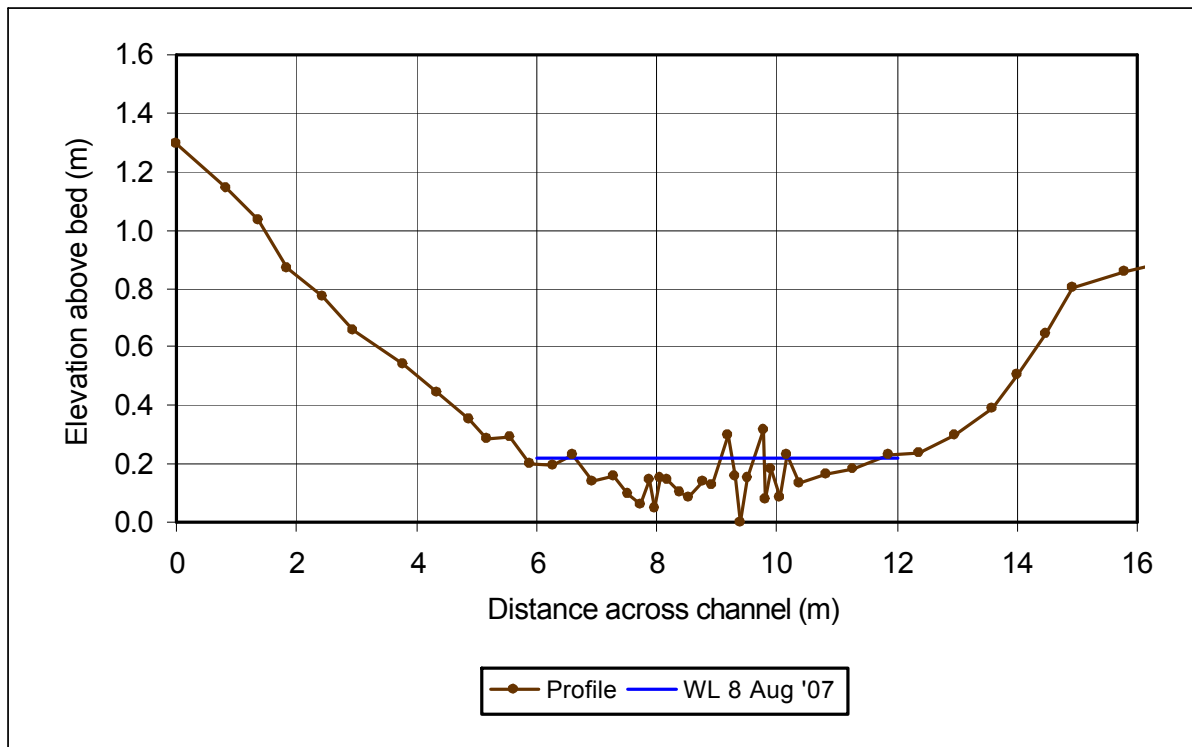
**Figure A10** Cross-sectional profile for EWR 10 (Lower Suikerbos River), showing the water level (WL) surveyed on 9 Aug 2007 and the position of vegetation (Veg.) and geomorphological (Geom.) markers



**Figure A11** Cross-sectional profile for EWR 11 (Blesbokspruit), showing the water level (WL) surveyed on 10 Aug 2007 and the position of vegetation (Veg.) markers and geomorphological (Geom.) markers



**Figure A12** Cross-sectional profile for RE-EWR 1 (Klein Vaal River), showing the water level (WL) surveyed on 20 Sep 2007



**Figure A13** Cross-sectional profile for RE-EWR 2 (Mooi River), showing the water level (WL) surveyed on 8 Aug 2007

## A4 CONFIDENCE IN THE HYDRAULIC CHARACTERISATIONS

The confidence in hydraulic calibrations is provided in Table A2.

**Table A2 Confidence ratings for the hydraulic characterisations**

Site	REC	Season (dry/wet low & high flows)		Discharge, Q (m <sup>3</sup> /s)		Meas. range or values	Rating (Confidence)	Comments
				Exceedance (%)				
				95 <sup>1</sup>	(%) <sup>2</sup>			
1	B/C	Low	Dry	0.34	2.6 <sup>5</sup>	4.8 - 146	2	Complex site. Below meas. min. Q. Non-uniform flow conditions. Uncertainty flow class modelling.
			Wet	2.0	5.5 <sup>5</sup>		3	
		High	6, 18, 60 <sup>8</sup>		4		No meas. Qs between 17 & 146 m <sup>3</sup> /s.	
2	C	Low	Dry	0.15	0.65 <sup>5</sup>	0.30 - 318	4	No meas. Qs between 0.3 & 7.4 m <sup>3</sup> /s.
			Wet	0.40	1.9 <sup>5</sup>		4	
		High	2, 7, 30, 80 <sup>8</sup>		4		No meas. Qs between 0.3 & 7.4 m <sup>3</sup> /s.	
3	C	Low	Dry	0.0	0.48 <sup>4</sup>	0.040 - 398	3	Complex site. Two-dimensional hydraulic modelling.
			Wet	1.4	9.5 <sup>4</sup>		4	
		High	20, 60, 100 - 130 <sup>8,9</sup>		5		Suitable range meas. Qs.	
4	B/C	Low	Dry	5.6	12.0 <sup>4</sup>	10.0 - 17.2	3	Complex site. Below meas. min. Q. Non-uniform flow conditions. Non-horizontal water surfaces. Uncertainty flow class modelling.
			Wet	11.3	27 <sup>6</sup>		4	
		High	15 - 25, 40 - 96, 80 <sup>8</sup>		3		Above meas. max. Q.	
5	C	Low	Dry	4.8	12.5 <sup>4</sup>	14.2 - 110	3	Complex site. Below meas. min. Q. Non-uniform flow conditions. Uncertainty flow class modelling.
			Wet	6.6	44 <sup>4</sup>		4	
		High	50, 180 - 260, 400 - 570 <sup>8,9</sup>		3		Above meas. max. Q.	
6	B/C	Low	Dry	0.02	0.15 <sup>5</sup>	0.003, 1.0 and 4.3	3	Complex site. No meas. Qs between 0.003 & 1.0 m <sup>3</sup> /s.
			Wet	0.12	0.40 <sup>5</sup>		3	
		High	5, 15, 20 - 50 <sup>8,9</sup>		3		Complex site. Above meas. max. Q.	
7	A/B	Low	Dry	0.004	0.048 <sup>3</sup>	0.33	2	Uncertainty regarding stage at zero Q. Single meas. low Q.
			Wet	0.14	0.74 <sup>3</sup>		3	
		High	0.5, 1, 3, 5 <sup>10</sup>		3		Above meas. max. Q.	
8	C	Low	Dry	0.015	0.33 <sup>5</sup>	0.003 - 152	3	Complex site. Non-horizontal water surfaces. No meas. Qs between 0.003 & 6.8 m <sup>3</sup> /s
			Wet	0.42	1.52 <sup>5</sup>		3	
		High	8, 20, 70, 100 - 150 <sup>8,9</sup>		5		Suitable range meas. Qs.	
9	B/C	Low	Dry	0.06	0.11 <sup>5</sup>	0.040 - 25	4	Complex site. Non-horizontal water surfaces. Suitable range meas. Qs.
			Wet	0.18	0.28 <sup>5</sup>		4	
		High	1.5, 5, 8 - 20 <sup>8,9</sup>		3		Complex site. Single meas. high Q.	
10	C/D	Low	Dry	0.78	1.1 <sup>4</sup>	1.9 - 35	3	Below meas. min. Q.
			Wet	1.15	3.7 <sup>4</sup>		3	
		High	3, 5, 6, 11 <sup>10</sup>		4		Suitable range meas. Q.	
11	D	Low	Dry	0.30	0.38 <sup>4</sup>	1.9 - 26	2	Below meas. min. Q.
			Wet	0.37	2.4 <sup>4</sup>		3	
		High	3, 6, 12 <sup>10</sup>		5		Suitable range meas. Q.	
RE 1	C	Low	Dry	0.00	0.033	0.014, 6.9	3	No meas. Qs between 0.014 & 6.9 m <sup>3</sup> /s.
			Wet	0.073	0.18		3	
		High	1, 5, 8, >20 <sup>9,11</sup>		4		Above meas. max. Q.	



## **A5 TWO-DIMENSIONAL HYDRAULIC MODELLING AT EWR SITE 3 ON THE UPPER VAAL RIVER**

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The following discussion - background to two-dimensional (2-D) hydraulic modelling and application to EWR Site 3 on the Upper Vaal River - is an edited version of that provided by Birkhead (in press).

### **A5.1 BACKGROUND**

Two-dimensional hydraulic analyses account for both longitudinal and lateral flow components, and require three-dimensional (3-D) topographical information. The analyses are suitable where lateral flows are appreciable or where sites have divided channels at low flows with different stages or average velocities, and where the region of interest is not extensive.

Diversity of hydraulic conditions and hence the suitability for assessing ecological flows increases with hydraulic complexity, which, in turn, is associated with increasingly complex flow patterns. Most 2-D models are based on the St Venant Equations (which neglect vertical velocities and accelerations) and also assume a hydrostatic vertical pressure distribution. This limits accuracy in areas of steep slopes and rapid changes in bed slope (Steffler and Blackburn, 2006), conditions generally associated with rapids and riffles at low flows. It is therefore necessary to assess the value to ecological flow assessments of employing more sophisticated and rigorous methods of analysis (viz. 2-D or even 3-D). Kondolf *et al.* (2000) maintain that highly accurate hydraulic modelling may not be feasible for rivers with complex topography, and that it cannot resolve flow patterns at the spatial scales at which fish often respond to the environment.

Sites where one-dimensional (1-D) analyses can sensibly be applied are favoured for Reserve determination purposes in South Africa, due to resource constraints. For more hydraulically complex sites, the preference is for collection of additional field data rather than more rigorous hydraulic modelling. Additional data are associated with higher level Reserves.

Due to limited data collection in Rapid III assessments, they are best suited to sites with relatively simple hydraulic characteristics (viz. horizontal cross-river stage in a single channel, low and uniform flow resistance, uniform flow conditions and a site that is dry at the cessation of flow), which are nonetheless useful for flow assessment. At the Comprehensive level of assessment, 2-D hydraulic modelling may be appropriate where, for example, there are no sites suitable for 1-D analysis, or where ecological importance justifies more detailed descriptions and reduced uncertainty. Two-dimensional analyses use more representative topographical information (3-D Digital Terrain Models) to model spatially-explicit depth and depth-averaged velocity. These are used (through frequency analyses) to provide direct estimates of the composition and abundance of flow classes. Furthermore, 2-D modelling allows an assessment of depth connectivity, useful for assessing fish passage, but not provided for by cross-sectional profiles and characteristic depth-frequency distributions.

Hirschowitz *et al.* (2007) provide an assessment of various 2-D hydraulic models with reference to general characteristics, data and their use (topographical, boundary and initial conditions, and hydraulic calibration), and hydraulic limitations (simulation times, flow regime, rapidly-varied flow profiles, wetting and drying, and flow resistance). Based on these considerations, the authors give

certain reasons for selecting River2D (a finite-element hydraulic and habitat simulation model) for local use in ecohydraulic studies.

River2D, developed at the University of Alberta (Canada), is a 2-D depth-averaged finite element hydrodynamic model that has been customised for fish habitat evaluation studies. It comprises three modules relevant to South African conditions, one each for editing bed topography, for generating triangular finite element meshes, and for flow and habitat analyses, mesh editing and refinement. A broad discussion of these is provided by Hirschowitz *et al.* (2007). Two of the reasons cited for selecting River2D are worthy of further discussion - the recurrent problem of wetting and drying, and the value of nested spatial scales.

As water levels change, areas of the channel become wet or dry, and flows through these areas must be added or removed from the computation in a manner that does not compromise conservation of mass or computational stability (adapted from Wright (2001)). Several methods have been developed to account for this, some of which can accommodate changes within an element (a discrete area within the modelled region), but have difficulties when extending over several elements (Quecedo and Pastor, 2002). In Reserve studies, considerable attention is focussed on the low-flow component of the flow regime, where sites are typically characterised by large roughness elements. This requires the analysis of shallow flows with complex boundaries, which, in turn, produces computational instabilities. Accurate modelling requires detailed topographical surveys and the use of a dense mesh (lattice between elements), since flow through a number of adjacent nodes is required for numerical solutions. Furthermore, meshes may need to be reconstructed for different flows due to changes in the position of boundaries and orientation of streamlines (Panfil and Jacobson (1999)). River2D accounts for wetting and drying by using a continuous water surface that is either above or below bed level, with the subsurface conditions treated as flow through porous media. Although the wet-dry transition is treated well, velocities at the water's edge may be inaccurate (Hirschowitz *et al.*, 2007).

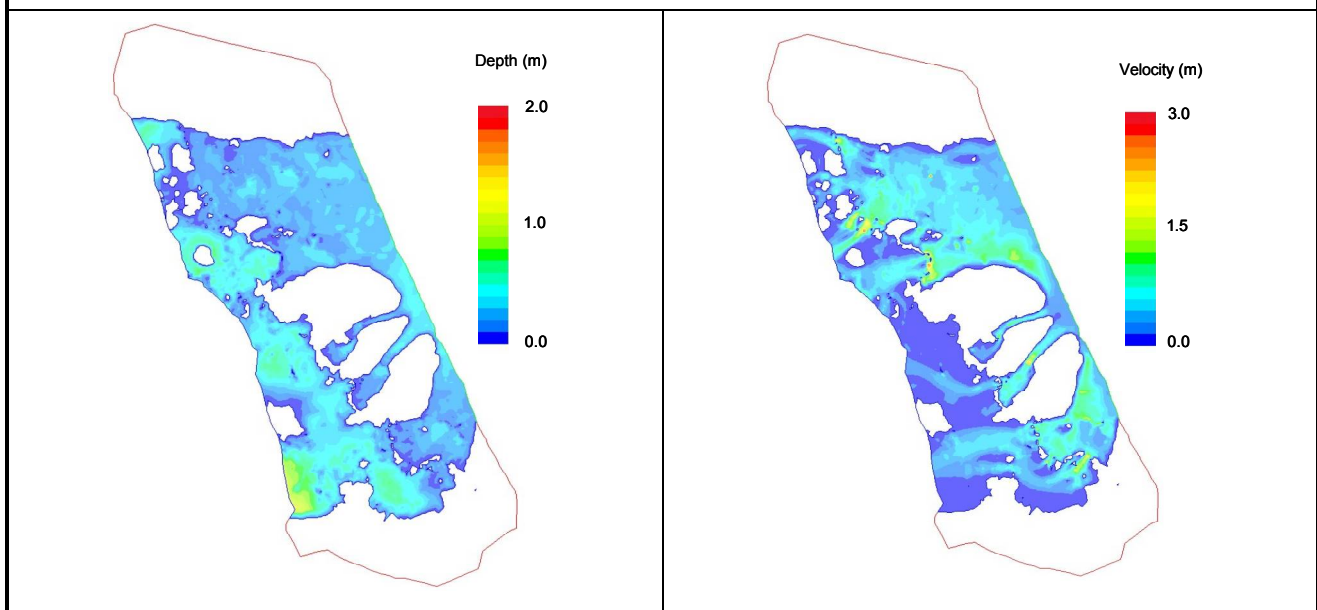
Two-dimensional modelling may be applied at different spatial scales, depending on the required resolution. For a given resolution, the spatial extent is limited by the maximum number of elements that can realistically be included (due to program limitations and long simulation times). At a coarse resolution, a long river stretch may be modelled, whereas at a fine resolution, only a small section may be analysed. River2D includes the useful capability of nesting spatial scales - a finer resolution may be used where higher accuracy is required, or a modelled region may be extracted and reanalysed at a finer resolution.

## A5.2 APPLICATION

River2D was applied in this Comprehensive Reserve assessment at Site 3 on the Upper Vaal River, shown in Figure A14 at discharges of 0.040 and 14.5 m<sup>3</sup>/s. Conventional survey techniques were used to develop a DTM for an approx. 50 m length of river, and the modelled depths and velocity magnitudes for a discharge of 5.0 m<sup>3</sup>/s are illustrated in Figure A15.



**Figure A14** Bedrock rapid at EWR Site 3 on the Upper Vaal River at discharge of 0.040 (17 Sep 2007) and 14.5 m<sup>3</sup>/s (8 Apr 2008) (Photographs D Louw)



**Figure A15** Extent of the modelled area at EWR Site 3 on the Upper Vaal River. The inundated region for a discharge of 5.0 m<sup>3</sup>/s is rendered using the 'hot-cold' shading representing depth (left) velocity magnitude (right). Flow direction is from right to left - note the three islands in Figure A14

River2D results may be exported in text file format - a useful feature for the post-processing of point hydraulic variables (e.g. velocity and shear velocity magnitudes, depth, stage, Froude number). For Reserve analyses using flow classes, such as in this study, this is necessary for statistical analysis of depth-velocity point values. For analyses to be statistically valid, values are best exported using a regular grid. Furthermore, modelled values may also be extracted to text

files for any location within the modelled region. This is a necessary feature for comparing modelled and measured data for selected flows, as well as for extracting hydraulic information, such as rating data - as was necessary in this study to determine the discharges that inundate vegetation surveyed with the modelled region of interest.

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**APPENDIX B: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 2: GROOTDRAAI**

## B1 EWR 2: GROOTDRAAI (VAAL RIVER) – DETERMINATION OF STRESS INDICES

Appendix C provides supporting information for the determination of stress indices of EWR 2 Grootdraai (Chapter 2 and 3 of the Main Report, Volume 1).

### B1.1 FISH INDICATOR SPECIES

**Fish indicator group 1: Large semi rheophilic (LSR) guild: *Labeobarbus aeneus* (BAEN)** has a maximum size is approximately 50 cm. Its optimal preferred general habitat is Slow Deep (SD), Fast Shallow (FS) and Fast Deep (FD) with suitable cover provided by substrate and water column depth. This spawning habitat requirement of this species is FD and FS habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require FS habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and SS over substrate, and seek refuge in SD at night.

**Fish indicator group 2: Small semi-rheophilic (SSR) guild: *Barbus anoplus* (BANO)** only reaches a maximum size of approximately 12 cm. Its optimal preferred general habitat is SD and Slow Shallow (SS) preferably with overhanging vegetation or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock and even undercut banks) as general habitat. This most important difference of this species in relation to indicator 1 (BEAN) is the requirement of high flows overtopping banks and inundating vegetation for spawning purposes. Spawning takes place during the summer when rivers are swollen after rains. It lays its adhesive eggs amidst vegetation. The larvae hatch within 3 days and begin to swim and feed after 6/7 days. Flows should remain adequate to allow migration between reaches, thus pools should remain connected during wet season. Water levels providing inundated vegetation should last long enough for spawning, egg hatching and larvae development. Larvae and juveniles require SS and SD with adequate cover to allow optimal development and survival.

The habitat requirements for the different life stages of the LSR indicator fish species is summarised in Table B1 and the SSR guild is summarised in Table B2. Information in Bold type face indicates crucial habitat during the given life stage.

**Table B1 Habitat requirements for different life stages of indicators species included in the LSR guild**

Species	Spawning	Egg and embryo development	Larvae	Juveniles	Adults
BAEN	Flow habitat: <b>FS, FI over substrate</b> . Spawning season: Spring to mid summer (Sep – Jan). Fast (>0.3 m/s) with substrate (Gravel and cobbles). Flowing water, well oxygenated and low sediments loads. BAEN breeds from spring through to mid-summer after the first substantial rains of the season.	Flow habitat: <b>FS with substrate (gravel/cobbles)</b> . Flows to last long enough for the egg to hatch out and embryos to develop. Sudden pulse after spawning may cause many of the eggs to be washed out of the spawning beds and die in the deeper less oxygenated pools and also be smothered by silt. Also if the flow subsides it could result in higher temperatures and lower oxygen thus killing the developing embryos or leaving them stranded. The fertilised eggs of BAEN incubate for three to eight days at 18 - 21.5 C, thereafter the embryos remain in the <b>gravel</b> for a further	Flow habitat: <b>SD with substrate</b> . Spawning season: Oct – Feb. Cover, flow, oxygen and low silt loads. At swim-up they require suitable flows to move them away from the spawning beds to the nursery areas usually shallow backwaters which are warmer. If the backwaters are not there due to too high or too low flows the larval fish will die out as this is a very critical stage where they have to start eating. Larvae are initially inactive and sink to the bottom, not becoming mobile	Flow habitat: <b>FS, FI and SS with substrates. SD at night</b> .	Flow habitat: <b>SD, FD, FI and FS with substrates and water column</b> .

		period.	until four to six days after hatching. At this stage, they begin feeding on microscopic organisms.		
<b>BKIM</b>	Flow habitat: <b>FS and FD with substrates</b> (Gravel, cobbles) flowing water, well oxygenated and low sediments loads. The breeding season extends from mid to late summer. The species requires <b>gravel beds</b> in flowing water to spawn.	Flow habitat: <b>FS and FI with substrate (gravel / cobbles)</b> . Flows to last long enough for the embryos to develop and hatch out. The incubation period for BKIM is two to three days and larvae become mobile after a further three to four days at 23 - 25 C.	Flow habitat: <b>SD with substrate</b> .	Flow habitat: <b>FI and SD with substrates</b> .	Flow habitat: <b>SD, FD and FI with substrates and water column</b> .

**Table B2 Habitat requirements for different life stages of indicators species included in the SSR guild**

Species	Spawning	Egg and embryo development	Larvae	Juveniles	Adults
<b>BANO</b>	Flow habitat: <b>SD, and SS (&gt; 0.1 m) and marginal vegetation</b> . Spawning season: Oct - Jan. Cue: Increased flow, temp., and water quality. Spawning takes place during the summer among flooded vegetation where adhesive eggs are.	Flow habitat: <b>SD, and SS (&gt; 0.1 m) and marginal vegetation</b> . Months: Oct - Jan. > 16°C. Incubation: 4 – 5 days. Flows to last long enough for the egg to hatch out and embryos to develop.	Nursery areas (> 0.1 m) and <b>margins of SS, SD</b> . Backwaters formed by increased flow. Cover: Overhanging vegetation. Duration larval period: 2 months.	Flow habitat: Mostly <b>SD and SS (&gt; 0.1 m)</b> . Cover: Overhanging vegetation and undercut banks. Duration 3 – 6 months. Low flow refuge (June - Sep) <b>SS (&gt; 0.1 m), and SD</b> . Cover: Cobbles, rocks and overhanging vegetation.	Flow habitat: <b>SS, and SD</b> . Cover: Cobbles and rocks, overhanging vegetation, and undercut banks. Duration: 3 – 6 months. Low flow refuge (Jun – Sep): <b>SS (&gt; 0.1 m) and SD</b> . Cover: Cobbles, rocks overhanging vegetation.

**B1.2 FISH STRESS INDEX**

The abundance of fish velocity-depth classes are provided in Table B3.

**Table B3 EWR 2: Habitat suitability for the SSR and LSR guild**

LSR and SSR GUILD									
Depth classes	Discharges (m <sup>3</sup> /s)								
	0.15	0.3	0.4	0.9	1.5	3.4	5.5	7.4	10
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	4	4	4	6	6	6	8	8	8
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	4	4	4	6	6	6	8	8	6
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	10	10	10	10	10	8	6	6	6
Slow Shallow and Slow Deep	4	4	4	4	4	6	6	6	6
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	8	8	8	6	6	6	6	6	6
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	8	6	6	4	4	6	6	6	6
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	10	8	8	6	6	6	6	6	6
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	10	10	10	8	6	4	4	4	4
FAST TOTAL >0.1 m DEEP	10	8	8	6	4	4	4	4	4

The fish stress index is provided in Table B4.

**Table B4 Fish stress index**

Habitat	Discharges (m <sup>3</sup> /s)								
	0.15	0.3	0.4	0.9	1.5	3.4	5.5	7.4	10
<b>SMALL SEMI-RHEOPHILIC (SSR) GUILD</b>									
Spawning & nursery habitat	0.5	0.5	0.5	1	1	2	2	3	5
Abundance	0.5	2	2	3	3	4	5	5	5
Cover	1	2	2	3	3	3	4	4	5
Connectivity (lateral & longitudinal)	1	2	2	3	3	4	4	4	5
Water Quality (esp. O <sub>2</sub> and Temp.)	2	2	2	3	4	5	5	5	5
<b>Species stress: BANO</b>	<b>8</b>	<b>7</b>	<b>7</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>
<b>LARGE SEMI-RHEOPHILIC (LSR) GUILD</b>									
Spawning & nursery habitat	0	0.5	0.5	2.5	2.5	4	4.5	5	5
Abundance	0.5	1.5	1.5	2.5	3	4	4.5	5	5
Cover	1	1.5	1.5	2.5	3	4	4.5	5	5
Connectivity (lateral & longitudinal)	0.5	2	2	3	3.5	4	4.5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0.5	2	2	3	4	4.5	4.5	5	5
<b>Species stress: BAEN</b>	<b>9</b>	<b>7</b>	<b>7</b>	<b>5</b>	<b>4</b>	<b>2</b>	<b>1</b>	<b>0</b>	<b>0</b>

**B1.3 MACROINVERTEBRATE STRESS INDEX**

The habitat flow index for flow dependent macroinvertebrate (FDI) taxa is provided in Table B5 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table B5 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)											FLOW (m <sup>3</sup> /s)	
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>		VFBR <sup>12</sup>
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	7	12	18	27	4	7	10	15	0	0	0	0	3.666
1	All habitats plentiful, high quality. Fast, wide WP.	9	15	22	23	4	7	10	10	0	0	0	0	2.57
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	16	23	27	10	5	7	9	3	0	0	0	0	1.087
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	19	27	25	7	5	7	7	2	0	0	0	0	0.767
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	23	31	21	5	6	8	5	1	0	0	0	0	0.518
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	32	36	11	2	8	9	3	0	0	0	0	0	0.262
6	Critical habitat residual. Low quality, moderate/slow velocity.	35	35	9	1	9	9	2	0	0	0	0	0	0.198

7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	42	32	6	0	10	8	1	0	1	0	0	0	0.104
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	58	21	1	0	15	5	0	0	0	0	0	0	0.027
9	Standing water habitats only, very low quality. No flow.	78	2	0	0	19	1	0	0	0	0	0	0	0.001
10	Only hyporheic refugia, no surface water.	0	0	0	0	0	0	0	0	0	0	0	0	0.001

1 Very Slow over Coarse Sediment  
 4 Very Fast over Coarse Sediment  
 7 Fast over Fine Sediment  
 10 Slow over Bedrock  
 13 Fringing vegetation

2 Slow over Coarse Sediment  
 5 Very Slow over Fine Sediment  
 8 Very Fast over Fine Sediment  
 11 Fast over Bedrock

3 Fast over Coarse Sediment  
 6 Slow over Fine Sediment  
 9 Very Slow over Bedrock  
 12 Very Fast over Bedrock

The stress index for FDI taxa is provided in Table B6 which rates the response of the species according to various biotic response metrics.

**Table B6 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
0.56	0.3	1.72	0.57	24.3	All flow dependent macroinvertebrates very abundant and healthy.	3.666	0
0.5	0.28	1.52	0.5	21.6	90% rheophilic species persist.	2.570	1
0.38	0.21	1.08	0.34	17.9	Most rheophilic species persist, but slight (80%) reduction.	1.087	2
0.34	0.19	0.94	0.29	16.5	Most rheophilic species persist, but abundances reduced.	0.767	3
0.3	0.16	0.81	0.25	15.9	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	0.518	4
0.26	0.13	0.57	0.17	14.8	Critical life-stages of sensitive rheophilic species at risk or non-viable.	0.262	5
0.24	0.11	0.5	0.15	14.2	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	0.198	6
0.2	0.09	0.4	0.12	12.3	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.	0.104	7
0.14	0.05	0.26	0.07	8.5	Some rheophilic species persist, but at very low numbers; All life stages of most rheophilic species at risk or non-viable.	0.027	8
0.06	0.01	0.1	0.03	1.6	Mostly pool dwellers; all life stages of most rheophilic species non-viable.	0.001	9
					Only pools dwellers.		10

## B2 EWR 2: GROOTDRAAI (VAAL RIVER) – DETERMINATION OF EWR SCENARIOS

### B2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table B7 for the LSR guild and Table B8 for the SSR guild.

**Table B7 Low flow requirements: LSR guild**

GENERAL
<p><b>INDICATOR:</b> The large semi-rheophilic species <i>Labeobarbus aeneus</i> (BAEN) is the indicator species 1 selected for this EWR site. The maximum size is approximately 50 cm. Its optimal preferred general habitat is Slow Deep (SD), Fast Shallow (FS) and Fast Deep (FD) with suitable cover provided by substrate and water column depth. This spawning habitat requirement of this species is FD and FS habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and SS over substrate, and seek refuge in SD at night. Flows set for BAEN should suffice in general for the flow requirements of <i>Labeobarbus kimberleyensis</i> (BKIM), <i>Labeo capensis</i> (LCAP) and <i>Austroglanis sclateri</i> (ASCL) present at this site.</p>
PES and REC: FISH EC C (ECOSTATUS C)
<p><b>Dry Season maintenance</b> BAEN, as a semi-rheophilic species, can survive during the dry season without continuous flows (especially the adults which do well in deep pools). For the optimal survival conditions for juveniles adequate fast shallow habitat should be maintained for a period of the time. SD with adequate depth should also be maintained to meet the requirements of adults, as well as juveniles (especially at night when these deeper areas are used for refuge to avoid extreme temperature fluctuations during the winter months). This is the optimal stress level (flows) where these critical habitats will be maintained in adequate abundance to ensure the survival of this indicator species at the site. FD habitats will be lost under this stress level, but adequate FI and FS will be maintained to meet the requirements of the juveniles.</p>
<p><b>Dry Season drought</b> BAEN being semi-rheophilic can survive periods with no flow, especially when occurring during the winter (dry) season. The most critical habitat for survival of this species during drought periods in the dry season is to ensure that adequate depths in pools (both SD and Slow Shallow (SS)) are maintained. This habitat component plays an important role as refuge area to survive temperature fluctuations during the cold winter months. Very limited flows are still required for maintenance of some FS habitats for especially juvenile survival, and to maintain adequate oxygen levels in the pools, which should be available at this stress level in very low abundance, but adequate to maintain the present status.</p>
<p><b>Wet Season maintenance</b> Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (&gt;0.3 m/s and &lt;0.3 m deep) and FD (&gt;0.3 m/s and &gt;0.3 m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development. The recommended stress level should maintain adequate fast habitats (especially FS and Fast Intermediate (FI)) to allow for the requirements as described above for the different life stages of BAEN during the wet season to maintain it within a Category C. Increased stress will result in critical changes and reduction in these important habitats and may result in deterioration of the PES.</p>
<p><b>Wet Season drought</b> During a drought in the wet season flows should at least allow for limited breeding and survival habitats for BAEN. Under the recommended stress level, limited breeding habitat in the form of FS will be available for this species to at least allow survival and future existence of the species at the site (survival of drought period). Some critical fast shallow habitats should be available for some period to enable spawning, egg and larvae development. Limited fast shallow and adequate SD habitats should be maintained under these conditions for the survival of juveniles and adults during this period.</p>

BUILDING BLOCK <sup>1</sup>	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS <sup>2</sup>	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	9	9	0.15
Maintenance	Dry	55%	6	6	0.65
Drought	Wet	8%	7	7	0.4
Maintenance	Wet	55%	5	5	0.9
<b>AEC up: FISH EC C (ECOSTATUS B)</b>					
<p>The Frequency of Occurrence (FROC) of BAEN for the PES of a category C was already optimal at this EWR site. It is therefore envisaged that improved flows (closer to the natural hydrological regime) may not have any significant improvement in conditions for BAEN, and therefore not reflect an improved category. Improved flows may however be beneficial for other semi-rheophilic species, such as BKIM and LCAP. Should the aquatic macroinvertebrates justify decreased stress for a category B; a short review can be done to see whether it will have a change on the other fish species at this site.</p>					
<b>AEC down: FISH EC D (ECOSTATUS C/D)</b>					
<b>General</b>					
<p>If the base flows is reduced significantly (especially during summer), it will have an impact on this and other semi-rheophilic species with a requirement for flow during especially the spawning and migration period. It can therefore be expected that the FROC of BAEN (and other semi-rheophilic species) will be reduced under such conditions. The deterioration in water quality associated with the decreased flows may further influence BAEN, especially smaller life stages (egg development, embryos and larvae, as well as juvenile survival). General lower flows may lead to reduced quality (more embeddedness by fine silt and benthic algae), as well as reduced abundance of optimal spawning habitats (fast habitats over good quality substrate, preferable gravel).</p>					
<b>Dry Season maintenance</b>					
<p>Decreased flows during the dry seasons would reduce the habitats crucial for the survival of juvenile and adult BAEN. This would be reflected by very low abundance of fast habitats (approximately 20 % FS and FI), which would reduce the survival of especially juvenile BAEN, which has a preference for fast habitats. Decreased flows (lower than reference condition) will also aggravate the secondary impacts (water quality deterioration and siltation of substrates) and thereby negatively impact on the feeding and survival habitats for BAEN. Decreased flows will also reduce the depth of SD habitats, which are important survival habitats for over wintering of juvenile and adult BAEN, as adequate depth is required in SD to buffer temperature fluctuations in dry (cold) season, which will result in decreased FROC and abundance of BAEN, resulting in a lower category than present.</p>					
<b>Wet Season maintenance</b>					
<p>Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (&gt; 0.3 m/s and &lt; 0.3 m deep) and FD (&gt;0.3m/s and &gt;0.3 m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require FS habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development. The recommended stress level would provide very limited fast habitats (especially FS and FI) to allow for the requirements as described above for the different life stages of BAEN during the wet season and would probably result in deterioration into a category D. This will be associated to both decreased in abundance and condition of breeding, nursery and refuge habitats, as well as water quality deterioration as a result of decreased flows (decreased oxygen levels, increased temperature). It will also reduce the depth of SD habitats and jeopardise the role these habitats play to provide refuge to juveniles and adults from night time temperature fluctuations.</p>					
BUILDING BLOCK <sup>1</sup>	SEASON	STRESS DURATION	SPP STRESS	INTEG <sup>2</sup> STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	7	7	0.4
Maintenance	Wet	55%	6	6	0.65

<sup>1</sup> Flow building block refers to drought and maintenance flows.

<sup>2</sup> Integrated

**Table B8 Low flow requirements: SSR guild**

<b>GENERAL</b>					
<p><b>INDICATOR:</b> The small semi-rheophilic species <i>Barbus anoplus</i> (BANO) was selected as indicator species 2 for this EWR site, due to its different habitat requirements than indicator species 1 (BAEN). BANO only reaches a maximum size of approximately 12 cm. Its optimal preferred general habitat is Slow Deep (SD) and Slow-Shallow (SS) preferably with overhanging vegetation or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock and even undercut banks) as general habitat. This most important difference of this species in relation to indicator 1 (BEAN) is the requirement of high flows overtopping banks and inundating vegetation for spawning purposes. Spawning takes place during the summer when rivers are swollen after rains. It lays its adhesive eggs amidst vegetation. The larvae hatch within 3 days and begin to swim and feed after 6 / 7 days. Flows should remain adequate to allow migration between reaches, thus pools should remain connected during wet season. Water levels providing inundated vegetation should last long enough for spawning, egg hatching and larvae development. Larvae and juveniles require SS and SD with adequate cover to allow optimal development and survival. Flows set for BANO should provide in general for the flow requirements of other small-semi rheophilic species and even species such as LUMB and CGAR, as well as limnophilic species (PPHI and TSPA).</p>					
<b>PES and REC: FISH EC C (ECOSTATUS C)</b>					
<p><b>Dry Season maintenance</b> BANO, as a moderately tolerant small semi-rheophilic has a high preference for SD and SS with cover (especially overhanging and aquatic vegetation, although they also use large rocky substrates as preferred cover). This species should be able to survive long periods of no or limited flow as long as adequate SD and SS habitats are maintained. It is recommended that although they are not directly dependant on fast habitats for survival, that the maintenance of some fast habitats will ensure longitudinal connectivity allowing movement for feeding and recruitment. Some flow will furthermore be required to sustain water quality within acceptable levels and flush waste products from the pools. Their survival in this period would depend on the maintenance of their food source, but being omnivorous and having a varied diet, they are generally able to survive stressed conditions.</p>					
<p><b>Dry Season drought</b> BANO a moderately tolerant semi-rheophilic species with high preference for SD and SS habitats with cover of aquatic vegetation and overhang, although they also make use of large rocky substrate such as cobbles to bedrock and undercut banks, especially in periods of stress/low flows, when inundated vegetation is limited or absent. During dry season droughts, this species will be able to handle high habitat stress and survive periods of no flow, as long as some surface water remains available as pools and backwaters. Maintenance of SS (and limited SD) with cover (under these conditions probable no inundated vegetation will be available but they will make use of substrate as cover for survival.</p>					
<p><b>Wet Season maintenance:</b> The optimal habitat of this species during wet season is a requirement of inundated vegetation for spawning and egg development that should ideally be provided by floods. After spawning and breeding, it is important that some level of aquatic vegetation and overhanging vegetation is maintained for a period to allow survival of larvae and juveniles. At the mentioned stress level flow should be some inundation of macrophytes and thereby creating some preferred habitat in the form of overhanging vegetation and aquatic vegetation. The closer to natural hydrological regime will further improve the presence of riparian vegetation, and possibly also aquatic vegetation, and thereby also improve the availability of their preferred cover type (overhanging vegetation and aquatic macrophytes). The provision of adequate cover is especially important at the site due to the presence of alien predator <i>Micropterus salmoides</i> (MSAL).</p>					
<p><b>Wet Season drought</b> During drought in the wet season, BANO will require some SS and SD (with adequate depth) and cover to survive. At this stress there will most probably be no optimal cover available to this species in the form of overhanging vegetation and aquatic vegetations, and they should seek refuge under large substrates (especially boulders). It is also recommended that some flow should remain to ensure that pools remain connected (by FS) and allow movement of this species and to maintain an acceptable water quality for the different life stages of this species (should spawning and egg development have taken place during floods, if occurrence during droughts). These conditions should remain at the recommended stress level/flows.</p>					
<b>BUILDING BLOCK</b>	<b>SEASON</b>	<b>STRESS DURATION</b>	<b>SPP STRESS</b>	<b>INTEG STRESS</b>	<b>FLOW (m<sup>3</sup>/s)</b>
Drought	Dry	5%	10	10	0.001
Maintenance	Dry	55%	8	9.2	0.275
Drought	Wet	5%	8	9.2	0.275
Maintenance	Wet	55%	6	6	0.65
<b>AEC up: FISH EC C (ECOSTATUS B)</b>					
It is estimated that an improvement in the base flows (closer to natural hydrological regime) may not result in a					

significant improvement of BANO. Some slight improved conditions may be related to improved cover created by higher water levels (increased water levels should result in more inundated vegetation as cover), which may provide more protection from the predatory MSAL. It is however estimated that improved conditions (decreased stress) as reflected by the aquatic macroinvertebrates for this category should provide adequate conditions for improved conditions for BANO. Overall improved flows may not be able to improve the FROC of this species to such an extent to enable improved category, as the primary impact on this species is non-flow related (impact of alien predatory MSAL). It should be reflected in improved FROC of both adult and juvenile individuals, and increased abundance. Improved water quality. The deterioration in water quality associated with the decreased flows may further influence BANO, especially smaller life stages (egg development, embryos and larvae, as well as juvenile survival).

**AEC down: FISH EC D (ECOSTATUS C)**

**General**

If the base flows is reduced significantly (especially during summer), it will have an impact on this and other semi-rheophilic species primarily related to loss of habitat and cover. Decreased flows will result in overall decrease and even absence of inundated vegetation and overhanging vegetation as cover and this species will have to retreat to substrate as the only cover available. The deterioration in water quality associated with the decreased flows may further influence BANO, especially smaller life stages (egg development, embryos and larvae, as well as juvenile survival).

**Dry Season maintenance**

BANO, as a moderately tolerant small semi-rheophilic has a high preference for SD and SS with cover (especially overhanging and aquatic vegetation, although they also use large rocky substrates as preferred cover). This species should be able to survive long periods of no or limited flow as long as adequate SD and SS habitats are maintained. Although they are not directly dependant on fast habitats for survival, should the flows be further reduced it very limited fast habitat will be available and therefore the connection of pools may be lost or reduced, which will limit longitudinal migration for feeding and recruitment. Less flow will furthermore result in lower water quality and a build-up of waste products in the pools, which may further reduce the water quality and therefore survival and abundance of BANO. Lower water levels may also reduce cover for this species with a greater level of predation by the alien MSAL.

**Wet Season maintenance**

The optimal habitat of this species during wet season is a requirement of inundated vegetation for spawning and egg development that should ideally be provided by floods. After spawning and breeding, it is important that some level of aquatic vegetation and overhanging vegetation is maintained for a period to allow survival of larvae and juveniles. At the mentioned stress level flow would probably not provide abundant inundated macrophytes and therefore very limited abundance of their preferred habitat in the form of overhanging vegetation and aquatic vegetation will be available under this stress condition. The provision of adequate cover is especially important at the site due to the presence of alien predator MSAL and due to the decreased level of cover provided at this stress level, an increased impact by MSAL can be expected, resulting in decreased FROC and abundance of BANO. Very limited fast habitats (mostly FVS and very limited FS) will be available and connectivity between pools may therefore also reduce with a resultant negative impact on the FROC of BANO, and a resultant decrease in the EC.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	10	10	0.001
Maintenance	Wet	55%	8	9.2	0.12

**B2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES**

The FDI low flow requirements are summarised in Table B9 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

**Table B9 Low flow requirements: FDI taxa**

GENERAL					
<b>INDICATOR:</b> Hydropsychid caddisflies and Simuliidae (i.e., common, flow dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.					
PES and REC: MACROINVERTEBRATE EC C (ECOSTATUS C)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.16 m, and average current velocity is 0.25 m/s (Spp Stress 4). This will enable flow-dependent macroinvertebrates to overwinter without significant detrimental impacts on the overall population.					
<b>Dry Season drought</b> Average depth needed for dry season drought is 0.25 m, and average current velocity is 0.16 m/s (Spp Stress 5.5). This will enable flow-dependent macroinvertebrates to survive a drought.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.21 m, and average current velocity is 0.34 m/s (Spp Stress 2). This will provide suitable habitats during summer.					
<b>Wet Season drought</b> Average depth needed for wet season drought is 0.17 m, and average current velocity is 0.27 m/s (Spp Stress 3.5).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	5.5	9	0.15
Maintenance	Dry	55%	4	7	0.4
Drought	Wet	5%	3.5	7	0.4
Maintenance	Wet	55%	2	3.8	1.88
AEC up: MACROINVERTEBRATE EC B/C (ECOSTATUS B)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.19 m, and average current velocity is 0.29 m/s (Spp Stress 3).					
<b>Wet Season maintenance:</b> Average depth needed for wet season maintenance is 0.26 m, and average current velocity is 0.41 m/s (Spp Stress 1.5).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	3	5.3	0.825
Maintenance	Wet	55%	1.5	3.5	2.45
AEC down: MACROINVERTEBRATE EC C/D (ECOSTATUS C/D)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.26 m, and average current velocity is 0.17 m/s (Spp Stress 5).					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.34 m, and average current velocity is 0.29 m/s (Spp Stress 3).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	5	7.6	0.325
Maintenance	Wet	55%	3	5.3	0.825

### B2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table B10.

**Table B10 Functions for each Flood Class**

Flood Class	Function/Motivation	
CLASS I RANGE (M <sup>3</sup> /S): 4 DAILY AVERAGE: 2 DURATION: 3	Fish	Class I floods contribute to the establishment of optimum spawning habitat through flushing of fine sediments and benthic algae from substrates. These flows may also stimulate some migratory action, although it may be more related to changes in water quality than (physico-chemical stimuli) than stimulus to flow alteration. These floods will also provide increased depth of rapid/riffle and possible migration barriers and therefore assist in creating more favourable migratory habitats (lateral and longitudinal). Some resetting of water quality and flushing out fine sediments will occur. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Five of these per year, any time during the wet season, are recommended for a macroinvertebrate Category C, and two for a Category D.
CLASS II RANGE (M <sup>3</sup> /S): 6 – 10 DAILY AVERAGE: 7 DURATION: 5	Fish	Class II floods are especially important to create suitable spawning habitat for vegetation breeders. It is estimated that the recommended floods will provide sufficient habitats based on volume and duration to create favourable conditions. These recommended floods furthermore closely resemble those that can be expected under natural conditions. It furthermore provides other important functions regarding fish biology, such as migratory cues, flushing of fines from habitat (especially substrate spawning habitats) and creating the required nursery habitats. The frequency, extent and duration as recommended for the PES and AECs should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Three of these per year are recommended for a macroinvertebrate Category C: one at the beginning of the wet season (Oct/Nov), one during the wet season, and one towards the end of the wet season (Feb/Mar). Two of these per year are recommended for a macroinvertebrate Category D: one at the beginning of the wet season (Oct / Nov), and one towards the end of the wet season (Feb/Mar).
CLASS III RANGE (M <sup>3</sup> /S): 11 - 50 DAILY AVERAGE: 30 DURATION: 5	Fish	Class III floods are similar in importance as Class II floods, and would provide the same functions as described for Class II floods. Although these floods will occur at the end of the wet season/summer, they may still provide important functions to species that breed into the late summer periods.
CLASS IV RANGE (M <sup>3</sup> /S): 70 - 100 DAILY AVERAGE: 80 DURATION: 6	Fish	Class IV floods will in essence also provide the same functions as Class II and III floods, although the velocities may be too high at the time of flood to provide breeding and nursery areas. These areas will become available during the receding flood, and are therefore an important function of this level of flood. The extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category. Although these floods will occur at the end of the wet season/summer, they may still provide important functions to species that breed into the late summer periods.

## B2.4 EWR RULES

**Table B11 EWR 2 assurance rules for PES and REC: C**

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 Summary of IFR rule curves for: V\_Ewr2 Natural Monthly Flows  
 Determination based on defined BBM Table with site specific assurance rules.  
 Regional Type: Vaal PES and REC = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.133	1.111	1.066	0.987	0.862	0.693	0.500	0.321	0.196	0.139
Nov	2.925	2.620	2.339	2.051	1.599	1.297	0.952	0.633	0.408	0.306
Dec	3.223	2.863	2.523	2.163	1.642	1.273	0.903	0.610	0.434	0.364
Jan	19.261	15.221	11.969	9.174	5.492	3.982	2.651	1.732	1.246	1.066
Feb	10.577	8.637	7.017	5.544	3.593	2.636	1.792	1.209	0.901	0.787
Mar	2.594	2.529	2.397	2.166	1.824	1.404	0.983	0.650	0.450	0.370
Apr	1.398	1.363	1.292	1.168	0.985	0.759	0.534	0.355	0.248	0.205
May	1.134	1.108	1.058	0.968	0.828	0.637	0.419	0.218	0.077	0.012
Jun	0.992	0.970	0.926	0.847	0.724	0.557	0.367	0.191	0.067	0.000
Jul	0.864	0.849	0.822	0.772	0.690	0.569	0.413	0.241	0.094	0.013
Aug	0.792	0.779	0.753	0.707	0.633	0.522	0.378	0.221	0.086	0.012
Sep	0.865	0.851	0.826	0.780	0.705	0.594	0.450	0.293	0.157	0.083
Reserve flows without High Flows										
Oct	0.994	0.974	0.935	0.866	0.757	0.609	0.441	0.285	0.175	0.126
Nov	1.420	1.394	1.341	1.245	1.096	0.894	0.664	0.451	0.300	0.232
Dec	1.678	1.638	1.556	1.412	1.199	0.937	0.675	0.468	0.343	0.294
Jan	1.871	1.814	1.696	1.496	1.220	0.913	0.643	0.457	0.358	0.321
Feb	2.426	2.353	2.202	1.945	1.590	1.197	0.851	0.611	0.485	0.438
Mar	1.818	1.774	1.684	1.525	1.292	1.005	0.717	0.490	0.353	0.299
Apr	1.398	1.363	1.292	1.168	0.985	0.759	0.534	0.355	0.248	0.205
May	1.134	1.108	1.058	0.968	0.828	0.637	0.419	0.218	0.077	0.012
Jun	0.992	0.970	0.926	0.847	0.724	0.557	0.367	0.191	0.067	0.000
Jul	0.864	0.849	0.822	0.772	0.690	0.569	0.413	0.241	0.094	0.013
Aug	0.792	0.779	0.753	0.707	0.633	0.522	0.378	0.221	0.086	0.012
Sep	0.865	0.851	0.826	0.780	0.705	0.594	0.450	0.293	0.157	0.083
Natural Duration curves										
Oct	36.466	7.236	5.813	4.096	2.875	2.404	1.747	1.165	0.650	0.362
Nov	67.438	43.499	23.476	16.300	10.795	7.778	6.076	4.684	1.184	0.694
Dec	84.528	57.658	34.819	29.574	20.975	14.740	9.692	5.839	3.297	1.635
Jan	61.675	42.525	31.228	27.319	18.873	17.805	11.776	9.256	6.101	3.047
Feb	108.999	35.553	28.356	18.531	14.509	11.004	8.470	6.242	4.477	2.538
Mar	37.138	24.175	15.898	11.835	8.979	7.676	5.190	3.457	1.676	1.109
Apr	16.211	11.254	6.883	5.883	3.912	3.009	2.176	1.809	1.254	0.459
May	8.789	4.443	2.838	2.285	1.512	1.221	1.023	0.926	0.732	0.209
Jun	4.298	2.805	2.029	1.644	1.350	1.111	1.003	0.849	0.320	0.000
Jul	2.953	2.356	1.844	1.400	1.236	1.049	0.922	0.848	0.508	0.127
Aug	2.378	1.968	1.609	1.415	1.198	0.971	0.851	0.747	0.560	0.239
Sep	3.600	2.442	1.906	1.331	1.142	1.011	0.880	0.683	0.498	0.313

**Table B12 EWR 2 assurance rules for AEC up: B**

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Summary of IFR rule curves for: V\_Ewr2 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal AEC UP = B

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.213	2.168	2.078	1.917	1.664	1.323	0.933	0.573	0.319	0.203
Nov	3.906	3.580	3.256	2.889	2.315	1.848	1.315	0.822	0.474	0.317
Dec	4.481	4.084	3.671	3.181	2.468	1.863	1.258	0.778	0.491	0.375
Jan	21.910	17.516	13.923	10.760	6.584	4.725	3.085	1.953	1.356	1.133
Feb	12.370	10.365	8.609	6.906	4.638	3.329	2.175	1.378	0.957	0.801
Mar	3.703	3.607	3.409	3.063	2.552	1.924	1.296	0.798	0.500	0.380
Apr	2.177	2.121	2.004	1.799	1.497	1.125	0.754	0.459	0.283	0.212
May	1.520	1.486	1.419	1.298	1.109	0.854	0.562	0.293	0.103	0.017
Jun	1.246	1.218	1.163	1.064	0.910	0.700	0.461	0.240	0.084	0.000
Jul	1.147	1.128	1.091	1.025	0.917	0.756	0.548	0.321	0.124	0.017
Aug	1.024	1.007	0.974	0.915	0.818	0.675	0.490	0.286	0.111	0.015
Sep	1.098	1.081	1.048	0.989	0.892	0.748	0.562	0.358	0.182	0.086

Reserve flows without High Flows

Oct	1.474	1.444	1.384	1.276	1.107	0.879	0.619	0.378	0.208	0.131
Nov	2.402	2.354	2.257	2.084	1.813	1.445	1.027	0.640	0.367	0.243
Dec	2.936	2.860	2.703	2.430	2.025	1.528	1.030	0.636	0.400	0.305
Jan	3.178	3.073	2.857	2.489	1.981	1.419	0.922	0.580	0.399	0.332
Feb	4.219	4.081	3.795	3.307	2.636	1.891	1.234	0.781	0.541	0.452
Mar	2.965	2.889	2.731	2.454	2.046	1.544	1.041	0.643	0.405	0.309
Apr	2.177	2.121	2.004	1.799	1.497	1.125	0.754	0.459	0.283	0.212
May	1.520	1.486	1.419	1.298	1.109	0.854	0.562	0.293	0.103	0.017
Jun	1.246	1.218	1.163	1.064	0.910	0.700	0.461	0.240	0.084	0.000
Jul	1.147	1.128	1.091	1.025	0.917	0.756	0.548	0.321	0.124	0.017
Aug	1.024	1.007	0.974	0.915	0.818	0.675	0.490	0.286	0.111	0.015
Sep	1.098	1.081	1.048	0.989	0.892	0.748	0.562	0.358	0.182	0.086

Natural Duration curves

Oct	36.466	7.236	5.813	4.096	2.875	2.404	1.747	1.165	0.650	0.362
Nov	67.438	43.499	23.476	16.300	10.795	7.778	6.076	4.684	1.184	0.694
Dec	84.528	57.658	34.819	29.574	20.975	14.740	9.692	5.839	3.297	1.635
Jan	61.675	42.525	31.228	27.319	18.873	17.805	11.776	9.256	6.101	3.047
Feb	108.999	35.553	28.356	18.531	14.509	11.004	8.470	6.242	4.477	2.538
Mar	37.138	24.175	15.898	11.835	8.979	7.676	5.190	3.457	1.676	1.109
Apr	16.211	11.254	6.883	5.883	3.912	3.009	2.176	1.809	1.254	0.459
May	8.789	4.443	2.838	2.285	1.512	1.221	1.023	0.926	0.732	0.209
Jun	4.298	2.805	2.029	1.644	1.350	1.111	1.003	0.849	0.320	0.000
Jul	2.953	2.356	1.844	1.400	1.236	1.049	0.922	0.848	0.508	0.127
Aug	2.378	1.968	1.609	1.415	1.198	0.971	0.851	0.747	0.560	0.239
Sep	3.600	2.442	1.906	1.331	1.142	1.011	0.880	0.683	0.498	0.313

**Table B13 EWR 2 assurance rules for AEC down: C/D**

Desktop Version 2, Printed on 2008/07/03  
 Summary of IFR rule curves for: V\_Ewr2 Natural Monthly Flows  
 Determination based on defined BBM Table with site specific assurance rules.  
 Regional Type: Vaal AEC DOWN = C/D

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.639	0.628	0.605	0.563	0.498	0.410	0.310	0.217	0.151	0.122
Nov	1.037	0.975	0.910	0.832	0.710	0.600	0.474	0.357	0.275	0.238
Dec	2.357	2.021	1.733	1.462	1.073	0.866	0.659	0.494	0.396	0.356
Jan	17.914	13.980	10.861	8.245	4.807	3.524	2.392	1.611	1.198	1.045
Feb	9.140	7.253	5.741	4.452	2.755	2.080	1.484	1.073	0.856	0.775
Mar	0.959	0.940	0.901	0.833	0.732	0.608	0.484	0.385	0.326	0.303
Apr	0.733	0.717	0.686	0.630	0.548	0.447	0.346	0.266	0.218	0.199
May	0.638	0.624	0.595	0.545	0.465	0.358	0.236	0.123	0.043	0.007
Jun	0.638	0.624	0.595	0.545	0.465	0.358	0.236	0.123	0.043	0.000
Jul	0.576	0.567	0.548	0.515	0.460	0.380	0.275	0.161	0.062	0.008
Aug	0.576	0.567	0.548	0.515	0.460	0.380	0.275	0.161	0.062	0.008
Sep	0.643	0.634	0.615	0.582	0.528	0.448	0.344	0.231	0.133	0.079

Reserve flows without High Flows

Oct	0.639	0.628	0.605	0.563	0.498	0.410	0.310	0.217	0.151	0.122
Nov	0.769	0.756	0.732	0.689	0.620	0.528	0.422	0.325	0.256	0.225
Dec	0.812	0.797	0.765	0.711	0.630	0.530	0.431	0.352	0.305	0.286
Jan	0.821	0.802	0.764	0.698	0.608	0.507	0.418	0.357	0.325	0.313
Feb	0.989	0.969	0.926	0.853	0.753	0.641	0.543	0.476	0.440	0.426
Mar	0.812	0.797	0.766	0.711	0.631	0.532	0.434	0.355	0.309	0.290
Apr	0.733	0.717	0.686	0.630	0.548	0.447	0.346	0.266	0.218	0.199
May	0.638	0.624	0.595	0.545	0.465	0.358	0.236	0.123	0.043	0.007
Jun	0.638	0.624	0.595	0.545	0.465	0.358	0.236	0.123	0.043	0.000
Jul	0.576	0.567	0.548	0.515	0.460	0.380	0.275	0.161	0.062	0.008
Aug	0.576	0.567	0.548	0.515	0.460	0.380	0.275	0.161	0.062	0.008
Sep	0.643	0.634	0.615	0.582	0.528	0.448	0.344	0.231	0.133	0.079

Natural Duration curves

Oct	36.466	7.236	5.813	4.096	2.875	2.404	1.747	1.165	0.650	0.362
Nov	67.438	43.499	23.476	16.300	10.795	7.778	6.076	4.684	1.184	0.694
Dec	84.528	57.658	34.819	29.574	20.975	14.740	9.692	5.839	3.297	1.635
Jan	61.675	42.525	31.228	27.319	18.873	17.805	11.776	9.256	6.101	3.047
Feb	108.999	35.553	28.356	18.531	14.509	11.004	8.470	6.242	4.477	2.538
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Apr	16.211	11.254	6.883	5.883	3.912	3.009	2.176	1.809	1.254	0.459
May	8.789	4.443	2.838	2.285	1.512	1.221	1.023	0.926	0.732	0.209
Jun	4.298	2.805	2.029	1.644	1.350	1.111	1.003	0.849	0.320	0.000
Jul	2.953	2.356	1.844	1.400	1.236	1.049	0.922	0.848	0.508	0.127
Aug	2.378	1.968	1.609	1.415	1.198	0.971	0.851	0.747	0.560	0.239
Sep	3.600	2.442	1.906	1.331	1.142	1.011	0.880	0.683	0.498	0.313

**APPENDIX C: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 3: GLADDEDRIFT**

## C1 EWR3: GLADDEDRIFT (VAAL RIVER) – DETERMINATION OF STRESS INDICES

Appendix C provides supporting information for the determination of stress indices of EWR 3 Gladdedrft (Chapter 4 and 5 of the Main Report, Volume 1).

### C1.1 FISH INDICATOR SPECIES

**Fish indicator group 1: Large semi rheophilic (LSR) guild:** *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM) was selected as indicator species. Refer to Appendix B, Section B1.1.

### C1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table C1.

**Table C1 EWR 3: Habitat suitability for the LSR guild**

LSR GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0	0.04	0.24	1.36	2.5	5	7.7	12	15	22	30
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	0	5	5	3	2	1	1	1	1	1	1
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	0	5	5	5	4	3	2	2	1	1	1
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	0	1	1	1	1	1	1	2	2	2	2
Slow Shallow and Slow Deep	0	6	6	6	5	4	3	4	3	3	3
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	0	1	1	1	1	1	1	1	1	1	0
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	0	1	1	2	3	3	3	2	2	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	0	0	0	1	1	2	2	2	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	0	0	0	1	1	2	3	4	5	7	8
FAST TOTAL >0.1 m DEEP	0	0	0	2	2	4	5	6	6	8	9

The fish stress index is provided in Table C2.

**Table C2 Fish stress index**

Habitat	Discharges (m <sup>3</sup> /s)										
	0	0.04	0.24	1.36	2.5	5	7.7	12	15	22	30
<b>LARGE SEMI-RHEOPHILIC (LSR) GUILD</b>											
Spawning habitat	0	0	0	2	2.5	3	3.5	4	4.5	4.5	5
Nursery habitat	0	0.5	1	2	2.5	3	4	4.5	5	5	5
Abundance	0	0.5	0.5	1	1.5	2	2.5	3	4	4.5	5
Cover	0	0.5	0.5	1	1.5	2	2.5	3	4	4.5	5
Connectivity (lateral & longitudinal)	0	0.5	1	2	2.5	3	3.5	4	4	4.5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	0.5	0.5	1.5	2	2.5	3	4	4.5	5	5
<b>Species stress: BAEN</b>	<b>10</b>	<b>9.17</b>	<b>8.83</b>	<b>6.83</b>	<b>5.83</b>	<b>4.83</b>	<b>3.67</b>	<b>2.5</b>	<b>1.33</b>	<b>0.67</b>	<b>0</b>

### C1.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for flow dependent macroinvertebrate (FDI) taxa is provided in Table C3 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table C3 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)				MODIFIER	FLOW (m <sup>3</sup> /s)
		VCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>		
0	Zero stress pegged at naturalized hydrology wet season maintenance base flow.	9.0	9.8	12.4	68.8		30
1	All habitats plentiful, high quality. Fast, wide WP.	21.1	18.9	30.0	30.0		8
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	22.3	20.8	32.2	24.7		6
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	24.1	26.8	31.7	17.5		4
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	26.3	37.0	28.5	8.2		2
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	56.5	29.2	12.1	2.2		0.8
6	Critical habitat residual. Low quality, moderate/slow velocity.	72.3	23.4	3.8	0.6		0.5
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	96.3	3.6	0.2	-		0.1
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	100.0	0.0	0.0	-	Algae	0.04
9	Standing water habitats only, very low quality. No flow.	100.0	-	-	-	Algae	0.03
10	Only hyporheic refugia, no surface water.	100.0	-	-	-	Algae	0.001

1 Very Slow over Coarse Sediment

2 Slow over Coarse Sediment

3 Fast over Coarse Sediment

4 Very Fast over Coarse Sediment

The stress index for FDI taxa is provided in Table C4 which rates the response of the species according to various biotic response metrics.

**Table C4 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
1.87	0.79	2.12	0.85	68.01	All flow dependent macroinvertebrates very abundant and healthy.	30	0
1.22	0.34	1.43	0.45	55.34	90% rheophilic species persist.	8	1
1.15	0.30	1.30	0.40	53.53	Most rheophilic species persist, but slight (80%) reduction.	6	2
1.05	0.25	1.16	0.34	50.25	Most rheophilic species persist, but abundances reduced.	4	3
0.93	0.21	1.01	0.27	45.50	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	2	4
0.82	0.15	0.58	0.14	29.98	Critical life-stages of sensitive rheophilic species at risk or non-viable.	0.8	5
0.79	0.13	0.37	0.08	22.48	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	0.5	6

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
0.74	0.14	0.08	0.02	12.99	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.	0.1	7
0.73	0.14	0.04	0.01	11.59	Some rheophilic species persist, but at very low numbers; All life stages of most rheophilic species at risk or non-viable.	0.04	8
0.54	0.11	0.03	0.01	8.62	Mostly pool dwellers; all life stages of most rheophilic species non-viable.	0.03	9
0.00	0.00	0.00	0.00	0.00	Only pools dwellers.	0.001	10

## C2 EWR 3: GLADDEDRIFT (VAAL RIVER) – DETERMINATION OF EWR SCENARIOS

### C2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table C5 for the LSR guild.

**Table C5 Low flow requirements: LSR guild**

GENERAL					
<p><b>INDICATOR:</b> This group generally requires FS, FI and FD flow-depth categories over good quality substrate (gravel and cobbles) for spawning. Egg and embryo development also takes place in these habitats, while larvae prefer SD with substrate as optimal habitats. Juvenile and adult specimens have a high preference for SD, FS, FI and FD habitats with substrate and water column as cover. Flows should furthermore remain adequate to allow migration between reaches, thus depth in riffle and rapids should remain adequate, especially during the wet season.</p>					
<p align="center"><b>PES and REC: FISH OVERALL IN C EC (ECOSTATUS C)</b>  <b>LSR Dry Season EC D</b>  <b>LSR Wet Season EC C</b></p>					
<p><b>Dry Season maintenance</b>                      It is estimated that the PES of the LSR guild is generally in a D EC during the dry maintenance period. The maximum allowable fish stress levels to maintain the LSR in a category D is provided in Figure C1. At a recommended fish stress level of 9.3 (30% duration) the total habitat suitability score is 1.6 out of 20 (8% of optimal dry season habitat suitability). It is estimated that these habitat conditions should be adequate to maintain this guild within this reach within a D EC during the dry season.</p>					
<p><b>Dry Season drought</b>                      The recommended fish stress level of 10 for the dry season drought would result in habitat unsuitable for any life stages of the LR species. It is however estimated that they will take refuge in pools or downstream reaches or rivers and recolonise this section when conditions improve.</p>					
<p><b>Wet Season maintenance</b>                      It is estimated that the present ecological status of the LSR) guild is generally in a category C during the wet maintenance period. The maximum allowable fish stress levels to maintain the LSR in a C EC is provided in Figure C2. At this recommended fish stress level of 4.5 (30% duration) the total habitat suitability score is 9.8 out of 30 (32% of optimal wet season habitat suitability). It is estimated that these habitat conditions should be adequate to maintain this guild within this reach within a category C during the dry season.</p>					
<p><b>Wet Season drought</b>                      The maximum allowable fish stress levels during wet season droughts is 6.9 (5% duration). This equates to a total habitat suitability score of 0.9 out of 30 (3% of optimal wet season habitat suitability). The allowable flows for the wet season drought to remain within the PES would result in very low to low habitat suitability but should allow this guild to survive these critical periods and maintain some level of recruitment.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	10.00	10	0.001
Maintenance	Dry	30%	9.3	9.3	0.098
	Dry	50%	8.4	8.4	0.48
Drought	Wet	5%	6.9	6.9	1.374
Maintenance	Wet	30%	4.5	4.5	5.89
	Wet	50%	3.2	3.2	9.51
<p align="center"><b>AEC up: FISH OVERALL IN B EC (ECOSTATUS B)</b>  <b>LSR Dry Season EC C</b>  <b>LSR Wet Season EC B</b></p>					
<p><b>General</b>                      Improved moderate floods should improve the substrate quality (flushing of sediment and algae), which should have a</p>					

positive impact on species such as BKIM. Closer to natural base flows, especially during the winter (low flow months) will furthermore improve habitat conditions for various species (especially semi-rheophilic species) such as BAEN, BKIM, and LCAP.

**Dry Season maintenance**

It is recommended that the ecological status of the LSR guild should be maintained in a category C during the dry maintenance period. The maximum allowable fish stress levels to maintain the LSR guild in a C EC is provided in Figure C1. At a recommended fish stress level of 8 (30% duration) the total habitat suitability would be 57% of what can be expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach in a C EC during the dry season.

**Wet Season maintenance**

It is recommended that the ecological status of the large LSR guild should be maintained in a category B during the wet maintenance period. The maximum allowable fish stress levels to maintain the LSR guild in a B EC is provided in Figure C2. At a recommended fish stress level of 2.3 (30% duration) the total habitat suitability would be 85% of what can be expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach in a category B during the dry season.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	0.1%	9.56	9.56	0.062
	Dry	10%	9.28	9.28	0.101
Maintenance	Dry	30%	8	8	0.71
	Dry	50%	7.26	7.26	1.124
Drought	Wet	0.1%	6.9	6.9	1.37
	Wet	10%	4.5	4.5	5.89
Maintenance	Wet	30%	2.3	2.3	12.351
	Wet	50%	1.8	1.8	14.332

**AEC down: FISH OVERALL IN D EC (ECOSTATUS D)  
LSR Dry Season EC E  
LSR Wet Season EC D**

**General**

Decreased base flows and occurrence of zero flows will result in loss of fast habitats and especially decreased substrate quality (increased siltation and benthic algal growth), that will negatively affect species such as ASCL, BAEN, BKIM and LCAP. Decreased base flows will further reduce the already low abundance of vegetation as cover for fish, which can be expected to also affect species with a preference for this cover type (BANO, *Barbus paludinosus* (BPAU), and PPHI)

**Dry Season maintenance**

An alternative EC for the LSR guild during the dry maintenance period is a category E. The maximum allowable fish stress levels to maintain the LSR guild in a E EC is provided in Figure C1. At a fish stress level of 10 (30% duration) the total habitat suitability would be 0% of what can be expected under natural conditions, resulting in very poor status of this fish assemblage during the dry period.

**Wet Season maintenance**

An alternative EC for the LSR guild during the wet maintenance period is a category D. The maximum allowable fish stress levels to maintain the LSR guild in a category D during the wet season is provided in Figure C2. At a fish stress level of 5.26 (30% duration) the total habitat suitability would be 52.5% of what can be expected under natural conditions, adequate to maintain this fish guild in a category D in the wet season.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
	Dry	10%	10	10	0.001
Maintenance	Dry	30%	10	10	0.001
	Dry	50%	9.07	9.07	0.13
	Wet	10%	6.2	6.2	2.102
Maintenance	Wet	30%	5.2	5.2	4.342
	Wet	50%	4.8	4.8	5.266

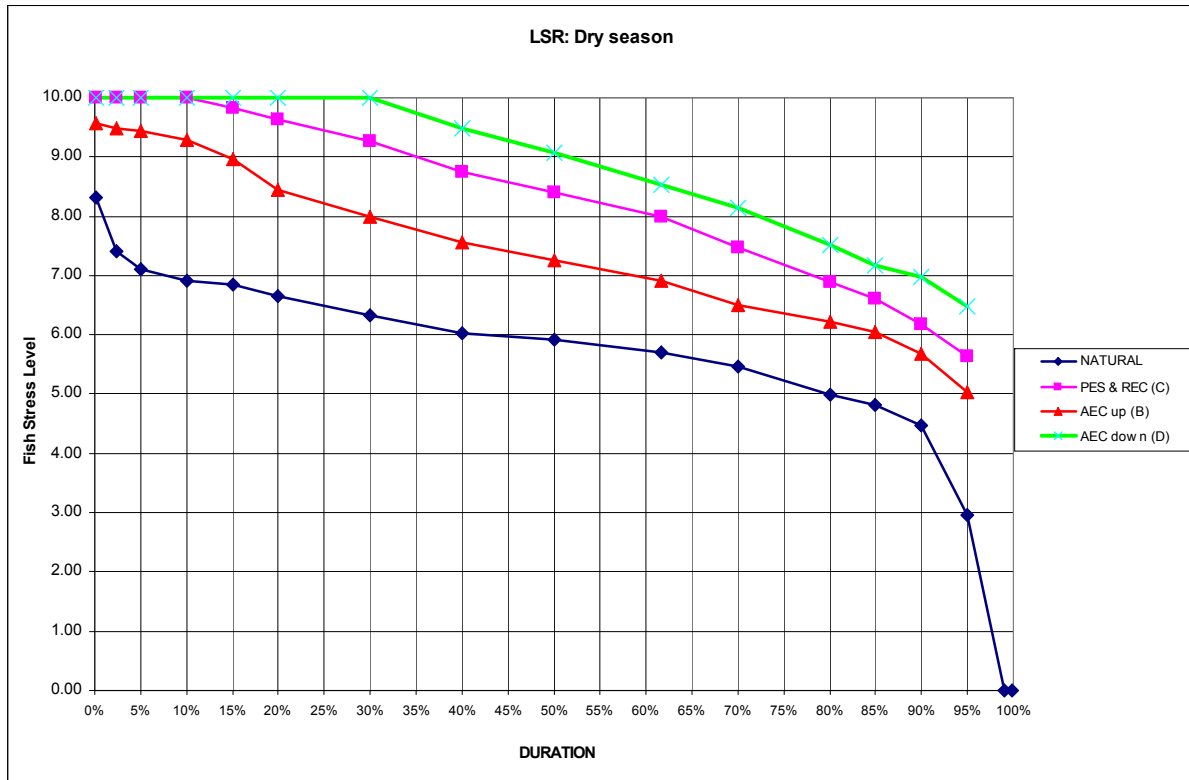


Figure C1 Dry Season LSR fish stress at different flow durations for the various ECs

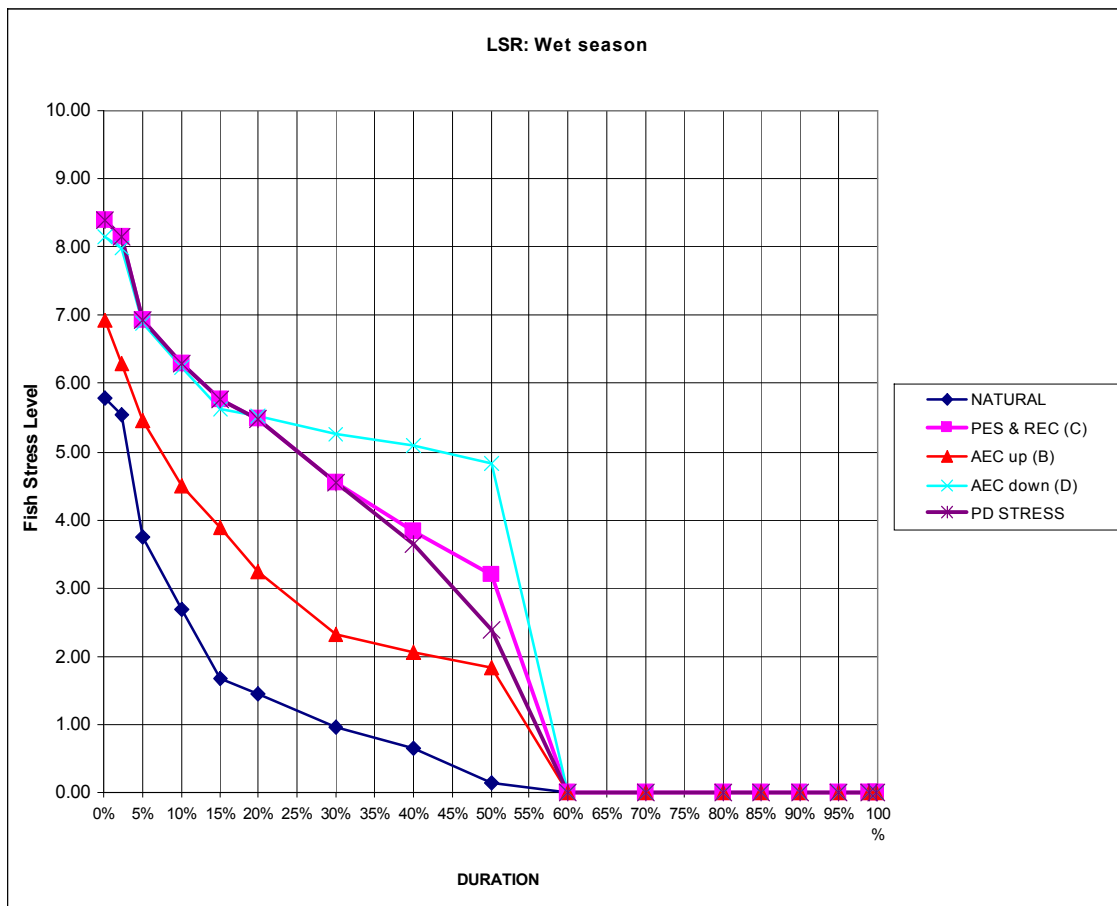


Figure C2 Wet Season LSR fish stress at different flow durations for the various ECs

## C2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table C6 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

**Table C6 Low flow requirements: FDI taxa**

GENERAL					
<b>INDICATOR:</b> Hydropsychid caddisflies and Simuliidae (i.e., common, flow dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.					
PES and REC: MACROINVERTEBRATE EC C (ECOSTATUS C)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.14 m, and average current velocity is 0.017 m/s (Spp Stress 7). At these flows the majority (97%) of flow is very slow, and critical habitats are absent. (Note that the hydraulic values were based on a two dimensional model of the study site, and so the results are not directly comparable to data obtained from a single cross-section).					
<b>Dry Season drought</b> The present condition for macroinvertebrates at this site is known to be Category C, even though the river stops flowing. This means that the macroinvertebrates are able to withstand temporary cessation of flow, and recover once flows resume.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.29 m, and average current velocity is 0.40 m/s (Spp Stress 2). This will provide suitable habitats during summer. A wide range of current speeds is available.					
<b>Wet Season drought</b> Average depth needed for wet season drought is 0.13 m, and average current velocity is 0.0809 m/s (Spp Stress 6). Fast and Fast flows comprise 4% of the flow speeds available.					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	10	10	0.001
Maintenance	Dry	50%	7	9.3	0.098
Drought	Wet	5%	6	8.2	0.596
Maintenance	Wet	50%	2	4.6	5.682
AEC up: MACROINVERTEBRATE EC B/C (ECOSTATUS B)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.15 m, and average current velocity is 0.12 m/s (Spp Stress 5.5). Fast and Fast flows comprise 11% of the flow speeds available.					
<b>Dry Season drought</b> Average depth needed for dry season drought is 0.15 m, and average current velocity is 0.008 m/s (Spp Stress 8). Wetted perimeter is significantly reduced (11.59 m). All current speeds are very slow.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.31 m, and average current velocity is 0.43 m/s (Spp Stress 1.6).					

Fast and Fast flows comprise 59% of the flow speeds available.					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	8	9.7	0.427
Maintenance	Dry	50%	5.5	8.2	0.6
Maintenance	Wet	50%	1.6	4	7
<b>AEC down: MACROINVERTEBRATE EC D (ECOSTATUS D)</b>					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.15 m, and average current velocity is 0.008 m/s (Spp Stress 8). Current speeds are all very slow.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.21 m, and average current velocity is 0.27 m/s (Spp Stress 4). Fast and very fast flows comprise 36% of the current speeds available.					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	8	9.7	0.427
Maintenance	Wet	50%	4	6	2.31

### C2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table C7.

**Table C7 Functions for each Flood Class**

Flood Class	Function/Motivation	
CLASS: I RANGE (M <sup>3</sup> /S): 20 DAILY AVERAGE: 20 DURATION: 4	Fish	Class I floods are very important floods for fish and serves as migration cues and to maintain adequate longitudinal connectivity for migration. These floods will also flush fines and algae from substrates to ensure adequate conditions in substrates, a very important habitat for spawning of many of the species. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation and contributes to the creation of acceptable nursery areas. Some resetting of water quality will also take place, and the changes in water quality may also serve as stimulus to cue migratory activity and even gonad development. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Five of these per year, any time during the wet season, are recommended for a macroinvertebrate Category C or B/C, and two for a Category D.
CLASS: II RANGE (M <sup>3</sup> /S): 40 - 80 DAILY AVERAGE: 80 DURATION: 6	Fish	Class II floods are similar in importance as Class I floods and have the same functionality as Class I floods. Their occurrence at lower frequency makes them only slightly less important for the fish assemblages than Class I. Secondary channels will be inundated by these floods which will create favourable spawning and refuge habitats for some species.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Three of these per year are recommended for a macroinvertebrate Category C or B/C: one at the beginning of the wet season (Oct/Nov), one during the wet season, and one towards the end of the wet season (Feb/Mar). Two of these per year are recommended for a macroinvertebrate Category D: one at the beginning of the wet season (Oct/Nov), and one towards the end of the wet season (Feb/Mar).
CLASS: III RANGE (M <sup>3</sup> /S): 100 – 130	Fish	Class III floods also provide similar functions as Class I, but due to its lower frequency it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even

Flood Class	Function/Motivation	
		spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.
CLASS : IV RANGE (M <sup>3</sup> /S): 200	Fish	Class IV floods also provide similar functions as Class I, but due to its lower frequency of occurrence it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.

## C2.4 EWR RULES

**Table C8 EWR 3 assurance rules for PES and REC: C**

Desktop Version 2, Printed on 2008/09/10  
 Summary of IFR rule curves for: V\_Ewr3 Natural Monthly Flows  
 Determination based on defined BBM Table with site specific assurance rules.  
 Regional Type: Vaal PES and REC = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.556	2.513	2.430	2.280	2.033	1.670	1.205	0.710	0.306	0.115
Nov	5.172	5.087	4.922	4.625	4.135	3.414	2.492	1.510	0.708	0.331
Dec	10.112	9.435	8.757	7.988	6.690	5.620	4.232	2.711	1.400	0.683
Jan	11.063	10.527	9.981	9.358	8.565	7.298	5.950	4.188	2.262	0.873
Feb	25.785	23.670	21.735	19.831	17.762	14.439	11.818	8.393	4.649	1.950
Mar	9.529	9.422	9.226	8.879	8.293	7.363	6.001	4.222	2.277	0.875
Apr	4.615	4.540	4.394	4.130	3.696	3.058	2.242	1.371	0.661	0.327
May	2.245	2.208	2.135	2.004	1.788	1.471	1.065	0.633	0.280	0.114
Jun	1.117	1.099	1.063	0.998	0.890	0.732	0.530	0.315	0.139	0.057
Jul	0.989	0.971	0.938	0.878	0.778	0.632	0.445	0.245	0.083	0.006
Aug	0.576	0.566	0.546	0.511	0.453	0.368	0.259	0.143	0.048	0.004
Sep	0.797	0.783	0.756	0.708	0.628	0.510	0.359	0.198	0.067	0.005

Reserve flows without High Flows										
Oct	2.556	2.513	2.430	2.280	2.033	1.670	1.205	0.710	0.306	0.115
Nov	5.172	5.087	4.922	4.625	4.135	3.414	2.492	1.510	0.708	0.331
Dec	6.540	6.438	6.241	5.887	5.307	4.449	3.335	2.116	1.065	0.490
Jan	7.752	7.665	7.505	7.220	6.740	5.979	4.864	3.407	1.815	0.667
Feb	11.121	10.998	10.769	10.364	9.682	8.598	7.011	4.938	2.672	1.038
Mar	7.416	7.333	7.180	6.909	6.451	5.725	4.662	3.273	1.754	0.659
Apr	4.615	4.540	4.394	4.130	3.696	3.058	2.242	1.371	0.661	0.327
May	2.245	2.208	2.135	2.004	1.788	1.471	1.065	0.633	0.280	0.114
Jun	1.117	1.099	1.063	0.998	0.890	0.732	0.530	0.315	0.139	0.057
Jul	0.989	0.971	0.938	0.878	0.778	0.632	0.445	0.245	0.083	0.006
Aug	0.576	0.566	0.546	0.511	0.453	0.368	0.259	0.143	0.048	0.004
Sep	0.797	0.783	0.756	0.708	0.628	0.510	0.359	0.198	0.067	0.005

Natural Duration curves										
Oct	70.923	22.095	10.928	8.834	6.687	4.857	4.096	3.230	1.333	0.605
Nov	106.412	72.728	50.000	31.354	27.022	16.084	10.301	8.291	4.402	2.778
Dec	146.677	99.754	66.368	48.006	38.620	24.474	19.486	12.269	6.623	2.834
Jan	116.275	83.057	59.741	47.547	37.115	30.907	25.310	15.248	10.114	4.850
Feb	165.332	83.569	50.132	34.540	28.336	22.499	18.895	16.171	11.103	3.344
Mar	70.105	47.715	35.129	31.239	19.153	13.945	11.757	8.453	4.712	1.941
Apr	34.290	19.796	15.000	12.361	9.070	7.361	5.224	3.665	2.596	0.702
May	12.407	8.382	5.933	4.648	3.726	3.006	2.348	1.885	1.165	0.534
Jun	8.796	6.022	3.989	3.063	2.674	2.292	1.775	1.586	0.772	0.505
Jul	6.575	4.607	3.663	3.237	2.688	2.337	1.964	1.658	1.344	0.538
Aug	5.821	4.626	3.506	2.976	2.490	2.277	1.960	1.635	1.355	1.042
Sep	11.038	5.285	3.700	3.318	2.820	2.431	2.014	1.690	1.107	0.629

**Table C9 EWR 3 assurance rules for AEC up: B**

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Summary of IFR rule curves for: V\_Ewr3 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal AEC UP = B

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	4.585	4.511	4.366	4.104	3.674	3.040	2.230	1.366	0.662	0.330
Nov	12.487	11.750	10.974	10.039	8.465	7.023	5.176	3.209	1.605	0.849
Dec	14.547	13.802	12.994	11.991	10.308	8.671	6.546	4.218	2.212	1.115
Jan	15.897	15.307	14.663	13.866	12.779	11.045	9.014	6.359	3.457	1.364
Feb	32.560	30.370	28.295	26.145	23.658	19.674	16.084	11.393	6.266	2.569
Mar	14.004	13.848	13.561	13.052	12.193	10.830	8.834	6.226	3.375	1.320
Apr	7.903	7.776	7.527	7.077	6.337	5.249	3.857	2.373	1.162	0.592
May	4.086	4.020	3.891	3.657	3.273	2.708	1.986	1.215	0.587	0.291
Jun	2.294	2.257	2.184	2.052	1.834	1.515	1.106	0.670	0.315	0.148
Jul	2.072	2.038	1.972	1.853	1.657	1.368	0.998	0.604	0.283	0.131
Aug	1.410	1.387	1.342	1.260	1.125	0.927	0.673	0.403	0.182	0.078
Sep	1.782	1.753	1.696	1.593	1.423	1.174	0.855	0.515	0.237	0.107

Reserve flows without High Flows

Oct	4.585	4.511	4.366	4.104	3.674	3.040	2.230	1.366	0.662	0.330
Nov	8.797	8.656	8.378	7.878	7.055	5.844	4.295	2.644	1.297	0.663
Dec	10.975	10.806	10.478	9.890	8.925	7.499	5.650	3.623	1.877	0.922
Jan	12.586	12.446	12.187	11.728	10.954	9.726	7.928	5.578	3.010	1.158
Feb	17.897	17.697	17.329	16.678	15.578	13.833	11.277	7.938	4.288	1.657
Mar	12.061	11.926	11.678	11.238	10.497	9.320	7.596	5.344	2.883	1.108
Apr	7.903	7.776	7.527	7.077	6.337	5.249	3.857	2.373	1.162	0.592
May	4.086	4.020	3.891	3.657	3.273	2.708	1.986	1.215	0.587	0.291
Jun	2.294	2.257	2.184	2.052	1.834	1.515	1.106	0.670	0.315	0.148
Jul	2.072	2.038	1.972	1.853	1.657	1.368	0.998	0.604	0.283	0.131
Aug	1.410	1.387	1.342	1.260	1.125	0.927	0.673	0.403	0.182	0.078
Sep	1.782	1.753	1.696	1.593	1.423	1.174	0.855	0.515	0.237	0.107

Natural Duration curves

Oct	70.923	22.095	10.928	8.834	6.687	4.857	4.096	3.230	1.333	0.605
Nov	106.412	72.728	50.000	31.354	27.022	16.084	10.301	8.291	4.402	2.778
Dec	146.677	99.754	66.368	48.006	38.620	24.474	19.486	12.269	6.623	2.834
Jan	116.275	83.057	59.741	47.547	37.115	30.907	25.310	15.248	10.114	4.850
Feb	165.332	83.569	50.132	34.540	28.336	22.499	18.895	16.171	11.103	3.344
Mar	70.105	47.715	35.129	31.239	19.153	13.945	11.757	8.453	4.712	1.941
Apr	34.290	19.796	15.000	12.361	9.070	7.361	5.224	3.665	2.596	0.702
May	12.407	8.382	5.933	4.648	3.726	3.006	2.348	1.885	1.165	0.534
Jun	8.796	6.022	3.989	3.063	2.674	2.292	1.775	1.586	0.772	0.505
Jul	6.575	4.607	3.663	3.237	2.688	2.337	1.964	1.658	1.344	0.538
Aug	5.821	4.626	3.506	2.976	2.490	2.277	1.960	1.635	1.355	1.042
Sep	11.038	5.285	3.700	3.318	2.820	2.431	2.014	1.690	1.107	0.629

**Table C10 EWR 3 assurance rules for AEC down: C/D**

Desktop Version 2, Printed on 2008/09/10  
 Summary of IFR rule curves for: V\_Ewr3 Natural Monthly Flows  
 Determination based on defined BBM Table with site specific assurance rules.  
 Regional Type: Vaal AEC DOWN = C/D

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.145	1.127	1.092	1.028	0.923	0.768	0.570	0.360	0.188	0.107
Nov	2.437	2.400	2.328	2.197	1.982	1.666	1.262	0.831	0.479	0.313
Dec	6.690	6.070	5.502	4.930	3.956	3.364	2.596	1.755	1.030	0.633
Jan	4.154	4.110	4.029	3.886	3.644	3.261	2.699	1.965	1.163	0.584
Feb	20.722	18.668	16.845	15.140	13.406	10.614	8.771	6.363	3.731	1.833
Mar	6.132	6.066	5.946	5.731	5.370	4.797	3.957	2.860	1.661	0.797
Apr	2.162	2.130	2.067	1.953	1.766	1.490	1.138	0.762	0.456	0.312
May	0.991	0.975	0.945	0.891	0.801	0.669	0.501	0.321	0.175	0.106
Jun	0.429	0.422	0.409	0.386	0.348	0.292	0.220	0.144	0.082	0.052
Jul	0.369	0.362	0.350	0.327	0.290	0.236	0.166	0.092	0.031	0.002
Aug	0.165	0.162	0.156	0.146	0.130	0.105	0.074	0.041	0.014	0.001
Sep	0.272	0.267	0.258	0.241	0.214	0.174	0.122	0.067	0.023	0.002

Reserve flows without High Flows

Oct	1.145	1.127	1.092	1.028	0.923	0.768	0.570	0.360	0.188	0.107
Nov	2.437	2.400	2.328	2.197	1.982	1.666	1.262	0.831	0.479	0.313
Dec	3.119	3.074	2.986	2.830	2.573	2.193	1.700	1.160	0.694	0.440
Jan	4.154	4.110	4.029	3.886	3.644	3.261	2.699	1.965	1.163	0.584
Feb	6.059	5.996	5.879	5.673	5.325	4.773	3.965	2.908	1.754	0.921
Mar	3.808	3.769	3.695	3.566	3.347	2.999	2.491	1.826	1.100	0.576
Apr	2.162	2.130	2.067	1.953	1.766	1.490	1.138	0.762	0.456	0.312
May	0.991	0.975	0.945	0.891	0.801	0.669	0.501	0.321	0.175	0.106
Jun	0.429	0.422	0.409	0.386	0.348	0.292	0.220	0.144	0.082	0.052
Jul	0.369	0.362	0.350	0.327	0.290	0.236	0.166	0.092	0.031	0.002
Aug	0.165	0.162	0.156	0.146	0.130	0.105	0.074	0.041	0.014	0.001
Sep	0.272	0.267	0.258	0.241	0.214	0.174	0.122	0.067	0.023	0.002

Natural Duration curves

Oct	70.923	22.095	10.928	8.834	6.687	4.857	4.096	3.230	1.333	0.605
Nov	106.412	72.728	50.000	31.354	27.022	16.084	10.301	8.291	4.402	2.778
Dec	146.677	99.754	66.368	48.006	38.620	24.474	19.486	12.269	6.623	2.834
Jan	116.275	83.057	59.741	47.547	37.115	30.907	25.310	15.248	10.114	4.850
Feb	165.332	83.569	50.132	34.540	28.336	22.499	18.895	16.171	11.103	3.344
Mar	70.105	47.715	35.129	31.239	19.153	13.945	11.757	8.453	4.712	1.941
Apr	34.290	19.796	15.000	12.361	9.070	7.361	5.224	3.665	2.596	0.702
May	12.407	8.382	5.933	4.648	3.726	3.006	2.348	1.885	1.165	0.534
Jun	8.796	6.022	3.989	3.063	2.674	2.292	1.775	1.586	0.772	0.505
Jul	6.575	4.607	3.663	3.237	2.688	2.337	1.964	1.658	1.344	0.538
Aug	5.821	4.626	3.506	2.976	2.490	2.277	1.960	1.635	1.355	1.042
Sep	11.038	5.285	3.700	3.318	2.820	2.431	2.014	1.690	1.107	0.629

**APPENDIX D: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 6: KLIP**

## D1 EWR 6: KLIP (KLIP RIVER) – DETERMINATION OF STRESS INDICES

Appendix D provides supporting information for the determination of stress indices of EWR 6 Klip (Chapter 6 and 7 of the Main Report, Volume 1).

### D1.1 FISH INDICATOR SPECIES

**Fish indicator group 1: Large semi-rheophilic (LSR) guild:** *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM) was selected as indicator species. Refer to Appendix B, Section B1.1.

**Fish indicator group 2: Small semi-rheophilic (SSR) guild:** *Barbus anoplus* (BANO) was selected as indicator species. Refer to Appendix B, Section B1.1.

### D1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table D1.

**Table D1 EWR 6: Habitat suitability for the SSR and LSR guild**

SSR AND LSR GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0.00	0.02	0.02	0.10	0.10	0.14	0.57	0.72	0.72	1.95	2.31
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	0.	2	2	4	4	4	6	6	6	8	8
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	10	6	6	4	4	4	4	4	4	4	10
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	10	10	10	10	10	10	10	10	10	10	10
Slow Shallow and Slow Deep	10	6	6	4	4	4	4	4	4	4	4
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	10	10	10	8	8	8	6	6	6	8	8
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	10	10	10	8	8	8	4	4	4	4	10
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	10	10	10	10	10	10	6	6	6	6	6
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	10	10	10	10	10	10	8	8	8	4	4
FAST TOTAL >0.1 m DEEP	10	10	10	10	10	10	6	6	6	4	4

The fish stress index is provided in Table D2.

**Table D2 Fish stress index**

Habitat	Discharges (m <sup>3</sup> /s)										
	0.00	0.02	0.02	0.10	0.10	0.14	0.57	0.72	0.72	1.95	2.31
<b>SMALL SEMI-RHEOPHILIC (SSR) GUILD</b>											
Spawning & nursery habitat	0	0.5	0.5	1	1	1	1.5	3	3	5	5
Abundance	2	2	2	3	3	4	4	4	4	5	5
Cover	2	3	3	4	4	4	5	5	5	5	5
Connectivity (lateral & longitudinal)	1	1	1	2	2	2	3	4	4	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	2	2	2	3	3	3	4	4	4	5	5
<b>Species stress: BANO</b>	<b>10</b>	<b>6</b>	<b>6</b>	<b>5</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>0</b>	<b>0</b>
<b>LARGE SEMI-RHEOPHILIC (LSR) GUILD</b>											
Spawning & nursery habitat	0	0	0	0.5	0.5	1.5	4	4.5	4.5	5	5
Abundance	0	0	0	1.5	1.5	2	3	3.5	3.5	5	5
Cover	0	0	0	1.5	1.5	2	4	4.5	4.5	5	5
Connectivity (lateral & longitudinal)	0	0	0	1	1	2	4	4	4	4.5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0.5	0.5	0.5	2	2	2	4	4.5	4.5	5	5
<b>Species stress: BAEN</b>	<b>10</b>	<b>9</b>	<b>9</b>	<b>7</b>	<b>7</b>	<b>6</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>0</b>	<b>0</b>

**D1.3 MACROINVERTEBRATE STRESS INDEX**

The habitat flow index for flow dependent macroinvertebrate (FDI) taxa is provided in Table D3 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table D3 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	6	12	18	32	1	2	3	6	2	4	5	9		2.727
1	All habitats plentiful, high quality. Fast, wide WP.	10	16	24	20	1	2	4	3	3	5	7	6		1.629
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	15	22	25	9	2	3	4	1	4	6	7	2		0.9
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	19	26	19	5	3	4	3	1	6	8	6	1		0.572
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	22	28	16	4	3	4	2	1	6	8	5	1		0.446
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	27	32	10	2	4	5	1	0	7	9	3	1		0.258

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)											MODIFIER	FLOW (m <sup>3</sup> /s)	
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>			VFBR <sup>12</sup>
6	Critical habitat residual. Low quality, moderate/slow velocity.	39	27	4	0	6	4	1	0	11	7	1	0		0.095
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	53	16	0	0	8	2	0	0	16	5	0	0	Algae	0.024
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	66	4	0	0	9	1	0	0	19	1	0	0	Algae	0.003
9	Standing water habitats only, very low quality. No flow.	70	0	0	0	10	0	0	0	20	0	0	0	Algae	0.001
10	Only hyporheic refugia, no surface water.	0	0	0	0	0	0	0	0	0	0	0	0		-

1 Very Slow over Coarse Sediment  
 4 Very Fast over Coarse Sediment  
 7 Fast over Fine Sediment  
 10 Slow over Bedrock

2 Slow over Coarse Sediment  
 5 Very Slow over Fine Sediment  
 8 Very Fast over Fine Sediment  
 11 Fast over Bedrock

3 Fast over Coarse Sediment  
 6 Slow over Fine Sediment  
 9 Very Slow over Bedrock  
 12 Very Fast over Bedrock

The stress index for FDI taxa is provided in Table D4 which rates the response of the species according to various biotic response metrics.

**Table D4 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
0.56	0.3	1.86	0.63	18.6	All flow dependent macroinvertebrates very abundant and healthy.	2.727	0
0.5	0.26	1.45	0.46	17.4	90% rheophilic species persist.	1.629	1
0.44	0.21	1.05	0.33	16.9	Most rheophilic species persist, but slight (80%) reduction.	0.900	2
0.4	0.17	0.84	0.26	16.4	Most rheophilic species persist, but abundances reduced.	0.572	3
0.38	0.16	0.76	0.23	16.0	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	0.446	4
0.34	0.13	0.59	0.17	14.7	Critical life-stages of sensitive rheophilic species at risk or non-viable.	0.258	5
0.28	0.09	0.38	0.11	12.4	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	0.095	6
0.22	0.05	0.24	0.07	8.8	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.	0.024	7
0.16	0.04	0.12	0.03	3.3	Some rheophilic species persist, but at very low numbers; All life stages of most rheophilic species at risk or non-viable.	0.003	8
0.14	0.04	0.07	0.02	2.4	Mostly pool dwellers; all life stages of most rheophilic species non-viable.	0.001	9
					Only pools dwellers.	-	10

## D2 EWR 6: KLIP (KLIP RIVER) – DETERMINATION OF EWR SCENARIOS

### D2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table D5 for the LSR guild and Table D6 for the SSR guild.

**Table D5 Low flow requirements: LSR guild**

GENERAL					
<p><b>INDICATOR:</b> The large semi-rheophilic species BAEN is the indicator species 1 selected for this EWR site. The maximum size is approximately 50 cm. Its optimal preferred general habitat is Slow Deep (SD), Fast Shallow (FS) and Fast Deep (FD) with suitable cover provided by substrate and water column depth. This spawning habitat requirement of this species is FD and FS habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and SS over substrate, and seek refuge in SD at night. Flows set for BAEN should suffice in general for the flow requirements of BKIM, LCAP and ASCL present at this site.</p>					
PES and REC: FISH EC B (ECOSTATUS B/C)					
<p><b>Dry Season maintenance</b> BAEN, as a semi-rheophilic species, can survive during the dry season without continuous flows (especially the adults which do well in deep pools). For the optimal survival conditions for juveniles adequate FS habitat should be maintained for a period of the time. SD with adequate depth should also be maintained to meet the requirements of adults, as well as juveniles (especially at night when these deeper areas are used for refuge to avoid extreme temperature fluctuations during the winter months). This is the optimal stress level (6.5) (flows) where some these critical habitats will be maintained in adequate abundance to ensure the survival of this indicator species at the site. Very limited FS will be maintained, to allow for optimal survival habitat of juvenile BAEN. These flows will also ensure that adequate depth remains in the SD and SS (pools) for maintenance of especially adult BAEN in the reach.</p>					
<p><b>Dry Season drought</b> BAEN being semi-rheophilic can survive periods with no flow, especially when occurring during the winter (dry) season. The most critical habitat for survival of this species during drought periods in the dry season is to ensure that adequate depths in pools (both SD and SS) are maintained. This habitat component plays an important role as refuge area to survive temperature fluctuations during the cold winter months. At this stress level/flow these refuge habitats critical for survival (SD and SS) will be maintained and the slight flows should at least maintain acceptable level of water quality for this moderately tolerant species.</p>					
<p><b>Wet Season maintenance</b> Once the indicator species (BAEN) has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (&gt; 0.3 m/s and &lt; 0.3 m deep) and FD (&gt; 0.3 m/s and &gt; 0.3 m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development. The recommended stress level should maintain adequate fast habitats (especially FS and FI) to allow for the requirements as described above for the different life stages of BAEN during the wet season to maintain it within a category B.</p>					
<p><b>Wet Season drought</b> During a drought in the wet season flows should at least allow for limited breeding and survival habitats for BAEN. Under the recommended stress level, limited breeding habitat in the form of FS will be available for this species to at least allow survival and future existence of the species at the site (survival of drought period). Some critical FS habitats should be available for some period to enable spawning, egg and larvae development. Very limited FS and adequate SD habitats should be available at the recommended stress level for the survival of juveniles and adults during this period.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)

Drought	Dry	5%	9	9	0.02
Maintenance	Dry	55%	6.5	6.5	0.12
Drought	Wet	8%	6.5	6.5	0.12
Maintenance	Wet	55%	2.5	2.5	0.736

**AEC down: FISH EC C (ECOSTATUS C)**

**General**

A further decrease in lo flows and increased zero flows will result in a loss in fast habitats which will have an impact on the semi-rheophilic species or species (reduced FROC and abundance) with a preference for fast habitats. Further water quality deterioration may also further reduce the FROC and abundances of intolerant species and especially early life stages. The loss in substrate quality due to increased sedimentation as a result of decreased flushing will also directly affect all species with a requirement for clean substrates for spawning and feeding.

**Dry Season maintenance**

Decreased flows during the dry seasons would reduce the optimal survival habitats of juvenile and adult BAEN. This stress level will result in very low abundance of fast shallow habitats (no FI and FD), important for the survival of especially juvenile BAEN. Decreased flows (lower than reference condition) will also aggravate the secondary impacts (water quality deterioration and siltation of substrates) and thereby negatively impact on the feeding and survival habitats for BAEN. Decreased flows will also reduce the depth of SD habitats, which are important survival habitats for over wintering of juvenile and adult BAEN, as adequate depth is required in SD to buffer temperature fluctuations in dry (cold) season, which will result in decreased FROC and abundance of BAEN, resulting in a lower category than present.

**Wet Season maintenance**

Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (> 0.3 m/s and < 0.3 m deep) and FD (> 0.3 m/s and > 0.3m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development.

The recommended stress level would provide very limited FD habitats (flow duration graphs indicate that under natural and present conditions their FD habitats would have been present 45% of time). Reduced FS and FI will however be available to allow for the requirements as described above for the different life stages of BAEN during the wet season and would probably result in deterioration into a category C. This will be associated with both a decrease in abundance and condition of breeding, nursery and refuge habitats, as well as water quality deterioration as a result of decreased flows (decreased oxygen levels, increased temperature). It will also reduce the depth of SD habitats and jeopardise the role these habitats play to provide refuge to juveniles and adults from night time temperature fluctuations.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	7	7	0.15
Maintenance	Wet	55%	3	3	0.572

**Table D6 Low flow requirements: SSR guild**

GENERAL
<p><b>INDICATOR:</b> The SSR species BANO was selected at indicator species 2 for this EWR site, due to its different habitat requirements than indicator species 1 (BAEN). BANO only reaches a maximum size of approximately 12 cm. Its optimal preferred general habitat is Slow Deep (SD) and Slow-Shallow (SS) preferably with overhanging vegetation or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock and even undercut banks) as general habitat. This most important difference of this species in relation to indicator 1 (BEAN) is the requirement of high flows overtopping banks and inundating vegetation for spawning purposes. Spawning takes place during the summer when rivers are swollen after rains. It lays its adhesive eggs amidst vegetation. The larvae hatch within 3 days and begin to swim and feed after 6/7 days. Flows should remain adequate to allow migration between reaches, thus pools should remain connected during wet season. Water levels providing inundated vegetation should last long enough for spawning, egg hatching and larvae development. Larvae and juveniles require SS and SD with adequate cover to allow optimal development and survival. Flows set for BANO should provide in general for the flow requirements of other small-semi rheophilic species and even species such as LUMB and CGAR,</p>

as well as limnophilic species (PPHI and TSPA).

**PES and REC: FISH EC B (ECOSTATUS B/C)**

**Dry Season maintenance**

BANO, as a moderately tolerant small semi-rheophilic has a high preference for SD and SS with cover (especially overhanging and aquatic vegetation, although they also use large rocky substrates as preferred cover). This species should be able to survive long periods of no or limited flow as long as adequate SD and SS habitats are maintained. The recommended stress level will probably result in limited flow, but this species will well be able to survive for the duration of the dry season without fast habitats, as long as the pools are maintained.

**Dry Season drought**

BANO a moderately tolerant semi-rheophilic species with high preference for SD and SS habitats with cover of aquatic vegetation and overhang, although they also make use of large rocky substrate such as cobbles to bedrock and undercut banks, especially in periods of stress/low flows, when inundated vegetation is limited or absent. During dry season droughts, this species will be able to handle high habitat stress and survive periods of no flow, as long as some surface water remains available as pools and backwaters. Maintenance of SS (and limited SD) with cover (under these conditions probable no inundated vegetation will be available but they will make use of substrate as cover for survival).

**Wet Season maintenance**

The optimal habitat of this species during wet season is a requirement of inundated vegetation for spawning and egg development that should ideally be provided by floods. After spawning and breeding, it is important that some level of aquatic vegetation and overhanging vegetation is maintained for a period to allow survival of larvae and juveniles. This is an abundant species in this system, and to maintain it in the current category some provision of their optimal habitat should be made. Under the recommended stress level, some inundated vegetation will be maintained to ensure the availability of at least some of this species optimal habitat requirement (overhanging vegetation and aquatic vegetation).

**Wet Season drought**

During drought in the wet season, BANO will require SS and SD (with adequate depth) and cover to survive. At this stress there will most probably be no optimal cover available to this species in the form of overhanging vegetation and aquatic vegetations, and they should seek refuge under large substrates (especially boulders). It is also recommended that some flow should remain to ensure that pools remain connected (by FS) and allow movement of this species and to maintain an acceptable water quality for the different life stages of this species (should spawning and egg development have taken place during floods).

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	9	10	0.001
Maintenance	Dry	55%	7	7	0.15
Drought	Wet	5%	5.5	9	0.02
Maintenance	Wet	55%	1.75	2.5	0.735

**AEC down: FISH EC C (ECOSTATUS C)**

**General**

If the base flows is reduced significantly (especially during summer), it will have an impact on this and other semi-rheophilic species primarily related to loss of habitat and cover. Decreased flows will result in overall decrease and even absence of inundated vegetation and overhanging vegetation as cover and this species will have to retreat to substrate as the only cover available. The deterioration in water quality associated with the decreased flows may further influence BANO, especially smaller life stages (egg development, embryos and larvae, as well as juvenile survival).

**Dry Season maintenance**

BANO, as a moderately tolerant small semi-rheophilic has a high preference for SD and SS with cover (especially overhanging and aquatic vegetation, although they also use large rocky substrates as preferred cover). This species should be able to survive long periods of no or limited flow as long as adequate SD and SS habitats are maintained. Although they are not directly dependant on fast habitats for survival, should the flows be further reduced it very limited fast habitat will be available and therefore the connection of pools may be lost or reduced, which will limit longitudinal migration for feeding and recruitment. Less flow will furthermore result in lower water quality and a build-up of waste products in the pools, which may further reduce the water quality and therefore survival and abundance of BANO.

**Wet Season maintenance**

The optimal habitat of this species during wet season is a requirement of inundated vegetation for spawning and egg development that should ideally be provided by floods. After spawning and breeding, it is important that some level of aquatic vegetation and overhanging vegetation is maintained for a period to allow survival of larvae and juveniles. At the mentioned stress level flow would probably not provide abundant inundated macrophytes and therefore very limited

abundance of their preferred habitat in the form of overhanging vegetation and aquatic vegetation will be available under this stress condition. Very limited fast habitats (mostly Fast Very Shallow (FVS) and very limited FS) will be available and connectivity between pools may therefore also be reduced with a resultant negative impact on the FROC of BANO, and a resultant decrease in the EC.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	10	10	0.001
Maintenance	Wet	55%	4.5	7	0.15

## D2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table D7 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

**Table D7 Low flow requirements: FDI taxa**

GENERAL					
<b>INDICATOR:</b> Perlidae and Psephenidae (i.e., sensitive, flow dependent taxa). The minimum depth requirements for these taxa are 15 cm, and the optimal current speeds are 0.6 m/s. These taxa are sensitive to deterioration in water quality, and are not expected to tolerate wide fluctuations in flow and water quality conditions.					
PES and REC: MACROINVERTEBRATE EC B (ECOSTATUS B/C)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.09 m, and average current velocity is 0.11 m/s (Spp Stress 6). This will enable FDIs to overwinter without significant detrimental impacts on the overall population.					
<b>Dry Season 20 % duration</b> Average depth needed is 0.07 m, and average current velocity is 0.08 m/s (Spp Stress 6.5).					
<b>Dry Season drought</b> Average depth needed for dry season drought is 0.04 m, and average current velocity is 0.03 m/s (Spp Stress 8). This will enable flow-dependent macroinvertebrates to survive a drought.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.26 m, and average current velocity is 0.46 m/s (Spp Stress 1). This will inundate some marginal vegetation, and provide suitable habitats during summer.					
<b>Wet Season 20 % duration</b> Average depth needed is 0.15 m, and average current velocity is 0.22 m/s (Spp Stress 4.5). Inflection point in wetted perimeter.					
<b>Wet Season drought</b> Average depth needed for wet season drought is 0.09 m, and average current velocity is 0.11 m/s (Spp Stress 6).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	8	9.5	0.0105
Maintenance	Dry	55%	6	7	0.15
	Dry	20%	6.5	8	0.12
Drought	Wet	5%	6	7	0.15

Maintenance	Wet	55%	1	1	1.629
	Wet	20%	4.5	4.5	0.364
<b>AEC down: MACROINVERTEBRATE EC C (ECOSTATUS C)</b>					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.15 m, and average current velocity is 0.06 m/s (Spp Stress 7.5). This will enable FDIs to overwinter without significant detrimental impacts on the overall population.					
<b>Dry Season 20 % duration</b> Average depth needed is 0.07 m, and average current velocity is 0.08 m/s (Spp Stress 6.5). Residual critical habitat (FCS) available, but insufficient current speeds for Perlidae.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.16 m, and average current velocity is 0.23 m/s (Spp Stress 4). This will provide suitable habitats during summer for Category C.					
<b>Wet Season 20 % duration</b> Average depth needed is 0.15 m, and average current velocity is 0.20 m/s (Spp Stress 5).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	20%	6.5	8	0.06
Maintenance	Dry	55%	7.5	9.2	0.105
Drought	Wet	20%	5	5	0.358
Maintenance	Wet	55%	4	4	0.446

## D2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table D8.

**Table D8 Functions for each Flood Class**

Flood Class	Function/Motivation	
CLASS I RANGE (M <sup>3</sup> /S): 5 – 7 DAILY AVERAGE: 5 DURATION: 3	Fish	Class I floods contribute to the establishment of optimum spawning habitat through flushing of fine sediments and benthic algae from substrates. It also provides migratory cues, both in terms of flow changes and water quality changes, and provides adequate connectivity for migration. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation (BANO, BPAL, and <i>Labeo umbratus</i> (LUMB)). It furthermore contributes to the creation of acceptable nursery areas. Some resetting of water quality and flushing out fine sediments will occur. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to flush organic flocculants and mobilise fines (1-2 mm sands) in order to improve biotope suitability. Five of these per year, any time during the wet season, are recommended for a macroinvertebrate Category C, and two for a Category D.
CLASS II RANGE (M <sup>3</sup> /S): 10 - 15 DAILY AVERAGE: 15 DURATION: 5	Fish	Class II floods are similar in importance as Class I floods and have the same functionality as Class I floods. Their occurrence at lower frequency makes them less important for the fish assemblages.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Three of these per year are recommended for a macroinvertebrate Category C: one at the beginning of the wet season (Oct/Nov), one during the wet season, and one towards the end of the wet season (Feb/Mar). Two of these per year are recommended for a macroinvertebrate Category D: one at the beginning of the wet season (Oct/Nov), and one towards the end of the wet season (Feb/Mar).
CLASS III RANGE (M <sup>3</sup> /S):	Fish	Class III floods also provide similar functions as Class I, but due to its lower frequency become less important to the general requirements of fish

Flood Class	Function/Motivation	
20 - 50		assemblages in this river reach.
CLASS IV RANGE (M <sup>3</sup> /S): >90	Fish	Class IV floods also provide similar functions as Class I, but due to its lower frequency become less important to the general requirements of fish assemblages in this river reach.

## D2.4 EWR RULES

**Table D9 EWR 6 assurance rules for PES and REC: B/C**

Desktop Version 2, Printed on 2008/07/03

Summary of IFR rule curves for: V\_Ewr6 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal PES and REC = B/C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.727	0.712	0.683	0.631	0.550	0.366	0.258	0.194	0.097	0.052
Nov	2.126	1.863	1.629	1.399	1.041	0.832	0.593	0.372	0.216	0.112
Dec	1.696	1.554	1.411	1.247	0.991	0.778	0.535	0.310	0.152	0.078
Jan	4.523	3.902	3.364	2.855	2.059	1.642	1.167	0.727	0.417	0.277
Feb	2.552	2.381	2.197	1.969	1.611	1.275	0.892	0.537	0.287	0.165
Mar	1.245	1.219	1.168	1.077	0.934	0.740	0.519	0.315	0.171	0.106
Apr	0.786	0.769	0.735	0.674	0.579	0.450	0.303	0.167	0.071	0.027
May	0.524	0.513	0.490	0.450	0.387	0.303	0.206	0.116	0.053	0.024
Jun	0.262	0.257	0.247	0.229	0.200	0.162	0.118	0.077	0.048	0.035
Jul	0.262	0.257	0.247	0.228	0.199	0.160	0.115	0.073	0.044	0.031
Aug	0.184	0.180	0.173	0.160	0.139	0.112	0.081	0.052	0.031	0.022
Sep	0.197	0.193	0.185	0.172	0.150	0.121	0.088	0.057	0.036	0.026
Reserve flows without High Flows										
Oct	0.393	0.386	0.370	0.342	0.299	0.240	0.173	0.111	0.067	0.047
Nov	0.786	0.771	0.739	0.682	0.594	0.473	0.336	0.210	0.120	0.080
Dec	1.048	1.025	0.980	0.900	0.775	0.605	0.411	0.232	0.105	0.048
Jan	1.310	1.284	1.230	1.135	0.985	0.783	0.552	0.338	0.187	0.119
Feb	1.834	1.796	1.720	1.584	1.371	1.083	0.754	0.450	0.236	0.139
Mar	1.245	1.219	1.168	1.077	0.934	0.740	0.519	0.315	0.171	0.106
Apr	0.786	0.769	0.735	0.674	0.579	0.450	0.303	0.167	0.071	0.027
May	0.524	0.513	0.490	0.450	0.387	0.303	0.206	0.116	0.053	0.024
Jun	0.262	0.257	0.247	0.229	0.200	0.162	0.118	0.077	0.048	0.035
Jul	0.262	0.257	0.247	0.228	0.199	0.160	0.115	0.073	0.044	0.031
Aug	0.184	0.180	0.173	0.160	0.139	0.112	0.081	0.052	0.031	0.022
Sep	0.197	0.193	0.185	0.172	0.150	0.121	0.088	0.057	0.036	0.026
Natural Duration curves										
Oct	8.539	3.203	1.486	0.930	0.582	0.366	0.258	0.194	0.097	0.052
Nov	15.486	6.759	5.382	3.364	2.022	1.431	0.729	0.556	0.270	0.112
Dec	17.152	9.543	6.530	4.241	3.035	2.274	1.624	1.001	0.485	0.078
Jan	15.901	9.125	6.564	5.029	3.416	2.617	1.927	1.318	0.579	0.306
Feb	25.231	10.909	6.209	4.299	3.671	2.567	1.939	1.653	1.290	0.165
Mar	8.442	6.470	4.208	3.263	2.423	2.076	1.303	0.724	0.511	0.116
Apr	4.109	2.901	2.133	1.389	1.154	0.934	0.575	0.428	0.174	0.058
May	2.072	1.254	0.877	0.594	0.478	0.373	0.235	0.183	0.093	0.052
Jun	1.343	0.745	0.517	0.413	0.301	0.270	0.220	0.131	0.089	0.046
Jul	0.948	0.653	0.437	0.340	0.239	0.220	0.183	0.134	0.071	0.049
Aug	0.676	0.411	0.306	0.265	0.224	0.194	0.149	0.116	0.075	0.041
Sep	1.705	0.610	0.374	0.247	0.208	0.162	0.135	0.104	0.066	0.039

**Table D10 EWR 6 assurance rules for AEC down: C**

Desktop Version 2, Printed on 2008/07/03

Summary of IFR rule curves for : V\_Ewr6 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type : Vaal AEC DOWN = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.213	0.209	0.202	0.188	0.167	0.139	0.106	0.076	0.055	0.045
Nov	1.096	0.964	0.848	0.733	0.555	0.450	0.331	0.221	0.144	0.109
Dec	1.173	1.043	0.923	0.801	0.610	0.485	0.342	0.210	0.116	0.074
Jan	3.852	3.246	2.737	2.281	1.569	1.265	0.919	0.598	0.372	0.270
Feb	1.570	1.421	1.280	1.130	0.894	0.723	0.528	0.348	0.221	0.163
Mar	0.597	0.585	0.563	0.523	0.461	0.376	0.279	0.190	0.127	0.098
Apr	0.425	0.416	0.398	0.366	0.316	0.247	0.169	0.097	0.046	0.023
May	0.284	0.278	0.266	0.245	0.212	0.168	0.117	0.070	0.037	0.022
Jun	0.199	0.195	0.188	0.175	0.154	0.126	0.094	0.065	0.044	0.035
Jul	0.170	0.167	0.161	0.150	0.132	0.108	0.081	0.055	0.038	0.030
Aug	0.121	0.119	0.114	0.106	0.094	0.077	0.057	0.039	0.027	0.021
Sep	0.142	0.139	0.134	0.125	0.110	0.090	0.068	0.047	0.032	0.025

Reserve flows without High Flows

Oct	0.213	0.209	0.202	0.188	0.167	0.139	0.106	0.076	0.055	0.045
Nov	0.426	0.418	0.403	0.375	0.331	0.271	0.203	0.140	0.096	0.076
Dec	0.525	0.514	0.492	0.454	0.393	0.311	0.218	0.131	0.070	0.042
Jan	0.639	0.628	0.604	0.562	0.495	0.406	0.303	0.209	0.142	0.112
Feb	0.852	0.836	0.803	0.745	0.654	0.531	0.391	0.261	0.169	0.128
Mar	0.597	0.585	0.563	0.523	0.461	0.376	0.279	0.190	0.127	0.098
Apr	0.425	0.416	0.398	0.366	0.316	0.247	0.169	0.097	0.046	0.023
May	0.284	0.278	0.266	0.245	0.212	0.168	0.117	0.070	0.037	0.022
Jun	0.199	0.195	0.188	0.175	0.154	0.126	0.094	0.065	0.044	0.035
Jul	0.170	0.167	0.161	0.150	0.132	0.108	0.081	0.055	0.038	0.030
Aug	0.121	0.119	0.114	0.106	0.094	0.077	0.057	0.039	0.027	0.021
Sep	0.142	0.139	0.134	0.125	0.110	0.090	0.068	0.047	0.032	0.025

Natural Duration curves

Oct	8.539	3.203	1.486	0.930	0.582	0.366	0.258	0.194	0.097	0.052
Nov	15.486	6.759	5.382	3.364	2.022	1.431	0.729	0.556	0.270	0.112
Dec	17.152	9.543	6.530	4.241	3.035	2.274	1.624	1.001	0.485	0.078
Jan	15.901	9.125	6.564	5.029	3.416	2.617	1.927	1.318	0.579	0.306
Feb	25.231	10.909	6.209	4.299	3.671	2.567	1.939	1.653	1.290	0.165
Mar	8.442	6.470	4.208	3.263	2.423	2.076	1.303	0.724	0.511	0.116
Apr	4.109	2.901	2.133	1.389	1.154	0.934	0.575	0.428	0.174	0.058
May	2.072	1.254	0.877	0.594	0.478	0.373	0.235	0.183	0.093	0.052
Jun	1.343	0.745	0.517	0.413	0.301	0.270	0.220	0.131	0.089	0.046
Jul	0.948	0.653	0.437	0.340	0.239	0.220	0.183	0.134	0.071	0.049
Aug	0.676	0.411	0.306	0.265	0.224	0.194	0.149	0.116	0.075	0.041
Sep	1.705	0.610	0.374	0.247	0.208	0.162	0.135	0.104	0.066	0.039

**APPENDIX E: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 7: UPPER WILGE**

## E1 EWR 7: UPPER WILGE (WILGE RIVER) – DETERMINATION OF STRESS INDICES

Appendix E provides supporting information for the determination of stress indices of EWR 7 Upper Wilge (Chapter 8 and 9 of the Main Report, Volume 1).

### E1.1 FISH INDICATOR SPECIES

**Fish indicator group 1: Small semi-rheophilic (SSR) guild:** The small semi-rheophilic species *Barbus anoplus* (BANO) and *Barbus paludinosus* (BPAL), together with *Labeobarbus aeneus* (BAEN) were selected as indicators at this site. All species present at this site are classified as semi-rheophilic. It is thought that the large semi-rheophilic BAEN would not utilise this habitat for spawning and nursery areas, but juveniles and adults utilise it. The two small semi-rheophilic species, namely BANO and BPAL was therefore used as indicators to determine the stress for aspects such as spawning and nursery habitats, while all species were considered for abundance/cover, connectivity and flow related water quality metrics.

### E1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table E1.

**Table E1 EWR 7: Habitat suitability for the SSR guild**

Depth classes	SSR GUILD										
	Discharges (m <sup>3</sup> /s)										
	0	0.02	0.06	0.07	0.1	0.22	0.33	0.5	0.7	0.9	1.06
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	10	3	2	1	1	1	1	1	1	1	1
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	8	9	9	8	0	4	3	2	2	2	2
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	0	0	0	0	2	5	5	5	5	5	4
Slow Shallow and Slow Deep	8	9	9	8	2	9	8	7	7	7	6
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	0	0	1	0	0	1	1	1	1	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	0	0	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	0	0	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	0	0	1	1	1	2	2	3	4	4	4
FAST TOTAL >0.1 m DEEP	0	0	2	2	2	3	3	4	5	5	5

The fish stress index is provided in Table E2

**Table E2 Fish stress index**

Habitat	Discharges (m <sup>3</sup> /s)										
	0	0.02	0.06	0.07	0.1	0.22	0.33	0.5	0.7	0.9	1.06
<b>SMALL SEMI-RHEOPHILIC (SSR) GUILD</b>											
Spawning habitat	0	0	0	0	0	1	2.5	3	4	4.5	5
Nursery habitat	0	0	0.5	0.5	0.5	2	2.5	3	4	4.5	5
Abundance	0	0.5	0.5	0.5	1.5	2.5	3	4	4.5	5	5
Cover	0	0.5	0.5	0.5	1.5	2.5	3	4	4.5	5	5
Connectivity (lateral & longitudinal)	0	1	2	3	4	4	4	4.5	4.5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	0.5	1	1.5	2	3	4	5	5	5	5
<b>Species stress: BANO</b>	<b>10</b>	<b>9.17</b>	<b>8.5</b>	<b>8</b>	<b>6.83</b>	<b>5</b>	<b>3.67</b>	<b>2.17</b>	<b>1.17</b>	<b>0.33</b>	<b>0</b>

**E1.3 MACROINVERTEBRATE STRESS INDEX**

The habitat flow index for marginal vegetation macroinvertebrate (MVI) taxa is provided in Table E3 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table E3 Habitat suitability for MVI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>	
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	0	0	0	0	20	36	36	8	0	0	0	0	0.9
1	All habitats plentiful, high quality. Fast, wide WP.	0	0	0	0	22	39	33	6	0	0	0	0	0.73
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	0	0	0	0	25	45	25	4	0	0	0	0	0.49
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	0	0	0	0	30	49	18	3	0	0	0	0	0.32
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	0	0	0	0	33	51	14	2	0	0	0	0	0.25
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	0	0	0	0	36	51	11	1	0	0	0	0	0.19
6	Critical habitat residual. Low quality, moderate/slow velocity.	0	0	0	0	40	51	9	1	0	0	0	0	0.14
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	0	0	0	0	47	46	6	0	0	0	0	0	0.12
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	0	0	0	0	47	46	6	0	0	0	0	0	0.09
9	Standing water habitats only, very low quality. No flow.	0	0	0	0	98	2	0	0	0	0	0	0	0.001
10	Only hyporheic refugia, no surface water.	0	0	0	0	100	0	0	0	0	0	0	0	-

1 Very Slow over Coarse Sediment  
 4 Very Fast over Coarse Sediment  
 7 Fast over Fine Sediment  
 10 Slow over Bedrock

2 Slow over Coarse Sediment  
 5 Very Slow over Fine Sediment  
 8 Very Fast over Fine Sediment  
 11 Fast over Bedrock

3 Fast over Coarse Sediment  
 6 Slow over Fine Sediment  
 9 Very Slow over Bedrock  
 12 Very Fast over Bedrock

The stress index for MVI taxa is provided in Table E4 which rates the response of the species according to various biotic response metrics.

**Table E4 Macroinvertebrate (MVI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
1.26	0.78	0.89	0.3	4.9	All flow dependent macroinvertebrates very abundant and healthy.	<b>1.06</b>	0
1.16	0.72	0.83	0.27	4.6	90% rheophilic species persist.	<b>0.74</b>	1
1	0.62	0.72	0.24	4.1	Most rheophilic species persist, but slight (80%) reduction.	<b>0.53</b>	2
0.86	0.53	0.62	0.2	3.7	Most rheophilic species persist, but abundances reduced.	<b>0.41</b>	3
0.78	0.48	0.57	0.18	3.4	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	<b>0.3</b>	4
0.7	0.44	0.52	0.16	3.2	Critical life-stages of sensitive rheophilic species at risk or non-viable.	<b>0.22</b>	5
0.62	0.4	0.47	0.15	2.9	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	<b>0.15</b>	6
0.58	0.37	0.44	0.14	2.8	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.	<b>0.12</b>	7
0.52	0.32	0.4	0.12	2.6	Some rheophilic species persist, but at very low numbers; All life stages of most rheophilic species at risk or non-viable.	<b>0.09</b>	8
0.08	0.04	0.09	0.03	0.7	Mostly pool dwellers; all life stages of most rheophilic species non-viable.	<b>0.03</b>	9
0.02	0.01	0.04	0.01	0.2	Only pools dwellers.	<b>0</b>	10

## E2 EWR 7: UPPER WILGE (WILGE RIVER) – DETERMINATION OF EWR SCENARIOS

### E2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table E5 for the SSR guild.

**Table E5 Low flow requirements: SSR guild**

GENERAL					
<p><b>INDICATOR:</b> The small semi-rheophilic species BANO and BPAL, together with BAEN were selected as indicators at this site. BANO only reaches a maximum size of approximately 12 cm. Its optimal preferred general habitat is SD and SS preferably with overhanging vegetation or aquatic vegetation as cover, although they also make use of large substrates (cobble, boulders and bedrock and even undercut banks) as general habitat. Spawning takes place during the summer when rivers are swollen after rains. It lays its adhesive eggs amidst vegetation. The larvae hatch within 3 days and begin to swim and feed after 6/7 days. Flows should remain adequate to allow migration between reaches, thus pools should remain connected during wet season. Water levels providing inundated vegetation should last long enough for spawning, egg hatching and larvae development. Larvae and juveniles require SS and SD with adequate cover to allow optimal development and survival. The large semi-rheophilic species BAEN reaches a maximum size of approximately 50 cm. Its optimal preferred general habitat is SD, FS and FD with suitable cover provided by substrate and water column depth. Its spawning habitat requirement is FS, FI and potentially lower end of FD habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and SS over substrate, and seek refuge in SD at night.</p>					
PES and REC: FISH EC B (ECOSTATUS A/B)					
<p><b>Dry Season maintenance</b> It is estimated that the PES of the SSR guild is generally in a category B during the dry maintenance period. It is estimated that at a recommended fish stress level of 7.25 (40% duration) the total habitat suitability would be adequate to sustain the semi-rheophilic fish species at this site and maintain it in the PES.</p>					
<p><b>Dry Season drought</b> The recommended fish stress level of 9.49 for the dry season drought would result in relatively low habitat suitability for the semi rheophilic fish guild but as they do not require flowing habitats during the dry season, and adequate habitat will be available, it is estimated that they will remain within the present state.</p>					
<p><b>Wet Season maintenance</b> It is estimated that the PES of the SSR guild is generally in a category A during the wet maintenance period. The maximum allowable fish stress levels to maintain the SR in a category A is provided in Figure E1. At this recommended fish stress level of 1.25 (40% duration) the habitat suitability will be 92% of the expected optimal wet season habitat suitability under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach within a category A during the dry season and overall in a fish category B.</p>					
<p><b>Wet Season drought</b> The maximum allowable fish stress levels during wet season droughts is 5.3 (5% duration). This equates to a total habitat suitability score of 93% of optimal wet season habitat suitability expected during natural droughts. These flows would enable the maintenance of this fish guild at this site in a category A during the wet season.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	9.49	9.4	0.0184
Maintenance	Dry	40%	7.25	8	0.093
Drought	Wet	5%	5.3	5.75	0.199
Maintenance	Wet	40%	1.25	1.25	0.688
AEC down: FISH EC C (ECOSTATUS C)					
<p><b>General</b> Decreased base flows will result in a loss of FS and FD habitats, which will probably reduce the FROC of BAEN, a species with a high requirement for this habitat type.</p>					

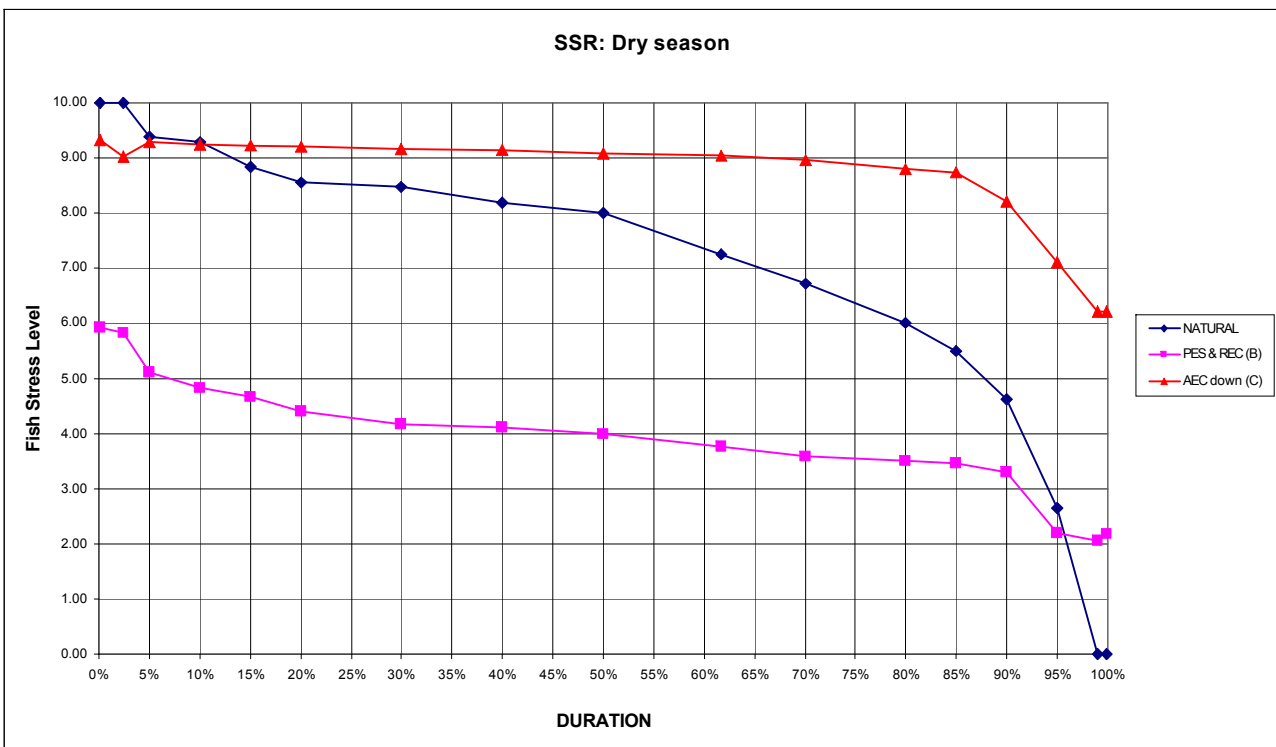
**Dry Season maintenance**

A decrease in flow during the dry season is expected to reduce the fish to a category C as a result of loss of suitable habitats for some life stages of the semi-rheophilic species. The maximum allowable fish stress levels to maintain the SSR in a category C is estimated to be 7.64 (40% duration).

**Wet Season maintenance**

Decreased flows during the wet season will also result in reduced habitat availability for the different life stages of the semi-rheophilic species. At a fish stress level of 2.15 (40% duration) the habitat suitability will be 82% of what can be expected during the dry season under natural flow conditions.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	40%	7.64	8.3	0.072
Maintenance	Wet	40%	2.15	2.15	0.512



**Figure E1 Dry Season SSR fish stress at different flow durations for the various ECs**

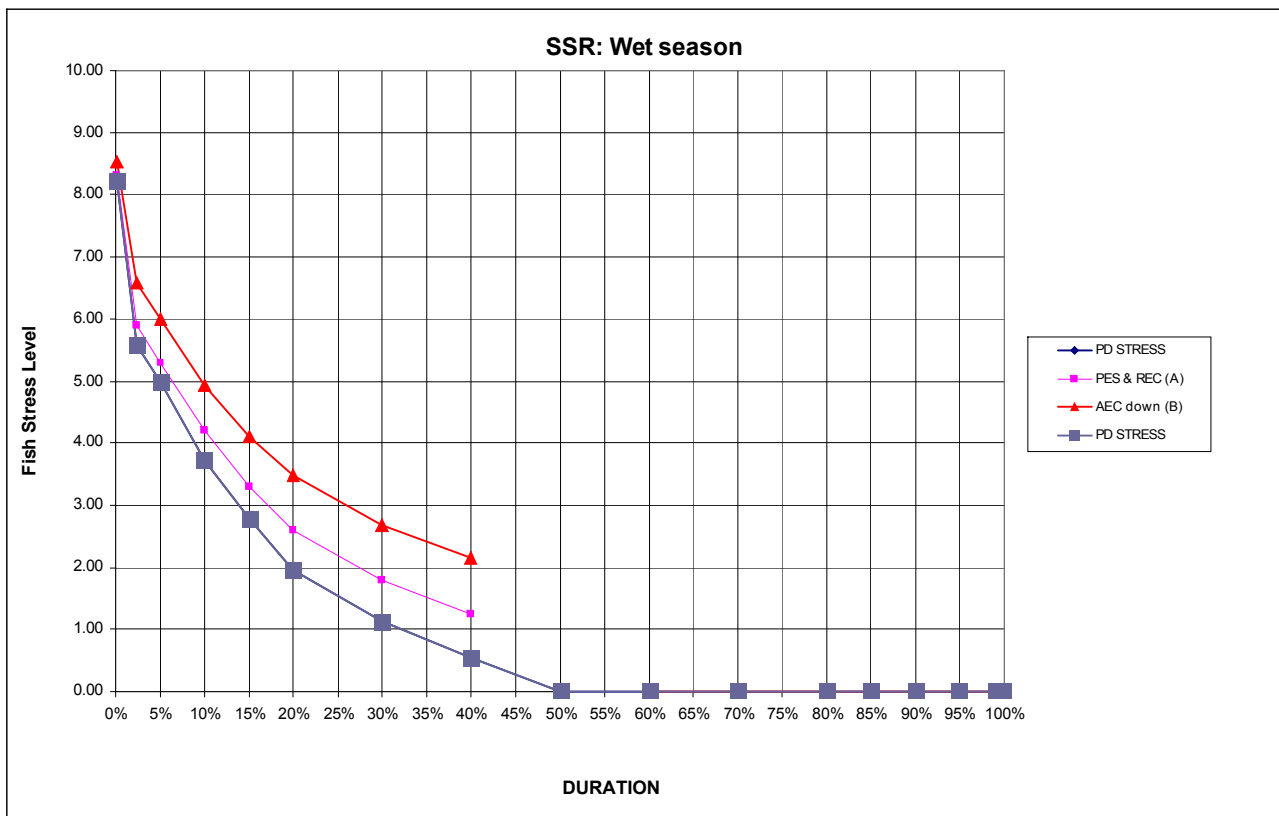


Figure E2 Wet Season SSR fish stress at different flow durations for the various ECs

## E2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The MVI low flow requirements are summarised in Table E6 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

Table E6 Low flow requirements: MVI taxa

GENERAL
<b>INDICATOR:</b> Macroinvertebrates inhabiting marginal vegetation only (i.e., mainly Hemiptera). These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions. The main consideration in setting flows was the depth that marginal vegetation was inundated (at least 10 cm), but allowing sufficient light penetration (less than 50 cm). Flow-dependent taxa were not found or expected within this oxbow dominated system.
PES and REC: MACROINVERTEBRATE EC B (ECOSTATUS A/B)
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 12 cm, and maximum depth is 60 cm, which is considered sufficient (Spp Stress 8.5).
<b>Dry Season drought</b>

Average depth needed for dry season drought is 10 cm, and maximum depth is 54 cm (Spp Stress 9).

#### Wet Season maintenance

Average depth needed for wet season maintenance is 0.34 m, and maximum depth is 1.2 m (Spp Stress 1). This will provide suitable vegetation habitats during summer.

#### Wet Season drought

Average depth needed for wet season drought is 0.13 m, and maximum depth is 0.78 m (Spp Stress 6).

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	9	9.9	0.004
Maintenance	Dry	60%	8.5	8.7	0.048
Drought	Wet	5%	6	6.3	0.141
Maintenance	Wet	60%	1	1	0.74

#### AEC down: MACROINVERTEBRATE EC C/D (ECOSTATUS C)

#### Dry Season maintenance

Average depth needed for dry season maintenance is 0.1 m (i.e. some vegetation inundated).

#### Wet Season maintenance

Average depth needed for wet season maintenance is 0.25 m (Spp Stress 3). Crucial marginal vegetation present and abundant.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	60%	9	9.8	0.007
Maintenance	Wet	60%	3	3.8	0.322

## E2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table E7.

**Table E7 Functions for each Flood Class**

Flood Class	Function/Motivation	
CLASS: I RANGE (M <sup>3</sup> /S): 1 DAILY AVERAGE: 0.5 DURATION: 2	Fish	Class I floods are very important floods for fish and serves as migration cues and to maintain adequate longitudinal connectivity for migration. These floods will also flush fines and algae from substrates to ensure adequate conditions in substrates, a very important habitat for spawning of many of the species. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation and contributes to the creation of acceptable nursery areas. Some resetting of water quality will also take place, and the changes in water quality may also serve as stimulus to cue migratory activity and even gonad development. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Six of these per year, any time during the wet season, are recommended for a macroinvertebrate Category B, and three for a Category C/D.
CLASS: II RANGE (M <sup>3</sup> /S): 2 - 3 DAILY AVERAGE: 1 DURATION: 2	Fish	Class II floods are similar in importance as Class I floods and have the same functionality as Class I floods. Their occurrence at lower frequency makes them only slightly less important for the fish assemblages than Class I. Secondary channels will be inundated by these floods which will create favourable spawning and refuge habitats for some species.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope. Four of these per year are recommended during the wet season for a macroinvertebrate Category B. Two of these per year are recommended for a macroinvertebrate Category C/D.

Flood Class	Function/Motivation	
CLASS: III RANGE (M <sup>3</sup> /S): 8 -9 DAILY AVERAGE: 3 DURATION: 3	Fish	Class III floods also provide similar functions as Class I, but due to its lower frequency it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.
	Macroinvertebrates	Functions as above. Two of these per year are recommended during the wet season for a macroinvertebrate Category B. These high flows are particularly important to recharge the wide floodplains.
CLASS : IV RANGE (M <sup>3</sup> /S): <11 DAILY AVERAGE: 5 DURATION: 3	Fish	Class IV floods also provide similar functions as Class I, but due to its lower frequency of occurrence it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.
	Macroinvertebrates	The purpose of these floods is to inundate the riparian wetlands and recharge oxbow lakes. One of these per year is recommended for a Category B.

## E2.4 EWR RULES

**Table E8 EWR 7 assurance rules for PES and REC: A/B (B)**

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Summary of IFR rule curves for: V\_EWR7 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal REC = B

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.179	0.176	0.171	0.160	0.143	0.117	0.084	0.049	0.019	0.003
Nov	0.506	0.476	0.446	0.410	0.349	0.293	0.221	0.144	0.069	0.035
Dec	0.977	0.887	0.805	0.720	0.577	0.488	0.372	0.231	0.105	0.049
Jan	1.043	0.972	0.905	0.836	0.757	0.629	0.516	0.367	0.205	0.082
Feb	1.575	1.460	1.354	1.245	1.062	0.889	0.715	0.540	0.300	0.127
Mar	0.668	0.661	0.647	0.623	0.583	0.518	0.424	0.291	0.166	0.069
Apr	0.410	0.403	0.390	0.367	0.324	0.270	0.196	0.115	0.044	0.006
May	0.256	0.252	0.243	0.168	0.134	0.108	0.078	0.060	0.025	0.002
Jun	0.128	0.126	0.122	0.112	0.093	0.069	0.054	0.034	0.012	0.001
Jul	0.077	0.076	0.073	0.068	0.061	0.049	0.035	0.019	0.006	0.000
Aug	0.072	0.071	0.068	0.064	0.056	0.046	0.032	0.018	0.006	0.000
Sep	0.103	0.101	0.098	0.092	0.081	0.066	0.053	0.035	0.020	0.013

Reserve flows without High Flows

Oct	0.154	0.151	0.146	0.137	0.122	0.100	0.071	0.041	0.015	0.001
Nov	0.359	0.354	0.343	0.324	0.292	0.246	0.186	0.121	0.066	0.035
Dec	0.462	0.455	0.441	0.417	0.377	0.319	0.242	0.159	0.087	0.047
Jan	0.565	0.559	0.548	0.527	0.493	0.439	0.359	0.255	0.141	0.059
Feb	0.797	0.788	0.772	0.743	0.694	0.617	0.504	0.357	0.195	0.079
Mar	0.643	0.635	0.622	0.599	0.560	0.498	0.408	0.289	0.160	0.067
Apr	0.410	0.403	0.390	0.367	0.324	0.270	0.196	0.115	0.044	0.006
May	0.256	0.252	0.243	0.168	0.134	0.108	0.078	0.060	0.025	0.002
Jun	0.128	0.126	0.122	0.112	0.093	0.069	0.054	0.034	0.012	0.001
Jul	0.077	0.076	0.073	0.068	0.061	0.049	0.035	0.019	0.006	0.000
Aug	0.072	0.071	0.068	0.064	0.056	0.046	0.032	0.018	0.006	0.000
Sep	0.103	0.101	0.098	0.092	0.081	0.066	0.053	0.035	0.020	0.013

Natural Duration curves

Oct	1.359	0.709	0.497	0.302	0.183	0.138	0.086	0.075	0.045	0.022
Nov	2.951	1.690	1.154	0.783	0.498	0.386	0.293	0.212	0.069	0.035
Dec	2.897	1.747	1.393	1.079	0.795	0.556	0.411	0.231	0.105	0.049
Jan	3.069	2.087	1.628	1.247	0.922	0.754	0.556	0.452	0.265	0.082
Feb	4.092	2.286	1.575	1.273	1.062	0.889	0.715	0.542	0.331	0.182
Mar	1.740	1.415	1.217	0.974	0.702	0.571	0.459	0.291	0.187	0.093
Apr	0.910	0.710	0.563	0.471	0.324	0.282	0.220	0.147	0.077	0.027
May	0.478	0.310	0.243	0.168	0.134	0.108	0.078	0.060	0.041	0.015
Jun	0.313	0.185	0.139	0.112	0.093	0.069	0.054	0.046	0.027	0.008
Jul	0.284	0.164	0.105	0.093	0.078	0.063	0.049	0.045	0.026	0.000
Aug	0.250	0.153	0.112	0.090	0.071	0.063	0.052	0.049	0.022	0.000
Sep	0.432	0.224	0.150	0.112	0.081	0.066	0.054	0.046	0.039	0.027

**Table E9 EWR 7 assurance rules for AEC down: C**

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Summary of IFR rule curves for: V\_EWR7 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal AEC DOWN = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.101	0.099	0.096	0.090	0.080	0.065	0.047	0.027	0.010	0.001
Nov	0.251	0.240	0.228	0.212	0.186	0.159	0.124	0.087	0.055	0.035
Dec	0.354	0.335	0.315	0.292	0.252	0.216	0.169	0.118	0.074	0.049
Jan	0.415	0.405	0.393	0.375	0.350	0.309	0.256	0.187	0.112	0.057
Feb	1.320	1.215	1.118	1.023	0.919	0.753	0.620	0.446	0.256	0.119
Mar	0.443	0.439	0.430	0.415	0.389	0.348	0.289	0.211	0.126	0.064
Apr	0.245	0.241	0.233	0.219	0.196	0.161	0.117	0.068	0.026	0.004
May	0.144	0.141	0.137	0.128	0.114	0.093	0.067	0.038	0.014	0.001
Jun	0.086	0.085	0.082	0.077	0.068	0.056	0.040	0.023	0.008	0.001
Jul	0.058	0.057	0.055	0.051	0.045	0.037	0.026	0.014	0.005	0.000
Aug	0.050	0.049	0.048	0.045	0.040	0.032	0.023	0.013	0.004	0.000
Sep	0.065	0.064	0.062	0.059	0.054	0.046	0.036	0.025	0.016	0.012

Reserve flows without High Flows

Oct	0.101	0.099	0.096	0.090	0.080	0.065	0.047	0.027	0.010	0.001
Nov	0.202	0.199	0.194	0.184	0.167	0.143	0.113	0.079	0.051	0.035
Dec	0.260	0.256	0.249	0.236	0.216	0.185	0.146	0.102	0.065	0.044
Jan	0.371	0.367	0.360	0.347	0.326	0.292	0.242	0.177	0.106	0.054
Feb	0.593	0.587	0.575	0.554	0.519	0.463	0.382	0.275	0.158	0.074
Mar	0.415	0.411	0.403	0.389	0.365	0.327	0.271	0.198	0.119	0.061
Apr	0.245	0.241	0.233	0.219	0.196	0.161	0.117	0.068	0.026	0.004
May	0.144	0.141	0.137	0.128	0.114	0.093	0.067	0.038	0.014	0.001
Jun	0.086	0.085	0.082	0.077	0.068	0.056	0.040	0.023	0.008	0.001
Jul	0.058	0.057	0.055	0.051	0.045	0.037	0.026	0.014	0.005	0.000
Aug	0.050	0.049	0.048	0.045	0.040	0.032	0.023	0.013	0.004	0.000
Sep	0.065	0.064	0.062	0.059	0.054	0.046	0.036	0.025	0.016	0.012

Natural Duration curves

Oct	1.359	0.709	0.497	0.302	0.183	0.138	0.086	0.075	0.045	0.022
Nov	2.951	1.690	1.154	0.783	0.498	0.386	0.293	0.212	0.069	0.035
Dec	2.897	1.747	1.393	1.079	0.795	0.556	0.411	0.231	0.105	0.049
Jan	3.069	2.087	1.628	1.247	0.922	0.754	0.556	0.452	0.265	0.082
Feb	4.092	2.286	1.575	1.273	1.062	0.889	0.715	0.542	0.331	0.182
Mar	1.740	1.415	1.217	0.974	0.702	0.571	0.459	0.291	0.187	0.093
Apr	0.910	0.710	0.563	0.471	0.324	0.282	0.220	0.147	0.077	0.027
May	0.478	0.310	0.243	0.168	0.134	0.108	0.078	0.060	0.041	0.015
Jun	0.313	0.185	0.139	0.112	0.093	0.069	0.054	0.046	0.027	0.008
Jul	0.284	0.164	0.105	0.093	0.078	0.063	0.049	0.045	0.026	0.000
Aug	0.250	0.153	0.112	0.090	0.071	0.063	0.052	0.049	0.022	0.000
Sep	0.432	0.224	0.150	0.112	0.081	0.066	0.054	0.046	0.039	0.027

**APPENDIX F: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 8: BAVARIA**

## F1 EWR 8: BAVARIA (WILGE RIVER) – DETERMINATION OF STRESS INDICES

Appendix F provides supporting information for the determination of stress indices of EWR 8 Grootdraai (Chapter 10 and 11 of the Main Report, Volume 1).

### F1.1 FISH INDICATOR SPECIES

**Fish indicator group 1: Large semi-rheophilic (LSR) guild:** *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM) was selected as indicator species. Refer to Appendix B, Section B1.1.

**Fish indicator group 2: Small semi rheophilic (SSR) guild:** *Barbus anoplus* (BANO) was selected as indicator species. Refer to Appendix B, Section B1.1.

### F1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table F1.

**Table F1 EWR 8: Habitat suitability for the SSR and LSR guild**

SSR AND LSR GUILD										
Depth classes	Discharges (m <sup>3</sup> /s)									
	0.003	0.015	0.24	0.6	1.23	1.8	2.9	5	6.8	25
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	0	4	4	4	6	6	6	6	6	8
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	10	4	4	4	4	4	4	4	6	6
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	10	10	10	10	8	8	6	6	6	6
Slow Shallow and Slow Deep	10	4	4	4	4	4	4	4	4	6
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	10	10	8	6	6	8	6	6	6	8
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	10	10	8	6	6	6	6	6	6	6
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	10	10	8	8	6	6	6	6	6	8
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	10	10	8	8	6	6	6	4	4	4
FAST TOTAL >0.1 m DEEP	10	10	8	6	6	6	4	4	4	4

The fish stress index is provided in Table F2.

**Table F2 Fish stress index**

Habitat	Discharges (m <sup>3</sup> /s)									
	0.003	0.015	0.24	0.6	1.23	1.8	2.9	5	6.8	25
<b>SMALL SEMI-RHEOPHILIC (SSR) GUILD</b>										
Spawning & nursery habitat	0	1	2	2	2.5	2.5	2.5	3	3	5
Abundance	0.5	1	2	3	4	4	4	5	5	5
Cover	0.5	2	2	3	3	3	3	3	3	5
Connectivity (lateral & longitudinal)	0.5	1	2	3	4	4	4	4	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	1	2	2	3	4	4	4	4	5	5
<b>Species stress: BANO</b>	<b>9</b>	<b>7</b>	<b>6</b>	<b>4</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>0</b>
<b>LARGE SEMI-RHEOPHILIC (LSR) GUILD</b>										

Habitat	Discharges (m <sup>3</sup> /s)									
	0.003	0.015	0.24	0.6	1.23	1.8	2.9	5	6.8	25
Spawning & nursery habitat	0	0	0.5	1	2	3	4	4.5	5	5
Abundance	0	0.5	1	2	3	3.5	4	4.5	4.5	5
Cover	0	0.5	1	2	2.5	3	3.5	4	4.5	5
Connectivity (lateral & longitudinal)	0	0.5	1	1.5	2	2.5	3	4	4.5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	0.5	2	2.5	3	3.5	4	4.5	5	5
<b>Species stress: BAEN</b>	<b>10</b>	<b>9</b>	<b>8</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>

### F1.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for flow dependent macroinvertebrate (FDI) taxa is provided in Table F3 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table F3 Habitat suitability for FDI taxa**

Habitat Flow Response Index	Habitat Response	HABITAT ABUNDANCE AND SUITABILITY (%)													FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>	VEG <sup>13</sup>	
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	8	15	24	34	2	4	6	8	0	0	0	0	8	1.6
1	All habitats plentiful, high quality. Fast, wide WP.	8	16	26	30	2	4	6	7	0	0	0	0	6	1.35
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	10	18	29	23	3	5	7	6	0	0	0	0	3	0.94
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	14	23	31	13	3	6	8	3	0	0	0	0	0	0.59
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	18	27	27	8	5	7	7	2	0	0	0	0	0	0.36
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	23	33	19	4	6	8	5	1	0	0	0	0	0	0.22
6	Critical habitat residual. Low quality, moderate/slow velocity.	28	37	12	2	7	9	3	1	0	0	0	0	0	0.12
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	31	37	10	2	8	9	3	0	0	0	0	0	0	0.09
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	51	27	2	0	13	7	1	0	0	0	0	0	0	0.016
9	Standing water habitats only, very low quality. No flow.	70	10	0	0	18	2	0	0	0	0	0	0	0	0.002
10	Only hyporheic refugia, no surface water.	80	0	0	0	20	0	0	0	0	0	0	0	0	0.001

- 1 Very Slow over Coarse Sediment
- 4 Very Fast over Coarse Sediment
- 7 Fast over Fine Sediment
- 10 Slow over Bedrock
- 13 Fringing vegetation

- 2 Slow over Coarse Sediment
- 5 Very Slow over Fine Sediment
- 8 Very Fast over Fine Sediment
- 11 Fast over Bedrock

- 3 Fast over Coarse Sediment
- 6 Slow over Fine Sediment
- 9 Very Slow over Bedrock
- 12 Very Fast over Bedrock

The stress index for FDI taxa is provided in Table F4 which rates the response of the species according to various biotic response metrics.

**Table F4 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
0.48	0.21	1.63	0.57	14.6	All flow dependent macroinvertebrates very abundant and healthy.	1.35	0
0.46	0.2	1.52	0.53	12.9	90% rheophilic species persist.	0.94	1
0.42	0.18	1.37	0.46	12.6	Most rheophilic species persist, but slight (80%) reduction.	0.59	2
0.38	0.16	1.13	0.37	11.1	Most rheophilic species persist, but abundances reduced.	0.46	3
0.34	0.14	0.95	0.29	9.2	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	0.36	4
0.3	0.13	0.75	0.24	7.6	Critical life-stages of sensitive rheophilic species at risk or non-viable.	0.22	5
0.26	0.11	0.61	0.19	6.3	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	0.12	6
0.24	0.1	0.57	0.17	5.8	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.	0.09	7
0.16	0.05	0.31	0.09	3.6	Some rheophilic species persist, but at very low numbers; All life stages of most rheophilic species at risk or non-viable.	0.016	8
0.11	0.02	0.16	0.06	1.9	Mostly pool dwellers; all life stages of most rheophilic species non-viable.	0.002	9
0.02	0.01	0.08	0.02	0.1	Only pools dwellers.	0.001	10

## F2 EWR 8: BAVARIA (WILGE RIVER) – DETERMINATION OF EWR SCENARIOS

### F2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table F5 for the LSR guild and Table F6 for the SSR guild.

**Table F5 Low flow requirements: LSR guild**

GENERAL
<p><b>INDICATOR:</b> The large semi-rheophilic species BAEN is the indicator species 1 selected for this EWR site. The maximum size is approximately 50 cm. Its optimal preferred general habitat is SD, FS and FD with suitable cover provided by substrate and water column depth. This spawning habitat requirement of this species is FD and FS habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and SS over substrate, and seek refuge in SD at night. Flows set for BAEN should suffice in general for the flow requirements of BKIM, LCAP and ASCL present at this site.</p>
PES and REC: FISH EC C (ECOSTATUS C)
<p><b>Dry Season maintenance</b>                      BAEN, as a semi-rheophilic species, can survive during the dry season without continuous flows (especially the adults which do well in deep pools). For the optimal survival conditions of juveniles adequate FS habitat should be maintained for a period of the time. SD with adequate depth should also be maintained to meet the requirements of adults, as well as juveniles (especially at night when these deeper areas are used for refuge to avoid extreme temperature fluctuations during the winter months).</p> <p>At this stress level some fast habitat will be maintained (some FS, FI and limited FD) which will provide adequate survival habitat for especially the juveniles, which prefer FS habitats during daytime. Also provides feeding habitat for adults during the dry season (maintain food source/macroinvertebrate assemblages in fast habitats) and maintain some SD as refuge areas (especially at night by adults and juveniles to escape from extreme temperature fluctuations in shallow waters).</p>
<p><b>Dry Season drought</b>                      BAEN being semi-rheophilic can survive periods with no flow, especially when occurring during the winter (dry) season. The most critical habitat for survival of this species during drought periods in the dry season is to ensure that adequate depths in pools (both SD and SS) are maintained. This habitat component plays an important role as refuge area to survive temperature fluctuations during the cold winter months. Very limited flows are still required for maintenance of some FS habitats (no FD and FI) for especially juvenile survival, and to maintain adequate oxygen levels in the pools, which should be available at this stress level in very low abundance, but adequate to maintain the present status.</p>
<p><b>Wet Season maintenance</b>                      Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (&gt; 0.3 m/s and &lt; 0.3 m deep) and FD (&gt; 0.3 m/s and &gt; 0.3 m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require FS habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development.</p> <p>The recommended stress level should maintain adequate fast habitats (FS, FI and FD) to allow for the requirements as described above for the different life stages of BAEN during the wet season to maintain it within a category C.</p>
<p><b>Wet Season drought</b>                      During a drought in the wet season flows should at least allow for limited breeding and survival habitats for BAEN. Under the recommended stress level, limited breeding habitat in the form of FS will be available for this species to at least allow survival and future existence of the species at the site (survival of drought period). Some critical FS habitats should be available for some period to enable spawning, egg and larvae development. Limited FS and adequate SD habitats should be maintained under these conditions for the survival of juveniles and adults during this period.</p>

At this recommended stress level, all the fast habitats (FD, FS and FI) will still be present, albeit in a very low abundance.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	9	9	0.015
Maintenance	Dry	55%	7.5	7.5	0.33
Drought	Wet	8%	7	7	0.42
Maintenance	Wet	55%	4.5	4.5	1.515

#### AEC up: FISH EC B (ECOSTATUS B/C)

##### General

The FROC of BAEN was already optimal in a PES category C at this EWR site. It is therefore envisaged that improved flows (closer to the natural hydrological regime) would not have any significant improvement in conditions for BAEN, and therefore not reflect an improved category.

#### AEC down: FISH EC D (ECOSTATUS D)

##### General

Should a dam be constructed and base flows decrease further, it can be expected that the FROC of semi-rheophilic species will be influenced negatively. Their feeding and breeding habitats (especially FS, FD) will be deteriorated with a resultant impact on their overall FROC within the reach. It can therefore be expected that the FROC of the indicator species BAEN (and also ASCL and LCAP) will be reduced under such conditions. Deterioration in water quality may lead to a further decrease in FROC of some species, especially early life stages.

##### Dry Season maintenance

Decreased flows during the dry seasons would reduce the habitats crucial for the survival of juvenile and adult BAEN. This would be reflected by very low abundance of fast habitats (approximately 20 % fast shallow and fast intermediate), which would reduce the survival of especially juvenile BAEN, which has a preference for fast habitats. Decreased flows (lower than reference condition) will also aggravate the secondary impacts (water quality deterioration and siltation of substrates) and thereby negatively impact on the feeding and survival habitats for BAEN. Decreased flows will also reduce the depth of SD habitats, which are important survival habitats for over wintering of juvenile and adult BAEN, as adequate depth is required in SD to buffer temperature fluctuations in dry (cold) season, which will result in decreased FROC and abundance of BAEN, resulting in a lower category than present.

At this recommended stress level, limited FS and FI will still be available, but FD will be lost during the dry season. This should be adequate to sustain the BAEN assemblage, through the provision of FS for juveniles, and adequate flow to sustain pools and acceptable flow related water quality for all life stages. The decreased abundance and overall condition of preferred habitat of this species can however be expected to result in a decrease in FROC and abundance, resulting in a decrease in EC towards a category D.

##### Wet Season maintenance

Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (> 0.3 m/s and < 0.3 m deep) and FD (> 0.3 m/s and > 0.3 m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development.

The recommended stress level would provide very limited fast habitats (10 % of transect FS, 4 % FI and 4 % FD) to allow for the requirements as described above for the different life stages of BAEN during the wet season. The lower than natural and present composition of these habitat types, can be expected to result in deterioration into a D EC. This will be associated with both decreased in abundance and condition of breeding, nursery and refuge habitats, as well as water quality deterioration as a result of decreased flows (decreased oxygen levels, increased temperature). It will also reduce the depth of SD habitats and jeopardise the role these habitats play to provide refuge to juveniles and adults from night time temperature fluctuations.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	8	8	0.24
Maintenance	Wet	55%	5.75	5.75	0.758

**Table F6 Low flow requirements: SSR guild**

GENERAL
<p><b>INDICATOR:</b> The small semi-rheophilic species <i>BANO</i> was selected as indicator species 2 for this EWR site, due to its different habitat requirements than indicator species 1 (BAEN). <i>BANO</i> only reaches a maximum size of approximately 12 cm. Its optimal preferred general habitat is SD and SS preferably with overhanging vegetation or aquatic vegetation as cover, although they also make use of large substrates (cobble, boulders and bedrock and even undercut banks) as general habitat. This most important difference of this species in relation to indicator 1 (BEAN) is the requirement of high flows overtopping banks and inundating vegetation for spawning purposes. Spawning takes place during the summer when rivers are swollen after rains. It lays its adhesive eggs amidst vegetation. The larvae hatch within 3 days and begin to swim and feed after 6/7 days. Flows should remain adequate to allow migration between reaches, thus pools should remain connected during wet season. Water levels providing inundated vegetation should last long enough for spawning, egg hatching and larvae development. Larvae and juveniles require SS and SD with adequate cover to allow optimal development and survival. Flows set for <i>BANO</i> should provide in general for the flow requirements of other small-semi rheophilic species and even species such as <i>Labeo umbratus</i> (LUMB) and <i>Clarias gariepinus</i> (CGAR), as well as limnophilic species (<i>Pseudocrenilabrus philander</i> (PPHI) and <i>Tilapia sparrmanii</i> (TSPA)).</p> <p><b>General</b> It is estimated that an improvement in the base flows (closer to natural hydrological regime) or even a decrease in base flows will not result in a significant improvement or deterioration of the <i>BANO</i> assemblage. The primary impact on this species (and other small barb species at the site) is related to the presence of the predatory alien <i>Micropterus salmoides</i> (MSAL). The only significant improvement in the <i>BANO</i> assemblage is therefore expected to be related to the control of this alien species. No changes in flows are therefore discussed, as it is estimated that it would not be significant for this indicator species, both in terms of increased and decreased flows.</p>

## F2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table F7 below.

**Table F7 Low flow requirements: FDI taxa**

GENERAL					
<p><b>INDICATOR:</b> Hydropsychid caddisflies and blackflies (i.e. common flow-dependent taxa), as well as Leptophlebiidae. The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.</p>					
PES and REC: MACROINVERTEBRATE EC C/D (ECOSTATUS C)					
<p><b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.12 m, and average current velocity is 0.13 m/s (Spp Stress 5.5). This will enable flow-dependent macroinvertebrates to overwinter without significant detrimental impacts on the overall population.</p>					
<p><b>Dry Season drought</b> Average depth needed for dry season drought is 0.08 m, and average current velocity is 0.07 m/s (Spp Stress 6.5). This will enable flow-dependent macroinvertebrates to survive a drought.</p>					
<p><b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.22 m, and average current velocity is 0.22 m/s (Spp Stress 4). At these flows there is an inflection point in wetted perimeter. This will provide suitable habitats during summer.</p>					
<p><b>Wet Season drought</b> Average depth needed for wet season drought is 0.12 m, and average current velocity is 0.13 m/s (Spp Stress 5.5).</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	6.5	9	0.015
Maintenance	Dry	55%	5.5	8.5	0.128
Drought	Wet	5%	5.5	8.5	0.128
Maintenance	Wet	55%	4	6.5	0.51

AEC up: MACROINVERTEBRATE EC C (ECOSTATUS B/C)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.22 m, and average current velocity is 0.22 m/s (Spp Stress 4).					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.27 m, and average current velocity is 0.26 m/s (Spp Stress 3.5).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	4	6.5	0.51
Maintenance	Wet	55%	3.5	4	1.8
AEC down: MACROINVERTEBRATE EC D (ECOSTATUS D)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.08 m, and average current velocity is 0.07 m/s (Spp Stress 6). At these flows there is no more fast flow.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.15 m, and average current velocity is 0.6 m/s (Spp Stress 5). At these flows there is an inflection point in depth and velocity.					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	6	8.7	0.0825
Maintenance	Wet	55%	5	8	0.24

## F2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table F8.

**Table F8 Functions for each Flood Class**

Flood Class	Function / Motivation	
CLASS I RANGE (M <sup>3</sup> /S): 6 - 12 DAILY AVERAGE: 8 DURATION: 4	Fish	Class I floods contribute to the establishment of optimum spawning habitat through flushing of fine sediments and benthic algae from substrates. It also provides migratory cues, both in terms of flow changes and water quality changes, and provides adequate connectivity for migration. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation (BANO, BPAL, and LUMB). It furthermore contributes to the creation of acceptable nursery areas. Some resetting of water quality and flushing out fine sediments will occur. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Five of these per year, any time during the wet season, are recommended for a macroinvertebrate Category C, and two for a Category D.
CLASS II RANGE (M <sup>3</sup> /S): 15 - 30 DAILY AVERAGE: 20 DURATION: 5	Fish	Class II floods are similar in importance as Class I floods and have the same functionality as Class I floods. Their occurrence at lower frequency makes them less important for the fish assemblages.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Three of these per year are recommended for a macroinvertebrate Category C: one at the beginning of the wet season (Oct/Nov), one during the wet season, and one towards the end of the wet season (Feb / Mar). Two of these per year are recommended for a macroinvertebrate Category D: one at the beginning of the wet season (Oct/Nov), and one towards the end of the wet season (Feb/Mar).
CLASS III RANGE (M <sup>3</sup> /S):	Fish	Class III floods also provide similar functions as Class I, but due to its lower frequency become less important to the general requirements of fish

Flood Class	Function / Motivation	
65 - 90 DAILY AVERAGE: 70 DURATION: 6		assemblages in this river reach.
CLASS IV RANGE (M <sup>3</sup> /S): 100 – 150	Fish	Class IV floods also provide similar functions as Classes I, but due to its lower frequency become less important to the general requirements of fish assemblages in this river reach.

## F2.4 EWR RULES

**Table F9 EWR 8 assurance rules for PES and REC: C**

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Summary of IFR rule curves for: v\_Ewr8 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal PES and REC = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.403	1.373	1.314	1.208	1.042	0.817	0.560	0.323	0.156	0.080
Nov	2.430	2.178	1.947	1.712	1.343	1.101	0.825	0.569	0.389	0.308
Dec	5.997	5.119	4.372	3.690	2.625	2.131	1.568	1.047	0.679	0.513
Jan	16.141	13.419	11.161	9.186	6.100	4.918	3.570	2.323	1.444	1.045
Feb	7.104	6.124	5.282	4.499	3.276	2.672	1.982	1.344	0.894	0.690
Mar	1.777	1.745	1.682	1.570	1.393	1.154	0.881	0.629	0.451	0.370
Apr	1.421	1.396	1.345	1.253	1.110	0.917	0.696	0.492	0.348	0.283
May	0.922	0.903	0.865	0.796	0.689	0.544	0.379	0.226	0.118	0.069
Jun	0.638	0.625	0.598	0.550	0.474	0.372	0.256	0.148	0.072	0.038
Jul	0.567	0.555	0.530	0.486	0.417	0.323	0.217	0.118	0.049	0.017
Aug	0.468	0.458	0.438	0.402	0.346	0.269	0.183	0.102	0.046	0.020
Sep	0.569	0.559	0.539	0.503	0.447	0.371	0.285	0.205	0.148	0.123

Reserve flows without High Flows

Oct	0.751	0.735	0.702	0.643	0.551	0.427	0.285	0.154	0.061	0.019
Nov	1.180	1.159	1.117	1.042	0.925	0.766	0.585	0.418	0.300	0.246
Dec	1.379	1.354	1.305	1.218	1.081	0.895	0.683	0.487	0.349	0.286
Jan	1.564	1.536	1.481	1.382	1.227	1.017	0.778	0.556	0.400	0.330
Feb	1.990	1.956	1.886	1.762	1.567	1.303	1.002	0.724	0.528	0.439
Mar	1.777	1.745	1.682	1.570	1.393	1.154	0.881	0.629	0.451	0.370
Apr	1.421	1.396	1.345	1.253	1.110	0.917	0.696	0.492	0.348	0.283
May	0.922	0.903	0.865	0.796	0.689	0.544	0.379	0.226	0.118	0.069
Jun	0.638	0.625	0.598	0.550	0.474	0.372	0.256	0.148	0.072	0.038
Jul	0.567	0.555	0.530	0.486	0.417	0.323	0.217	0.118	0.049	0.017
Aug	0.468	0.458	0.438	0.402	0.346	0.269	0.183	0.102	0.046	0.020
Sep	0.569	0.559	0.539	0.503	0.447	0.371	0.285	0.205	0.148	0.123

Natural Duration curves

Oct	29.977	14.064	10.286	5.903	3.689	2.755	1.747	1.512	0.862	0.452
Nov	60.980	35.972	22.635	15.926	9.973	7.589	5.810	4.201	1.439	0.737
Dec	58.330	35.510	28.103	22.166	16.502	11.354	8.094	4.540	2.080	0.952
Jan	63.064	42.813	31.761	25.299	18.836	15.636	10.924	9.577	5.164	1.647
Feb	81.911	49.463	31.341	25.107	22.330	17.551	14.687	10.904	6.465	3.580
Mar	35.880	29.570	24.197	18.963	13.803	11.540	9.013	6.119	3.707	1.900
Apr	18.233	13.870	11.532	9.483	6.362	5.502	4.360	2.955	1.968	0.621
May	9.453	6.153	4.757	3.368	2.744	2.169	1.568	1.228	0.814	0.299
Jun	6.134	3.584	2.716	2.373	1.890	1.358	1.096	0.887	0.559	0.197
Jul	5.626	3.237	2.221	1.826	1.576	1.277	0.963	0.874	0.545	0.019
Aug	5.208	3.047	2.177	1.807	1.385	1.273	1.049	0.945	0.448	0.022
Sep	9.194	4.375	3.044	2.238	1.647	1.350	1.038	0.938	0.760	0.521

**Table F10 EWR 8 assurance rules for AEC up: B/C**

Desktop Version 2, Printed on 2008/07/04

Summary of IFR rule curves for: v\_Ewr8 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal AEC UP = B/C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.567	1.534	1.467	1.348	1.162	0.909	0.621	0.355	0.167	0.082
Nov	2.645	2.389	2.148	1.895	1.500	1.222	0.904	0.611	0.404	0.310
Dec	6.209	5.326	4.570	3.871	2.779	2.250	1.646	1.087	0.694	0.515
Jan	16.382	13.654	11.386	9.391	6.276	5.053	3.659	2.370	1.460	1.048
Feb	7.485	6.497	5.638	4.825	3.555	2.886	2.123	1.417	0.920	0.694
Mar	2.629	2.580	2.481	2.305	2.030	1.656	1.231	0.837	0.559	0.433
Apr	1.576	1.547	1.489	1.386	1.223	1.004	0.753	0.522	0.358	0.284
May	1.124	1.100	1.053	0.969	0.837	0.658	0.454	0.265	0.132	0.072
Jun	0.833	0.815	0.779	0.716	0.616	0.481	0.328	0.186	0.085	0.040
Jul	0.715	0.699	0.668	0.612	0.525	0.406	0.271	0.147	0.059	0.019
Aug	0.666	0.652	0.623	0.571	0.491	0.381	0.256	0.141	0.059	0.022
Sep	0.787	0.772	0.743	0.690	0.606	0.494	0.366	0.247	0.163	0.125

Reserve flows without High Flows

Oct	0.945	0.924	0.883	0.809	0.693	0.536	0.357	0.191	0.074	0.021
Nov	1.395	1.369	1.318	1.226	1.082	0.887	0.665	0.459	0.314	0.249
Dec	1.591	1.561	1.503	1.399	1.235	1.014	0.761	0.528	0.363	0.288
Jan	1.805	1.772	1.706	1.588	1.403	1.152	0.867	0.603	0.417	0.332
Feb	2.372	2.328	2.242	2.087	1.845	1.517	1.143	0.798	0.554	0.443
Mar	2.007	1.970	1.897	1.766	1.561	1.283	0.966	0.673	0.467	0.373
Apr	1.576	1.547	1.489	1.386	1.223	1.004	0.753	0.522	0.358	0.284
May	1.124	1.100	1.053	0.969	0.837	0.658	0.454	0.265	0.132	0.072
Jun	0.833	0.815	0.779	0.716	0.616	0.481	0.328	0.186	0.085	0.040
Jul	0.715	0.699	0.668	0.612	0.525	0.406	0.271	0.147	0.059	0.019
Aug	0.666	0.652	0.623	0.571	0.491	0.381	0.256	0.141	0.059	0.022
Sep	0.787	0.772	0.743	0.690	0.606	0.494	0.366	0.247	0.163	0.125

Natural Duration curves

Oct	29.977	14.064	10.286	5.903	3.689	2.755	1.747	1.512	0.862	0.452
Nov	60.980	35.972	22.635	15.926	9.973	7.589	5.810	4.201	1.439	0.737
Dec	58.330	35.510	28.103	22.166	16.502	11.354	8.094	4.540	2.080	0.952
Jan	63.064	42.813	31.761	25.299	18.836	15.636	10.924	9.577	5.164	1.647
Feb	81.911	49.463	31.341	25.107	22.330	17.551	14.687	10.904	6.465	3.580
Mar	35.880	29.570	24.197	18.963	13.803	11.540	9.013	6.119	3.707	1.900
Apr	18.233	13.870	11.532	9.483	6.362	5.502	4.360	2.955	1.968	0.621
May	9.453	6.153	4.757	3.368	2.744	2.169	1.568	1.228	0.814	0.299
Jun	6.134	3.584	2.716	2.373	1.890	1.358	1.096	0.887	0.559	0.197
Jul	5.626	3.237	2.221	1.826	1.576	1.277	0.963	0.874	0.545	0.019
Aug	5.208	3.047	2.177	1.807	1.385	1.273	1.049	0.945	0.448	0.022
Sep	9.194	4.375	3.044	2.238	1.647	1.350	1.038	0.938	0.760	0.521

**Table F11 EWR 8 assurance rules for AEC down: D**

Desktop Version 2, Printed on 2008/07/04

Summary of IFR rule curves for: v\_Ewr8 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal AEC DOWN = D

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.355	1.327	1.269	1.167	1.007	0.790	0.543	0.314	0.152	0.079
Nov	2.174	1.928	1.708	1.493	1.156	0.957	0.730	0.520	0.372	0.305
Dec	2.319	2.076	1.857	1.635	1.288	1.067	0.815	0.581	0.417	0.342
Jan	15.778	13.064	10.823	8.876	5.835	4.714	3.436	2.253	1.419	1.041
Feb	6.684	5.714	4.890	4.141	2.970	2.436	1.827	1.263	0.866	0.686
Mar	1.331	1.309	1.266	1.188	1.067	0.903	0.716	0.543	0.421	0.366
Apr	1.108	1.090	1.053	0.986	0.882	0.741	0.580	0.432	0.327	0.279
May	0.737	0.722	0.692	0.638	0.554	0.440	0.311	0.190	0.106	0.067
Jun	0.553	0.541	0.518	0.477	0.412	0.324	0.224	0.131	0.066	0.037
Jul	0.442	0.432	0.413	0.379	0.325	0.253	0.170	0.094	0.040	0.016
Aug	0.368	0.360	0.345	0.317	0.273	0.213	0.146	0.083	0.039	0.019
Sep	0.462	0.454	0.439	0.412	0.369	0.311	0.245	0.184	0.141	0.122

Reserve flows without High Flows

Oct	0.589	0.576	0.551	0.505	0.433	0.336	0.225	0.122	0.050	0.017
Nov	0.924	0.909	0.878	0.824	0.738	0.622	0.491	0.369	0.282	0.243
Dec	1.108	1.090	1.053	0.987	0.883	0.743	0.583	0.435	0.330	0.283
Jan	1.201	1.182	1.142	1.072	0.962	0.813	0.644	0.487	0.376	0.326
Feb	1.571	1.545	1.494	1.403	1.261	1.067	0.847	0.643	0.500	0.434
Mar	1.331	1.309	1.266	1.188	1.067	0.903	0.716	0.543	0.421	0.366
Apr	1.108	1.090	1.053	0.986	0.882	0.741	0.580	0.432	0.327	0.279
May	0.737	0.722	0.692	0.638	0.554	0.440	0.311	0.190	0.106	0.067
Jun	0.553	0.541	0.518	0.477	0.412	0.324	0.224	0.131	0.066	0.037
Jul	0.442	0.432	0.413	0.379	0.325	0.253	0.170	0.094	0.040	0.016
Aug	0.368	0.360	0.345	0.317	0.273	0.213	0.146	0.083	0.039	0.019
Sep	0.462	0.454	0.439	0.412	0.369	0.311	0.245	0.184	0.141	0.122

Natural Duration curves

Oct	29.977	14.064	10.286	5.903	3.689	2.755	1.747	1.512	0.862	0.452
Nov	60.980	35.972	22.635	15.926	9.973	7.589	5.810	4.201	1.439	0.737
Dec	58.330	35.510	28.103	22.166	16.502	11.354	8.094	4.540	2.080	0.952
Jan	63.064	42.813	31.761	25.299	18.836	15.636	10.924	9.577	5.164	1.647
Feb	81.911	49.463	31.341	25.107	22.330	17.551	14.687	10.904	6.465	3.580
Mar	35.880	29.570	24.197	18.963	13.803	11.540	9.013	6.119	3.707	1.900
Apr	18.233	13.870	11.532	9.483	6.362	5.502	4.360	2.955	1.968	0.621
May	9.453	6.153	4.757	3.368	2.744	2.169	1.568	1.228	0.814	0.299
Jun	6.134	3.584	2.716	2.373	1.890	1.358	1.096	0.887	0.559	0.197
Jul	5.626	3.237	2.221	1.826	1.576	1.277	0.963	0.874	0.545	0.019
Aug	5.208	3.047	2.177	1.807	1.385	1.273	1.049	0.945	0.448	0.022
Sep	9.194	4.375	3.044	2.238	1.647	1.350	1.038	0.938	0.760	0.521

**APPENDIX G: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 9: SUIKERBOS US**

## G1 EWR 9: SUIKERBOS US (SUIKERBOSRAND RIVER) - DETERMINATION OF STRESS INDICES)

Appendix G provides supporting information for the determination of stress indices of EWR 9 Suikerbos US (Chapter 12 and 13 of the Main Report, Volume 1).

### G1.1 FISH INDICATOR SPECIES

**Fish indicator group 1: Large semi-rheophilic (LSR) guild:** *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM) was selected as indicator species. Refer to Appendix B, Section B1.1.

**Fish indicator group 2: Small semi-rheophilic (SSR) guild:** *Barbus anoplus* (BANO) was selected as indicator species. Refer to Appendix B, Section B1.1.

### G1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table G1.

**Table G1 EWR 9: Habitat suitability for the SSR and LSR guild**

SSR AND LSR GUILD								
Depth classes	Discharges (m <sup>3</sup> /s)							
	0.04	0.07	0.08	0.11	0.17	0.25	0.30	0.8
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	4	4	4	4	4	4	6	6
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	4	4	4	4	4	4	4	4
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	10	10	10	10	10	10	10	8
Slow Shallow and Slow Deep	4	4	4	4	4	4	4	4
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	6	6	6	6	6	6	8	8
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	8	8	8	8	6	6	6	6
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	10	8	8	8	8	8	8	6
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	10	10	10	10	10	8	8	6
FAST TOTAL >0.1 m DEEP	10	8	8	8	8	8	8	6

The fish stress index is provided in Table G2.

**Table G2 Fish stress index**

Habitat	Discharges (m <sup>3</sup> /s)							
	0.04	0.07	0.08	0.11	0.17	0.25	0.30	0.8
<b>SMALL SEMI-RHEOPHILIC (SSR) GUILD</b>								
Spawning & nursery habitat	0.5	0.5	1	2	2	3	3	5
Abundance	1	2	2	3	3.5	4	4.5	5
Cover	0.5	1	1	2	3	3.5	4	4.5
Connectivity (lateral & longitudinal)	0.5	1	1	3	3.5	4	4.5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	1	3	3	4	4	5	5	5
<b>Species stress: BANO</b>	<b>9</b>	<b>7</b>	<b>7</b>	<b>5</b>	<b>4</b>	<b>2</b>	<b>2</b>	<b>0</b>
<b>LARGE SEMI REOPHYLLIC (LSR) GUILD</b>								
Spawning & nursery habitat	0	0.5	0.5	1	2	3	3.5	5
Abundance	0	1	1	2	3	4	4	5
Cover	0.5	1	1	2	3	4	4	5
Connectivity	0	1.5	1.5	3	3.5	4	4.5	5

Habitat	Discharges (m <sup>3</sup> /s)							
	0.04	0.07	0.08	0.11	0.17	0.25	0.30	0.8
(lateral & longitudinal)								
Water Quality (esp. O <sub>2</sub> and Temp.)	0.5	1.5	1.5	3	4	4.5	5	5
<b>Species stress: BANO</b>	<b>9</b>	<b>7</b>	<b>7</b>	<b>6</b>	<b>4</b>	<b>2</b>	<b>1</b>	<b>0</b>

### G1.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for flow dependent macroinvertebrate (FDI) taxa is provided in Table G3 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table G3 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>2</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VVFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VVFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	7	11	13	4	4	6	7	2	9	14	17	5		1.726
1	All habitats plentiful, high quality. Fast, wide WP.	9	13	10	3	5	7	6	1	12	17	13	4		1.05
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	12	15	7	2	7	8	4	1	15	18	9	2		0.5
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	14	15	5	1	8	9	3	1	18	19	6	1		0.28
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	15	16	4	0	8	9	2	0	20	21	5	0	Sediment and algae	0.1
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	15	16	4	0	8	9	2	0	20	21	5	0	Sediment and algae	0.086
6	Critical habitat residual. Low quality, moderate/slow velocity.	16	16	3	0	9	9	2	0	21	21	4	0	Sediment and algae	0.030
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	17	16	3	0	10	9	2	0	20	19	4	0	Sediment and algae	0.015
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	24	10	1	0	14	6	0	0	31	13	1	0	Sediment and algae	0.003
9	Standing water habitats only, very low quality. No flow.	27	8	0	0	15	4	0	0	35	11	0	0		0.001
10	Only hyporheic refugia, no surface water.	0	0	0	0	0	0	0	0	0	0	0	0		-

1 Very Slow over Coarse Sediment

4 Very Fast over Coarse Sediment

7 Fast over Fine Sediment

10 Slow over Bedrock

2 Slow over Coarse Sediment

5 Very Slow over Fine Sediment

8 Very Fast over Fine Sediment

11 Fast over Bedrock

3 Fast over Coarse Sediment

6 Slow over Fine Sediment

9 Very Slow over Bedrock

12 Very Fast over Bedrock

The stress index for FDI taxa is provided in Table G4 which rates the response of the species according to various biotic response metrics.

**Table G4 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
0.68	0.38	1.01	0.32	18.1	All flow dependent macroinvertebrates very abundant and healthy.	1.726	0
0.58	0.29	0.85	0.27	17.4	90% rheophilic species persist.	1.05	1
0.46	0.21	0.7	0.21	15.0	Most rheophilic species persist, but slight (80%) reduction.	0.5	2
0.38	0.16	0.6	0.18	13.1	Most rheophilic species persist, but abundances reduced.	0.28	3
0.28	0.1	0.52	0.15	9.4	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	0.1	4
0.26	0.09	0.49	0.15	8.4	Critical life-stages of sensitive rheophilic species at risk or non-viable.	0.086	5
0.2	0.07	0.47	0.14	5.1	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	0.03	6
0.16	0.06	0.42	0.13	3.7	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.	0.015	7
0.1	0.04	0.27	0.08	1.6	Some rheophilic species persist, but at very low numbers; All life stages of most rheophilic species at risk or non-viable.	0.003	8
0.06	0.03	0.23	0.07	0.6	Mostly pool dwellers; all life stages of most rheophilic species non-viable.	0.001	9
					Only pools dwellers.		10

## **G2 EWR 9: SUIKERBOS US (SUIKERBOSRAND RIVER) – DETERMINATION OF EWR SCENARIOS**

### **G2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH**

The fish low flow requirements for the EWR scenarios are summarised in Table G5 for the LSR guild and Table G6 for the SSR guild.

**Table G5 Low flow requirements: LSR guild**

<b>GENERAL</b>
<p><b>INDICATOR:</b> The large semi-rheophilic species BAEN is the indicator species 1 selected for this EWR site. The maximum size is approximately 50 cm. Its optimal preferred general habitat is SD, FS and FD with suitable cover provided by substrate and water column depth. This spawning habitat requirement of this species is FD and FS habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and SS over substrate, and seek refuge in SD at night. Flows set for BAEN should suffice in general for the flow requirements of BKIM, LCAP and ASCL present at this site.</p>
<b>PES: FISH EC D (ECOSTATUS C)</b>
<p><b>Dry Season maintenance</b>                      BAEN, as a semi-rheophilic species, can survive during the dry season without continuous flows (especially the adults which do well in deep pools). For the optimal survival conditions of juveniles adequate fast shallow habitat should be maintained for a period of the time. SD with adequate depth should also be maintained to meet the requirements of adults, as well as juveniles (especially at night when these deeper areas are used for refuge to avoid extreme temperature fluctuations during the winter months).</p> <p>At this stress level very limited fast habitat will be maintained (3% FS and 1% FI and no FD on the transect) which will provide adequate survival habitat for especially the juveniles, which prefer some FS habitats especially during daytime. Also provides feeding habitat for adults during the dry season (maintain food source / invertebrate assemblages in fast habitats) and maintain some SD as refuge areas (especially at night by adults and juveniles to escape from extreme temperature fluctuations in shallow waters).</p>
<p><b>Dry Season drought</b>                      BAEN being semi-rheophilic can survive periods with no flow, especially when occurring during the winter (dry) season. The most critical habitat for survival of this species during drought periods in the dry season is to ensure that adequate depths in pools (both SD and SS) are maintained. This habitat component plays an important role as refuge area to survive temperature fluctuations during the cold winter months. Very limited flows are still required for maintenance of some FS habitats (no FD and FI) for especially juvenile survival, and to maintain adequate oxygen levels in the pools, which should be available at this stress level in very low abundance, but adequate to maintain the present status during drought periods in dry months. At this stress level very limited FS (3% of transect) will be available to meet the requirements as mentioned above, and to maintain the LSR in the PES during drought conditions in the dry season.</p>
<p><b>Wet Season maintenance</b>                      Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (&gt;0.3 m/s and &lt;0.3 m deep) and FD (&gt;0.3 m/s and &gt;0.3 m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development.</p> <p>The recommended stress level should maintain adequate fast habitats (FS, FI and FD) to allow for the requirements as described above for the different life stages of BAEN during the wet season to maintain it within a category D.</p>
<p><b>Wet Season drought</b>                      During a drought in the wet season flows should at least allow for limited breeding and survival habitats for BAEN. Under the recommended stress level, limited breeding habitat in the form of FS will be available for this species to at least allow survival and future existence of the species at the site (survival of drought period). Some critical fast shallow habitats should be available for some period to enable spawning, egg and larvae development. Limited fast</p>

shallow and adequate SD habitats should be maintained under these conditions for the survival of juveniles and adults during this period.

Lowest stress level where some FD (very limited) will still be available, but at least adequate FS and FI will be maintained.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	9	9	0.04
Maintenance	Dry	55%	7	7	0.08
Drought	Wet	8%	7	7	0.08
Maintenance	Wet	55%	0.8	3.5	0.23

**REC: FISH EC C (ECOSTATUS B/C)**

**General**

Improved hydrological regime (higher or more natural base flows especially in winter) could result in suitable habitats for the maintenance of some semi-rheophilic species presently absent or in low abundance in this reach. Improved flows will also result in better fast-shallow habitats with potential improvement in FROC of BAEN (and BKIM). Improved flows may also result in improved water quality which would be reflected by higher FROC of some species and especially survival of early life stages (which are often more intolerant to flow related water quality).

**Dry Season maintenance**

Increased flows during the dry seasons would improve the habitats crucial for the survival of juvenile and adult BAEN. This would be reflected by improved availability of fast habitats (especially FI), which should improve the survival of especially juvenile BAEN, which has a preference for fast habitats. Improved flows from present conditions will also improve secondary aspects (water quality, substrates quality) and thereby have a positive impact on the feeding and survival habitats for BAEN. Increased flows will also increase the depth of SD habitats, which are important survival habitats for over wintering of juvenile and adult BAEN, as adequate depth is required in SD to buffer temperature fluctuations in dry (cold) season.

At this recommended stress level, the abundance and availability of FS and FI habitat will be improved although FD habitats will still not be available during the dry season. The improvement in the FS and FI should however result in the above mentioned improvement of habitat suitability for BAEN, which should be reflected by improved FROC and abundance of this species, with a resultant increase in EC of this fish guild and an overall improvement of the fish assemblage towards a category C.

**Wet Season maintenance**

Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (>0.3m/s and <0.3m deep) and FD (>0.3m/s and >0.3m deep) habitat over good quality substrate (especially gravel) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning, egg and embryo development. The eggs and embryos require fast-shallow habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development.

The recommended stress level would improve the availability of the above mentioned habitat requirements of BEAN during the wet season. This can be expected to result in improved spawning success, increased survival of fry and juveniles and increased abundance and FROC of all live stages of BAEN. This will result in improved EC for BAEN and contribute to an overall improvement of the fish EC towards a C.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	55%	5	5	0.13
Maintenance	Wet	55%	0.4	1.9	0.55

**Table G6 Low flow requirements: SSR guild**

<b>GENERAL</b>					
<p><b>INDICATOR:</b> The small semi-rheophilic species BANO was selected at indicator species 2 for this EWR site, due to its different habitat requirements than indicator species 1 (BAEN). BANO only reaches a maximum size of approximately 12 cm. Its optimal preferred general habitat is SD and SS preferably with overhanging vegetation or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock and even undercut banks) as general habitat. This most important difference of this species in relation to indicator 1 (BEAN) is the requirement of high flows overtopping banks and inundating vegetation for spawning purposes. Spawning takes place during the summer when rivers are swollen after rains. It lays its adhesive eggs amidst vegetation. The larvae hatch within 3 days and begin to swim and feed after 6/7 days. Flows should remain adequate to allow migration between reaches, thus pools should remain connected during wet season. Water levels providing inundated vegetation should last long enough for spawning, egg hatching and larvae development. Larvae and juveniles require SS and SD with adequate cover to allow optimal development and survival. Flows set for BANO should provide in general for the flow requirements of other small-semi rheophilic species and even species such as LUMB and CGAR, as well as limnophilic species (PPHI and TSPA).</p>					
<b>PES: FISH EC D (ECOSTATUS C)</b>					
<p><b>Dry Season maintenance</b> BANO, as a moderately tolerant small semi-rheophilic has a high preference for SD and SS with cover (especially overhanging and aquatic vegetation, although they also use large rocky substrates as preferred cover). This species should be able to survive long periods of no or limited flow as long as adequate SD and SS habitats are maintained. It is recommended that although they are not directly dependant on fast habitats for survival, that the maintenance of some fast habitats will ensure longitudinal connectivity allowing movement for feeding and recruitment. Some flow will furthermore be required to sustain water quality within acceptable levels and flush waste products from the pools. Their survival in this period would depend on the maintenance of their food source, but being omnivorous and having a varied diet, they are generally able to survive stressed conditions.</p> <p>At the mentioned stress level, some fast shallow will be maintained but the most important refuge areas, namely SD and SS will be available. No Inundated vegetation will be available at this stress level (their preferred cover type), but it should be reflective of a category D (largely modified from natural conditions). Under these conditions they will make use of substrate as cover to survive through the dry season.</p>					
<p><b>Dry Season drought</b> BANO a moderately tolerant semi-rheophilic species with high preference for SD and SS habitats with cover of aquatic vegetation and overhang, although they also make use of large rocky substrate such as cobbles to bedrock and undercut banks, especially in periods of stress / low flows, when inundated vegetation is limited or absent. During dry season droughts, this species will be able to handle high habitat stress and survive periods of no flow, as long as some surface water remains available as pools and backwaters. This stress level will ensure maintenance of SS and SD with cover (under these conditions no inundated vegetation will be available but they will make use of substrate as cover for survival).</p>					
<p><b>Wet Season maintenance</b> The optimal habitat of this species during wet season is a requirement of inundated vegetation for spawning and egg development that should ideally be provided by floods. After spawning and breeding, it is important that some level of aquatic vegetation and overhanging vegetation is maintained for a period to allow survival of larvae and juveniles. At the mentioned stress level flow should be adequate to ensure some inundation of macrophytes (especially in SD) and thereby creating some preferred habitat in the form of overhanging vegetation and aquatic vegetation. The provision of adequate cover is especially important at the site due to the presence of alien predator MSAL.</p>					
<p><b>Wet Season drought</b> During drought in the wet season, BANO will require some SS and SD (with adequate depth) and cover to survive. At this stress there will most probably be no optimal cover available to this species in the form of overhanging vegetation and aquatic vegetations, and they should seek refuge under large substrates (especially boulders). It is also recommended that some flow should remain to ensure that pools remain connected (by FS) and allow movement of this species and to maintain an acceptable water quality for the different life stages of this species (should spawning and egg development have taken place during floods, if occurrence during droughts), which should be available at this stress level.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	10	10	0.04
Maintenance	Dry	55%	7	7	0.08
Drought	Wet	5%	7	7	0.08
Maintenance	Wet	55%	2	3	0.28
<b>REC: FISH EC C (ECOSTATUS B/C)</b>					

**General**

Improved hydrological regime (higher or more natural base flows especially in winter) could result in suitable habitats for the maintenance of some semi-rheophilic species presently absent or in low abundance in this reach. The smaller barb species will however not be improved by flow alteration, as their habitats are presently suitable, and it is estimated that the primary impact on this group is the predatory alien MSAL.

**G2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES**

The FDI low flow requirements are summarised in Table G7 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

**Table G7 Low flow requirements: FDI taxa**

GENERAL					
<b>INDICATOR:</b> Hydropsychid caddisflies and blackflies (i.e. common flow-dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.					
PES: MACROINVERTEBRATE EC D (ECOSTATUS C)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.09 m, and average current velocity is 0.15 m/s (Spp Stress 5). This will enable flow-dependent macroinvertebrates to overwinter without significant detrimental impacts on the overall population.					
<b>Dry Season drought</b> Average depth needed for dry season drought is 0.05 m, and average current velocity is 0.11 m/s (Spp Stress 7). This will enable flow-dependent macroinvertebrates to survive a drought.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.16 m, and average current velocity is 0.18 m/s (Spp Stress 3). This will provide suitable habitats during summer.					
<b>Wet Season drought</b> Average depth needed for wet season drought is 0.09 m, and average current velocity is 0.15 m/s (Spp Stress 5).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	7	9.8	0.0088
Maintenance	Dry	55%	5	7	0.08
Drought	Wet	5%	5	7	0.08
Maintenance	Wet	55%	3	3	0.28
REC: MACROINVERTEBRATE EC C (ECOSTATUS B/C)					
<b>Dry Season Maintenance</b> Average depth needed for dry season maintenance is 0.01 m, and average current velocity is 0.15 m/s (Spp Stress 4).					
<b>Wet Season Maintenance</b> Average depth needed for wet season maintenance is 0.19 m, and average current velocity is 0.19 m/s (Spp Stress 2.5).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)

Maintenance	Dry	55%	4	6.5	0.095
Maintenance	Wet	55%	2.5	2.5	0.39

## G2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table G8.

**Table G8 Functions for each Flood Class**

Flood Class	Function / Motivation	
CLASS I RANGE (M <sup>3</sup> /S): 1 - 2	Fish	Class I floods contribute to the establishment of optimum spawning habitat through flushing of fine sediments and benthic algae from substrates. It also provides migratory cues, both in terms of flow changes and water quality changes, and provides adequate connectivity for migration. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation (BANO, BPAL, and LUMB). It furthermore contributes to the creation of acceptable nursery areas. Some resetting of water quality and flushing out fine sediments will occur. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrate	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Five of these per year, any time during the wet season, are recommended for a macroinvertebrate Category C, and two for a Category D.
CLASS II RANGE (M <sup>3</sup> /S): 3 - 6	Fish	Class II floods are similar in importance as Class I floods and have the same functionality as Class I floods. Their occurrence at lower frequency makes them slightly less important for the fish assemblages.
	Macroinvertebrate	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Three of these per year are recommended for a macroinvertebrate Category C: one at the beginning of the wet season (Oct/Nov), one during the wet season, and one towards the end of the wet season (Feb/Mar). Two of these per year are recommended for a macroinvertebrate Category D: one at the beginning of the wet season (Oct/Nov), and one towards the end of the wet season (Feb/Mar).
CLASS III RANGE (M <sup>3</sup> /S): 8 - 20	Fish	Class III floods also provide similar functions as Class I, but due to its lower frequency become less important to the general requirements of fish assemblages in this river reach.
CLASS IV RANGE (M <sup>3</sup> /S): >40	Fish	Class IV floods also provide similar functions as Class I, but due to its lower frequency become less important to the general requirements of fish assemblages in this river reach.

## G2.4 EWR RULES

**Table G9 EWR 9 assurance rules for PES: C**

Desktop Version 2, Printed on 2009/10/11  
 Summary of IFR rule curves for: V\_EWR9 Natural Monthly Flows  
 Determination based on defined BBM Table with site specific assurance rules.  
 Regional Type: Vaal PES = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.276	0.271	0.261	0.244	0.217	0.181	0.139	0.100	0.073	0.061
Nov	0.453	0.412	0.373	0.332	0.269	0.224	0.173	0.126	0.093	0.077
Dec	0.404	0.364	0.328	0.292	0.234	0.196	0.152	0.112	0.084	0.071
Jan	1.015	0.871	0.748	0.636	0.460	0.377	0.282	0.195	0.133	0.105
Feb	0.759	0.674	0.598	0.523	0.405	0.334	0.254	0.179	0.127	0.103
Mar	0.256	0.252	0.243	0.228	0.205	0.173	0.136	0.103	0.079	0.068
Apr	0.228	0.224	0.217	0.204	0.184	0.156	0.125	0.096	0.075	0.066
May	0.204	0.200	0.194	0.182	0.165	0.140	0.112	0.087	0.069	0.061
Jun	0.175	0.173	0.167	0.158	0.143	0.123	0.101	0.080	0.065	0.058
Jul	0.116	0.115	0.113	0.109	0.103	0.093	0.081	0.068	0.057	0.051
Aug	0.094	0.093	0.091	0.088	0.083	0.076	0.066	0.055	0.046	0.041
Sep	0.109	0.107	0.105	0.101	0.095	0.085	0.073	0.059	0.047	0.041
Reserve flows without High Flows										
Oct	0.171	0.168	0.163	0.153	0.138	0.118	0.095	0.073	0.058	0.051
Nov	0.252	0.248	0.239	0.225	0.202	0.170	0.135	0.102	0.079	0.068
Dec	0.209	0.206	0.199	0.187	0.169	0.144	0.115	0.089	0.070	0.062
Jan	0.259	0.255	0.246	0.231	0.207	0.174	0.137	0.103	0.079	0.068
Feb	0.329	0.323	0.312	0.292	0.261	0.219	0.171	0.127	0.096	0.082
Mar	0.256	0.252	0.243	0.228	0.205	0.173	0.136	0.103	0.079	0.068
Apr	0.228	0.224	0.217	0.204	0.184	0.156	0.125	0.096	0.075	0.066
May	0.204	0.200	0.194	0.182	0.165	0.140	0.112	0.087	0.069	0.061
Jun	0.175	0.173	0.167	0.158	0.143	0.123	0.101	0.080	0.065	0.058
Jul	0.116	0.115	0.113	0.109	0.103	0.093	0.081	0.068	0.057	0.051
Aug	0.094	0.093	0.091	0.088	0.083	0.076	0.066	0.055	0.046	0.041
Sep	0.109	0.107	0.105	0.101	0.095	0.085	0.073	0.059	0.047	0.041
Natural Duration curves										
Oct	1.090	0.736	0.564	0.470	0.332	0.254	0.202	0.149	0.108	0.093
Nov	3.287	1.389	1.057	0.868	0.694	0.629	0.421	0.266	0.147	0.077
Dec	1.676	1.273	0.956	0.795	0.661	0.541	0.396	0.310	0.224	0.138
Jan	3.424	1.236	0.915	0.833	0.691	0.597	0.489	0.355	0.235	0.161
Feb	6.320	1.724	0.922	0.847	0.707	0.612	0.475	0.430	0.298	0.203
Mar	2.808	1.198	0.948	0.814	0.668	0.575	0.470	0.414	0.287	0.202
Apr	1.597	0.999	0.837	0.718	0.625	0.509	0.432	0.367	0.266	0.181
May	1.314	0.717	0.582	0.478	0.414	0.370	0.310	0.235	0.205	0.127
Jun	0.856	0.617	0.440	0.363	0.340	0.297	0.243	0.220	0.177	0.143
Jul	0.642	0.489	0.377	0.310	0.280	0.246	0.231	0.209	0.183	0.149
Aug	0.482	0.358	0.310	0.265	0.235	0.209	0.194	0.183	0.172	0.138
Sep	0.536	0.332	0.282	0.239	0.201	0.197	0.166	0.147	0.131	0.112

**Table G10 EWR 9 assurance rules for REC: B/C**

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Summary of IFR rule curves for: V\_EWR9 Natural Monthly Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal REC = B/C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.389	0.381	0.367	0.341	0.300	0.244	0.181	0.122	0.081	0.062
Nov	0.671	0.624	0.576	0.518	0.428	0.347	0.254	0.168	0.108	0.077
Dec	0.756	0.678	0.605	0.531	0.414	0.337	0.248	0.166	0.109	0.082
Jan	1.251	1.101	0.915	0.833	0.632	0.509	0.369	0.240	0.149	0.108
Feb	1.086	0.994	0.903	0.802	0.644	0.518	0.375	0.242	0.149	0.106
Mar	0.489	0.480	0.461	0.428	0.375	0.304	0.223	0.148	0.095	0.071
Apr	0.409	0.402	0.386	0.359	0.316	0.258	0.192	0.131	0.087	0.068
May	0.352	0.345	0.332	0.309	0.273	0.223	0.167	0.115	0.079	0.062
Jun	0.272	0.267	0.258	0.241	0.214	0.178	0.136	0.098	0.072	0.059
Jul	0.199	0.196	0.192	0.183	0.169	0.148	0.121	0.092	0.066	0.052
Aug	0.146	0.144	0.141	0.135	0.125	0.110	0.091	0.070	0.051	0.042
Sep	0.131	0.130	0.127	0.122	0.113	0.100	0.084	0.066	0.050	0.041
Reserve flows without High Flows										
Oct	0.289	0.283	0.273	0.254	0.224	0.184	0.138	0.096	0.066	0.053
Nov	0.470	0.461	0.443	0.411	0.361	0.293	0.215	0.144	0.093	0.070
Dec	0.367	0.361	0.347	0.323	0.284	0.233	0.174	0.119	0.081	0.063
Jan	0.494	0.485	0.466	0.432	0.379	0.307	0.225	0.149	0.095	0.071
Feb	0.656	0.643	0.617	0.572	0.500	0.403	0.292	0.190	0.118	0.085
Mar	0.489	0.480	0.461	0.428	0.375	0.304	0.223	0.148	0.095	0.071
Apr	0.409	0.402	0.386	0.359	0.316	0.258	0.192	0.131	0.087	0.068
May	0.352	0.345	0.332	0.309	0.273	0.223	0.167	0.115	0.079	0.062
Jun	0.272	0.267	0.258	0.241	0.214	0.178	0.136	0.098	0.072	0.059
Jul	0.199	0.196	0.192	0.183	0.169	0.148	0.121	0.092	0.066	0.052
Aug	0.146	0.144	0.141	0.135	0.125	0.110	0.091	0.070	0.051	0.042
Sep	0.131	0.130	0.127	0.122	0.113	0.100	0.084	0.066	0.050	0.041
Natural Duration curves										
Oct	1.090	0.736	0.564	0.470	0.332	0.254	0.202	0.149	0.108	0.093
Nov	3.287	1.389	1.057	0.868	0.694	0.629	0.421	0.266	0.147	0.077
Dec	1.676	1.273	0.956	0.795	0.661	0.541	0.396	0.310	0.224	0.138
Jan	3.424	1.236	0.915	0.833	0.691	0.597	0.489	0.355	0.235	0.161
Feb	6.320	1.724	0.922	0.847	0.707	0.612	0.475	0.430	0.298	0.203
Mar	2.808	1.198	0.948	0.814	0.668	0.575	0.470	0.414	0.287	0.202
Apr	1.597	0.999	0.837	0.718	0.625	0.509	0.432	0.367	0.266	0.181
May	1.314	0.717	0.582	0.478	0.414	0.370	0.310	0.235	0.205	0.127
Jun	0.856	0.617	0.440	0.363	0.340	0.297	0.243	0.220	0.177	0.143
Jul	0.642	0.489	0.377	0.310	0.280	0.246	0.231	0.209	0.183	0.149
Aug	0.482	0.358	0.310	0.265	0.235	0.209	0.194	0.183	0.172	0.138
Sep	0.536	0.332	0.282	0.239	0.201	0.197	0.166	0.147	0.131	0.112

**APPENDIX H: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS INDICES AND EWR SCENARIOS OF EWR 10: SUIKERBOS DS**

# H1 EWR 10: SUIKERBOS DS (SUIKERBOSRAND RIVER) – DETERMINATION OF STRESS INDICES

Appendix H provides supporting information for the determination of stress indices of EWR 10 Suikerbos DS (Chapter 15 and 16 of the Main Report, Volume 1).

## H1.1 FISH INDICATOR SPECIES

### Fish indicator group 1: Large semi-rheophilic species (BAEN, BKIM)

Indicator species: *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM). Refer to Appendix B, Section B1.1.

### Fish indicator group 2: Small limnophilic (LIM) species (PPHI, TSPA)

The small limnophilic species, *Pseudocrenilabrus philander* (PPHI) and *Tilapia sparrmanii* (TSPA) were considered as potential valuable indicators at this site as a result of too much water, and therefore too high flows for species with a preference for slow habitats. Its optimal preferred general habitat is Slow Deep (SD) and Slow Shallow (SS) preferably with overhanging vegetation, undercut banks or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock) as general habitat. Breeding takes place during the spring and summer, with males constructing nests in soft substrates. Optimal habitats for egg and larvae development, nursery areas and in general for juveniles and adults are SD and SS habitats.

The habitat requirements for the different life stages of the LIM indicator fish species is summarised in Table H1. Information in Bold type face indicates crucial habitat during the given life stage.

**Table H1 Habitat requirements for different life stages of indicators species included in the LIM guild**

Species	Spawning	Egg and embryo development	Larvae	Juveniles	Adults
PPHI	Flow habitat: <b>SS and SD</b> . Spawning season: Early spring - late summer. Males defend a territory, construct a simple cleared nest and attract ripe females. Eggs are laid in the nest, fertilized and collected by the female. The females withdraw to a nursery to brood the eggs until juvenile stage	Flow habitat: <b>SS and SD</b> . The females withdraw to a nursery to brood the eggs until juvenile stage	Flow habitat: <b>SS and SD</b> .	Flow habitat: <b>SS</b> . Preferred velocity: 0 m/s. Preferred depth: 10 cm. Substrate: Gravel/pebble.	Flow habitat: <b>SS and SD</b> . Preferred velocity: 0 m/s. Preferred depth: 10 cm. Substrate: Marginal vegetation/fines or gravel or boulder. Generally at flows below 0.15 m/s.
TSPA	Flow habitat: <b>SS and SD</b> . Males construct simple saucer-shaped nest in which eggs are guarded and tended by both parents.	Flow habitat: <b>SS and SD</b> .	Flow habitat: <b>SS and SD</b> . Newly hatched larvae attach to substrates by head glands but wriggle constantly for aeration. After 7 days fry are free swimming, remain in shoal and guarded by parents.	Flow habitat: <b>SS and SD</b> .	Flow habitat: <b>SS and SD</b> .

## H1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table H2 for decreased flows and in Table H3 for increased flows.

**Table H2 EWR 10: Habitat suitability for the LSR and LIM guild – DECREASED FLOWS**

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0	0.2	0.45	0.64	0.85	1	1.30	1.6	1.9	2.2	2.50
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	10	4	2	2	2	1	1	1	1	1	1
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	0	6	7	7	7	7	6	6	5	5	5
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	0	0	0	0	0	0	0	1	1	1	1
Slow Shallow and Slow Deep	0	6	7	7	7	7	6	7	6	6	6
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	0	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	0	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	0	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	0	0	1	1	1	1	2	2	3	3	4
FAST TOTAL >0.1 m DEEP	0	1	2	2	2	2	3	3	4	4	5

**Table H3 EWR 10: Habitat suitability for the LSR and LIM guild – INCREASED FLOWS**

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	2.50	3.50	4.40	5.00	6.00	7.00	8.00	9.00	11.00	30.00	60.00
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	1	1	1	1	1	1	1	1	1	0	0
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	5	3	3	2	2	1	1	1	1	1	1
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	1	1	1	1	2	2	2	2	2	1	1
Slow Shallow and Slow Deep	6	4	4	3	4	3	3	3	3	2	2
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	1	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	1	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	1	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	4	5	5	6	6	6	0	0	0	0	0
FAST TOTAL >0.1 m DEEP	5	6	6	7	7	7	1	1	1	1	1

The fish stress index is provided in Table H4 for decreased flows and H5 for increased flows.

**Table H4 Fish stress index – DECREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	0	0.2	0.45	0.64	0.85	1	1.30	1.6	1.9	2.2	2.50
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	0	3.5	3.5	4	4	4.5	4.5	5	5	5	5
Nursery habitat	0	4	4	4.5	4.5	4.5	5	5	5	5	5
Abundance	0	2.5	3	3	4	4	4.5	4.5	5	5	5
Cover	0	2.5	3	3	4	4	4.5	4.5	5	5	5
Connectivity (lateral & longitudinal)	0	3	3.5	4	4	4.5	4.5	5	5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	3	3	3.5	4	4.5	5	5	5	5	5

Species stress: PPHI	-10	-3.83	-3.3	-2.67	-1.8	-1.3	-0.67	-0.3	0	0	0
<b>LARGE SEMI-REOPHILIC (LSR) GUILD</b>											
Spawning habitat	0	0	0.5	1	2	3	3.5	4	4.5	5	5
Nursery habitat	0	0.5	1	1.5	2	2	2.5	3	4	5	5
Abundance	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Cover	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Connectivity (lateral & longitudinal)	0	0.5	1	2	2	2.5	3	4	4.5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	0.5	1	1.5	2	3	4	4.5	5	5	5
Species stress: BAEN	-10	-9.17	-8.17	-7	-6	-4.83	-3.67	-2.5	-1.33	-0.33	0

**Table H5 Fish stress index – INCREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	2.50	3.50	4.40	5.00	6.00	7.00	8.00	9.00	11.00	30.00	60.00
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	5	4.5	4	3.5	3	2.5	2	1	0.5	0	0
Nursery habitat	5	5	4.5	4.5	3.5	3	2.5	2	1	0.5	0
Abundance	5	5	4.5	4.5	4	4	3.5	3	2	1	0.5
Cover	5	5	4.5	4.5	4	4	3.5	3	2	1	0.5
Connectivity (lateral & longitudinal)	5	5	5	5	4.5	4	3.5	3	2.5	1	0.5
Water Quality (esp. O <sub>2</sub> and Temp.)	5	5	5	5	4.5	4.5	4	4	4	3.5	3
Species stress: PPHI	0	-0.17	-0.83	-1	-2.17	-2.67	-3.67	-4.67	-6	-7.67	-8.5
<b>LARGE SEMI-REOPHILIC (LSR) GUILD</b>											
Spawning habitat	5	4.5	4	3.5	3	2	1.5	1	0.5	0	0
Nursery habitat	5	5	4.5	4.5	4	4	3.5	3	3	1	0.5
Abundance	5	5	5	4.5	4.5	4	4	3.5	3.5	2	1
Cover	5	5	5	4.5	4.5	4	4	3.5	3.5	2	1
Connectivity (lateral & longitudinal)	5	5	5	5	4.5	4.5	4	4	4	3	2
Water Quality (esp. O <sub>2</sub> and Temp.)	5	5	5	5	5	5	4.5	4.5	4.5	4	4
Species stress: BAEN	-0	-0.17	-0.5	-1	-1.5	-2.17	-2.83	-3.5	-3.67	-6	-7.17

### H1.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for decreased and increased flows of the flow dependent macroinvertebrate (FDI) taxa is provided in Table H6 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table H6 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
<b>DECREASED FLOWS</b>															
-10	Only hyporheic refugia, no surface water.	85	0	0	0	15	0	0	0	0	0	0	0		0.001
-9	Standing water habitats only, very low quality. No flow.	72	13	0	0	13	2	0	0	0	0	0	0	Algae	0.002
-8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	71	14	0	0	13	2	0	0	0	0	0	0	Algae	0.009
-7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	63	22	1	0	11	4	0	0	0	0	0	0	Algae	0.04
-6	Critical habitat residual. Low quality, moderate/slow velocity.	46	33	6	0	8	6	1	0	0	0	0	0	Algae	0.169
-5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	34	37	12	2	6	7	2	0	0	0	0	0		0.517
-4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	29	35	17	5	5	6	3	1	0	0	0	0		0.876
-3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	26	31	21	6	5	5	4	1	0	0	0	0		1.207
-2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	23	28	25	8	4	5	4	1	0	0	0	0		1.6
-1	All habitats plentiful, high quality. Fast, wide WP.	18	25	29	12	3	4	5	2	0	0	0	0		2.196
0	Zero stress pegged at naturalized hydrology wet season maintenance base flow.	16	24	30	14	3	4	5	3	0	0	0	0		2.527
<b>INCREASED FLOWS</b>															
0	Zero stress pegged at naturalized hydrology wet season maintenance base flow.	16	24	30	14	3	4	5	3	0	0	0	0		2.527
1	All habitats plentiful, high quality. Fast, WP slightly increased.	15	23	31	17	3	4	5	3	0	0	0	0		2.895
2	Critical habitats sufficient. Quality slightly reduced, fast.	12	20	30	24	2	3	5	4	0	0	0	0		3.747
3	Reduced critical habitat reduced critical quality. Slight inundation and die-off or marginal zone.	9	17	27	31	2	3	5	6	0	0	0	0		4.775
4	Maximum current speeds stabilize. Average current speeds exceed 0.6 m/s. 40% loss of <i>Cyperus</i> .	6	12	20	45	1	2	4	10	0	0	0	0		8.328
5	Critical habitat reduced.	5	10	17	51	1	2	4	11	0	0	0	0		10.965
6	Average depths exceed 0.5 m, leading to potential light limitation.	4	8	15	49	1	3	5	15	0	0	0	0		12.428
7	Critical habitats very reduced.	4	7	14	49	1	3	5	18	0	0	0	0		13.989
8	Mostly fast flowing habitats. Critical habitats limited.	3	7	13	49	1	3	5	19	0	0	0	0		15.649
9	Fast flowing habitats only. 75% loss of marginal vegetation.	3	6	12	51	1	2	5	20	0	0	0	0		17.407
10	Bank full discharge. Habitats suitable for fast flowing taxa only. Critical habitats limited, high potential for erosion. Residual habitat for slow flowing taxa.	3	5	11	52	1	2	4	22	0	0	0	0		20.232

1 Very Slow over Coarse Sediment

4 Very Fast over Coarse Sediment

7 Fast over Fine Sediment

10 Slow over Bedrock

2 Slow over Coarse Sediment

5 Very Slow over Fine Sediment

8 Very Fast over Fine Sediment

11 Fast over Bedrock

3 Fast over Coarse Sediment

6 Slow over Fine Sediment

9 Very Slow over Bedrock

12 Very Fast over Bedrock

The stress index for FDI taxa for decreased and increased flows are provided in Table H7 which rates the response of the species according to various biotic response metrics.

**Table H7 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
<b>DECREASED FLOWS</b>							
0.02	0.01	0.06	0.02	35.2		0.001	<b>10</b>
0.08	0.05	0.18	0.05	0.3		0.002	<b>9</b>
0.14	0.04	0.18	0.05	0.9	Some rheophilic species persist, but at very low numbers. All life stages of most rheophilic species at risk or non-viable.	0.009	<b>8</b>
0.20	0.06	0.25	0.07	4.40	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.	0.040	<b>7</b>
0.28	0.11	0.39	0.11	10.00	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	0.169	<b>6</b>
0.38	0.18	0.58	0.17	15.00	Critical life-stages of sensitive rheophilic species at risk or non-viable.	0.517	<b>5</b>
0.44	0.22	0.72	0.21	19.70	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	0.876	<b>4</b>
0.48	0.25	0.83	0.25	21.90	Most rheophilic species persist, but abundances reduced.	1.207	<b>3</b>
0.52	0.28	0.95	0.28	22.80	Most rheophilic species persist, but slight (80%) reduction.	1.6	<b>2</b>
0.56	0.31	1.11	0.34	24.20	90% rheophilic species persist.	2.196	<b>1</b>
0.58	0.32	1.17	0.37	25.30	All flow dependent macroinvertebrates very abundant and healthy.	2.527	<b>0</b>
<b>INCREASED FLOWS</b>							
0.58	0.32	1.17	0.37	25.30	All flow dependent macroinvertebrates very abundant and healthy.	2.527	<b>0</b>
0.60	0.34	1.24	0.39	25.30		2.895	<b>-1</b>
0.64	0.37	1.41	0.46	25.50		3.747	<b>-2</b>
0.68	0.41	1.55	0.52	26.20		4.775	<b>-3</b>
0.80	0.48	1.85	0.70	26.40		8.328	<b>-4</b>
0.88	0.55	1.91	0.78	29.00		10.965	<b>-5</b>
0.92	0.53	1.97	0.83	29.30		12.428	<b>-6</b>
0.96	0.54	2.01	0.86	32.20		13.989	<b>-7</b>
1.00	0.58	2.02	0.90	34.10		15.649	<b>-8</b>
1.04	0.61	2.11	0.93	34.40		17.407	<b>-9</b>
1.10	0.66	2.17	0.99	34.80		20.232	<b>-10</b>

## H2 EWR 10: SUIKERBOS DS (SUIKERBOSRAND RIVER) – DETERMINATION OF EWR SCENARIOS

### H2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table H8 for the LSR guild and Table H9 for LIM guild.

**Table H8 Low flow requirements: LSR guild**

GENERAL					
<p><b>INDICATOR:</b> This group generally requires FS, FI and FD flow depth categories over good quality substrate (gravel and cobbles) for spawning. Egg and embryo development also takes place in these habitats, while larvae prefer SD with substrate as optimal habitats. Juvenile and adult specimens have a high preference for SD, FS, FI and FD habitats with substrate and water column as cover flows should furthermore remain adequate to allow migration between reaches, thus depth in riffle and rapids should remain adequate, especially during the wet season.</p>					
PES and REC: FISH OVERALL IN EC C/D (ECOSTATUS C/D) Upper limit of the PES band provided below					
<p><b>Dry Season maintenance</b> Presently there is more water at this site than under natural condition during the dry season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LSR in its PES is provided in Figure H1. It is estimated that at a fish stress level of 4.53 (50% duration) the total habitat suitability would be 186% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions (under present flows during the dry season, the habitat suitability percentage is 293% of natural condition). It is estimated that fish would remain in the PES at a fish stress level of 4.53 (50% duration) (Figure H1). Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity of the system. This will be the result of habitat deterioration through scouring and flooding, change in natural habitat composition at the site, altered food webs and population structures, etc.</p>					
<p><b>Dry Season drought</b> A fish stress level of 6.29 (5% duration) for the dry season drought would result in 182% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>					
<p><b>Wet Season 10% assurance</b> Presently there is more water at this site than under natural condition during the wet season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LSR in its PES is provided in Figure H2. It is estimated that at a fish stress level of 2.08 (10% duration) the total habitat suitability would be 185% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions (under present flows habitat suitability percentage is 293%). It is estimated that fish would remain in the PES at a fish stress level of 2.08 (10% duration) during the wet season (Figure H2). Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity of the system. This will be the result of habitat deterioration through scouring and flooding, change in natural habitat composition at the site, altered food webs and population structures, etc.</p>					
<p><b>Wet Season drought</b> A fish stress level of 2.5 (5% duration) for the wet season drought would result in 184% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+6.29	+6.29	0.78
Maintenance	Dry	50%	+4.53	+4.53	1.095
Drought	Wet	5%	+2.5	+2.5	1.6
Maintenance	Wet	10%	+2.08	+2.08	1.73
AEC up: FISH EC C (ECOSTATUS C) Upper limit of improved category (less flows than present during both seasons)					
<p><b>General</b> Decreased flows should create habitat conditions closer to those expected under natural conditions, which should be reflected by the fish assemblages at the site. Improved water quality should benefit the species with requirement for high quality water. It may therefore result in conditions suitable for BPAL, as well as the improved FROC of species such as ASCL, BKIM.</p>					

**Dry Season maintenance**

A further decrease in flow during the dry season is expected to improve the fish to a category C. The maximum fish stress levels to maintain the LSR in a category C is provided in Figure H1. At a fish stress level of 4.8 (50% duration) the total habitat suitability would be 168% of what can be expected under natural conditions. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.

**Wet Season maintenance**

A further decrease in flow during the wet season is expected to improve the fish to a category C. The maximum fish stress levels to maintain the LSR in a category C is provided in Figure H2. At a fish stress level of 2.5 (10% duration) the total habitat suitability would be 166% of what can be expected under natural conditions. As stated above, more suitable habitats will be available but any shift from natural conditions can be seen as a deterioration of the ecological integrity.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+4.8	+4.8	1.026
Maintenance	Wet	10%	+2.5	+2.5	1.6

**AEC down: FISH EC D (ECOSTATUS D )**  
**More flows than present during both seasons, lower limit of PES band**

**General**

Should flows increase further; conditions will deteriorate progressively until the LSR fish guild will deteriorate into the next ecological category. Further increase in base flows will further reduce the availability of slow habitats and alter the FROC of species with a preference/requirement for these habitats (BANO, TSPA, PPHI, LCAP, BAEN and even CGAR).

**Dry Season maintenance**

The maximum allowable fish stress levels that can be applied through increase in flow to maintain the LSR in its PES during the dry season is estimated to be - 3.5 (50% duration). This stress level should maintain flows adequate to support abundance, cover, connectivity and water quality similar to present conditions. Once this threshold is exceeded, the habitat suitability will be reduced to an extent where deterioration in the fish assemblage can be expected to occur.

**Wet Season maintenance**

The maximum allowable fish stress levels that can be applied through increase in flow to maintain the LSR in its PES during the wet season is estimated to be - 3.6 (10% duration). This stress level should maintain flows adequate to support spawning, nursery habitats, abundance, cover, connectivity and water quality similar to present conditions. Once this threshold is exceeded, the habitat suitability will be reduced to an extent where deterioration in the fish assemblage can be expected to occur.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	-3.5	-6	11
Maintenance	Wet	10%	-3.6	-6.1	11.03

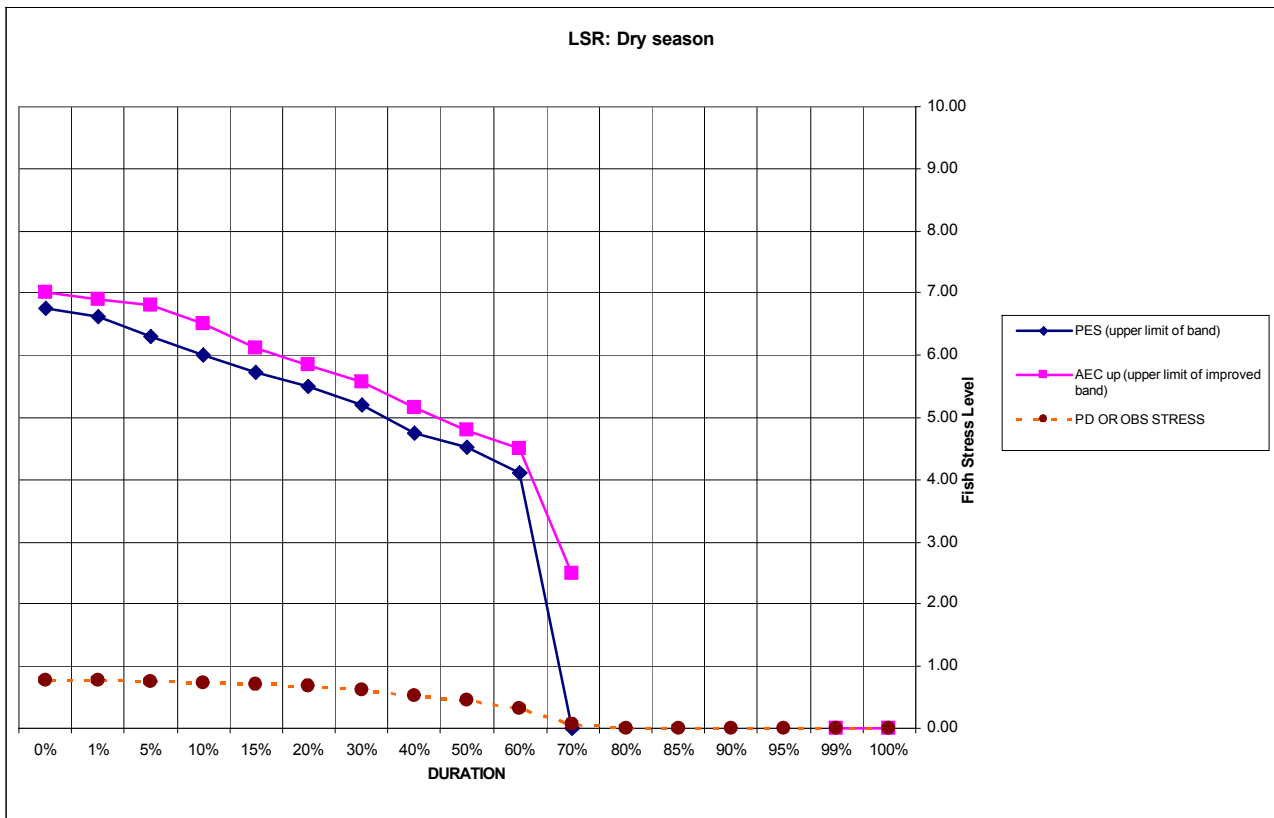


Figure H1 Dry Season LSR fish stress at different flow durations for the various ECs

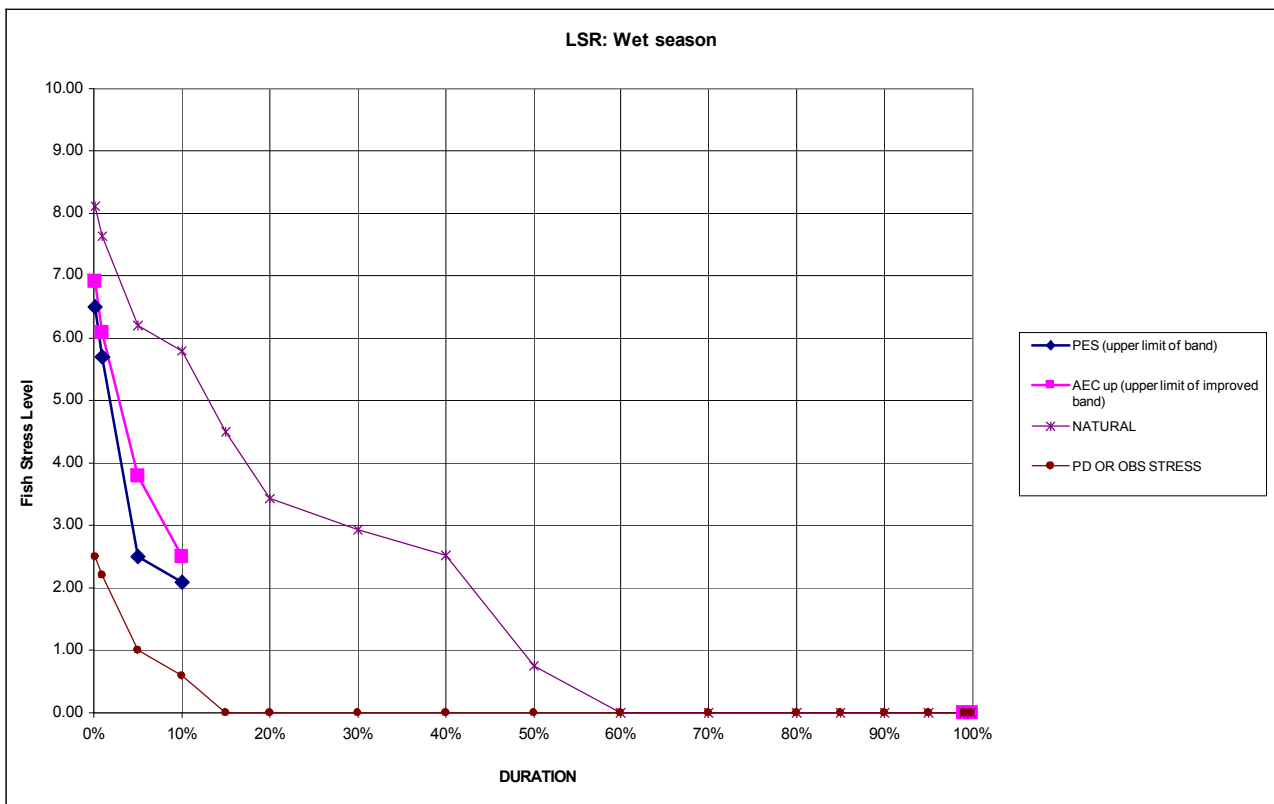


Figure H2 Wet Season LSR fish stress at different flow durations for the various ECs

**Table H9 Low flow requirements: LIM guild**

<b>GENERAL</b>					
<p><b>INDICATOR:</b> The optimal preferred general habitat for small limnophilic species is Slow Deep (SD) and Slow Shallow (SS) preferably with overhanging vegetation, undercut banks or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock) as general habitat. Breeding takes place during the spring and summer, with males constructing nests in soft substrates. Optimal habitats for egg and larvae development, nursery areas and in general for juveniles and adults are SD and SS habitats.</p>					
<b>PES and REC: FISH OVERALL IN EC C/D (ECOSTATUS C/D)</b>					
<b>Upper limit of the PES band</b>					
<p><b>Dry Season maintenance</b> Presently there is more water at this site than under natural condition during the dry season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LIMNO in its PES is provided in Figure H3. It is estimated that at a fish stress level of 0.49 (50% duration) the total habitat suitability would be 151% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions (under present flows during the dry season, the habitat suitability percentage is 157% of natural condition). It is estimated that fish would remain in the PES at a fish stress level of 0.49 (50% duration) (Figure H3). Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity of the system. This will be the result of habitat deterioration through scouring and flooding, change in natural habitat composition at the site, altered food webs and population structures, etc.</p>					
<p><b>Dry Season drought</b> A fish stress level of 0.58 (5% duration) for the dry season drought would result in 165% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>					
<p><b>Wet Season maintenance</b> Presently there is more water at this site than under natural condition during the wet season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LIMNO in its PES is provided in Figure H4. It is estimated that at a fish stress level of 0.6 (10% duration) the total habitat suitability would be 112% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions (under present flows habitat suitability percentage is 293%). It is estimated that limnophilic fish would remain in the PES at a fish stress level of 0.6 (10% duration) during the wet season (Figure H2). Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity of the system. This will be the result of habitat deterioration through scouring and flooding, change in natural habitat composition at the site, altered food webs and population structures, etc.</p>					
<p><b>Wet Season drought</b> A fish stress level of 1 (5% duration) for the wet season drought would result in 113% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+0.58	+2.2	1.678
Maintenance	Dry	50%	+0.49	+2	1.73
Drought	Wet	5%	+1	+4	1.21
Maintenance	Wet	10%	+0.6	+2.1	1.704
<b>AEC up: FISH EC C (ECOSTATUS C)</b>					
<b>Upper limit of improved category (less flows than present during both seasons)</b>					
<p><b>General</b> Decreased flows should create habitat conditions closer to those expected under natural conditions, which should be reflected by the fish assemblages at the site. Improved water quality should benefit the species with requirement for high quality water. It may therefore result in conditions suitable for BPAL, as well as the improved FROC of species such as ASCL, BKIM.</p>					
<p><b>Dry Season maintenance</b> A further decrease in flow during the dry season is expected to improve the ecological category of the limnophilic fish. The maximum fish stress levels to maintain the LIM guild in an improved ecological category is provided in Figure H3. At a fish stress level of 1.43 (50% duration) the total habitat suitability would be 134% of what can be expected under natural conditions. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.</p>					
<p><b>Wet Season maintenance</b> A further decrease in flow during the wet season is expected to improve the fish with one ecological category. The maximum fish stress levels to maintain the LIMNO in an improved category is provided in Figure H4. At a fish stress</p>					

level of 1.3 (10% duration) the total habitat suitability would be very similar to what can be expected under natural conditions.

Maintenance	Dry	50%	+1.43	+4.8	1.026
Maintenance	Wet	10%	+1.3	+4.7	1.049

**AEC down: FISH EC D (ECOSTATUS D)**  
**More flows than present during both seasons, lower limit of PES band**

**General**

Should flows increase further; conditions will deteriorate progressively until the limnophilic fish guild is expected to deteriorate into the next ecological category. Further increase in base flows will further reduce the availability of slow habitats and alter the FROC of species with a preference/requirement for these habitats (BANO, TSPA, PPHI, LCAP, BAEN and even CGAR).

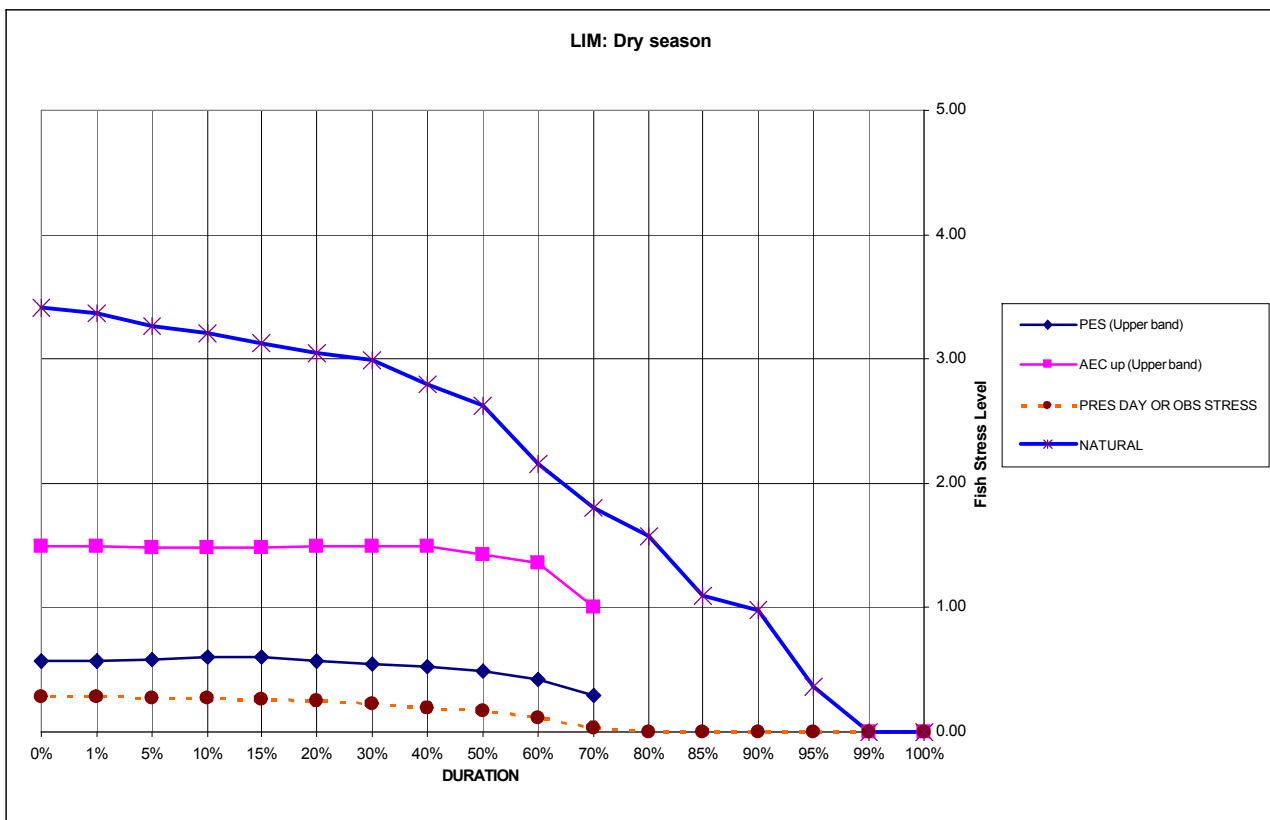
**Dry Season maintenance**

The maximum allowable fish stress levels that can be applied through increase in flow to maintain the LIM guild in its PES during the dry season is estimated to be - 2.2 (50% duration). This stress level should maintain flows adequate to support abundance, cover, connectivity and water quality similar to present conditions. Once this threshold is exceeded, the habitat suitability will be reduced to an extent where deterioration in the fish assemblage can be expected to occur.

**Wet Season maintenance**

The maximum allowable fish stress levels that can be applied through increase in flow to maintain the LIM guild in its PES during the wet season is estimated to be - 2.1 (10% duration). This stress level should maintain flows adequate to support spawning, nursery habitats, abundance, cover, connectivity and water quality similar to present conditions. Once this threshold is exceeded, the habitat suitability will be reduced to an extent where deterioration in the fish assemblage can be expected to occur.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	-2.2	-3.3	5.85
Maintenance	Wet	10%	-2.1	-3.2	5.5



**Figure H3 Dry Season LIM fish stress at different flow durations for the various ECs**

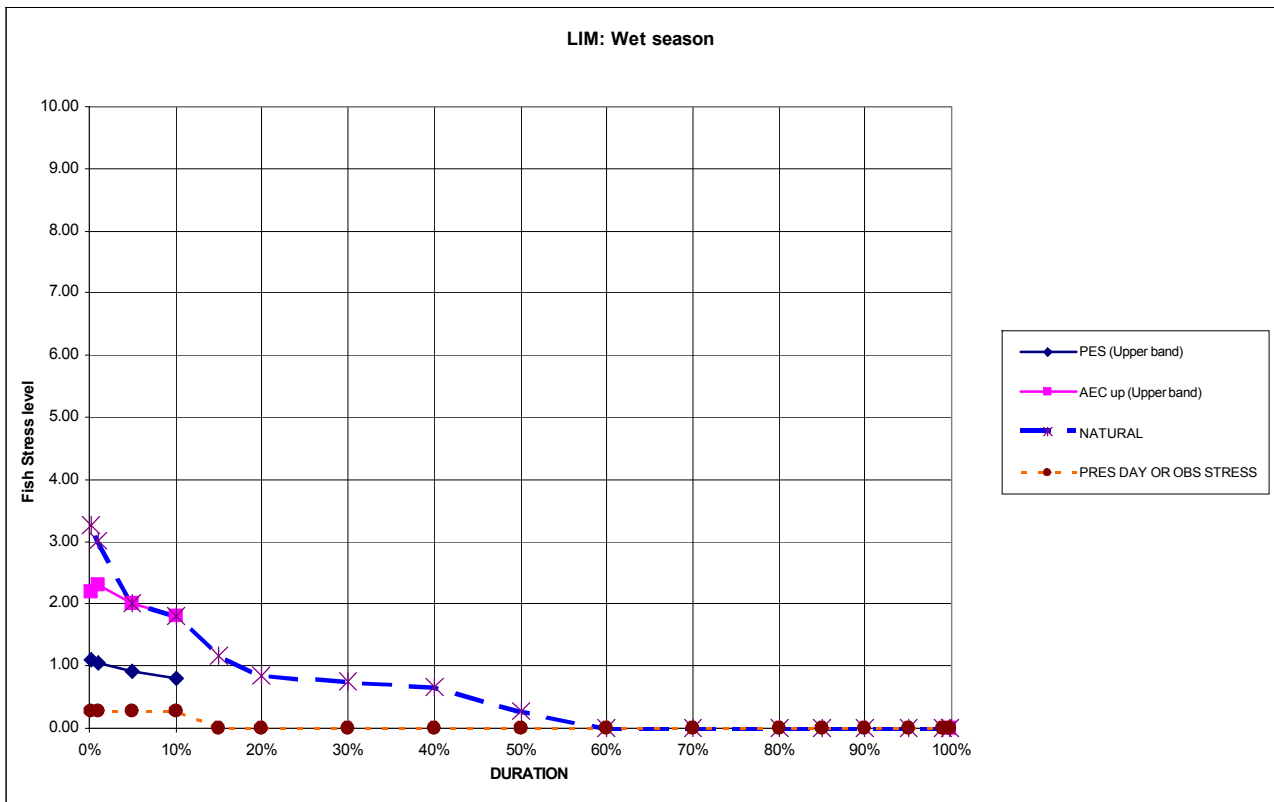


Figure H4 Wet Season LIM fish stress at different flow durations for the various ECs

## H2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table H10 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

Table H10 Low flow requirements: FDI taxa

GENERAL
<b>INDICATOR:</b> Hydropsychid caddisflies and Simuliidae (i.e., common, flow dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.
PES and REC: MACROINVERTEBRATE EC C/D (ECOSTATUS C/D)
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is between 0.29 and 0.31 m, and average current velocity is between 0.31 and 0.34 (Spp Stress between + 1.5 and - 1). Critical habitats (FCS) comprise between 28 and 31% of habitats available.
<b>Dry Season drought</b> Average depth needed for dry season drought is between 0.28 and 0.32 m, and average current velocity is between

0.28 and 0.37 m / s (Spp Stress between 0 and + 2). Critical habitats (FCS) comprise between 25 and 30% of habitats available.

#### Wet Season maintenance

Average depth needed for wet season maintenance is between 0.37 and 0.48 m, and average current velocity is 0.46 to 0.7 m / s (Spp Stress - 2 and - 4). Critical habitats (FCS) comprise between 20 and 30% of habitats available.

#### Wet Season drought

Average depth needed for wet season drought is between 0.25 and 0.31 m, and average current velocity is between 0.25 and 0.34 m / s (Spp Stress between + 1 and + 3). Critical habitats (FCS) comprise between 21 and 29% of habitats available.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+2	+2.5	1.6
Maintenance	Dry	50%	+1.5	+1.5	1.97
Drought	Wet	5%	3.2	4.2	1.146
Maintenance	Wet	50%	-2	-2	3.7

#### AEC up: MACROINVERTEBRATE EC C (ECOSTATUS C)

#### Dry Season maintenance

Average depth needed for dry season maintenance is between 0.25 and 0.29 m, and average current velocity is between 0.25 and 0.31 m/s (Spp Stress between + 3 and + 1.5). Critical habitats (FCS) comprise between 21 and 28 % of habitats available.

#### Dry Season drought

Average depth needed for dry season drought is between 0.25 and 0.28 m, and average current velocity is between 0.28 and 0.31 m/s (Spp Stress between + 2 and + 1.5). Critical habitats (FCS) comprise between 25 and 28% of habitats available.

#### Wet Season maintenance

Average depth needed for wet season maintenance is between 0.32 and 0.37 m, and average current velocity is 0.37 and 0.46 m/s (Spp Stress - 2 and 0). Critical habitats (FCS) comprise between 30 and 31% of habitats available.

#### Wet Season drought

Average depth needed for wet season drought is between 0.18 and 0.25 m, and average current velocity is between 0.17 and 0.25 m/s (Spp Stress between + 3 and + 5). Critical habitats (FCS) comprise between 12 and 21% of habitats available.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+4.5	+6.5	0.75
Maintenance	Dry	50%	+4	+5.5	0.91
Drought	Wet	5%	+4	+5.5	0.91
Maintenance	Wet	50%	0	0	2.5

#### AEC down: MACROINVERTEBRATE EC D (ECOSTATUS D)

#### Dry Season maintenance

Average depth needed for dry season maintenance is between 0.31 and 0.37 m, and average current velocity is between 0.34 and 0.46 m / s (Spp Stress between + 1 and - 2).

#### Dry Season drought

Average depth needed for dry season drought is between 0.32 and 0.34 m, and average current velocity is between 0.37 and 0.39 m / s (Spp Stress between 0 and - 1).

#### Wet Season maintenance

Average depth needed for wet season maintenance is 0.48 and 0.55 m, and average current velocity is between 0.70 and 0.78 m / s (Spp Stress - 4 and - 5).

#### Wet Season drought

Average depth needed for wet season drought is between 0.3 and 0.32 m, and average current velocity is 0.34 and 0.37 m / s (Spp Stress between - 1 and 0).

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	0	0	2.5

Maintenance	Dry	50%	-1	-1	2.9
Drought	Wet	5%	1	1	2.2
Maintenance	Wet	50%	-4	-4	8.3

## H2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table H11.

**Table H11 Functions for each Flood Class**

Flood Class	Function / Motivation	
CLASS: I RANGE (M <sup>3</sup> /S): 5 -6 DAILY AVERAGE: 3.5 DURATION: 3	Fish	Class 1 floods are very important floods for fish and serves as migration cues and to maintain adequate longitudinal connectivity for migration. These floods will also flush fines and algae from substrates to ensure adequate conditions in substrates, a very important habitat for spawning of many of the species. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation and contributes to the creation of acceptable nursery areas. Some resetting of water quality will also take place, and the changes in water quality may also serve as stimulus to cue migratory activity and even gonad development. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Four of these per year, any time during the wet season, are recommended for a macroinvertebrate Category C and C/D, and two for a Category D.
CLASS: II RANGE (M <sup>3</sup> /S): 8 - 12 DAILY AVERAGE: 6 DURATION: 4	Fish	Class 2 floods are similar in importance as Class 1 floods and have the same functionality as Class 1 floods. Their occurrence at lower frequency makes them only slightly less important for the fish assemblages than Class 1. Secondary channels will be inundated by these floods which will create favourable spawning and refuge habitats for some species.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Two of these per year are recommended for a macroinvertebrate Category C and C/D: one at the beginning of the wet season (Oct/Nov), one during the wet season, and one towards the end of the wet season (Feb/Mar). One of these per year are recommended for a macroinvertebrate Category D: one at the beginning of the wet season (Oct/Nov), and one towards the end of the wet season (Feb/Mar).
CLASS: III RANGE (M <sup>3</sup> /S): 20 -40 DAILY AVERAGE: 11 DURATION: 4	Fish	Class 3 floods also provide similar functions as Class 1, but due to its lower frequency it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.
	Macroinvertebrates	These freshets are recommended to clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. One of these per year at the beginning of the wet season is recommended for a macroinvertebrate Category C and C/D.
CLASS : IV RANGE (M <sup>3</sup> /S): 70 +	Fish	Class 4 floods also provide similar functions as Class 1, but due to its lower frequency of occurrence it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.

## H2.4 EWR RULES

**Table H12 EWR 10 assurance rules for PES and REC: C/D**

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Summary of IFR rule curves for: V\_EWR10 P.Day Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal PES and REC = C/D

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.656	1.640	1.607	1.549	1.453	1.311	1.130	0.937	0.780	0.706
Nov	2.593	2.562	2.503	2.395	2.219	1.959	1.626	1.271	0.982	0.846
Dec	2.748	2.715	2.650	2.533	2.339	2.055	1.692	1.304	0.988	0.839
Jan	3.331	3.301	3.246	3.147	2.979	2.711	2.322	1.821	1.295	0.968
Feb	4.868	4.821	4.734	4.578	4.313	3.893	3.279	2.491	1.662	1.147
Mar	3.367	3.336	3.279	3.178	3.006	2.731	2.332	1.818	1.278	0.943
Apr	2.975	2.939	2.867	2.738	2.526	2.214	1.814	1.388	1.041	0.877
May	2.316	2.290	2.239	2.146	1.995	1.771	1.485	1.181	0.932	0.816
Jun	1.904	1.885	1.847	1.778	1.665	1.499	1.287	1.061	0.876	0.789
Jul	1.492	1.479	1.454	1.408	1.332	1.221	1.078	0.927	0.803	0.745
Aug	1.409	1.397	1.373	1.330	1.258	1.154	1.020	0.877	0.760	0.705
Sep	1.491	1.478	1.451	1.402	1.322	1.205	1.054	0.894	0.764	0.702

Reserve flows without High Flows

Oct	1.656	1.640	1.607	1.549	1.453	1.311	1.130	0.937	0.780	0.706
Nov	2.316	2.290	2.239	2.147	1.996	1.774	1.490	1.187	0.940	0.823
Dec	2.481	2.452	2.395	2.293	2.124	1.877	1.560	1.223	0.947	0.818
Jan	2.588	2.567	2.528	2.457	2.337	2.147	1.869	1.511	1.136	0.903
Feb	3.592	3.560	3.500	3.393	3.211	2.922	2.500	1.958	1.388	1.034
Mar	2.875	2.850	2.803	2.721	2.580	2.357	2.031	1.613	1.173	0.900
Apr	2.975	2.939	2.867	2.738	2.526	2.214	1.814	1.388	1.041	0.877
May	2.316	2.290	2.239	2.146	1.995	1.771	1.485	1.181	0.932	0.816
Jun	1.904	1.885	1.847	1.778	1.665	1.499	1.287	1.061	0.876	0.789
Jul	1.492	1.479	1.454	1.408	1.332	1.221	1.078	0.927	0.803	0.745
Aug	1.409	1.397	1.373	1.330	1.258	1.154	1.020	0.877	0.760	0.705
Sep	1.491	1.478	1.451	1.402	1.322	1.205	1.054	0.894	0.764	0.702

Natural Duration curves

Oct	5.156	3.973	2.882	2.658	2.360	2.117	1.983	1.807	1.736	1.635
Nov	8.904	6.111	5.235	4.668	4.128	3.495	2.832	2.215	1.620	1.493
Dec	9.760	6.668	5.865	5.093	4.462	3.528	2.950	2.505	1.930	1.647
Jan	13.866	7.829	5.832	5.193	4.570	4.170	3.707	3.162	2.218	1.751
Feb	17.274	7.697	6.233	5.531	4.377	3.906	3.514	3.113	2.269	1.682
Mar	10.241	7.378	5.712	4.723	4.070	3.719	3.233	2.826	2.244	1.732
Apr	7.396	6.084	5.039	4.383	3.627	3.484	3.067	2.801	2.454	1.948
May	6.261	4.678	3.894	3.289	3.002	2.886	2.714	2.468	2.285	2.106
Jun	4.406	3.596	3.056	2.828	2.716	2.542	2.438	2.342	2.269	2.153
Jul	3.424	3.106	2.815	2.640	2.543	2.445	2.382	2.333	2.274	2.214
Aug	3.002	2.580	2.460	2.341	2.274	2.240	2.188	2.158	2.136	2.117
Sep	2.986	2.527	2.296	2.199	2.168	2.106	2.064	2.045	2.022	1.975

**Table H13 EWR 10 assurance rules for AEC up: C**

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Summary of IFR rule curves for: V\_EWR10 P.Day Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal AEC UP = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.231	1.219	1.196	1.155	1.086	0.985	0.856	0.719	0.607	0.554
Nov	2.261	2.232	2.174	2.071	1.901	1.651	1.331	0.990	0.711	0.580
Dec	2.325	2.295	2.235	2.128	1.951	1.692	1.359	1.005	0.716	0.580
Jan	2.847	2.819	2.767	2.673	2.513	2.259	1.890	1.414	0.914	0.604
Feb	3.977	3.935	3.858	3.720	3.486	3.114	2.571	1.873	1.140	0.684
Mar	2.700	2.673	2.624	2.535	2.385	2.145	1.797	1.348	0.877	0.584
Apr	2.310	2.280	2.220	2.113	1.936	1.675	1.342	0.987	0.697	0.561
May	2.023	1.997	1.947	1.857	1.709	1.491	1.213	0.916	0.673	0.559
Jun	1.735	1.714	1.674	1.602	1.483	1.307	1.083	0.844	0.649	0.557
Jul	1.447	1.431	1.401	1.346	1.256	1.123	0.954	0.773	0.625	0.556
Aug	1.232	1.221	1.199	1.161	1.097	1.004	0.884	0.757	0.653	0.604
Sep	1.159	1.149	1.128	1.091	1.029	0.939	0.824	0.701	0.601	0.554

Reserve flows without High Flows

Oct	1.231	1.219	1.196	1.155	1.086	0.985	0.856	0.719	0.607	0.554
Nov	2.023	1.997	1.947	1.857	1.709	1.491	1.213	0.916	0.673	0.559
Dec	2.094	2.068	2.015	1.921	1.766	1.537	1.245	0.933	0.679	0.560
Jan	2.199	2.178	2.139	2.069	1.952	1.764	1.491	1.139	0.770	0.541
Feb	2.851	2.822	2.769	2.673	2.512	2.254	1.879	1.396	0.889	0.574
Mar	2.258	2.236	2.196	2.124	2.002	1.808	1.525	1.161	0.778	0.541
Apr	2.310	2.280	2.220	2.113	1.936	1.675	1.342	0.987	0.697	0.561
May	2.023	1.997	1.947	1.857	1.709	1.491	1.213	0.916	0.673	0.559
Jun	1.735	1.714	1.674	1.602	1.483	1.307	1.083	0.844	0.649	0.557
Jul	1.447	1.431	1.401	1.346	1.256	1.123	0.954	0.773	0.625	0.556
Aug	1.232	1.221	1.199	1.161	1.097	1.004	0.884	0.757	0.653	0.604
Sep	1.159	1.149	1.128	1.091	1.029	0.939	0.824	0.701	0.601	0.554

Natural Duration curves

Oct	5.156	3.973	2.882	2.658	2.360	2.117	1.983	1.807	1.736	1.635
Nov	8.904	6.111	5.235	4.668	4.128	3.495	2.832	2.215	1.620	1.493
Dec	9.760	6.668	5.865	5.093	4.462	3.528	2.950	2.505	1.930	1.647
Jan	13.866	7.829	5.832	5.193	4.570	4.170	3.707	3.162	2.218	1.751
Feb	17.274	7.697	6.233	5.531	4.377	3.906	3.514	3.113	2.269	1.682
Mar	10.241	7.378	5.712	4.723	4.070	3.719	3.233	2.826	2.244	1.732
Apr	7.396	6.084	5.039	4.383	3.627	3.484	3.067	2.801	2.454	1.948
May	6.261	4.678	3.894	3.289	3.002	2.886	2.714	2.468	2.285	2.106
Jun	4.406	3.596	3.056	2.828	2.716	2.542	2.438	2.342	2.269	2.153
Jul	3.424	3.106	2.815	2.640	2.543	2.445	2.382	2.333	2.274	2.214
Aug	3.002	2.580	2.460	2.341	2.274	2.240	2.188	2.158	2.136	2.117
Sep	2.986	2.527	2.296	2.199	2.168	2.106	2.064	2.045	2.022	1.975

**APPENDIX I: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS INDICES  
AND EWR SCENARIOS OF EWR 11: BLESBOKSPRUIT**

# 11 EWR 11: BLESBOKSPRUIT (BLESBOKSPRUIT RIVER) – DETERMINATION OF STRESS INDICES

Appendix I provides supporting information for the determination of stress indices of EWR 11 Blesbokspruit (Chapter 17 and 18 of the Main Report, Volume 1).

## 11.1 FISH INDICATOR SPECIES

### Fish indicator group 1: Large semi-rheophilic species (BAEN, BKIM)

Indicator species: *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM). Refer to Appendix B, Section B1.1.

### Fish indicator group 2: Small limnophilic (LIM) species (PPHI, TSPA)

Indicator species: *Pseudocrenilabrus philander* (PPHI) and *Tilapia sparrmanii* (TSPA). Refer to Appendix K, Section K1.1

## 11.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table I1 for decreased flows and in Table I2 for increased flows.

**Table I1 EWR 11: Habitat suitability for the LSR and LIM guild – DECREASED FLOWS**

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0	0.05	0.1	0.15	0.2	0.24	0.30	0.4	0.5	0.6	0.70
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	10	9	8	7	5	5	4	3	3	2	2
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	0	1	2	3	4	4	5	5	5	5	5
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	0	0	0	0	0	0	0	0	0	0	0
Slow Shallow and Slow Deep	0	1	2	3	4	4	5	5	5	5	5
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	0	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	0	1	1	1	1	1	1	2	2	2	3
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	0	0	0	0	0	0	1	1	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	0	0	0	0	0	0	0	0	0	0	0
FAST TOTAL >0.1 m DEEP	0	0	0	0	0	0	1	1	1	1	1

**Table I2 EWR 11: Habitat suitability for the LSR and LIM guild – INCREASED FLOWS**

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0.70	1.50	1.90	2.18	2.25	3.70	4.40	8.00	11.80	17.20	24.00
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	2	1	1	1	1	1	1	0	0	0	0
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	5	4	4	4	3	3	3	1	1	1	1
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	0	0	0	0	0	1	1	2	2	2	2
Slow Shallow and Slow Deep	5	4	4	4	3	4	4	3	3	3	3
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	1	1	1	1	1	1	1	1	1	0	0
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	3	2	2	2	2	1	1	1	1	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	1	3	4	4	4	1	1	1	1	1	1

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0.70	1.50	1.90	2.18	2.25	3.70	4.40	8.00	11.80	17.20	24.00
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	0	1	1	2	2	5	6	0	0	0	0
FAST TOTAL >0.1 m DEEP	1	4	5	6	6	6	7	1	1	1	1

The fish stress index is provided in Table I3 for decreased flows and I4 for increased flows.

**Table I3 Fish stress index – DECREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	0	0.05	0.1	0.15	0.2	0.24	0.30	0.4	0.5	0.6	0.70
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	0	0	1	1.5	2	2.5	3	3.5	4	4.5	5
Nursery habitat	0	1	1.5	2	2.5	3	3	3.5	4	4.5	5
Abundance	0	1.5	2	2.5	3	3.5	4	4.5	4.5	5	5
Cover	0	1.5	2	2.5	3	3.5	4	4.5	4.5	5	5
Connectivity (lateral & longitudinal)	0	0.5	1.5	2.5	3	3.5	4	4.5	5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	0.5	1	2	3	3.5	4	4.5	5	5	5
<b>Species stress: PPHI</b>	<b>10</b>	<b>8.3</b>	<b>7</b>	<b>5.7</b>	<b>4.5</b>	<b>3.5</b>	<b>2.7</b>	<b>1.7</b>	<b>1</b>	<b>0.3</b>	<b>0</b>
<b>LARGE SEMIREOPHILIC (LSR) GUILD</b>											
Spawning habitat	0	0	0	0.5	1	2	2.5	3.5	4	4.5	5
Nursery habitat	0	0.5	1	1.5	2	2.5	3	4	4.5	4.5	5
Abundance	0	0.5	1	1.5	2	2.5	2.5	3.5	4.5	5	5
Cover	0	0.5	1	1.5	2	2.5	2.5	3.5	4.5	5	5
Connectivity (lateral & longitudinal)	0	0.5	0.5	0.5	1	2	3	3.5	4	4.5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	0.5	1	2	2.5	3	3.5	4	4.5	5	5
<b>Species stress: BAEN</b>	<b>10</b>	<b>9.2</b>	<b>8.5</b>	<b>7.5</b>	<b>6.5</b>	<b>5.2</b>	<b>4.3</b>	<b>2.7</b>	<b>1.3</b>	<b>0.5</b>	<b>0</b>

**Table I4 Fish stress index – INCREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	0.70	1.5	1.90	2.18	2.25	3.70	4.40	8.00	11.80	17.20	24.00
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	5	4	3.5	3	3	2.5	2.5	2	1	0	0
Nursery habitat	5	4	3.5	3	3	2.5	2	1	0.5	0	0
Abundance	5	5	4	3.5	3	2.5	2	1	1	0.5	0.5
Cover	5	5	4	3.5	3	2.5	2	1	1	0.5	0.5
Connectivity (lateral & longitudinal)	5	4.5	4	3.5	3.5	3	2.5	2	1	0.5	0.5
Water Quality (esp. O <sub>2</sub> and Temp.)	5	5	5	5	4.5	4.5	4	4	4	3.5	3
<b>Species stress: PPHI</b>	<b>-0</b>	<b>-0.83</b>	<b>-2</b>	<b>-2.83</b>	<b>-3.3</b>	<b>-4.17</b>	<b>-5</b>	<b>-6.3</b>	<b>-7.17</b>	<b>-8.3</b>	<b>-8.5</b>
<b>LARGE SEMIREOPHILIC (LSR) GUILD</b>											
Spawning habitat	5	5	4.5	4.5	4.5	4	3.5	3	2	1.5	1.5
Nursery habitat	5	4.5	4.5	4	4	3.5	3.5	3	2	1	0.5
Abundance	5	5	4.5	4.5	4.5	3.5	3	3	2.5	2	1
Cover	5	5	4.5	4.5	4.5	3.5	3	3	2.5	2	1

Habitat	Discharges (m <sup>3</sup> /s)										
	0.70	1.5	1.90	2.18	2.25	3.70	4.40	8.00	11.80	17.20	24.00
Connectivity (lateral & longitudinal)	5	5	4.5	4.5	4.5	4	4	4	3	3	3
Water Quality (esp. O <sub>2</sub> and Temp.)	5	5	5	5	5	5	4.5	4.5	4.5	4.5	4.5
Species stress: BAEN	-0	-0.17	-0.83	-1	-1	-2.17	-2.83	-3.17	-4.5	-5.3	-6.17

### 11.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for decreased and increased flows of the flow dependent macroinvertebrate (FDI) taxa is provided in Table I5 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table I5 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
<b>DECREASED FLOWS</b>															
10	Only hyporheic refugia, no surface water.	50	0	0	0	30	0	0	0	20	0	0	0		0.001
9	Standing water habitats only, very low quality. No flow.	42	8	0	0	25	5	0	0	17	3	0	0	Algae	0.003
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	40	10	0	0	24	6	0	0	16	4	0	0	Algae	0.008
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	34	15	1	0	21	9	0	0	14	6	0	0	Algae	0.02
6	Critical habitat residual. Low quality, moderate/slow velocity.	23	23	4	0	14	14	3	0	9	9	2	0	Algae	0.111
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	20	24	6	1	12	14	3	0	8	9	2	0		0.172
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	18	24	7	1	11	14	4	1	7	10	3	0		0.25
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	16	23	9	2	10	14	6	1	6	9	3	1		0.345
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	15	21	11	3	9	13	7	2	6	8	4	1		0.461
1	All habitats plentiful, high quality. Fast, wide WP.	13	19	14	4	8	11	9	2	5	8	6	2		0.611
0	Zero stress pegged at naturalized hydrology wet season maintenance base flow.	12	17	17	5	7	10	10	3	4	6	6	2		0.796
<b>INCREASED FLOWS</b>															
0	Zero stress pegged at naturalized hydrology wet season maintenance base flow.	12	17	17	5	7	10	10	3	4	6	6	2		0.796
1	All habitats plentiful, high quality. Fast, WP slightly increased.	9	14	19	9	5	8	11	5	4	5	7	4		1.268
2	Critical habitats sufficient. Quality slightly reduced, fast.	6	11	17	16	4	7	10	10	2	4	6	6		2.025
3	Reduced critical habitat reduced critical quality.	6	11	16	17	4	6	10	10	2	4	6	7		2.441
4	Maximum current speeds stabilize. Average current speeds exceed 0.6 m/s.	6	10	16	18	3	6	10	11	2	4	6	7		3.129
5	Critical habitat reduced. Entire marginal zone inundated.	5	10	16	19	3	6	10	12	2	4	6	7		4.438
6	Average depths exceed 0.5 m leading to	4	9	15	22	3	5	9	13	2	4	6	9		5.942

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)	
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>			
	potential light limitation. Marginal zone inundated and reduced by about 50 %.															
7	Critical habitats very reduced.	3	7	13	27	2	4	8	16	1	3	5	11		11.992	
8	Mostly fast flowing habitats. Critical habitats limited.	3	7	12	28	2	4	7	17	1	3	5	11		13.327	
9	Fast flowing habitats only. 75% loss of marginal vegetation.	3	6	12	29	2	4	7	17	1	2	5	12		15.202	
10	Bank full discharge. Habitats suitable for fast flowing taxa only. Critical habitats limited, high potential for erosion. Residual habitat for slow flowing taxa.	3	6	10	32	2	3	6	19	1	2	4	12		22.595	

1 Very Slow over Coarse Sediment  
 4 Very Fast over Coarse Sediment  
 7 Fast over Fine Sediment  
 10 Slow over Bedrock

2 Slow over Coarse Sediment  
 5 Very Slow over Fine Sediment  
 8 Very Fast over Fine Sediment  
 11 Fast over Bedrock

3 Fast over Coarse Sediment  
 6 Slow over Fine Sediment  
 9 Very Slow over Bedrock  
 12 Very Fast over Bedrock

The stress index for FDI taxa is provided in Table I6 which rates the response of the species according to various biotic response metrics.

**Table I6 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
<b>DECREASED FLOWS</b>							
0.02	0.01	0.08	0.02	0.6		0.001	<b>10</b>
0.06	0.02	0.19	0.05	2.5		0.003	<b>9</b>
0.08	0.02	0.21	0.06	5.2	Some rheophilic species persist, but at very low numbers. All life stages of most rheophilic species at risk or nonviable.	0.008	<b>8</b>
0.1	0.04	0.28	0.08	7.1	Some rheophilic species persist, but most disappear. All lifestages of sensitive rheophilic species at risk or nonviable.	0.02	<b>7</b>
0.16	0.07	0.45	0.13	12.9	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species nonviable and at risk for some less sensitive species.	0.111	<b>6</b>
0.18	0.08	0.52	0.16	14.1	Critical lifestages of sensitive rheophilic species at risk or nonviable.	0.172	<b>5</b>
0.2	0.09	0.6	0.18	15.0	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	0.250	<b>4</b>
0.22	0.11	0.66	0.2	16.2	Most rheophilic species persist, but abundances reduced.	0.345	<b>3</b>
0.24	0.12	0.74	0.23	17.3	Most rheophilic species persist, but slight (80%) reduction.	0.461	<b>2</b>
0.26	0.14	0.84	0.26	17.8	90% rheophilic species persist.	0.611	<b>1</b>
0.28	0.15	0.94	0.3	18.1	All flow dependent macroinvertebrates very abundant and healthy.	0.796	<b>0</b>
<b>INCREASED FLOWS</b>							
0.28	0.15	0.94	0.3	18.1	All flow dependent macroinvertebrates very abundant and healthy.	0.796	<b>0</b>
0.32	0.19	1.18	0.37	18.6		1.268	<b>-1</b>
0.36	0.22	1.48	0.49	19.4		2.025	<b>-2</b>
0.4	0.25	1.53	0.5	20.2		2.441	<b>-3</b>
0.46	0.3	1.51	0.51	21.3		3.129	<b>-4</b>

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
0.56	0.39	1.52	0.54	22.0		4.438	-5
0.66	0.47	1.57	0.57	22.7		5.942	-6
0.98	0.75	1.72	0.68	24.4		11.992	-7
1.04	0.8	1.77	0.7	24.7		13.327	-8
1.12	0.87	1.78	0.73	25.1		15.202	-9
1.4	1.12	1.95	0.81	26.0		22.595	-10

## 12 EWR 11: BLESBOKSPRUIT (BLESBOKSPRUIT RIVER) – DETERMINATION OF EWR SCENARIOS

### 12.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table I7 for the LSR guild and Table I8 for the LIM guild.

**Table I7 Low flow requirements: LSR guild**

GENERAL					
<p><b>INDICATOR:</b> This group generally requires FS, FI and FD flow depth categories over good quality substrate (gravel and cobbles) for spawning. Egg and embryo development also takes place in these habitats, while larvae prefer SD with substrate as optimal habitats. Juvenile and adult specimens have a high preference for SD, FS, FI and FD habitats with substrate and water column as cover flows should furthermore remain adequate to allow migration between reaches, thus depth in riffle and rapids should remain adequate, especially during the wet season.</p>					
PES: FISH OVERALL IN EC D (ECOSTATUS D) Upper limit of the PES band provided below:					
<p><b>Dry Season maintenance</b> Presently there is more water at this site than under natural condition during the dry season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LSR in its PES is provided in Figure I1. It is estimated that at a fish stress level of 3.2 (50% duration) the total habitat suitability would be 129% of what can be expected under natural conditions. The habitat composition at the site is higher than expected during natural conditions as a result of flows still being higher than under natural conditions. It is estimated that fish would remain in the PES at a fish stress level of 3.2 (50% duration) (Figure I1). Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity of the system. This will be the result of habitat deterioration through scouring and flooding, change in natural habitat composition at the site, altered food webs and population structures, etc.</p>					
<p><b>Dry Season drought</b> A fish stress level of 4.5 (5% duration) for the dry season drought would result in 204% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>					
<p><b>Wet Season maintenance</b> Presently there is more water at this site than under natural condition during the wet season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LSR in its PES is provided in Figure I2. It is estimated that at a fish stress level of 0.76 (20% duration) the total habitat suitability would be 138% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions. It is estimated that fish would remain in the PES at a fish stress level of 0.76 (20% duration) during the wet season (Figure I2). Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity of the system. This will be the result of habitat deterioration through scouring and flooding, change in natural habitat composition at the site, altered food webs and population structures, etc.</p>					
<p><b>Wet Season drought</b> A fish stress level of 3 (5% duration) for the wet season drought would result in 162% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	4.5	4.5	0.3
Maintenance	Dry	50%	3.2	3.2	0.38
Drought	Wet	5%	3	3.3	0.379
Maintenance	Wet	20%	0.76	1.4	0.551
REC: FISH EC C (ECOSTATUS D) Upper limit of improved category (less flows than present during both seasons)					
<p><b>General</b> Decreased flows should create habitat conditions closer to those expected under natural conditions, which should be reflected by the fish assemblages at the site. Improved water quality will directly benefit species intolerant to water quality deterioration such as BPAL, and also LCAP, BAEN, ASCL and BANO (moderately tolerant to changes). Improved water quality (decreased nutrients) should result in decreased growth of filamentous algae, with resultant</p>					

improved substrate quality (especially in riffles/rapids). This should provide suitable habitats for ASC and LCAP to recolonise this river section.

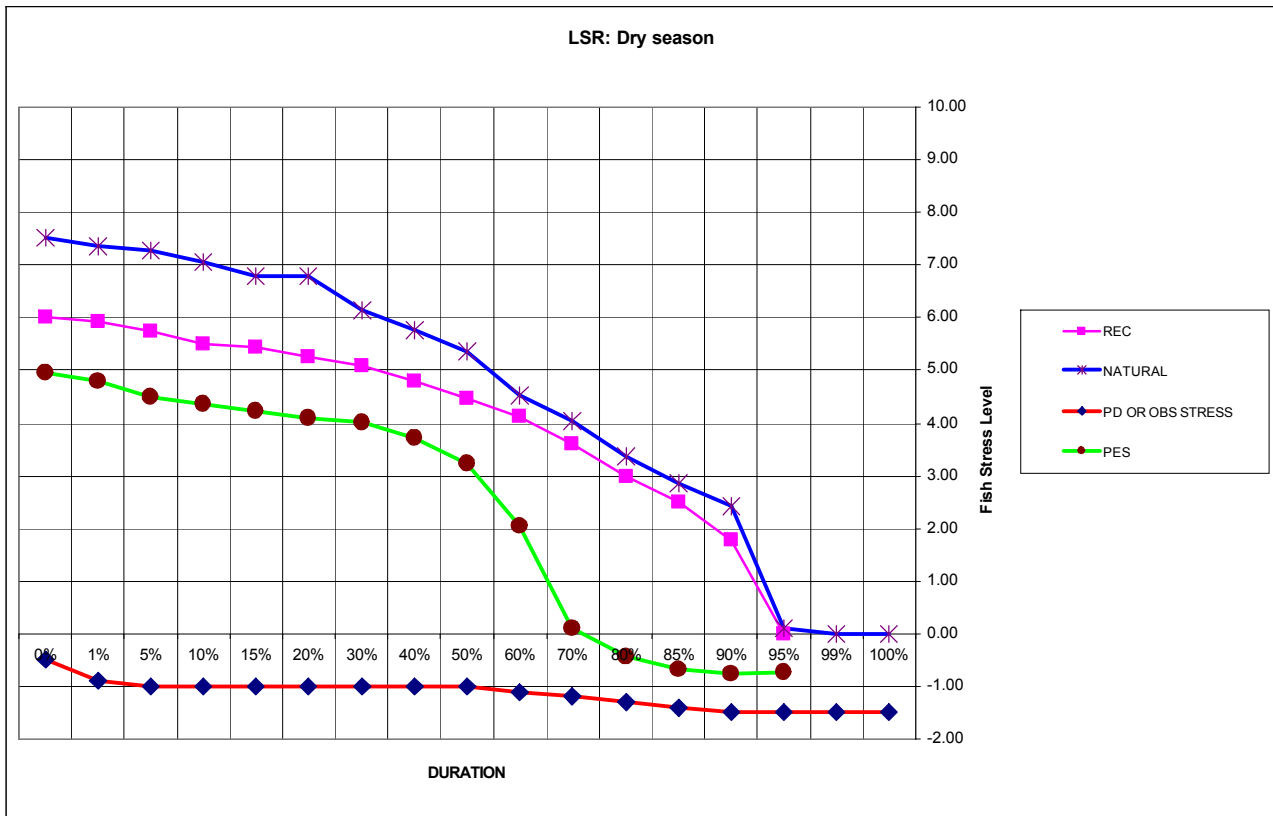
**Dry Season maintenance**

A further decrease in flow during the dry season is expected to improve the fish to a category C. The maximum fish stress levels to maintain the LSR in a category C is provided in Figure I1. At a fish stress level of 4.5 (50% duration) the total habitat suitability would be 126% of what can be expected under natural conditions. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.

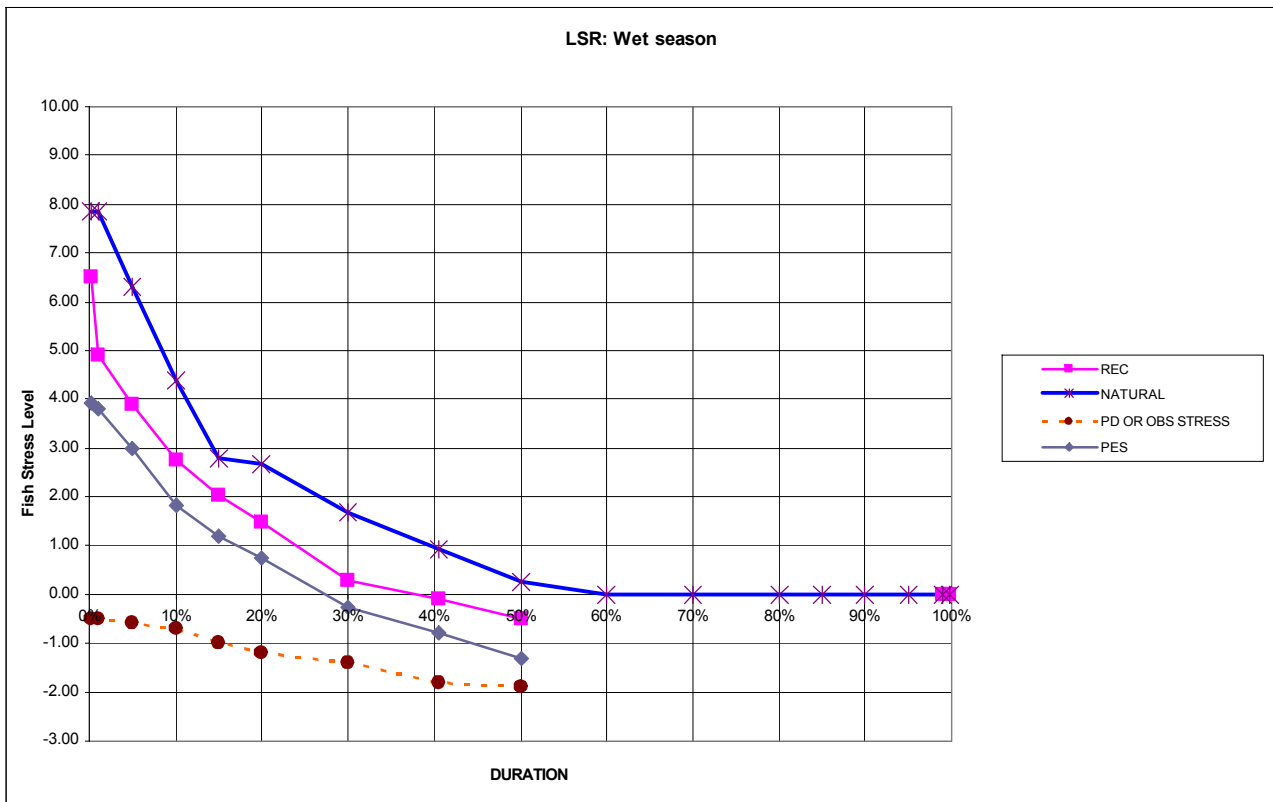
**Wet Season maintenance**

A further decrease in flow during the wet season is expected to improve the fish to a category C. The maximum fish stress levels to maintain the LSR in a category C is provided in Figure I2. At a fish stress level of 1.47 (20% duration) the total habitat suitability would be 127% of what can be expected under natural conditions. As stated above, more suitable habitats will be available but any shift from natural conditions can be seen as a deterioration of the ecological integrity.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	4.5	4.5	0.3
Maintenance	Wet	20%	1.47	1.47	0.5



**Figure I1 Dry Season LSR fish stress at different flow durations for the various ECs**

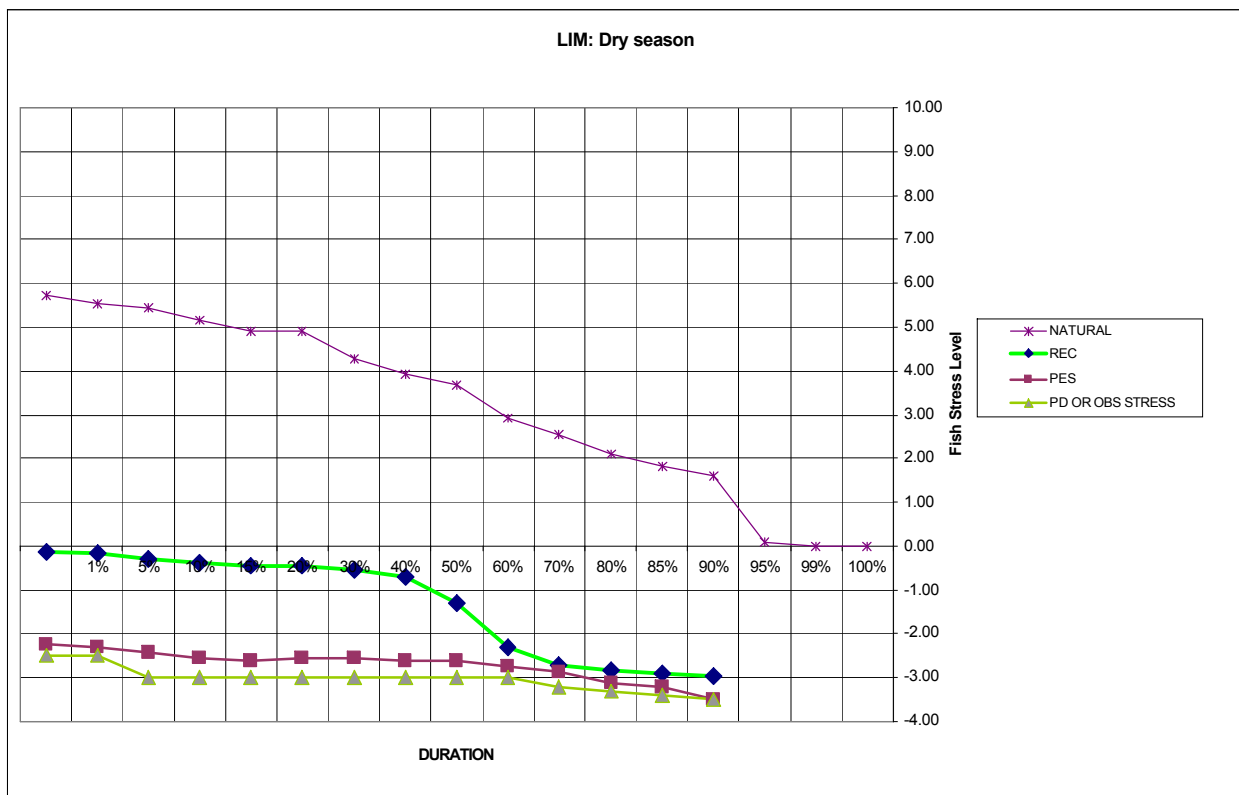


**Figure I2 Wet Season LSR fish stress at different flow durations for the various ECs**

**Table I8 Low flow requirements: LIM guild**

GENERAL
<p><b>INDICATOR:</b> The optimal preferred general habitat for small limnophilic species is SD and SS preferably with overhanging vegetation, undercut banks or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock) as general habitat. Breeding takes place during the spring and summer, with males constructing nests in soft substrates. Optimal habitats for egg and larvae development, nursery areas and in general for juveniles and adults are SD and SS habitats.</p>
PES: FISH OVERALL IN EC D (ECOSTATUS D) Upper limit of the PES band provided below:
<p><b>Dry Season maintenance</b> Presently there is more water at this site than under natural condition during the dry season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LIM guild in its PES is provided in Figure I3. It is estimated that at a fish stress level of 2.6 (50% duration) the total habitat suitability would be 108% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions. It is estimated that fish would remain in the PES up to a fish stress level of 2.6 (50% duration) (Figure I3). Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity of the system. This will be the result of habitat deterioration through scouring and flooding, change in natural habitat composition at the site, altered food webs and population structures, etc.</p>
<p><b>Dry Season drought</b> A fish stress level of 2.4 (5% duration) for the dry season drought would result in 149% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>
<p><b>Wet Season maintenance</b> Presently there is more water at this site than under natural condition during the wet season, and an improvement can therefore be gained through a reduction in flow. The upper band of fish stress levels to maintain the LIMNO in its PES is provided in Figure I4. It is estimated that at a fish stress level of 0.17 (20% duration) the total habitat suitability would be adequate to sustain the PES of the limnophilic guild during the wet season.</p>
<p><b>Wet Season drought</b> A fish stress level of 0.49 (5% duration) for the wet season drought would result in 154% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its PES during drought periods.</p>

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	-2.4	-2.4	2.02
Maintenance	Dry	50%	-2.6	-2.6	2.08
Drought	Wet	5%	0.46	0.8	0.048
Maintenance	Wet	20%	-0.17	-0.1	0.757
<b>REC: FISH EC C (ECOSTATUS D)</b>					
<b>Upper limit of improved category (less flows than present during both seasons)</b>					
<b>General</b>					
Improved water quality will directly benefit species intolerant to water quality deterioration such as BPAL, and also LCAP, BAEN, ASCL and BANO (moderately tolerant to changes). Improved water quality (decreased nutrients) should result in decreased growth of filamentous algae, with resultant improved substrate quality (especially in riffles/rapids).					
<b>Dry Season maintenance</b>					
A further decrease in flow during the dry season is expected to improve the ecological category of the limnophilic fish. The maximum fish stress levels to maintain the LIM guild in an improved ecological category is provided in Figure I3. At a fish stress level of 1.3 (50% duration) the total habitat suitability would be similar what can be expected under natural conditions.					
<b>Wet Season maintenance</b>					
A further decrease in flow during the wet season is expected to improve the fish with one ecological category. The maximum fish stress levels to maintain the LIM guild in an improved category is provided in Figure I4. At a fish stress level of 0.77 (20% duration) the total habitat suitability would be 111% and therefore slightly higher than can be expected under natural conditions.					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	-1.3	-1.5	1.602
Maintenance	Wet	20%	0.77	1.5	0.536



**Figure I3 Dry Season LIM fish stress at different flow durations for the various ECs**

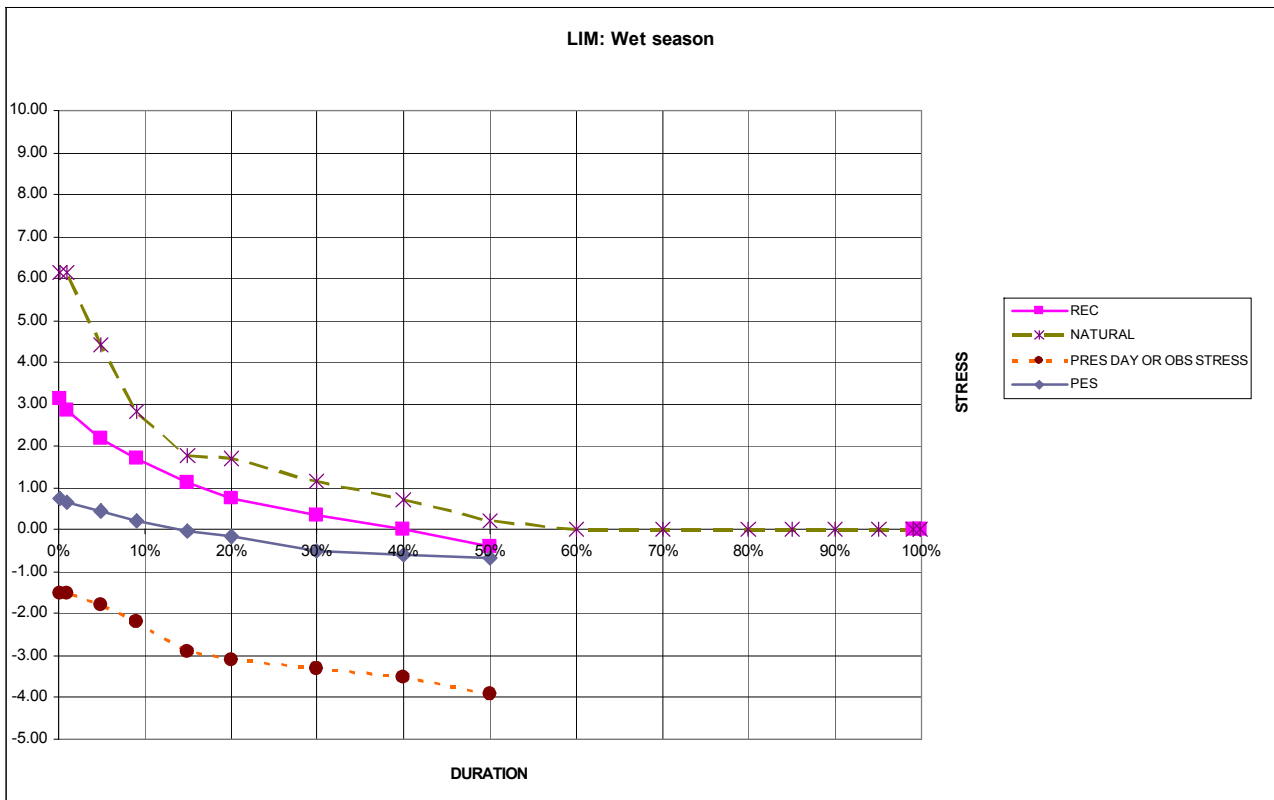


Figure 14 Wet Season LIM fish stress at different flow durations for the various ECs

## 12.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table I9 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

Table I9 Low flow requirements: FDI taxa

GENERAL
<b>INDICATOR:</b> Hydropsychid caddisflies and Simuliidae (i.e., common, flow dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m / s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.
PES: MACROINVERTEBRATE EC D/E (ECOSTATUS D)
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.15 m, and average current velocity is between 0.3 (Spp Stress 0). Critical habitat (FCS) comprises 17% of habitats available.
<b>Dry Season drought</b> Average depth needed for dry season drought is 0.13 m, and average current velocity is 0.24 m/s (Spp Stress -1.5). Critical habitat (FCS) comprises 13% of habitats available.

<p><b>Wet Season maintenance</b> Average depth needed for wet season maintenance is between 0.19 m, and average current velocity is 0.37 m/s (Spp Stress -1). Critical habitat (FCS) comprises 19% of habitats available.</p> <p><b>Wet Season drought</b> Average depth needed for wet season drought is 0.14 m, and average current velocity is 0.28 m/s (Spp Stress -0.5). Critical habitat (FCS) comprises 15% of habitats available.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	0	0	0.7
Maintenance	Dry	50%	-1.5	-1.5	2.216
Drought	Wet	5%	-0.5	-0.5	0.984
Maintenance	Wet	50%	-1	-1	1.268
<b>AEC up: MACROINVERTEBRATE EC D (ECOSTATUS D)</b>					
<p><b>Dry Season maintenance</b> Average depth needed for dry season maintenance is between 0.15 and 0.21 m, and average current velocity is between 0.3 and 0.4 m/s (Spp Stress between 0 and + 1.5). Critical habitats (FCS) comprise between 17 and 18% of habitats available.</p> <p><b>Dry Season drought</b> Average depth needed for dry season drought is between 0.15 and 0.14 m, and average current velocity is between 0.26 and 0.30 m/s (Spp Stress between 0 and 1.5). Critical habitats (FCS) comprise between 15 and 17% of habitats available.</p> <p><b>Wet Season maintenance</b> Average depth needed for wet season maintenance is between 0.19 and 0.25 m, and average current velocity is 0.37 and 0.5 m/s (Spp Stress - 3 and 1 1). Critical habitats (FCS) comprise between 16 and 19% of habitats available.</p> <p><b>Wet Season drought</b> Average depth needed for wet season drought is between 0.14 and 0.17 m, and average current velocity is between 0.27 and 0.33 m/s (Spp Stress between + 0.5 and - 0.5). Critical habitats (FCS) comprise between 14 and 18% of habitats available.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	1.5	1.5	0.535
Maintenance	Dry	50%	0	0	0.7
Drought	Wet	5%	0.5	0.5	0.655
Maintenance	Wet	50%	1.1	1.1	0.47

## 12.3 INSTREAM FLOOD FUNCTIONS

**Table 110 Functions for each Flood Class**

Flood Class	Function / Motivation	
<b>CLASS: I</b> RANGE (M <sup>3</sup> /S): 4 – 6 DAILY AVERAGE: 3 DURATION: 3	Fish	Class 1 floods are very important floods for fish and serves as migration cues and to maintain adequate longitudinal connectivity for migration. These floods will also flush fines and algae from substrates to ensure adequate conditions in substrates, a very important habitat for spawning of many of the species. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation and contributes to the creation of acceptable nursery areas. Some resetting of water quality will also take place, and the changes in water quality may also serve as stimulus to cue migratory activity and even gonad development. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrate	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Three of these per year, any time during the wet season, are recommended for a

Flood Class	Function / Motivation	
		macroinvertebrate Category D and D/E.
CLASS: II RANGE (M <sup>3</sup> /S): 8 10 DAILY AVERAGE: 6 DURATION: 3 +	Fish	Class 2 floods are similar in importance as Class 1 floods and have the same functionality as Class 1 floods. Their occurrence at lower frequency makes them only slightly less important for the fish assemblages than Class 1. Secondary channels will be inundated by these floods which will create favourable spawning and refuge habitats for some species.
	Macroinvertebrate	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Two of these per year are recommended for a macroinvertebrate Category D at the beginning of the wet season (Oct / Nov).
CLASS: III RANGE (M <sup>3</sup> /S): 17 25 DAILY AVERAGE: 12 DURATION: 4	Fish	Class 3 floods also provide similar functions as Class 1, but due to its lower frequency it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.
CLASS : IV RANGE (M <sup>3</sup> /S):	Fish	Class 4 floods also provide similar functions as Class 1, but due to its lower frequency of occurrence it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.

## 12.4 EWR RULES

**Table I11 EWR 11 assurance rules for PES (DRM D): D**

Desktop Version 2, Printed on 2008/09/12

Summary of IFR rule curves for: V\_EWR11 P.Day Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal PES = D

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.406	0.400	0.387	0.364	0.327	0.272	0.201	0.126	0.065	0.036
Nov	0.603	0.598	0.588	0.569	0.539	0.494	0.436	0.375	0.325	0.302
Dec	1.031	1.019	0.995	0.951	0.879	0.774	0.639	0.495	0.377	0.322
Jan	2.018	1.998	1.960	1.892	1.778	1.596	1.331	0.990	0.631	0.409
Feb	2.928	2.897	2.840	2.738	2.565	2.290	1.889	1.373	0.832	0.495
Mar	1.767	1.750	1.718	1.660	1.562	1.406	1.179	0.887	0.580	0.389
Apr	1.048	1.036	1.012	0.969	0.897	0.793	0.659	0.516	0.399	0.344
May	0.951	0.940	0.919	0.880	0.817	0.724	0.604	0.477	0.373	0.324
Jun	0.777	0.769	0.753	0.723	0.676	0.605	0.515	0.418	0.340	0.303
Jul	0.603	0.598	0.588	0.569	0.539	0.494	0.436	0.375	0.325	0.302
Aug	0.410	0.408	0.404	0.398	0.387	0.370	0.349	0.327	0.309	0.301
Sep	0.410	0.408	0.404	0.398	0.387	0.370	0.349	0.327	0.309	0.301
Reserve flows without High Flows										
Oct	0.406	0.400	0.387	0.364	0.327	0.272	0.201	0.126	0.065	0.036
Nov	0.603	0.598	0.588	0.569	0.539	0.494	0.436	0.375	0.325	0.302
Dec	0.777	0.769	0.753	0.723	0.676	0.605	0.515	0.418	0.340	0.303
Jan	1.124	1.114	1.096	1.063	1.008	0.920	0.791	0.626	0.453	0.345
Feb	1.249	1.238	1.217	1.181	1.119	1.020	0.876	0.691	0.496	0.376
Mar	1.145	1.135	1.116	1.082	1.026	0.935	0.803	0.634	0.456	0.345
Apr	1.048	1.036	1.012	0.969	0.897	0.793	0.659	0.516	0.399	0.344
May	0.951	0.940	0.919	0.880	0.817	0.724	0.604	0.477	0.373	0.324
Jun	0.777	0.769	0.753	0.723	0.676	0.605	0.515	0.418	0.340	0.303
Jul	0.603	0.598	0.588	0.569	0.539	0.494	0.436	0.375	0.325	0.302
Aug	0.410	0.408	0.404	0.398	0.387	0.370	0.349	0.327	0.309	0.301
Sep	0.410	0.408	0.404	0.398	0.387	0.370	0.349	0.327	0.309	0.301
Natural Duration curves										
Oct	3.170	2.688	2.412	2.263	2.106	2.065	1.945	1.859	1.815	1.744
Nov	4.653	3.769	3.326	2.940	2.623	2.58	2.265	2.060	1.694	1.512
Dec	4.898	4.264	3.890	3.498	3.207	2.748	2.449	2.162	1.863	1.564
Jan	6.713	4.368	3.853	3.416	3.162	3.017	2.726	2.348	2.068	1.785
Feb	6.672	4.638	4.171	3.650	3.187	3.001	2.877	2.575	2.025	1.703
Mar	5.563	4.469	4.017	3.364	3.058	2.867	2.662	2.404	1.990	1.736
Apr	4.853	4.225	3.785	3.414	2.990	2.770	2.654	2.411	2.257	1.929
May	4.398	3.468	3.132	2.894	2.647	2.535	2.445	2.352	2.221	2.091
Jun	3.275	2.785	2.627	2.519	2.423	2.326	2.249	2.211	2.188	2.141
Jul	2.737	2.576	2.464	2.397	2.341	2.307	2.285	2.255	2.233	2.214
Aug	2.681	2.348	2.300	2.277	2.251	2.221	2.210	2.192	2.180	2.169
Sep	2.585	2.365	2.280	2.242	2.207	2.164	2.145	2.130	2.110	2.083

**Table I12 EWR 11 assurance rules for REC (DRM C): D**

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Desktop Version 2, Printed on 2008/09/12

Summary of IFR rule curves for: V\_EWR11 P.Day Flows

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal REC = C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.360	0.354	0.343	0.323	0.289	0.240	0.176	0.109	0.054	0.028
Nov	0.507	0.502	0.492	0.475	0.447	0.405	0.351	0.294	0.248	0.226
Dec	0.862	0.852	0.831	0.794	0.733	0.643	0.527	0.405	0.304	0.257
Jan	1.628	1.612	1.581	1.527	1.435	1.289	1.075	0.801	0.513	0.334
Feb	2.380	2.355	2.309	2.227	2.088	1.866	1.544	1.128	0.692	0.421
Mar	1.424	1.410	1.384	1.337	1.259	1.133	0.950	0.715	0.468	0.315
Apr	0.867	0.857	0.836	0.799	0.739	0.650	0.535	0.414	0.315	0.268
May	0.795	0.786	0.767	0.734	0.679	0.598	0.495	0.385	0.296	0.253
Jun	0.651	0.644	0.630	0.604	0.563	0.502	0.423	0.340	0.272	0.240
Jul	0.507	0.502	0.493	0.475	0.447	0.406	0.353	0.297	0.250	0.229
Aug	0.363	0.360	0.356	0.347	0.332	0.311	0.284	0.255	0.232	0.221
Sep	0.363	0.360	0.355	0.346	0.332	0.310	0.282	0.252	0.228	0.217

Reserve flows without High Flows

Oct	0.360	0.354	0.343	0.323	0.289	0.240	0.176	0.109	0.054	0.028
Nov	0.507	0.502	0.492	0.475	0.447	0.405	0.351	0.294	0.248	0.226
Dec	0.651	0.644	0.630	0.604	0.563	0.501	0.423	0.339	0.271	0.239
Jan	0.907	0.899	0.884	0.857	0.812	0.740	0.635	0.501	0.359	0.271
Feb	1.026	1.017	1.000	0.969	0.918	0.836	0.717	0.564	0.404	0.304
Mar	0.922	0.913	0.898	0.871	0.825	0.751	0.644	0.506	0.361	0.271
Apr	0.867	0.857	0.836	0.799	0.739	0.650	0.535	0.414	0.315	0.268
May	0.795	0.786	0.767	0.734	0.679	0.598	0.495	0.385	0.296	0.253
Jun	0.651	0.644	0.630	0.604	0.563	0.502	0.423	0.340	0.272	0.240
Jul	0.507	0.502	0.493	0.475	0.447	0.406	0.353	0.297	0.250	0.229
Aug	0.363	0.360	0.356	0.347	0.332	0.311	0.284	0.255	0.232	0.221
Sep	0.363	0.360	0.355	0.346	0.332	0.310	0.282	0.252	0.228	0.217

Natural Duration curves

Oct	3.170	2.688	2.412	2.263	2.106	2.065	1.945	1.859	1.815	1.744
Nov	4.653	3.769	3.326	2.940	2.623	2.508	2.265	2.060	1.694	1.512
Dec	4.898	4.264	3.890	3.498	3.207	2.748	2.449	2.162	1.863	1.564
Jan	6.713	4.368	3.853	3.416	3.162	3.017	2.726	2.348	2.068	1.785
Feb	6.672	4.638	4.171	3.650	3.187	3.001	2.877	2.575	2.025	1.703
Mar	5.563	4.469	4.017	3.364	3.058	2.867	2.662	2.404	1.990	1.736
Apr	4.853	4.225	3.785	3.414	2.990	2.770	2.654	2.411	2.257	1.929
May	4.398	3.468	3.132	2.894	2.647	2.535	2.445	2.352	2.221	2.091
Jun	3.275	2.785	2.627	2.519	2.423	2.326	2.249	2.211	2.188	2.141
Jul	2.737	2.576	2.464	2.397	2.341	2.307	2.285	2.255	2.233	2.214
Aug	2.681	2.348	2.300	2.277	2.251	2.221	2.210	2.192	2.180	2.169
Sep	2.585	2.365	2.280	2.242	2.207	2.164	2.145	2.130	2.110	2.083

**APPENDIX J: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 1: UITKOMS**

## J1 EWR 1: UITKOMS (VAAL RIVER) – DETERMINATION OF STRESS INDICES

Appendix J provides supporting information for the determination of stress indices of EWR 1 Uitkoms (Chapter 19 and 20 of the Main Report, Volume 1).

### J1.1 FISH INDICATOR SPECIES

**Fish indicator group 1: Large semi rheophilic (LSR) guild: *Labeobarbus aeneus* (BAEN)** has a maximum size is approximately 50 cm. Its optimal preferred general habitat is Slow Deep (SD), Fast Shallow (FS) and Fast Deep (FD) with suitable cover provided by substrate and water column depth. This spawning habitat requirement of this species is FD and FS habitats with good quality substrate (gravel and other suitable rocky habitats). The eggs and embryos require FS habitats with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (still within the gravel substrates). Larvae require SD habitats with substrate, while juveniles prefer FS and SS over substrate, and seek refuge in SD at night.

**Fish indicator group 2: Small semi-rheophilic (SSR) guild: *Barbus anoplus* (BANO)** only reaches a maximum size of approximately 12 cm. Its optimal preferred general habitat is SD and Slow Shallow (SS) preferably with overhanging vegetation or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock and even undercut banks) as general habitat. This most important difference of this species in relation to indicator 1 (BEAN) is the requirement of high flows overtopping banks and inundating vegetation for spawning purposes. Spawning takes place during the summer when rivers are swollen after rains. It lays its adhesive eggs amidst vegetation. The larvae hatch within 3 days and begin to swim and feed after 6/7 days. Flows should remain adequate to allow migration between reaches, thus pools should remain connected during wet season. Water levels providing inundated vegetation should last long enough for spawning, egg hatching and larvae development. Larvae and juveniles require SS and SD with adequate cover to allow optimal development and survival.

The habitat requirements for the different life stages of the LSR indicator fish species is summarised in Table J1 and the SSR guild is summarised in Table J2. Information in Bold type face indicates crucial habitat during the given life stage.

**Table J1 Habitat requirements for different life stages of indicators species included in the LSR guild**

Species	Spawning	Egg and embryo development	Larvae	Juveniles	Adults
BAEN	Flow habitat: <b>FS, FI over substrate</b> . Spawning season: Spring to mid summer (Sep – Jan). Fast (>0.3 m/s) with substrate (Gravel and cobbles). Flowing water, well oxygenated and low sediments loads. BAEN breeds from spring through to mid-summer after the first substantial rains of the season.	Flow habitat: <b>FS with substrate (gravel/cobbles)</b> . Flows to last long enough for the egg to hatch out and embryos to develop. Sudden pulse after spawning may cause many of the eggs to be washed out of the spawning beds and die in the deeper less oxygenated pools and also be smothered by silt. Also if the flow subsides it could result in higher temperatures and lower oxygen thus killing the developing embryos or leaving them stranded. The fertilised eggs of BAEN incubate for three to eight days at 18 - 21.5 C, thereafter the embryos remain in the <b>gravel</b> for a further	Flow habitat: <b>SD with substrate</b> . Spawning season: Oct – Feb. Cover, flow, oxygen and low silt loads. At swim-up they require suitable flows to move them away from the spawning beds to the nursery areas usually shallow backwaters which are warmer. If the backwaters are not there due to too high or too low flows the larval fish will die out as this is a very critical stage where they have to start eating. Larvae are initially inactive and sink to the bottom, not becoming mobile	Flow habitat: <b>FS, FI and SS with substrates. SD at night</b> .	Flow habitat: <b>SD, FD, FI and FS with substrates and water column</b> .

Species	Spawning	Egg and embryo development	Larvae	Juveniles	Adults
		period.	until four to six days after hatching. At this stage, they begin feeding on microscopic organisms.		
<b>BKIM</b>	Flow habitat: <b>FS and FD with substrates</b> (Gravel, cobbles) flowing water, well oxygenated and low sediments loads. The breeding season extends from mid to late summer. The species requires <b>gravel beds</b> in flowing water to spawn.	Flow habitat: <b>FS and FI with substrate (gravel / cobbles)</b> . Flows to last long enough for the embryos to develop and hatch out. The incubation period for BKIM is two to three days and larvae become mobile after a further three to four days at 23 - 25 C.	Flow habitat: <b>SD with substrate</b> .	Flow habitat: <b>FI and SD with substrates</b> .	Flow habitat: <b>SD, FD and FI with substrates and water column</b> .

**Table J2 Habitat requirements for different life stages of indicators species included in the SSR guild**

Species	Spawning	Egg and embryo development	Larvae	Juveniles	Adults
<b>BANO</b>	Flow habitat: <b>SD, and SS (&gt; 0.1 m) and marginal vegetation</b> . Spawning season: Oct - Jan. Cue: Increased flow, temp., and water quality. Spawning takes place during the summer among flooded vegetation where adhesive eggs are.	Flow habitat: <b>SD, and SS (&gt; 0.1 m) and marginal vegetation</b> . Months: Oct - Jan. > 16°C. Incubation: 4 – 5 days. Flows to last long enough for the egg to hatch out and embryos to develop.	Nursery areas (> 0.1 m) and <b>margins of SS, SD</b> . Backwaters formed by increased flow. Cover: Overhanging vegetation. Duration larval period: 2 months.	Flow habitat: Mostly <b>SD and SS (&gt; 0.1 m)</b> . Cover: Overhanging vegetation and undercut banks. Duration 3 – 6 months. Low flow refuge (June - Sep) <b>SS (&gt; 0.1 m), and SD</b> . Cover: Cobbles, rocks and overhanging vegetation.	Flow habitat: <b>SS, and SD</b> . Cover: Cobbles and rocks, overhanging vegetation, and undercut banks. Duration: 3 – 6 months. Low flow refuge (Jun – Sep): <b>SS (&gt; 0.1 m) and SD</b> . Cover: Cobbles, rocks overhanging vegetation.

### J1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table J3.

**Table J3 EWR 1: Habitat suitability for the SSR and LSR guild**

SSR AND LSR GUILD																
Depth classes	Discharges (m <sup>3</sup> /s)															
	0	0.1	0.25	0.36	0.4	0.6	0.98	2.2	3	4.8	5.5	6.5	7	8	10	12
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	0	4	4	4	4	4	6	6	6	6	6	6	6	6	6	6
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	8	4	4	4	4	4	4	4	4	4	4	4	6	6	6	6
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	10	10	10	10	10	10	8	6	6	6	6	6	6	6	6	6
Slow Shallow and Slow Deep	8	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	10	10	8	8	8	8	8	8	8	8	6	6	6	6	6	10
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	10	10	8	8	8	8	8	6	6	6	10	6	6	6	6	6
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	10	10	10	8	8	8	8	8	8	6	8	8	6	6	8	6
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	10	10	10	8	8	8	8	6	6	6	6	4	4	4	4	4
FAST TOTAL >0.1 m DEEP	10	10	10	8	8	8	8	6	6	4	4	4	4	4	4	4

The fish stress index is provided in Table J4.

**Table J4 Fish stress index**

Habitat	Discharges (m <sup>3</sup> /s)														
	0	0.1	0.25	0.36	0.4	0.6	0.98	2.2	3	4.8	5.5	6.5	7	8	10
<b>SMALL SEMI RHEOPHILIC (SSR) GUILD</b>															
Spawning & nursery habitat	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2	3	3	5
Abundance	0.5	1	2	2	2	3	4	5	5	5	5	5	5	5	5

Cover	0	0	0	0.5	0.5	0.5	1	2	3	4	5	5	5	5	5
Connectivity (lateral & longitudinal)	0	0	0.5	1	1	1	1	2	3	4	5	5	5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0.5	0.5	1	2	2	2	3	4	5	5	5	5	5	5	5
<b>Species stress: BANO</b>	<b>9</b>	<b>9</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>0</b>
<b>LARGE SEMI-RHEOPHILIC (LSR) GUILD</b>															
Spawning & nursery habitat	0	0	0	0.5	0.5	0.5	1	2	3	3	4	5	5	5	5
Abundance	0.5	0.5	0.5	1	1	1	2	2	3	4	4	4	5	5	5
Cover	0.5	0.5	0.5	1	1	1	1	2	3	4	4	5	5	5	5
Connectivity (lateral & longitudinal)	0	0	0.5	1	1	1	2	2	3	4	4	4	4	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0.5	0.5	0.5	1	1	2	3	4	4	5	5	5	5	5	5
<b>Species stress: BAEN</b>	<b>9</b>	<b>9</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>0</b>

### J1.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for flow dependent macroinvertebrate (FDI) taxa is provided in Table J5 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table J5 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>	
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	4	6	7	3	8	11	14	7	8	12	14	6	7.765
1	All habitats plentiful, high quality. Fast, wide WP.	4	6	7	3	9	11	13	6	8	12	14	6	6.998
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	5	6	6	2	10	13	12	5	11	13	13	4	5.655
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	7	7	5	1	13	15	9	3	14	14	10	2	3.156
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	8	8	3	1	15	16	7	2	16	16	6	2	2.134
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	8	8	3	1	17	16	6	1	16	16	6	2	1.610
6	Critical habitat residual. Low quality, moderate/slow velocity.	9	8	2	0	19	16	5	0	19	17	4	0	1.016
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	13	6	1	0	27	12	1	0	26	12	2	0	0.274
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	18	2	0	0	36	4	0	0	36	4	0	0	0.029
9	Standing water habitats only, very low quality. No flow.	19	1	0	0	39	1	0	0	38	2	0	0	0.013
10	Only hyporheic refugia, no surface water.	0	0	0	0	0	0	0	0	0	0	0	0	0.001

- 1 Very Slow over Coarse Sediment
- 4 Very Fast over Coarse Sediment
- 7 Fast over Fine Sediment
- 10 Slow over Bedrock
- 13 Fringing vegetation

- 2 Slow over Coarse Sediment
- 5 Very Slow over Fine Sediment
- 8 Very Fast over Fine Sediment
- 11 Fast over Bedrock

- 3 Fast over Coarse Sediment
- 6 Slow over Fine Sediment
- 9 Very Slow over Bedrock
- 12 Very Fast over Bedrock

The stress index for FDI taxa is provided in Table J6 which rates the response of the species according to various biotic response metrics.

**Table J6 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
0.86	0.38	1.18	0.36	68.0	All flow dependent macroinvertebrates very abundant and healthy.	5.50	0
0.7	0.31	0.8	0.23	52.6	90% rheophilic species persist.	3.16	1
0.64	0.27	0.66	0.19	48.5	Most rheophilic species persist, but slight (80%) reduction.	2.13	2
0.62	0.26	0.63	0.18	47.0	Most rheophilic species persist, but abundances reduced.		3
0.6	0.25	0.6	0.17	45.4	All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.	1.61	4
0.54	0.21	0.51	0.14	40.0	Critical life-stages of sensitive rheophilic species at risk or non-viable.	1.02	5
0.52	0.2	0.46	0.13	38.1	Sensitive rheophilic species rare, critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.		6
0.48	0.18	0.4	0.11	34.3	Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.		7
0.44	0.16	0.36	0.1	30.4	Some rheophilic species persist, but at very low numbers; All life stages of most rheophilic species at risk or non-viable.		8
0.4	0.15	0.3	0.08	25.1	Mostly pool dwellers; all life stages of most rheophilic species non-viable.	0.27	9
					Only pools dwellers.	0.001	10

## J2 EWR 1: UITKOMS (VAAL RIVER) – DETERMINATION OF EWR SCENARIOS

### J2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table J7 for the LSR guild and Table J8 for the SSR guild.

**Table J7 Low flow requirements: LSR guild**

GENERAL					
<p><b>INDICATOR:</b> The large semi-rheophilic species BAEN is the indicator species 1 selected for this EWR site. Flows set for BAEN should suffice in general for the flow requirements of <i>Labeobarbus kimberleyensis</i> (BAEN), <i>Labeo capensis</i> (LCAP) and <i>Austroglanis sclateri</i> (ASCL).</p>					
PES and REC: FISH EC C (ECOSTATUS B/C)					
<p><b>Dry Season maintenance</b>                      BAEN, as a semi-rheophilic species, can survive during the dry season without continuous flows (especially the adults which do well in deep pools). For the optimal survival conditions of juveniles adequate FS habitat should be maintained for a period of the time. SD with adequate depth should also be maintained to meet the requirements of adults, as well as juveniles (especially at night when these deeper areas are used for refuge to avoid extreme temperature fluctuations during the winter months). This is the optimal stress level (flows) where these critical habitats will be maintained in adequate abundance to ensure the survival of this indicator species at the site.</p> <p>The dry maintenance stress that is recommended is lower than the natural reference stress for this period at this site. This is due to the fact that various secondary impacts (such as water quality deterioration, sedimentation) contributes to the current category C, and should the flows be reduced from its current level (higher than natural) to natural flows, the aggregate impact of the siltation and water quality deterioration may result in the EC being reduced to a lower category. This is the aggregated result of increased land-use resulting in increased sediment input, which will with the natural base flows result in increased embeddedness of substrate, which is an important spawning and feeding habitat for the indicator species. Decreased flows (similar to those under natural condition) under present conditions may also be inadequate for dilution of water quality variables of concern, and may especially lead to aggravated algal growth and deterioration of other water quality variables to unacceptable levels outside the tolerance level of the different life stages of BAEN. It is therefore essential that the current stress should not equal or exceed the natural stress level for the maintenance dry seasons, as this may result in a decrease in the eco-status to a lower category.</p>					
<p><b>Dry Season drought</b>                      BAEN being semi-rheophilic can survive periods with no flow during the winter (dry) season. The most critical habitat for survival of this species during drought periods in the dry season is to ensure that adequate depths in pools (both SD and SS) are maintained. This habitat component plays an important role as refuge area to survive temperature fluctuations during the cold winter months. Very limited flows are still required for maintenance of some FS habitats for especially juvenile survival, and to maintain adequate oxygen levels in the pools.</p>					
<p><b>Wet Season maintenance</b>                      Once the indicator species has received adequate stimuli to activate spawning migration (floods), adequate depth should be maintained in the riffle/rapid habitats to ensure free movement of breeding adults to suitable spawning grounds. Suitable spawning grounds for this species consist of FS (&gt;0.3 m/s and &lt;0.3 m deep) and FD (&gt;0.3 m/s and &gt;0.3 m deep) habitat over good quality substrate (especially gravel and cobble) from spring to mid summer. It is important that well oxygenated flowing water with low sediment loads are maintained for adequate periods to allow spawning and egg and embryo development. The eggs and embryos require FS with substrates, with flows lasting long enough for the eggs to hatch (3 – 8 days) and embryos to develop (within grave habitats and later in SD). Larvae are initially inactive and sink to the bottom, becoming mobile within 4 to 6 days afterwards when they move into suitable SD habitats. Juveniles prefer FS and SS over substrate, and also seek refuge in SD at night. Adequate water temperatures should also be maintained to allow spawning and also egg and embryo development.</p>					
<p><b>Wet Season drought</b>                      A wet season drought stress of 5.2 (flow of 2.2 m<sup>3</sup> / s) should allow for limited breeding and survival habitats for BAEN. Under these conditions limited breeding habitat will be available for this species to at least allow survival and future existence of the species at the site (survival of drought period). Some critical FS habitats should be available for a period to enable spawning, egg and larvae development. Some FS and adequate SD habitats should then be maintained for the survival of juveniles and adults during this period. (Had to increase from 5 % to 8 % to move from better than present day stress to equal present day stress).</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)

Drought	Dry	5%	9.1	9.1	0.243
Maintenance	Dry	55%	4.5	4.5	2.6
	Dry	20%	8.2	8.2	0.534
Drought	Wet	8%	5.2	5.2	1.956
Maintenance	Wet	55%	2	2	5.5

**Table J8 Low flow requirements: SSR guild**

GENERAL					
<b>INDICATOR:</b> Flows set for BANO should provide in general for the flow requirements of other small semi rheophilic species and even species such as <i>Labeo umbratus</i> (LUMB) and <i>Clarias gariepinus</i> (CGAR), as well as limnophilic species ( <i>Pseudocrenilabrus philander</i> (PPHI) and <i>Tilapia sparrmanii</i> (TSPA).					
PES and REC: FISH EC C (ECOSTATUS B/C)					
<b>Dry Season maintenance</b> BANO, as a moderately tolerant small semi-rheophilic has a high preference for SD and SS with cover (especially overhanging and aquatic vegetation, although they also use large rocky substrates as preferred cover). This species should be able to survive long periods of no or limited flow as long as adequate SD and SS habitats are maintained. It is recommended that although they are not directly dependant on fast habitats for survival, that the maintenance of some fast habitats will ensure longitudinal connectivity allowing movement for feeding and recruitment. Some flow will furthermore be required to sustain water quality within acceptable levels and flush waste products from the pools. Their survival in this period would depend on the maintenance of their food source, but being omnivorous and having a varied diet, they are generally able to survive stressed conditions.					
<b>Dry Season drought</b> BANO a moderately tolerant semi rheophilic species with high preference for SD and SS habitats with cover of aquatic vegetation and overhang, although they also make use of large rocky substrate such as cobbles to bedrock and undercut banks, especially in periods of stress / low flows, when inundated vegetation is limited or absent. During dry season droughts, this species will be able to handle high habitat stress and survive periods of no flow, as long as some surface water remains available as pools and backwaters. Maintenance of SS (and limited SD) with cover (under these conditions probable no inundated vegetation will be available but they will make use of substrate as cover for survival.					
<b>Wet Season maintenance</b> The optimal habitat of this species during wet season is a requirement of inundated vegetation for spawning and egg development that should ideally be provided by floods. After spawning and breeding, it is important that some level of aquatic vegetation and overhanging vegetation is maintained for a period to allow survival of larvae and juveniles. At the mentioned stress level flow should be adequate to ensure some inundation of macrophytes and thereby creating some preferred habitat in the form of overhanging vegetation and aquatic vegetation. The provision of adequate cover is especially important at the site due to the presence of alien predator <i>Micropterus salmoides</i> (MSAL).					
<b>Wet Season drought</b> During drought in the wet season, BANO will require some SS and SD (with adequate depth) and cover to survive. At this stress there will most probably be no optimal cover available to this species in the form of overhanging vegetation and aquatic vegetations, and they should seek refuge under large substrates (especially boulders). It is also recommended that some flow should remain to ensure that pools remain connected (by FS) and allow movement of this species and to maintain an acceptable water quality for the different life stages of this species (should spawning and egg development have taken place during floods, if occurrence during droughts).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	10	10	0.001
Maintenance	Dry	55%	6.2	6.5	0.885
Drought	Wet	5%	7	8.2	0.534
Maintenance	Wet	55%	3.5	3.5	3.9

## J2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table J9 below.

**Table J9 Low flow requirements: FDI taxa**

GENERAL					
<b>INDICATOR:</b> Hydropsychid caddisflies and Simuliidae (i.e., common, flow dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.					
PES and REC: MACROINVERTEBRATE EC C (ECOSTATUS B/C)					
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.20 m, and average current velocity is 0.13 m/s (spp stress 6). This will enable flow-dependent macroinvertebrates to over winter without significant detrimental impacts on the overall population.					
<b>Dry Season drought</b> Average depth needed for dry season drought is 0.16 m, and average current velocity is 0.10 m/s (spp stress 8). This will enable flow dependent macroinvertebrates to survive a drought.					
<b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.27 m, and average current velocity is 0.19 m/s (spp stress 2). This will provide suitable habitats during summer.					
<b>Wet Season drought</b> Average depth needed for wet season drought is 0.18 m, and average current velocity is 0.11 m/s (spp stress 7).					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	8	8.8	0.336
Maintenance	Dry	55%	6	7	0.79
Drought	Wet	5%	7	8	0.353
Maintenance	Wet	55%	2	5.1	2.078

## J2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table J11.

**Table J14 Functions for each Flood Class**

Flood Class	Component	Function/Motivation
CLASS I RANGE (M <sup>3</sup> /S): 8 - 10 DAILY AVERAGE: 6 DURATION: 3	Fish	Class I floods contribute to the establishment of optimum spawning habitat through flushing of fine sediments and benthic algae from substrates. Inundate some vegetation for species spawning in flooded marginal vegetation. Contributes to the creation of acceptable nursery areas. Some resetting of water quality and flushing out fine sediments will occur. The extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to flush organic flocculants and mobilise fines (1 - 2 mm sands) in order to improve biotope suitability. Five of these per year, any time during the wet season, are recommended for a macroinvertebrate Category C, and two for a Category D.

Flood Class	Component	Function/Motivation
<p>CLASS II RANGE (M<sup>3</sup>/S): 15 - 35 DAILY AVERAGE: 18 DURATION: 3</p>	Fish	<p>Class II floods are especially important to create suitable spawning habitat for vegetation breeders. It is estimated that the recommended floods will provide sufficient habitats based on volume and duration to create favourable conditions. These recommended floods furthermore closely resemble those that can be expected under natural conditions. It furthermore provides other important functions regarding fish biology, such as migration cues, flushing of fines from habitat (especially spawning habitats), creating the required nursery habitats. The extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.</p>
	Macroinvertebrates	<p>These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. Three of these per year are recommended for a macroinvertebrate Category C: one at the beginning of the wet season (Oct/Nov), one during the wet season, and one towards the end of the wet season (Feb/Mar). Two of these per year are recommended for a macroinvertebrate Category D: one at the beginning of the wet season (Oct/Nov), and one towards the end of the wet season (Feb/Mar).</p>
<p>CLASS III RANGE (M<sup>3</sup>/S): 200 - 340</p>	Fish	<p>Class IV floods will provide some stimulation for migration and ensure adequate depth for migratory species (especially to cross barriers through a drown out effect). It will also clean rocky/gravel spawning habitats, create suitable spawning habitat for vegetation breeders and reset water quality. The extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.</p>
<p>CLASS II RANGE (M<sup>3</sup>/S): 400</p>	Fish	<p>Class V floods have limited direct importance for fish, although it contributes to the overall integrity and functionality of the aquatic ecosystem. It will in some cases still provide stimulation for migration and clean rocky/gravel spawning habitats, create suitable spawning habitat for vegetation breeders and reset water quality. The extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.</p>

## J2.4 EWR RULES

**Table J10 EWR 1 assurance rules for PES and REC: B/C**

Desktop Version 2, Printed on 2008/07/02

Summary of IFR rule curves for: V\_EWR1 Present Day Monthly Flow

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal PES and REC = B/C

Data are given in m<sup>3</sup>/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	3.798	3.719	3.559	3.274	2.827	2.222	1.532	0.893	0.443	0.239
Nov	8.618	7.940	7.289	6.586	5.396	4.522	3.388	2.146	1.076	0.490
Dec	8.894	8.230	7.583	6.873	5.672	4.754	3.563	2.258	1.134	0.519
Jan	15.998	14.248	12.685	11.174	8.589	7.219	5.441	3.493	1.815	0.898
Feb	10.866	10.114	9.364	8.519	7.092	5.932	4.426	2.777	1.355	0.405
Mar	5.291	5.204	5.037	4.736	4.243	3.514	2.568	1.532	0.640	0.112
Apr	3.964	3.900	3.775	3.551	3.171	2.577	1.809	1.165	0.501	0.116
May	3.403	3.328	3.179	2.912	2.492	1.925	1.278	0.680	0.258	0.067
Jun	3.274	3.205	3.066	2.819	2.431	1.905	1.306	0.752	0.361	0.184
Jul	3.143	3.077	2.944	2.707	2.335	1.832	1.258	0.727	0.352	0.183
Aug	3.143	3.077	2.944	2.707	2.335	1.832	1.258	0.727	0.352	0.183
Sep	3.405	3.333	3.189	2.932	2.529	1.983	1.361	0.785	0.379	0.195

Reserve flows without High Flows

Oct	3.798	3.719	3.559	3.274	2.827	2.222	1.532	0.893	0.443	0.239
Nov	4.891	4.813	4.663	4.394	3.953	3.300	2.453	1.525	0.726	0.289
Dec	5.288	5.204	5.042	4.752	4.276	3.572	2.658	1.658	0.795	0.324
Jan	5.684	5.594	5.420	5.107	4.594	3.836	2.853	1.776	0.847	0.340
Feb	6.873	6.764	6.551	6.170	5.546	4.622	3.424	2.111	0.980	0.362
Mar	4.888	4.808	4.652	4.373	3.914	3.237	2.358	1.395	0.565	0.111
Apr	3.964	3.900	3.775	3.551	3.171	2.577	1.809	1.165	0.501	0.116
May	3.403	3.328	3.179	2.912	2.492	1.925	1.278	0.680	0.258	0.067
Jun	3.274	3.205	3.066	2.819	2.431	1.905	1.306	0.752	0.361	0.184
Jul	3.143	3.077	2.944	2.707	2.335	1.832	1.258	0.727	0.352	0.183
Aug	3.143	3.077	2.944	2.707	2.335	1.832	1.258	0.727	0.352	0.183
Sep	3.405	3.333	3.189	2.932	2.529	1.983	1.361	0.785	0.379	0.195

Natural Duration curves

Oct	20.848	7.288	6.489	5.977	5.556	5.205	4.854	3.711	1.557	0.814
Nov	41.651	25.104	15.278	11.508	8.260	7.114	5.598	4.938	2.604	0.899
Dec	53.364	34.088	22.431	17.533	14.483	9.424	7.183	6.392	5.141	1.396
Jan	38.460	26.579	18.869	16.947	12.410	10.170	8.471	6.179	5.126	2.882
Feb	66.791	25.149	18.295	11.359	8.908	7.941	6.089	4.245	1.885	0.405
Mar	21.991	16.234	10.010	6.952	5.600	5.175	3.939	2.535	1.128	0.112
Apr	9.576	6.894	5.741	4.429	3.171	2.577	1.809	1.470	0.768	0.116
May	5.365	5.149	4.981	4.626	3.640	2.841	1.583	1.042	0.721	0.302
Jun	5.340	5.208	5.096	5.046	4.568	3.661	2.465	1.331	0.891	0.667
Jul	5.518	5.257	5.126	5.037	4.969	4.394	3.465	1.206	0.971	0.631
Aug	5.395	5.272	5.134	5.040	4.962	4.876	3.483	1.501	0.986	0.750
Sep	5.907	5.532	5.147	5.069	5.000	4.892	3.808	2.967	1.100	0.779

**APPENDIX K: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 4: DENEYS**

## K1 EWR 4: DENEYS (VAAL RIVER) – DETERMINATION OF STRESS INDICES

Appendix K provides supporting information for the determination of stress indices of EWR 4 Grootdraai (Chapter 21 and 22 of the Main Report, Volume 1).

### K1.1 FISH INDICATOR SPECIES

#### Fish indicator group 1: Large semi-rheophilic species (BAEN, BKIM)

Indicator species: *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM). Refer to Appendix B, Section B1.1.

#### Fish indicator group 2: Small limnophilic (LIM) species (PPHI, TSPA)

The small limnophilic species, *Pseudocrenilabrus philander* (PPHI) and *Tilapia sparrmanii* (TSPA). Refer to Appendix H, Section H1.1

### K1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table K1 for decreased flows and in Table K2 for increased flows.

**Table K1 EWR 4: Habitat suitability for the LSR and LIM guild – DECREASED FLOWS**

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0	1	3	7	10	14	15	17	20	35	50
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	10	5	2	1	1	1	1	1	1	1	1
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	0	5	6	5	4	3	3	3	3	1	1
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	0	0	0	0	0	1	1	1	1	2	2
Slow Shallow and Slow Deep	0	5	6	5	4	4	4	4	4	3	3
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	0	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	0	1	2	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	0	1	2	3	2	1	1	1	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	0	0	1	2	3	5	5	5	6	7	8
FAST TOTAL >0.1 m DEEP	0	1	3	5	5	6	6	6	7	8	9

**Table K2 EWR 4: Habitat suitability for the LSR and LIM guild – INCREASED FLOWS**

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	50	60	75	80	96	105	120	130	140	150	170
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	1	1	0	0	0	0	0	0	0	0	0
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	1	1	1	1	1	1	1	1	1	0	0
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	2	2	2	2	1	1	1	1	1	1	1
Slow Shallow and Slow Deep	3	3	3	3	2	2	2	2	2	1	1
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	1	1	1	0	1	1	1	1	1	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	1	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	1	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	8	8	8	9	9	9	0	0	0	0	0

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	50	60	75	80	96	105	120	130	140	150	170
FAST TOTAL >0.1 m DEEP	9	9	9	10	10	10	1	1	1	1	1

The fish stress index is provided in Table K3 for decreased flows and K4 for increased flows.

**Table K3 Fish stress index – DECREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	0	1	3	7	10	14	15	17	20	35	50
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	0	1	2	3	3	3.5	4	4.5	5	5	5
Nursery habitat	0	2.5	3	4	4	4	4	4.5	5	5	5
Abundance	0	3.5	4	4	4	4	4	4.5	5	5	5
Cover	0	3.5	4	4	4	4	4	4.5	5	5	5
Connectivity (lateral & longitudinal)	0	3	3.5	4	4	4	4	4.5	5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	3	3.5	4	4.5	5	5	5	5	5	5
<b>Species stress: PPHI</b>	<b>10</b>	<b>4.5</b>	<b>3.33</b>	<b>2.33</b>	<b>2.17</b>	<b>1.83</b>	<b>1.67</b>	<b>0.83</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>LARGE SEMI-REOPHILIC (LSR) GUILD</b>											
Spawning habitat	0	1	2	3	3.5	3.5	4	4	4.5	5	5
Nursery habitat	0	1.5	2.5	3.5	4	4	4.5	4.5	4.5	5	5
Abundance	0	1	2	2.5	3	3.5	4	4	4.5	5	5
Cover	0	1	2	2.5	3	3.5	4	4	4.5	5	5
Connectivity (lateral & longitudinal)	0	0.5	1.5	2.5	3	4	4.5	4.5	5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	1	1.5	2	3	4	4.5	4.5	5	5	5
<b>Species stress: BAEN</b>	<b>10</b>	<b>8</b>	<b>6.17</b>	<b>4.67</b>	<b>3.5</b>	<b>2.5</b>	<b>1.5</b>	<b>1.5</b>	<b>0.67</b>	<b>0</b>	<b>0</b>

**Table K4 Fish stress index – INCREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	50	60	75	80	96	105	120	130	140	150	170
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	5.5	4.5	2.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Nursery habitat	5.5	4.5	2.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Abundance	5.5	4.5	2.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cover	5.5	4.5	2.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Connectivity (lateral & longitudinal)	5.5	4.5	4.5	3.5	3.5	2.5	2.5	1.5	1.5	0.5	0.5
Water Quality (esp. O <sub>2</sub> and Temp.)	5.5	5.5	4.5	4.5	4.5	3.5	3.5	3.5	3.5	3.5	3.5
<b>Species stress: PPHI</b>	<b>-0.5</b>	<b>-1.67</b>	<b>-3.83</b>	<b>-5.5</b>	<b>-7.5</b>	<b>-8.5</b>	<b>-8.5</b>	<b>-8.33</b>	<b>-8.67</b>	<b>-8.8</b>	<b>-9.5</b>
<b>LARGE SEMI-REOPHILIC (LSR) GUILD</b>											
Spawning habitat	5.5	4.5	4.5	3.5	3.5	2.5	2.5	1.5	0.5	0.5	0.5
Nursery habitat	5.5	4.5	4.5	3.5	2.5	2.5	1.5	0.5	0.5	0.5	0.5
Abundance	5.5	4.5	4.5	3.5	3.5	2.5	1.5	0.5	0.5	0.5	0.5
Cover	5.5	4.5	4.5	3.5	3.5	2.5	1.5	0.5	0.5	0.5	0.5
Connectivity	5.5	5.5	4.5	4.5	4.5	4.5	3.5	2.5	1.5	0.5	0.5

Habitat	Discharges (m <sup>3</sup> /s)										
	50	60	75	80	96	105	120	130	140	150	170
(lateral & longitudinal)											
Water Quality (esp. O <sub>2</sub> and Temp.)	5.5	5.5	5.5	5.5	4.5	4.5	4.5	4.5	3.5	3.5	2.5
Species stress: BAEN	-0.5	-0.67	-1.50	-2.3	-3.3	-4.3	-5.8	-7.5	-7.8	-8.17	-9.3

### K1.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for decreased and increased flows of the flow dependent macroinvertebrate (FDI) taxa is provided in Table K5 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table K5 Habitat suitability for FDI taxa – DECREASED and INCREASED FLOWS**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
<b>DECREASED FLOWS</b>															
10	Only hyporheic refugia, no surface water.	40	0	0	0	20	0	0	0	40	0	0	0		0.001
9	Standing water habitats only, very low quality. No flow.	34	6	0	0	17	3	0	0	34	6	0	0	Algae	0.026
8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	24	14	2	0	12	7	1	0	24	14	2	0	Algae	0.271
7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	23	15	2	0	11	7	1	0	24	15	2	0	Algae	0.387
6	Critical habitat residual. Low quality, moderate/slow velocity.	16	18	5	1	8	9	3	0	16	18	5	1	Algae	1.439
5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	11	15	11	3	6	7	6	2	11	15	11	3	Algae	3.68
4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	8	11	14	6	4	6	7	3	8	12	15	6		6.61
3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	6	10	15	9	3	5	7	4	6	10	15	9		9.31
2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	5	9	13	13	3	4	6	7	5	9	13	13		15.21
1	All habitats plentiful, high quality. Fast, wide WP.	4	8	12	16	2	4	6	8	4	8	12	16		21.13
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	2	5	9	24	1	2	4	12	2	5	9	25		49.2
<b>INCREASED FLOWS</b>															
0	All habitats in excess, very high quality. Very fast, very deep, very wide Wetted perimeter (WP).	2	5	9	24	1	2	4	12	2	5	9	25		49.2
-1	All habitats plentiful, high quality. Fast, WP slightly increased.	2	4	8	26	1	2	4	13	2	4	8	26		60.83
-2	Critical habitats sufficient. Quality slightly reduced, fast.	2	4	7	27	1	2	4	13	2	4	7	27		67.21
-3	Reduced critical habitat and reduced critical quality.	2	4	7	28	1	2	3	14	2	4	7	27		73.98
-4	Maximum current speeds stabilize. Average current speeds exceed 0.6 m/s.	2	3	7	28	1	2	3	14	2	3	7	28		81.16
-5	Critical habitat reduced.	2	3	6	29	1	2	3	15	2	3	6	28		92.68

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCs <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VsBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
-6	Average depths exceed 0.5 m leading to potential light limitation.	1	3	6	30	1	1	3	15	1	3	6	30		105.15
-7	Critical habitats very reduced.	1	2	5	31	1	1	3	16	1	2	5	32		118.58
-8	Mostly fast flowing habitats. Critical habitats limited.	1	2	5	32	1	1	2	16	1	2	5	32		133.01
-9	Fast flowing habitats only.	1	2	5	32	1	1	2	16	1	2	5	32		143.19
-10	Bank full discharge. Habitats suitable for fast flowing taxa only. Critical habitats limited and high potential for erosion. Residual habitat for slow flowing taxa.	1	2	4	33	0	1	2	16	1	2	4	34		153.83

1 Very Slow over Coarse Sediment  
 4 Very Fast over Coarse Sediment  
 7 Fast over Fine Sediment  
 10 Slow over Bedrock

2 Slow over Coarse Sediment  
 5 Very Slow over Fine Sediment  
 8 Very Fast over Fine Sediment  
 11 Fast over Bedrock

3 Fast over Coarse Sediment  
 6 Slow over Fine Sediment  
 9 Very Slow over Bedrock  
 12 Very Fast over Bedrock

The stress index for FDI taxa for decreased and increased flows are provided in Table K6 which rates the response of the species according to various biotic response metrics.

**Table K6 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
<b>DECREASED FLOWS</b>							
0.02	0.01	0.08	0.02	0.7		0.001	
0.12	0.03	0.18	0.05	16.9		0.026	
0.2	0.07	0.34	0.1	40.8	Some rheophilic species persist, but at very low numbers. All life stages of most rheophilic species at risk or non-viable.	0.271	<b>8</b>
0.22	0.07	0.35	0.11	50.1	Some rheophilic species persist, but most disappear. All life stages of sensitive rheophilic species at risk or non-viable.	0.387	<b>7</b>
0.3	0.13	0.57	0.17	68.2	Sensitive rheophilic species rare. Critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	1.439	<b>6</b>
0.38	0.18	0.86	0.26	78.6	Critical life stages of sensitive rheophilic species at risk or non-viable.	3.68	<b>5</b>
0.44	0.23	1.15	0.35	83.1	All life stages viable in limited areas. Critical life stages of some sensitive rheophilic species at risk.	6.61	<b>4</b>
0.48	0.26	1.28	0.42	87.3	Most rheophilic species persist, but abundances reduced.	9.31	<b>3</b>
0.58	0.34	1.53	0.49	95.2	Most rheophilic species persist, but slight (80 %) reduction.	15.21	<b>2</b>
0.66	0.4	1.6	0.55	98.8	90 % rheophilic species persist.	21.13	<b>1</b>
0.92	0.61	1.86	0.76	109.6	All flow dependent macroinvertebrates very abundant and healthy.	49.20	<b>0</b>
<b>INCREASED FLOWS</b>							
0.92	0.61	1.86	0.76	109.6	All flow dependent macroinvertebrates very abundant and healthy.	49.20	<b>0</b>
1	0.68	1.96	0.83	112.2		60.83	
1.04	0.71	1.99	0.86	112.6		67.21	
1.08	0.75	2.08	0.9	113.0		73.98	
1.12	0.79	2.07	0.94	113.4		81.16	

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
1.18	0.84	2.15	0.99	114.3		92.68	
1.24	0.89	2.26	1.05	115.9		105.15	
1.3	0.94	2.34	1.11	117.6		118.58	
1.36	0.98	2.43	1.17	119.1		133.01	
1.4	1.02	2.51	1.21	119.9		143.19	
1.44	1.05	2.59	1.25	120.6		153.83	

## K2 EWR 4: DENEYS (VAAL RIVER) – DETERMINATION OF EWR SCENARIOS

### K2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table K7 for the LSR guild and Table K7 for the LIM guild.

**Table K7 Low flow requirements: LSR guild**

GENERAL					
<p><b>INDICATOR:</b> This group generally requires FS, FI and FD flow depth categories over good quality substrate (gravel and cobbles) for spawning. Egg and embryo development also takes place in these habitats, while larvae prefer SD with substrate as optimal habitats. Juvenile and adult specimens have a high preference for SD, FS, FI and FD habitats with substrate and water column as cover. Flows should furthermore remain adequate to allow migration between reaches, thus depth in riffle and rapids should remain adequate, especially during the wet season.</p>					
<p align="center"><b>PES : FISH OVERALL IN C EC (ECOSTATUS C)</b>                      LSR Dry Season EC D                      LSR Wet Season EC C                      More flows than present in dry season but wet season remains the same as present.</p>					
<p><b>Dry Season maintenance</b>                      It is estimated that the present ecological status of the LSR guild is generally in a category D during the dry maintenance period. The maximum allowable fish stress levels to maintain the LSR in a category D is provided in Figure K1. It is estimated that at a recommended fish stress level of 1.9 (50% duration) the total habitat suitability would be 147% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach within a category D during the dry season. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.</p>					
<p><b>Dry Season drought</b>                      The recommended fish stress level of 4.4 for the dry season drought would result in 182% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in a category D during drought periods.</p>					
<p><b>Wet Season maintenance</b>                      It is estimated that the present ecological status of the large semi-rheophilic (LSR) guild is generally in a category C during the wet maintenance period. The maximum allowable fish stress levels to maintain the LSR in a category C is provided in Figure K2. At this recommended fish stress level of 2.14 (20% duration) the habitat suitability will be 78% of the expected optimal wet season habitat suitability under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach within a category C during the dry season.</p>					
<p><b>Wet Season drought</b>                      The maximum allowable fish stress levels during wet season droughts is 3.18 (5% duration). This equates to a total habitat suitability score of 68% of optimal wet season habitat suitability expected during natural droughts. These flows would enable the maintenance of this fish guild at this site in a category C during the wet season.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+4.4	+4	8.7
Maintenance	Dry	50%	+1.9	+1.9	14.45
Drought	Wet	5%	+3.18	+3.18	11.406
Maintenance	Wet	20%	+2.14	+2.14	14.76
<p align="center"><b>REC: FISH OVERALL IN B (ECOSTATUS B/C)</b>                      LSR Dry Season EC C                      LSR Wet Season EC B</p>					
<p><b>General</b>                      Due to the presence of too much water during both the wet and dry seasons, it is recommended that flows are reduced during the dry season to improve fish to a category C, and also reduce flows in the wet season to attain a fish category of B. Closer to natural seasonal variability in flow will increase the overall habitat conditions. Improved riffle/rapid habitats improved spawning habitat fir semi-rheophilics (BKIM, BAEN, LCAP, and ASCL).</p>					

**Dry Season maintenance**

It is recommended that the ecological status of the large semi-rheophilic (LSR) should be improved to a category C during the dry maintenance period. The maximum allowable fish stress levels to maintain the LSR in a category C is provided in Figure K1. At a recommended fish stress level of 2.7 (50% duration) the total habitat suitability would be 113% of what can be expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach in a category C during the dry season.

**Wet Season maintenance**

It is recommended that the ecological status of the large semi-rheophilic (LSR) should be improved to a category B during the wet maintenance period. The maximum allowable fish stress levels to maintain the LSR in a category B is provided in Figure K2. At a recommended fish stress level of 1.3 (20% duration) the total habitat suitability would be 88% of what can be expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach in a category B during the dry season.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+2.7	+2.7	12.96
Maintenance	Wet	20%	+1.3	+1.7	18.76

**AEC down: FISH OVERALL IN D (ECOSTATUS D)**

**LSR Dry Season EC D**

**More flows than present in dry season but wet season remains the same as present.**

**General**

Increased flow during the dry season will reduce the fish to a category D, and should wet season lows remain the same as present, the overall EcoStatus will deteriorate one category. Increased constant base flows will lead to a further loss in natural seasonal variability and more constant fast habitats and less slow habitats. Loss of variability in flow may reduce optimal habitats for species such as BAEN during the required periods.

**Dry Season maintenance:**

A further increase in flow during the dry season is expected to reduce the fish to a category D. The maximum allowable fish stress levels to maintain the LSR in a category D is provided in Figure K1. At a fish stress level of 0.5 (50% duration) the total habitat suitability would be 173% of what can be expected under natural conditions. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.

**Wet Season maintenance**

Remain as present.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+0.5	+0.5	35.565
Maintenance	Wet	n/a	n/a		

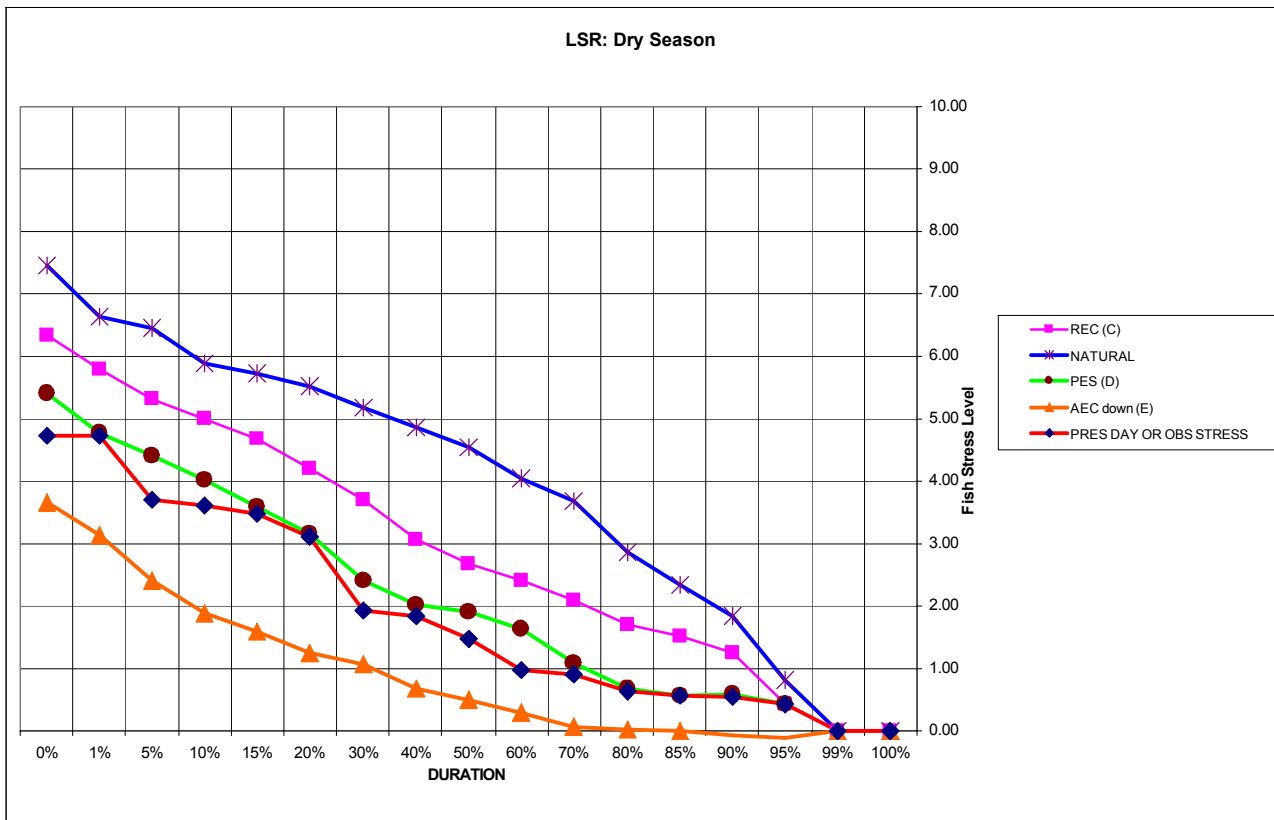


Figure K1 Dry Season LSR fish stress at different flow durations for the various ECs

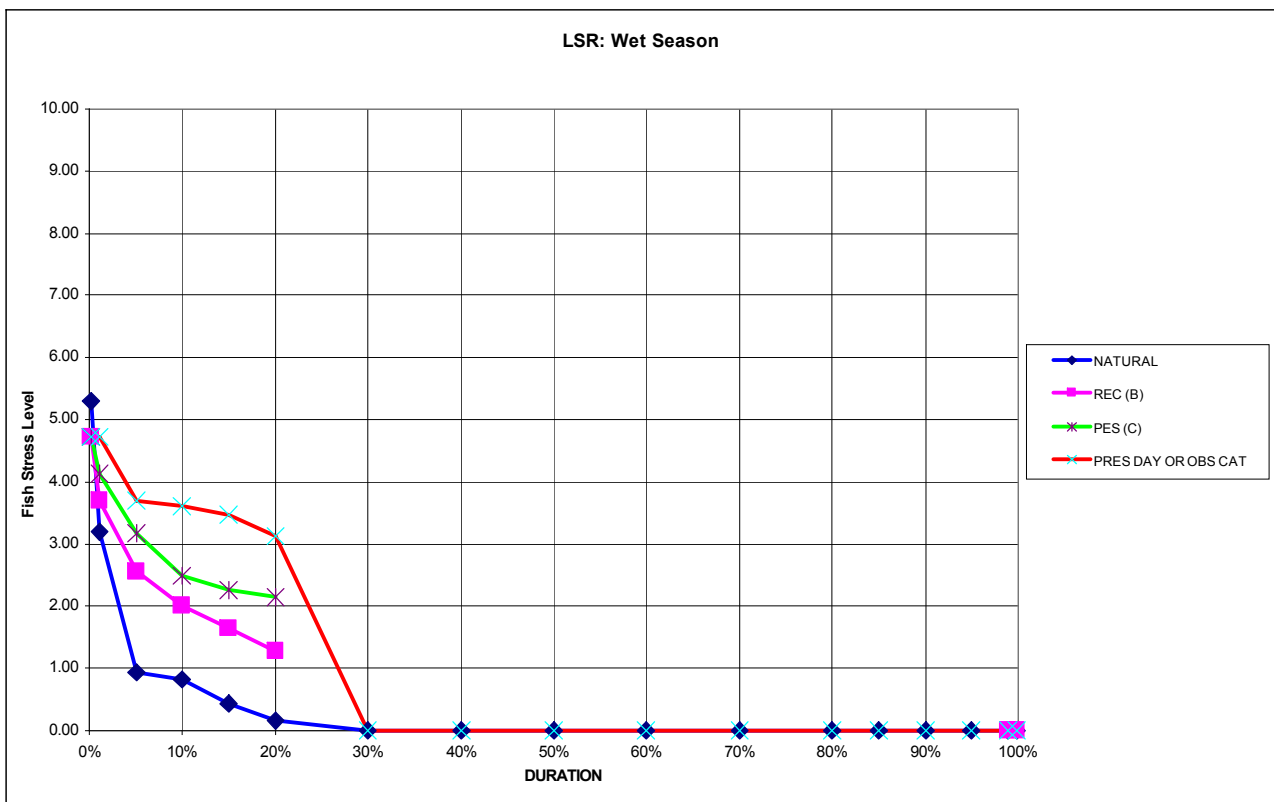


Figure K2 Wet Season LSR fish stress at different flow durations for the various ECs

**Table K8 Low flow requirements: LIM guild**

<b>GENERAL</b>					
<p><b>INDICATOR:</b> The optimal preferred general habitat for small limnophilic species is SD and SS preferably with overhanging vegetation, undercut banks or aquatic vegetation as cover, although they also make use of large substrates (cobble, boulders and bedrock) as general habitat. Breeding takes place during the spring and summer, with males constructing nests in soft substrates. Optimal habitats for egg and larvae development, nursery areas and in general for juveniles and adults are slow-deep and SS habitats.</p>					
<p><b>PES: FISH OVERALL IN C EC (ECOSTATUS C)</b>  <b>LIM Dry Season EC B</b>  <b>LIM Wet Season EC B/C</b></p>					
<p><b>Dry Season maintenance</b>                      It is estimated that the present ecological status of the limnophilic (LIM) guild is generally in a category B during the dry maintenance period. The maximum allowable fish stress levels to maintain the LIM guild in a category B is provided in Figure K3. At a recommended fish stress level of 1.1 (50% duration) the total habitat suitability would be 120% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach within a category B during the dry season. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.</p>					
<p><b>Dry Season drought</b>                      The recommended fish stress level of 2.66 for the dry season drought would result in 107% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in a category B during drought periods.</p>					
<p><b>Wet Season maintenance</b>                      It is estimated that the present ecological status of the LIM guild is generally in a category B/C during the wet maintenance period. The maximum allowable fish stress levels to maintain the LIM guild in a category B/C is provided in Figure K4. At a recommended fish stress level of 1.8 (20% duration) the habitat suitability will be 83% of the expected optimal wet season habitat suitability under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach within a category B/C during the dry season.</p>					
<p><b>Wet Season drought</b>                      The maximum allowable fish stress levels during wet season droughts is considered to be 2.4 (5% duration). This equates to a total habitat suitability score of 79% of optimal wet season habitat suitability expected during natural droughts. These flows would enable the maintenance of this fish guild at this site in a category B/C during the wet season.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+2.66	+4.8	5.856
Maintenance	Dry	50%	+1.1	+1.9	14.45
Drought	Wet	5%	+2.4	+4.2	5.124
Maintenance	Wet	20%	+1.8	+2.5	10
<p><b>REC: FISH OVERALL IN B (ECOSTATUS B/C)</b>  <b>LIM Dry Season EC A</b>  <b>LIM Wet Season EC B</b></p>					
<p><b>General</b>                      Closer to natural seasonal variability in flow will increase the overall habitat conditions. In summer more marginal vegetation inundation, increased spawning habitat for TSPA, CGAR, BANO, and BPAU. Closer to natural low flow periods will provide better refuge areas for species with preference for slow habitats (LUMB, BANO, TSPA, and PPHI).</p>					
<p><b>Dry Season maintenance</b>                      It is recommended that the ecological status of the LIM guild should be maintained in a category A during the dry maintenance period. The maximum allowable fish stress levels to maintain it in a category A is provided in Figure K3. At a recommended fish stress level of 1.8 (50% duration) the total habitat suitability would be 113 % of what can be expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach in a category A during the dry season.</p>					
<p><b>Wet Season maintenance</b>                      It is recommended that the ecological status of the LIM guild should be maintained in a category B during the wet maintenance period. The maximum allowable fish stress levels to maintain this guild in a category B is provided in Figure K4. At a recommended fish stress level of 1.3 (20% duration) the total habitat suitability would be 88% of what can be expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain</p>					

this guild within this reach in a category B during the dry season.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+1.8	+2.5	10
Maintenance	Wet	20%	+1.3	+2	15.21

**AEC down: FISH OVERALL IN D (ECOSTATUS D)**  
**LIM Dry Season EC C**  
**LIM Wet Season EC B/C**

**General**

Increased constant base flows will lead to a further loss in natural seasonal variability and more constant fast habitats and less slow habitats. This will affect especially marginal vegetation as cover and influence species such as BANO, BPAU, TSPA and PPHI.

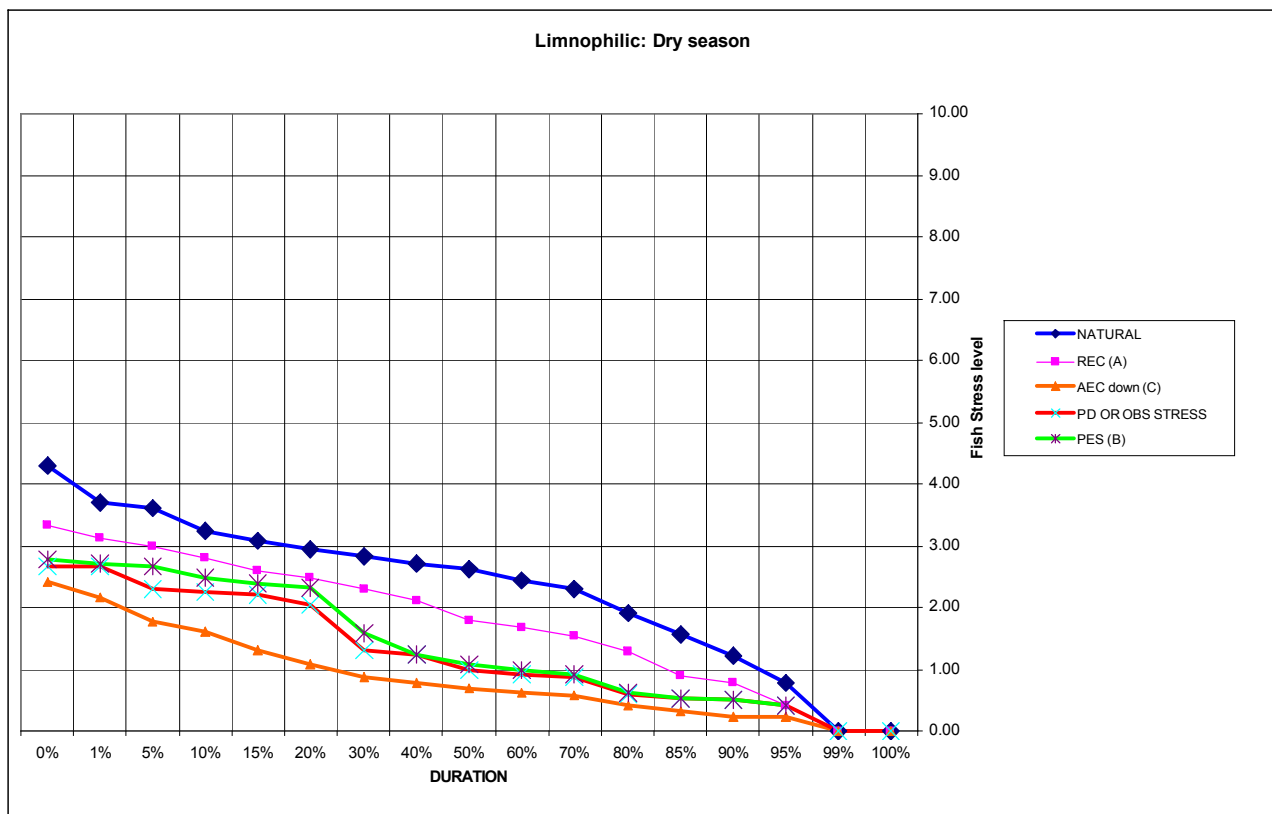
**Dry Season maintenance**

A further increase in flow during the dry season is expected to reduce the LIM guild to a category C. The maximum allowable fish stress levels to maintain this guild in a category C is provided in Figure K3. At a fish stress level of 0.7 (50% duration) the total habitat suitability would be 125% of what can be expected under natural conditions. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.

**Wet Season maintenance**

Remain as present.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+0.7	+0.8	26.904
Maintenance	Wet	n/a	n/a		



**Figure K3 Dry Season LIM fish stress at different flow durations for the various ECs**

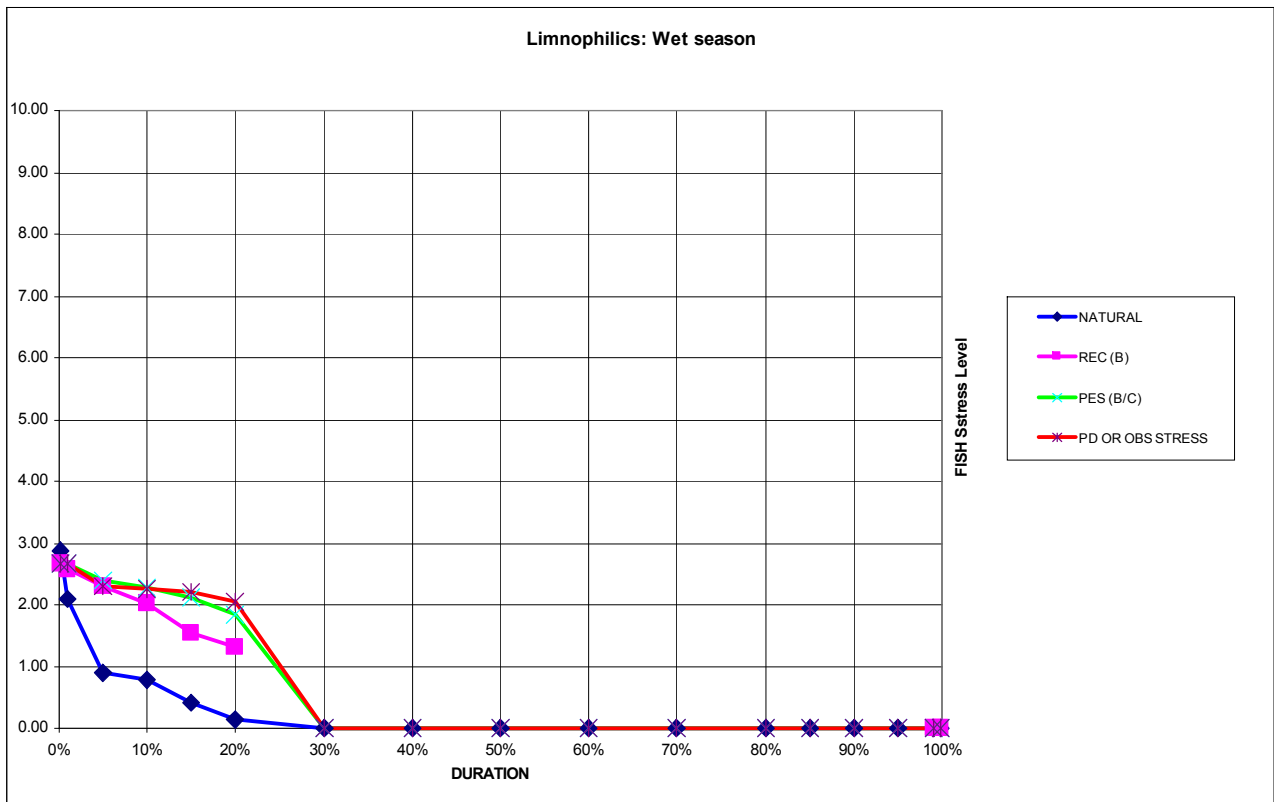


Figure K4 Wet Season LIM fish stress at different flow durations for the various ECs

## K2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table K9 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

Table K9 Low flow requirements: FDI taxa

GENERAL
<p><b>INDICATOR:</b> Hydropsychid caddisflies and Simuliidae (i.e., common, flow dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.</p>
PES: MACROINVERTEBRATE EC C/D (ECOSTATUS C)
<p><b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.29 m, and average current velocity is 0.45 m/s (Spp Stress -2.5).</p>
<p><b>Dry Season drought</b> Average depth needed for dry season maintenance is 0.21 m, and average current velocity is 0.3 m/s (Spp Stress -4.3). At these flows there is very limited very fast flow.</p>

<p><b>Wet Season maintenance</b> Average depth needed for wet season maintenance is 0.45 m, and the average current velocity is 0.59 m/s (Spp Stress - 0.8). A wide range of substrate – velocity categories are available.</p> <p><b>Wet Season drought</b> Average depth needed for wet season drought is 0.25 m, and average current velocity is 0.39 m/s (Spp Stress - 3.5).</p> <table border="1"> <thead> <tr> <th>BUILDING BLOCK</th> <th>SEASON</th> <th>STRESS DURATION</th> <th>SPP STRESS</th> <th>INTEG STRESS</th> <th>FLOW (m<sup>3</sup>/s)</th> </tr> </thead> <tbody> <tr> <td>Drought</td> <td>Dry</td> <td>5%</td> <td>+4.3</td> <td>+5.2</td> <td>5.56</td> </tr> <tr> <td>Maintenance</td> <td>Dry</td> <td>50%</td> <td>+2.5</td> <td>+3</td> <td>12</td> </tr> <tr> <td>Drought</td> <td>Wet</td> <td>5%</td> <td>+3.5</td> <td>+4.3</td> <td>7.92</td> </tr> <tr> <td>Maintenance</td> <td>Wet</td> <td>30%</td> <td>+0.8</td> <td>+0.8</td> <td>26.904</td> </tr> </tbody> </table> <p style="text-align: center;"><b>REC: MACROINVERTEBRATE EC C (ECOSTATUS B/C)</b></p> <p><b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.26 m, and average current velocity is 0.42 m/s (Spp Stress -3).</p> <p><b>Dry Season drought:</b> Average depth needed for dry season maintenance is 0.18 m, and average current velocity is 0.26 m/s (Spp Stress -5). At these flows there is very limited very fast flow.</p> <p><b>Wet Season maintenance</b> Average depth needed for wet season maintenance is between 0.37 m, and the average current velocity is 0.52 m/s (Spp Stress - 1.3). A wide range of current speeds and substrate types is available.</p> <p><b>Wet Season drought</b> Average depth needed for wet season drought is 0.23 m, and average current velocity is 0.35 m/s (Spp Stress - 4).</p> <table border="1"> <thead> <tr> <th>BUILDING BLOCK</th> <th>SEASON</th> <th>STRESS DURATION</th> <th>SPP STRESS</th> <th>INTEG STRESS</th> <th>FLOW (m<sup>3</sup>/s)</th> </tr> </thead> <tbody> <tr> <td>Drought</td> <td>Dry</td> <td>5%</td> <td>+5.0</td> <td>+5.8</td> <td>3.93</td> </tr> <tr> <td>Maintenance</td> <td>Dry</td> <td>50%</td> <td>+3.0</td> <td>+3.8</td> <td>9.36</td> </tr> <tr> <td>Drought</td> <td>Wet</td> <td>5%</td> <td>+4.0</td> <td>+4.8</td> <td>6.6</td> </tr> <tr> <td>Maintenance</td> <td>Wet</td> <td>30%</td> <td>+1.3</td> <td>+1.3</td> <td>19.35</td> </tr> </tbody> </table> <p style="text-align: center;"><b>AEC down: MACROINVERTEBRATE EC C/D (ECOSTATUS D)</b></p> <p>Increasing present day flows in both the wet and dry season is not expected to change the PES of macroinvertebrates from a C/D category.</p>						BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)	Drought	Dry	5%	+4.3	+5.2	5.56	Maintenance	Dry	50%	+2.5	+3	12	Drought	Wet	5%	+3.5	+4.3	7.92	Maintenance	Wet	30%	+0.8	+0.8	26.904	BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)	Drought	Dry	5%	+5.0	+5.8	3.93	Maintenance	Dry	50%	+3.0	+3.8	9.36	Drought	Wet	5%	+4.0	+4.8	6.6	Maintenance	Wet	30%	+1.3	+1.3	19.35
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)																																																												
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Maintenance	Wet	30%	+1.3	+1.3	19.35																																																												

### K2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table K10.

**Table K10 Functions for each Flood Class**

Flood Class	Function/Motivation	
CLASS: I RANGE (M <sup>3</sup> /S): 15 - 25 DAILY AVERAGE: DURATION: 3 - 5	Fish	Class I floods are very important floods for fish and serves as migration cues and to maintain adequate longitudinal connectivity for migration. These floods will also flush fines and algae from substrates to ensure adequate conditions in substrates, a very important habitat for spawning of many of the species. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation and contributes to the creation of acceptable nursery areas. Some resetting of water quality will also take place, and the changes in water quality may also serve as stimulus to cue migratory activity and even gonad development. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope. Four of these per year are recommended for a

Flood Class	Function/Motivation	
		macroinvertebrate Category C/D: one at the beginning of the wet season (Oct/Nov), two during the wet season, and one towards the end of the wet season (Feb/Mar).
CLASS: II RANGE (M <sup>3</sup> /S): 40 - 96 DAILY AVERAGE: DURATION: 5	Fish	Class II floods are similar in importance as Class I floods and have the same functionality as Class I floods. Their occurrence at lower frequency makes them only slightly less important for the fish assemblages than Class I. Secondary channels will be inundated by these floods which will create favourable spawning and refuge habitats for some species.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. One of these per year at the beginning of the wet season is recommended for a macroinvertebrate Category C/D.
CLASS: III RANGE (M <sup>3</sup> /S): 120 - 200 DAILY AVERAGE: DURATION:	Fish	Class III floods also provide similar functions as Class I, but due to its lower frequency it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.

## K2.4 EWR RULES

For the EWR rule table the table generated in the Fish Flow Habitat Assessment model (FFHA) was used as the DRM could not be applied. The EWR rule table includes low flows only.

**Table K11 EWR 4 assurance rules for PES: C**

Array	PRESENT/OBS											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.10%	361.41	1292.58	528.67	183.64	221.40	208.72	32.44	36.22	125.39	77.66	162.81	306.90
1.00%	361.41	1292.58	528.67	183.64	221.40	208.72	32.44	36.22	125.39	77.66	162.81	306.90
5.00%	361.41	1292.58	528.67	183.64	221.40	208.72	32.44	36.22	125.39	77.66	162.81	306.90
10.00%	250.90	449.32	327.81	54.40	19.38	20.41	28.15	32.74	40.51	41.07	54.01	139.64
15.00%	144.49	338.54	193.40	40.51	16.50	17.63	22.59	32.11	37.04	39.95	37.65	105.29
20.00%	115.74	79.37	140.38	21.99	16.13	17.63	20.05	30.24	35.80	36.96	33.56	76.16
30.00%	63.47	37.66	48.16	16.01	15.23	14.81	18.07	21.06	21.84	24.53	22.45	43.31
40.00%	20.98	20.42	24.64	14.74	13.37	14.54	16.76	19.27	21.06	20.91	21.03	33.27
50.00%	17.70	16.00	17.25	12.92	12.25	13.93	15.31	16.80	16.63	17.17	15.93	19.12
60.00%	13.96	13.81	14.93	12.35	11.24	11.92	13.70	15.53	16.17	15.68	13.62	11.46
70.00%	13.07	12.28	13.59	12.23	10.01	10.26	13.18	15.20	15.16	13.63	13.04	10.42
80.00%	8.33	10.33	10.86	7.83	8.18	9.30	11.69	11.61	12.85	12.96	10.22	9.33
85.00%	7.17	9.84	9.89	7.48	8.10	9.26	11.13	10.45	12.27	12.84	8.41	8.85
90.00%	6.83	8.97	7.80	7.48	7.88	8.49	10.68	10.01	11.57	12.73	8.29	7.06
95.00%	3.48	7.85	7.58	7.06	7.69	7.52	9.97	9.71	10.76	10.12	7.41	4.93
99.00%	0.51	3.62	2.68	6.83	6.98	2.45	7.02	6.83	6.64	7.65	6.29	1.08
99.90%	0.51	3.62	2.68	6.83	6.98	2.45	7.02	6.83	6.64	7.65	6.29	1.08

**APPENDIX L: SUPPORTING INFORMATION FOR THE DETERMINATION OF STRESS  
INDICES AND EWR SCENARIOS OF EWR 5: SCANDINAVIA**

## L1 EWR 5: SCANDINAVIA (VAAL RIVER) – DETERMINATION OF STRESS INDICES

Appendix L provides supporting information for the determination of stress indices of EWR 5 Scandinavia (Chapter 23 and 24 of the Main Report, Volume 1).

### L1.1 FISH INDICATOR SPECIES

#### Fish indicator group 1: Large semi-rheophilic species (BAEN, BKIM)

Indicator species: *Labeobarbus aeneus* (BAEN) and *Labeobarbus kimberleyensis* (BKIM). Refer to Appendix B, Section B1.1.

#### Fish indicator group 2: Small limnophilic (LIM) species (PPHI, TSPA)

The small limnophilic species, *Pseudocrenilabrus philander* (PPHI) and *Tilapia sparrmanii* (TSPA). Refer to Appendix K, Section K1.1

### L1.2 FISH STRESS INDEX

The abundance of fish velocity-depth classes are provided in Table L1 for decreased flows and Table L2 for increased flows.

**Table L1 EWR 5: Habitat suitability for the LSR and LIM guild – DECREASED FLOWS**

LSR and LIM GUILD											
Depth classes	Discharges (m <sup>3</sup> /s)										
	0	5	7	10	14	22	28	45	60	86	90
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	10	2	2	2	2	1	1	1	1	0	0
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	0	4	3	3	3	2	2	2	1	1	1
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	0	2	2	2	2	1	2	2	2	2	2
Slow Shallow and Slow Deep	0	6	5	5	5	3	4	4	3	3	3
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	0	1	1	2	2	2	1	1	1	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	0	1	1	1	1	2	1	1	1	1	1
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	0	1	1	1	1	1	1	2	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	0	2	2	3	3	3	4	5	7	8	8
FAST TOTAL >0.1 m DEEP	0	3	3	4	4	4	5	7	8	9	9

**Table L2 EWR 5: Habitat suitability for the LSR and LIM guild – INCREASED FLOWS**

Depth classes	Discharges (m <sup>3</sup> /s)										
	90	95	100	110	120	135	150	165	180	190	200
LSR and LIM GUILD											
Slow (<0.3 m/s) Very Shallow (<0.1 m) (SVS)	0	0	0	0	0	0	0	0	0	0	0
Slow (<0.3 m/s) Shallow (0.1 – 0.3 m) (SS)	1	1	1	1	1	1	1	1	1	1	1
Slow (<0.3 m/s) Deep (> 0.5 m) (SD)	2	2	2	2	2	2	2	2	2	2	2
Slow Shallow and Slow Deep	3	3	3	3	3	3	3	3	3	3	3
Fast (>0.3 m/s) Very Shallow (<0.1 m) (FVS)	1	1	1	1	1	1	0	1	0	1	1
Fast (>0.3 m/s) Shallow (0.1 – 0.3 m) (FS)	1	1	1	1	1	1	1	1	0	1	1

Depth classes	Discharges (m <sup>3</sup> /s)										
	90	95	100	110	120	135	150	165	180	190	200
Fast (>0.3 m/s) Intermediate (0.2 – 0.3) (FI)	1	1	1	1	1	1	1	1	1	1	1
Fast (>0.3 m/s) Deep (> 0.3 m) (FD)	8	8	8	8	8	9	0	0	0	0	0
FAST TOTAL >0.1 m DEEP	9	9	9	9	9	10	1	1	1	1	1

The fish stress index is provided in Table L3 for decreased flows and L4 for increased flows.

**Table L3 Fish stress index – DECREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	0	5	7	10	14	22	28	45	60	86	90
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	0	3	4	4	5	5	5	5	5	5	5
Nursery habitat	0	3	4	4	5	5	5	5	5	5	5
Abundance	0	3	4	4	5	5	5	5	5	5	5
Cover	0	3	4	4	5	5	5	5	5	5	5
Connectivity (lateral & longitudinal)	0	3	4	4	5	5	5	5	5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	3	4	4	5	5	5	5	5	5	5
<b>Species stress: PPHI</b>	<b>-10</b>	<b>-3</b>	<b>-2</b>	<b>-1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>LARGE SEMI-REOPHILIC (LSR) GUILD</b>											
Spawning habitat	0	0	1	2	2	3	3	4	4	5	5
Nursery habitat	0	1	2	2	3	3	4	4	4	5	5
Abundance	0	1	2	2	3	4	4	4	4	5	5
Cover	0	1	2	2	3	4	4	4	4	5	5
Connectivity (lateral & longitudinal)	0	0	1	2	3	3	4	4	5	5	5
Water Quality (esp. O <sub>2</sub> and Temp.)	0	0	1	2	3	3	4	4	5	5	5
<b>Species stress: BAEN</b>	<b>-10</b>	<b>-8.3</b>	<b>-7</b>	<b>-5.3</b>	<b>-4</b>	<b>-2.8</b>	<b>-2.17</b>	<b>-1.3</b>	<b>-0.67</b>	<b>0</b>	<b>0</b>

**Table L4 Fish stress index – INCREASED FLOWS**

Habitat	Discharges (m <sup>3</sup> /s)										
	90	95	100	110	120	135	150	165	180	190	200
<b>SMALL LIMNOPHILIC (LIM) GUILD</b>											
Spawning habitat	5	3	2	2	1	1	0	0	0	0	0
Nursery habitat	5	3	2	2	1	1	0	0	0	0	0
Abundance	5	3	2	2	1	1	0	0	0	0	0
Cover	5	3	2	2	1	1	0	0	0	0	0
Connectivity (lateral & longitudinal)	5	3	2	2	1	1	0	0	0	0	0
Water Quality (esp. O <sub>2</sub> and Temp.)	5	3	2	2	1	1	0	0	0	0	0
<b>Species stress: PPHI</b>	<b>0</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>10</b>
<b>LARGE SEMI-REOPHILIC (LSR) GUILD</b>											
Spawning habitat	5	5	4	3	2	2	1	1	0	0	0
Nursery habitat	5	5	4	3	2	1	1	0	0	0	0
Abundance	5	5	4	4	3	2	1	1	1	0	0

Habitat	Discharges (m <sup>3</sup> /s)										
	90	95	100	110	120	135	150	165	180	190	200
Cover	5	5	4	4	3	2	1	1	1	0	0
Connectivity (lateral & longitudinal)	5	5	5	5	4	4	4	4	3	3	3
Water Quality (esp. O <sub>2</sub> and Temp.)	5	5	5	5	5	4	4	4	3	3	2
<b>Species stress: BAEN</b>	<b>0</b>	<b>0</b>	<b>0.83</b>	<b>2</b>	<b>3.3</b>	<b>4.5</b>	<b>5.17</b>	<b>6.17</b>	<b>6.67</b>	<b>7.5</b>	<b>7.67</b>

### L1.3 MACROINVERTEBRATE STRESS INDEX

The habitat flow index for decreased and increased flows of the flow dependent macroinvertebrate (FDI) taxa is provided in Table L5 and provides the % occurrence of various velocity and substrate classes under different flow conditions.

**Table L5 Habitat suitability for FDI taxa**

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
<b>DECREASED FLOWS</b>															
-10	Only hyporheic refugia, no surface water.	40	0	0	0	20	0	0	0	40	0	0	0		0.001
-9	Standing water habitats only, very low quality. No flow.	23	14	2	0	12	7	1	0	24	15	2	0	Algae	0.2
-8	Flowing water habitats residual and of low quality. Slow trickle, very narrow WP.	18	17	5	0	9	8	2	0	18	17	5	0	Algae	0.59
-7	No critical habitat, other habitats moderate quality. Slow, narrow WP.	16	16	7	1	8	8	3	1	16	16	7	1	Algae	1.31
-6	Critical habitat residual. Low quality, moderate/slow velocity.	12	14	10	3	6	7	5	2	13	15	11	3	Algae	3.4
-5	Critical habitat very reduced, moderate/low quality. Moderate/slow velocity, few deep areas WP moderately/very reduced.	10	13	12	5	5	6	6	2	10	13	12	5		6.4
-4	Critical habitats limited and of moderate quality. Moderate velocity, some deep areas. Wide WP moderately reduced.	9	12	13	6	5	6	7	3	9	12	13	6		8.4
-3	Reduced critical habitat and critical quality. Moderate velocity, fairly deep.	8	11	14	8	4	5	7	4	8	10	13	8		12.2
-2	Critical habitats sufficient. Quality slightly reduced, fast, WP slightly reduced.	8	11	14	7	4	6	7	4	8	11	14	7		15.5
-1	All habitats plentiful, high quality. Fast, wide WP.	6	9	13	12	3	5	6	6	6	9	13	12		27.8
0	Zero stress pegged at naturalized hydrology wet season maintenance base flow.	3	5	9	24	1	3	4	12	3	5	9	23		87.1
<b>INCREASED FLOWS</b>															
0	Zero stress pegged at naturalized hydrology wet season maintenance base flow.	3	5	9	24	1	3	4	12	3	5	9	23		87.1
1	All habitats plentiful, high quality. Fast, WP slightly increased.	3	5	8	24	1	3	4	12	3	5	8	24		95
2	Critical habitats sufficient. Quality slightly reduced, fast.	2	5	8	25	1	2	4	12	2	5	8	26		99
3	Reduced critical habitat and reduced critical quality.	2	5	8	25	1	2	4	12	2	5	8	26		103.2
4	Maximum current speeds stabilize. Average current speeds exceed 0.6 m/s. 40 % loss of <i>Cyperus</i> .	2	5	8	25	1	2	4	13	2	5	8	25		107.4

Habitat Flow Response Index	HABITAT RESPONSE	HABITAT ABUNDANCE AND SUITABILITY (%)												MODIFIER	FLOW (m <sup>3</sup> /s)
		VSCS <sup>1</sup>	SCS <sup>2</sup>	FCS <sup>3</sup>	VFCS <sup>4</sup>	VSFS <sup>5</sup>	SFS <sup>6</sup>	FFS <sup>7</sup>	VFFS <sup>8</sup>	VSBR <sup>9</sup>	SBR <sup>10</sup>	FBR <sup>11</sup>	VFBR <sup>12</sup>		
5	Critical habitat reduced.	2	5	8	25	1	2	4	13	2	5	8	25		111.6
6	Average depths exceed 0.5 m, leading to potential light limitation.	2	4	7	26	1	2	4	13	2	4	7	27		116
7	Critical habitats very reduced.	2	4	7	26	1	2	4	13	2	4	7	27		120.4
8	Mostly fast flowing habitats. Critical habitats limited.	2	4	7	26	1	2	4	13	2	4	7	27		124.9
9	Fast-flowing habitats only. 75 % loss of marginal vegetation.	2	4	7	27	1	2	3	13	2	4	7	28		129.5
10	Bank full discharge. Habitats suitable for fast flowing taxa only. Critical habitats limited, high potential for erosion. Residual habitat for slow flowing taxa.	2	4	7	27	1	2	3	14	2	4	7	27		134.1

1 Very Slow over Coarse Sediment  
 4 Very Fast over Coarse Sediment  
 7 Fast over Fine Sediment  
 10 Slow over Bedrock

2 Slow over Coarse Sediment  
 5 Very Slow over Fine Sediment  
 8 Very Fast over Fine Sediment  
 11 Fast over Bedrock

3 Fast over Coarse Sediment  
 6 Slow over Fine Sediment  
 9 Very Slow over Bedrock  
 12 Very Fast over Bedrock

The stress index for FDI taxa for decreased and increased flows are provided in Table L6 which rates the response of the species according to various biotic response metrics.

**Table L6 Macroinvertebrate (FDI) stress index**

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
<b>DECREASED FLOWS</b>							
0.02	0.01	0.07	0.02	2.0		0.001	
0.24	0.13	0.36	0.1	15.0		0.2	
0.36	0.2	0.52	0.15	20.4	Some rheophilic species persist, but at very low numbers. All life stages of most rheophilic species at risk or non-viable.	0.59	-8
0.48	0.23	0.64	0.18	31.50	Some rheophilic species persist, but most disappear. All life stages of sensitive rheophilic species at risk or non-viable.	1.31	-7
0.66	0.28	0.85	0.25	51.80	Sensitive rheophilic species rare. Critical stages of sensitive rheophilic species non-viable and at risk for some less sensitive species.	3.4	-6
0.78	0.32	1.00	0.31	69.70	Critical life stages of sensitive rheophilic species at risk or non-viable.	6.4	-5
0.84	0.32	1.09	0.33	82.80	All life stages viable in limited areas. Critical life stages of some sensitive rheophilic species at risk.	8.4	-4
0.92	0.33	1.27	0.38	104.40	Most rheophilic species persist, but abundances reduced.	12.2	-3
1.00	0.34	1.21	0.38	126.40	Most rheophilic species persist, but slight (80 %) reduction.	15.5	-2
1.12	0.40	1.51	0.49	151.50	90 % rheophilic species persist.	27.8	-1
1.50	0.72	2.05	0.76	169.00	All flow dependent macroinvertebrates very abundant and healthy.	87.1	0
<b>INCREASED FLOWS</b>							
1.50	0.72	2.05	0.76	169.00	All flow dependent macroinvertebrates very abundant and healthy.	87.1	0
1.54	0.76	2.03	0.78	169.90		95	
1.56	0.78	2.08	0.79	170.30		99	
1.58	0.80	2.07	0.81	170.70		103.2	

Habitat characteristics					Biotic Response	Flow	Species Stress
Max depth (m)	Ave depth (m)	Max vel (m/s)	Ave vel (m/s)	WP (m)			
1.60	0.81	2.09	0.82	171.40		107.4	
1.62	0.83	2.12	0.83	172.40		111.6	
1.64	0.84	2.15	0.84	173.50		116	
1.66	0.86	2.14	0.86	174.60		120.4	
1.68	0.87	2.16	0.87	175.50		124.9	
1.70	0.89	2.21	0.88	175.70		129.5	
1.72	0.91	2.23	0.89	176.00		134.1	

## L2 EWR 5: SCANDINAVIA (VAAL RIVER) – DETERMINATION OF EWR SCENARIOS

### L2.1 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR FISH

The fish low flow requirements for the EWR scenarios are summarised in Table L7 for the LSR guild and Table L8 for LIM guild.

**Table L7 Low flow requirements: LSR guild**

GENERAL					
<p><b>INDICATOR:</b> This group generally requires FS, FI and FD flow-depth categories over good quality substrate (gravel and cobbles) for spawning. Egg and embryo development also takes place in these habitats, while larvae prefer SD with substrate as optimal habitats. Juvenile and adult specimens have a high preference for SD, FS, FI and FD habitats with substrate and water column as cover. Flows should furthermore remain adequate to allow migration between reaches, thus depth in riffle and rapids should remain adequate, especially during the wet season.</p>					
PES: FISH OVERALL IN EC C (ECOSTATUS C/D) (Maintain less water in dry season, more water in wet season)					
<p><b>Dry Season maintenance</b> The maximum allowable fish stress levels to maintain the LSR guild in its PES is provided in Figure L1. It is estimated that at a fish stress level of 4.5 (50 % duration) the total habitat suitability would be 135% of what can be expected under natural conditions, as a result of flows still being higher than expected under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within this reach in its present state. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.</p>					
<p><b>Dry Season drought</b> The recommended fish stress level of 8.7 for the dry season drought would result in 70.9% of the habitats that can be expected under natural conditions, and it is estimated that it would maintain this guild in its present state during drought periods.</p>					
<p><b>Wet Season 20% assurance</b> The maximum allowable fish stress levels to maintain the LSR in its present state is provided in Figure L2. At this recommended fish stress level of 3 the habitat suitability will be 68% of the expected optimal wet season habitat suitability under natural conditions. It is estimated that these habitat conditions should be adequate to maintain this guild within its present state.</p>					
<p><b>Wet Season drought</b> The maximum allowable fish stress levels during wet season droughts is 7.3 (5% duration). This equates to a total habitat suitability score of 43% of optimal wet season habitat suitability expected during natural droughts. These flows would enable the maintenance of this fish guild at this site in its PES during the wet season droughts.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+8.7	+8.7	3.75
Maintenance	Dry	50%	+4.5	+4.5	12.5
Drought	Wet	5%	+7.3	+7.3	6.55
Maintenance	Wet	20%	+3	+3	20.9
REC: FISH OVERALL IN EC B (ECOSTATUS C) Less flow than present during both seasons					
<p><b>General</b> Improved hydrological regime (closer to natural) will result in improved habitats condition for species. Improved habitat condition through flushing of sediment and algae from riffle/rapid will improve conditions for ASCL, with a resultant improved FROC. This will also have a positive impact on spawning habitats for species such as BAEN, BKIM and LCAP. Improved water quality may furthermore improve conditions for species such as BKIM, ASCL, LCAP, and BAEN.</p>					
<p><b>Dry Season maintenance</b> It is recommended that the ecological status of the LSR guild should be improved with one category during the dry maintenance period. This improvement should be attained at the fish stress levels provided in Figure L1 for an improved scenario. At a recommended fish stress level of 5 (50% duration) the total habitat suitability would be 114% of what can be expected under natural conditions. This is a vast improvement of the present 142% habitat suitability.</p>					

**Wet Season 20% assurance**

It is recommended that the ecological status of the LSR guild should be improved with one category during the wet maintenance period. The required fish stress levels to attain this improvement is provided in Figure L2. At a recommended fish stress level of 2 (20% duration) the total habitat suitability would be 89% of what can be expected under natural conditions. It is estimated that these habitat conditions should be adequate to improve this guild with one EC.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+5	+5	11
Maintenance	Wet	20%	+2	+2	31.4

**AEC down: FISH OVRALL IN EC D (ECOSTATUS D)**  
**More flows than present in dry season but wet season remains the same as present.**

**General**

A lack of floods, more fines and more embeddedness will lead to critical deterioration in the already limited riffle/rapid (FS) habitats in the reach. Increased flows during the dry season will alter the natural habitats and transform slow habitats into fast habitats. This will decrease the FROC of species such as ASCL, BAEN, BKIM, and LCAP.

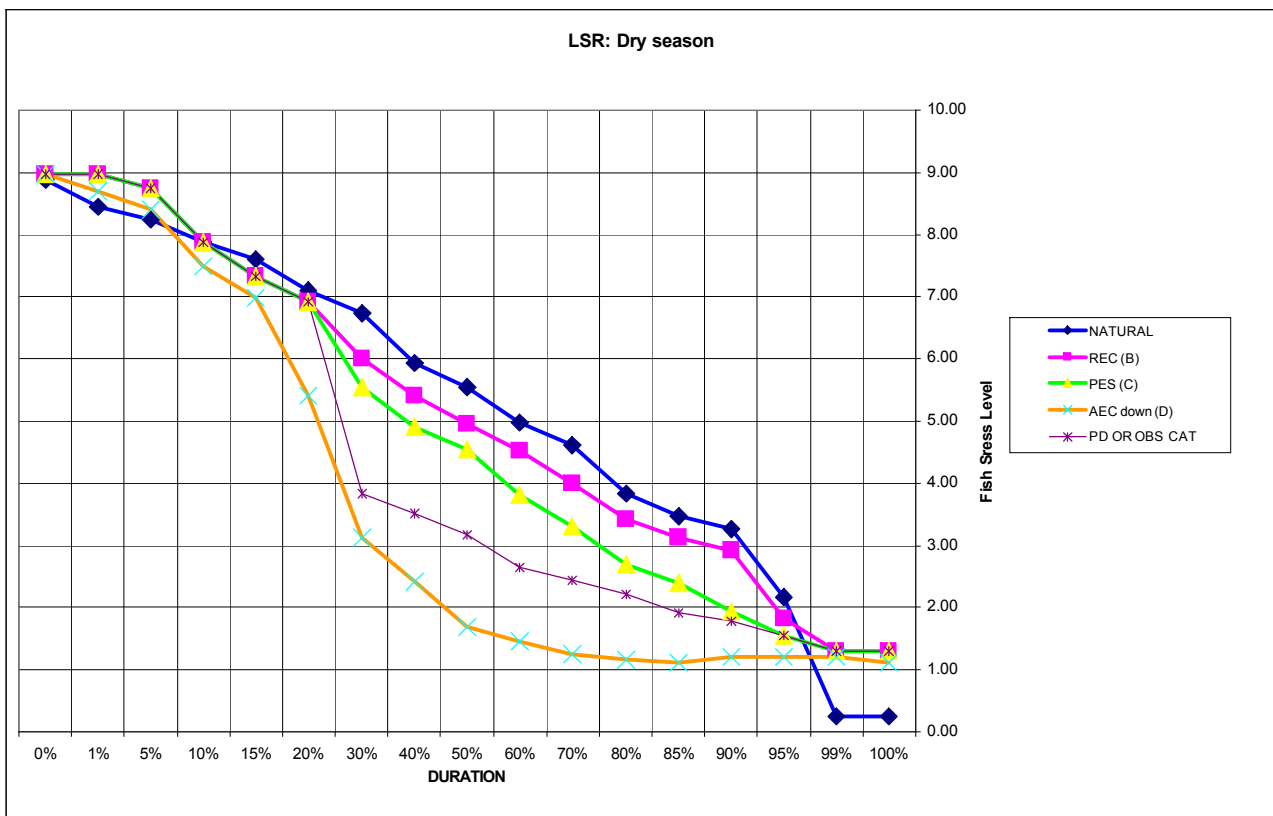
**Dry Season maintenance**

A further increase in flow during the dry season is expected to reduce the ecological status of the semi-rheophilic guild. The maximum allowable fish stress levels to reduce this guild by one category from its present status is provided in Figure L1. At a fish stress level of 1.7 (50% duration) the total habitat suitability would be 187% of what can be expected under natural conditions. Although more suitable habitats will therefore be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.

**Wet Season maintenance**

Remain as present (more than under natural conditions).

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+1.7	+1.7	37.73
Maintenance	Wet	n/a	n/a		



**Figure L1 Dry Season LSR fish stress at different flow durations for the various ECs**

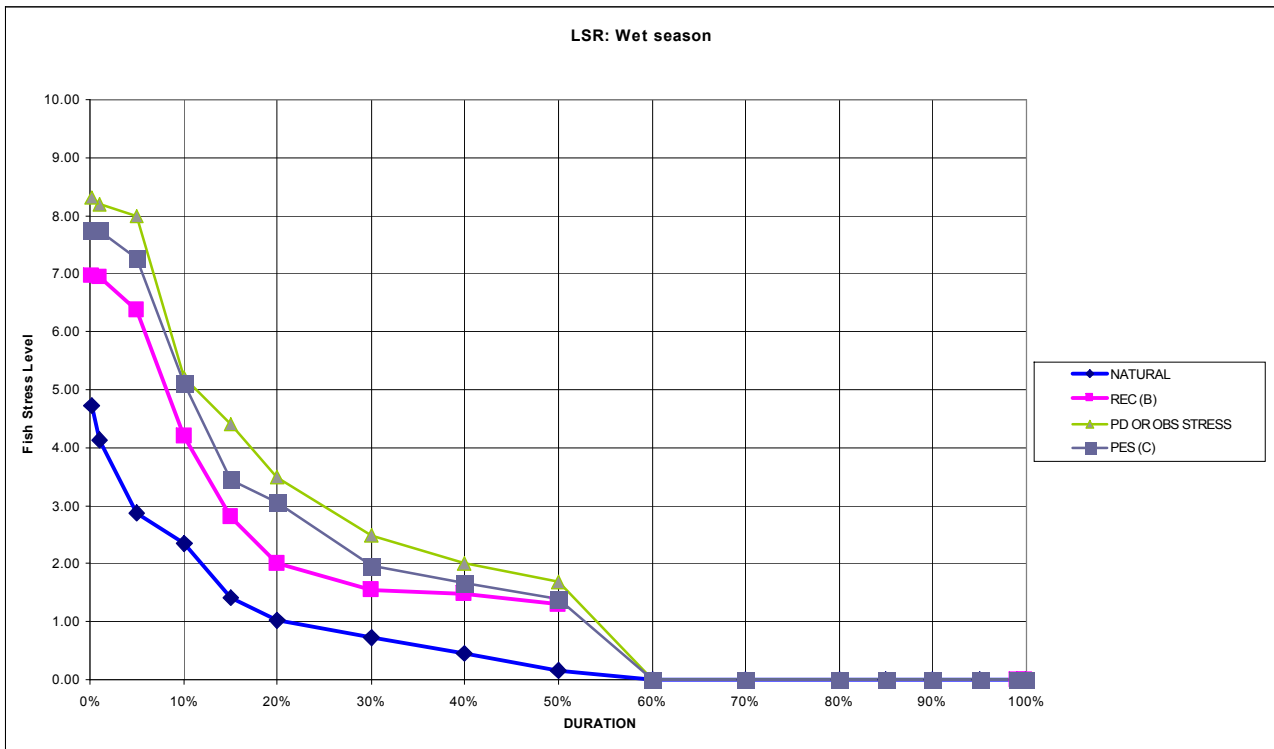


Figure L2 Wet Season LSR fish stress at different flow durations for the various ECs

Table L8 Low flow requirements: LIM guild

GENERAL					
<p><b>INDICATOR:</b> The optimal preferred general habitat for small limnophilic species is SD and SS preferably with overhanging vegetation, undercut banks or aquatic vegetation as cover, although they also make use of large substrates (cobbles, boulders and bedrock) as general habitat. Breeding takes place during the spring and summer, with males constructing nests in soft substrates. Optimal habitats for egg and larvae development, nursery areas and in general for juveniles and adults are SD and SS habitats.</p>					
AEC down: FISH OVERALL IN D (ECOSTATUS D)					
LIM Dry Season EC C					
LIM Wet Season remain as present					
<p><b>General</b> Limnophilic species are expected to primarily react to a further increase in flows, and were therefore only considered for that AEC down scenario. Further increased flows, especially during the dry season, will further reduce the availability of slow habitats, critical for various life stages of the limnophilic guild. Loss of marginal vegetation as a result of increased bank erosion will also be reflected by decreased FROC of species such as BANO, BTRI, BPAU, and TSPA and PPHI.</p>					
<p><b>Dry Season maintenance</b> A further increase in flow during the dry season is expected to further reduce the ecological status of the limnophilic guild. Figure L3 provides an indication of the expected stress that would result in a decrease in ecological status of this fish guild. It is estimated that at a fish stress level of 0.2 (50% duration) the total habitat suitability would be 110 % of what can be expected under natural conditions. Although more suitable habitats will be available, any shift from natural conditions will result in a negative impact on the ecological integrity. This will be the result of habitat deterioration, change in food webs and population structures, etc.</p>					
<p><b>Wet Season maintenance</b> Remain as present.</p>					
BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Maintenance	Dry	50%	+0.2	+0.4	75
Maintenance	Wet	n/a	n/a		

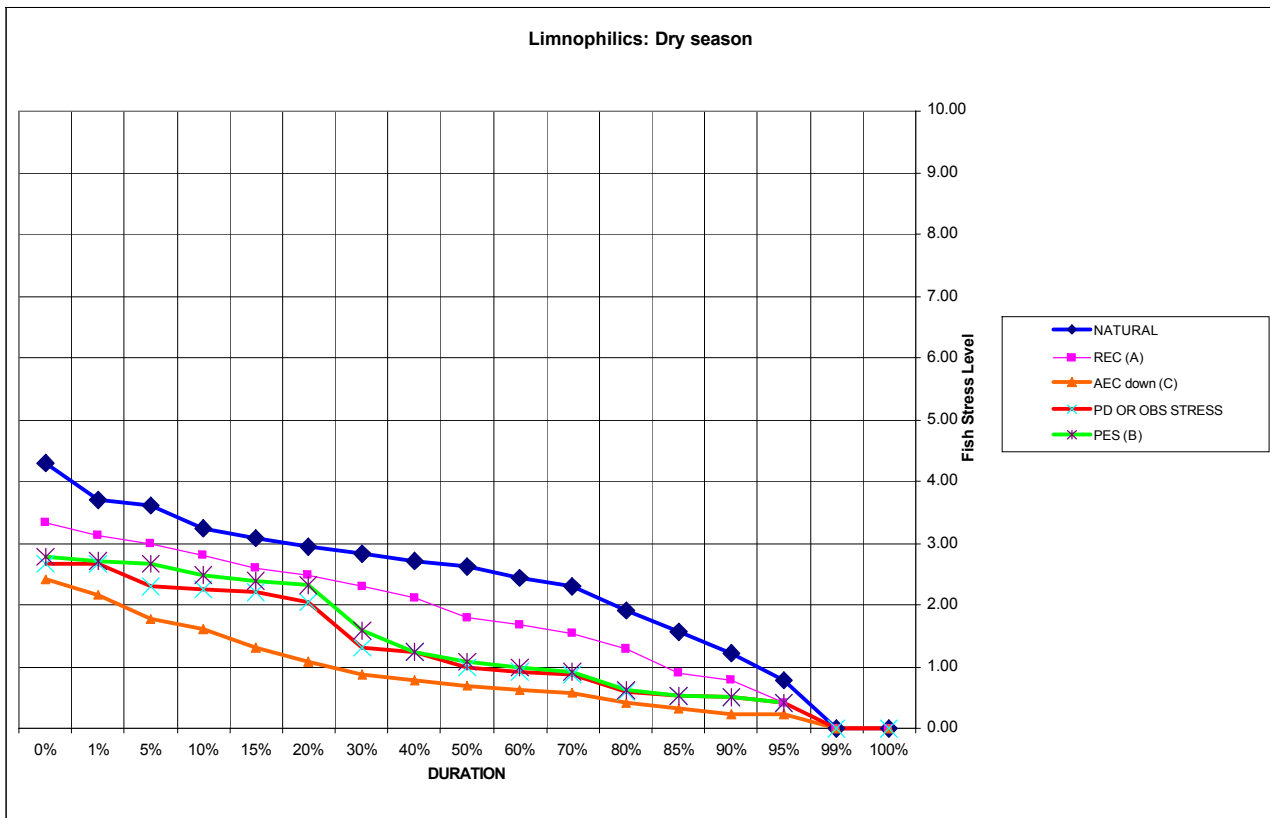


Figure L3 Dry Season LIM fish stress at different flow durations for the various ECs

## L2.2 LOW FLOW REQUIREMENTS IN TERMS OF STRESS FOR MACROINVERTEBRATES

The FDI low flow requirements are summarised in Table L9 below. NOTE: For macroinvertebrates the available indicator species at all sites in the upper Vaal Catchment tolerate wide fluctuations in flow and water quality conditions, and this makes it difficult to motivate for specific flow durations on the basis of indicator species alone. The assessment of macroinvertebrates requirements for all sites was therefore based largely on professional judgement of how overall macroinvertebrate biodiversity would respond to changes in hydraulic biotope availability. In general, a high diversity of macroinvertebrates can be expected when there are natural seasonal fluctuating water levels; when current speeds exceed 0.4 m/s; when depths exceed about 30 cm; and when there is an abundance of marginal vegetation.

Table L9 Low flow requirements: FDI taxa

GENERAL
<b>INDICATOR:</b> Hydropsychid caddisflies and Simuliidae (i.e., common, flow dependent taxa). The minimum depth requirements for these taxa are 10 cm, and maximum depths are about 30 cm. The optimal current speeds are 0.4 m/s. These taxa are not sensitive to deterioration in water quality, and are expected to tolerate wide fluctuations in flow and water quality conditions.
PES: MACROINVERTEBRATE EC C (ECOSTATUS C/D)
<b>Dry Season maintenance</b> Average depth needed for dry season maintenance is 0.33 m, and average current velocity is 0.38 m/s (Spp Stress - 3).
<b>Dry Season drought</b> Average depth needed for dry season maintenance is 0.28 m, and average current velocity is 0.25 m/s (Spp Stress -

6). At these flows there is very limited very fast flow.

#### Wet Season maintenance

Average depth needed for wet season maintenance is between 0.41 m, and the average current velocity is 0.51 m/s (Spp Stress - 0.9). A wide range of current speeds and substrate types is available.

#### Wet Season drought

Average depth needed for wet season drought is 0.32 m, and average current velocity is 0.33 m/s (Spp Stress - 4).

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+6	+8.6	5.9
Maintenance	Dry	50%	+3	+4.7	16.4
Drought	Wet	5%	+4	+6	8.8
Maintenance	Wet	30%	+0.9	+2	31.4

#### REC: MACROINVERTEBRATE EC C (ECOSTATUS C)

Increasing flows in both the wet and dry season is not expected to improve the EC of macroinvertebrates.

#### AEC down: MACROINVERTEBRATE EC C/D (ECOSTATUS D)

#### Dry Season maintenance

Average depth needed for dry season maintenance is 0.46 m, and average current velocity is 0.55 m/s (Spp Stress - 0.8).

#### Dry Season drought

Average depth needed for dry season maintenance is 0.28 m, and average current velocity is 0.38 m/s (Spp Stress - 6). At these flows there is very limited very fast flow.

BUILDING BLOCK	SEASON	STRESS DURATION	SPP STRESS	INTEG STRESS	FLOW (m <sup>3</sup> /s)
Drought	Dry	5%	+6	+6.5	7.9
Maintenance	Dry	50%	+0.8	+3.7	25.77

## L2.3 INSTREAM FLOOD FUNCTIONS

A description of the flood functions for biotic response is provided in Table L10.

**Table L10 Functions for each Flood Class**

Flood Class	Function/Motivation	
CLASS: I RANGE (M <sup>3</sup> /S): 40 – 100 DAILY AVERAGE: 50 DURATION: 3	Fish	Class I floods are very important floods for fish and serves as migration cues and to maintain adequate longitudinal connectivity for migration. These floods will also flush fines and algae from substrates to ensure adequate conditions in substrates, a very important habitat for spawning of many of the species. It should furthermore inundate some vegetation for species spawning in flooded marginal vegetation and contributes to the creation of acceptable nursery areas. Some resetting of water quality will also take place, and the changes in water quality may also serve as stimulus to cue migratory activity and even gonad development. The frequency, extent and duration as recommended for the PES and AEC should be adequate to provide the functions as required to maintain the fish within the specific category.
	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope. Four of these per year are recommended for a macroinvertebrate Category C: one at the beginning of the wet season (Oct/Nov), two during the wet season, and one towards the end of the wet season (Feb/Mar).
CLASS: II RANGE (M <sup>3</sup> /S): 180 - 260 DAILY AVERAGE:	Fish	Class II floods are similar in importance as Class I floods and have the same functionality as Class I floods. Their occurrence at lower frequency makes them only slightly less important for the fish assemblages than Class I. Secondary channels will be inundated by these floods which will create favourable spawning and refuge habitats for some species.

Flood Class	Function/Motivation	
DURATION: 3 - 5	Macroinvertebrates	These freshets are recommended to stimulate hatching of eggs, clear fines, scour substrate and inundate backwaters and marginal vegetation in order to create additional biotope, and reset water quality. One of these per year at the beginning of the wet season is recommended for a macroinvertebrate Category C.
CLASS: III RANGE (M <sup>3</sup> /S): 400 - 570	Fish	Class III floods also provide similar functions as Class I, but due to its lower frequency it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.
CLASS : IV RANGE (M <sup>3</sup> /S): 800	Fish	Class IV floods also provide similar functions as Class I, but due to its lower frequency of occurrence it is not essential for the flood functions required by the indigenous fish species. These floods, and especially their receding limbs will however be utilised by many of the fish species for migration and even spawning if takes place within the summer season. Important secondary channels will be inundated during these floods to create favourable habitat for some species.

## L2.4 EWR RULES

For the EWR rule table the table generated in the Fish Flow Habitat Assessment model (FFHA) was used as the DRM could not be applied. The EWR rule table includes low flows only.

**Table L11 EWR 5 assurance rules for PES: C/D**

PRESENT/OBS												
Array	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.10%	560.41	1774.97	645.53	175.93	360.29	247.30	264.34	46.30	590.28	673.91	483.41	323.70
1.00%	560.41	1774.97	645.53	175.93	360.29	247.30	264.34	46.30	590.28	673.91	483.41	323.70
5.00%	421.52	1338.87	323.33	125.00	161.29	39.35	38.46	41.07	115.35	100.06	182.87	268.07
10.00%	307.27	430.31	214.31	86.81	33.64	26.97	28.19	36.22	49.38	60.48	96.06	241.94
15.00%	193.77	183.74	154.94	76.39	30.09	26.62	27.52	33.27	43.21	49.66	76.77	156.81
20.00%	131.05	139.30	130.68	50.54	28.56	25.27	24.34	29.12	39.35	45.55	55.17	143.37
30.00%	75.04	50.84	58.99	36.50	26.81	21.72	20.87	26.66	32.95	36.25	42.05	71.68
40.00%	49.28	43.82	38.46	27.04	23.52	19.65	19.75	24.53	30.48	29.61	34.95	39.20
50.00%	38.46	37.24	33.23	22.18	17.66	14.70	18.11	19.60	23.03	27.07	26.27	32.89
60.00%	31.92	31.58	28.64	17.82	13.22	11.57	14.64	17.25	19.25	23.41	20.49	27.93
70.00%	28.79	26.46	21.58	14.08	9.37	9.68	10.57	15.08	14.81	17.14	15.51	19.49
80.00%	25.46	17.44	17.29	11.34	7.24	6.40	6.80	7.17	8.95	10.53	12.81	15.72
85.00%	20.50	13.60	12.69	8.26	5.97	5.56	5.71	6.50	8.14	9.18	10.73	13.63
90.00%	11.20	11.20	9.93	5.44	4.52	5.29	5.00	5.68	6.60	8.55	8.64	11.91
95.00%	9.89	7.23	6.83	4.36	3.18	3.22	3.57	3.66	4.51	6.16	7.66	8.92
99.00%	5.90	5.08	4.41	3.62	2.80	2.65	3.24	3.09	3.76	5.64	4.67	6.12
99.90%	5.11	4.75	4.29	3.39	2.43	2.03	2.79	3.08	2.92	2.33	3.83	5.26