

THUKELA WATER PROJECT DECISION SUPPORT PHASE

**RESERVE DETERMINATION MODULE
THUKELA SYSTEM INSTREAM FLOW REQUIREMENTS**

January 2004

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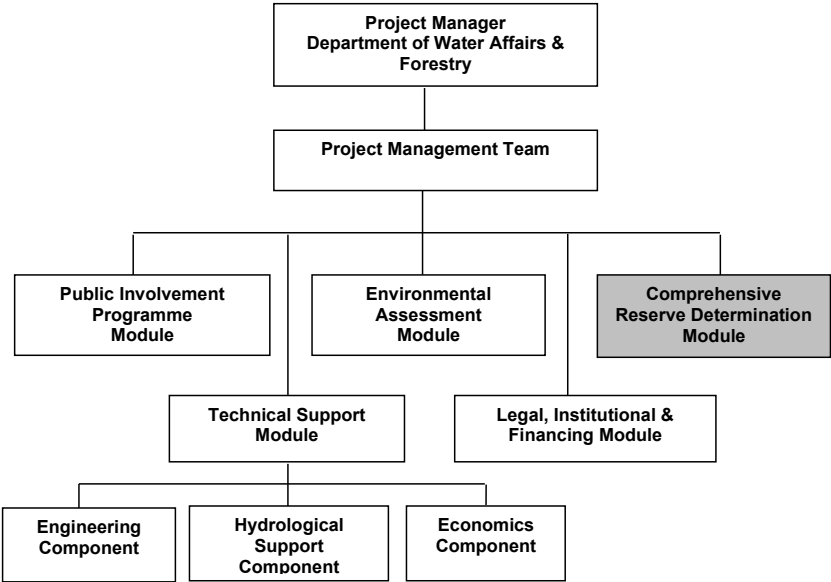
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STRUCTURE OF DECISION SUPPORT PHASE



**DEPARTMENT OF WATER AFFAIRS & FORESTRY
NATIONAL WATER RESOURCE PLANNING**

**THUKELA WATER PROJECT DECISION SUPPORT PHASE
RESERVE DETERMINATION MODULE THUKELA SYSTEM
INSTREAM FLOW REQUIREMENTS REPORT**

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EXECUTIVE SUMMARY

BACKGROUND

The Reserve Determination module involves quantification of the water resource required to meet objectives for the Thukela system under a series of scenarios defined during the course of the study. As an outcome of the Reserve Determination study, information will be made available in a manner that will allow for informed recommendations and decisions for the way forward. The specific objectives of this Reserve Determination Module are, therefore:

- Develop scenarios and test these with the DWAF and stakeholders;
- recommend one of these scenarios to represent the Ecological Reserve for the quality and quantity components for the river and estuary;
- determine the impact of the recommended Reserve on the allocatable yield;
- determine whether it is possible to supply the Reserve from existing and proposed schemes;
- and to provide mitigation measures if it is not.

The flow requirements/IFRs (quantity component of the Ecological Reserve) must be quantified for each Resource Unit and is documented in this report. The report is supported by an appendix document incorporating of all the specialist reports generated as part of this task.

PURPOSE OF THIS REPORT

The purpose of the main report is to

- Document a summary of the methods followed.
- Provide the sequential actions undertaken during the specialist meetings to produce the results.
- Provide a detailed explanation of the format of the report chapters for each IFR site in which the results are provided.
- Provide all the results for each IFR site.
- Provide the confidence associated with the results generated per IFR site.

The step-by-step method followed to provide the final flow recommendations for each IFR site is documented in this chapter only. The results for each site are subsequently recorded on a chapter-by-chapter basis. The approach followed in producing the results is explained section-by-section.

PROCESS FOLLOWED TO DETERMINE IFRS

The Flow-Stress Response method (FS-R) was used to provide the low flows, and a method adjusted from the standard Building Block Methodology (BBM; King & Louw, 1998) and Downstream Response to Imposed Flow Transformation (DRIFT; Brown, C & King, J) approach was followed to set high flows.

The basis of the FS-R method is the application of a generic stress index describing the progressive consequences of flow reduction to the flow-dependent biota and river processes. Here, the **stressors** (e.g. flow), hydraulics and associated habitat changes are related to biotic **stress responses** in terms of abundance, life stages, and persistence. The generic stress index is adjusted for use to be specific to both sites and components (fish, aquatic invertebrates, riparian vegetation). Here, it is important that both ends of the stress index range (i.e. zero and the upper stress value) are well described. The zero stress index relates to optimum and abundant habitat conditions under low flows. Stress 8 relates to a trickle, stress 9 to no flow (i.e. still pools present) and stress 10 to no surface water available.

A FS-R approach is being developed for high flows but has not yet been used in a Reserve determination study. The approach used for high flows in this study has elements of both the BBM and the DRIFT methodologies. The fish, invertebrate and riparian vegetation specialists provide the functions of floods (described as flood classes) and identify the size of the events using the hydraulic cross-sections, sediment transport modelling, photos and videos of known flows and interaction with the geomorphologists. The number of events of each flood class under natural conditions are determined. Pending on the objectives for each ERC, the number of events are subsequently recommended.

RESULTS

The table below summarises all the results as percentages of the natural MAR. The long term percentage (referred to as '% long') refers to the % of the natural MAR required to match the IFR time series generated by the IFR rules, i.e. including periods of drought, maintenance, between drought and maintenance and above maintenance flows. The '% tot' refers to the total maintenance IFR a percentage of natural MAR. The '% low' refers to the maintenance low flow IFR as a percentage of the natural MAR.

The colour code is as follows:

Category A		Category AB	
Category B		Category BC	
Category C		Category CD	
Category D		Category DE	
Category E		Category F	

The last column provides a confidence evaluation which is based on confidence evaluations on the biophysical input as well as the confidence in the conversion of hydraulic parameters to flow.

The sites with the highest confidence are IFR 1, 4, 9, 8, 11 and 14. Of these sites IFR 4, 9 and 11 are sites assessed in previous studies, i.e. more than normal information is available. Furthermore, for IFR sites 4, 11 and 14 sediment transport modelling as well as habitat modelling has been undertaken. This should result in higher confidence results.

The major purpose for a consistent confidence evaluation is that the information provided can serve to unpack the overall confidence evaluation. If further work is therefore required to increase confidence, the thrust of such work can be identified through this evaluation.

Further work to increase the confidence in the results can all be addressed as part of the monitoring programme and will be included during the design of the monitoring study.

IFR results

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
THUKELA RIVER														
A		C/D	-	22	9.2	B/C	-	35.5	19.1	B	-	40.84	24.4	Low, extrapolated
B	1	-	-	-	-	D	22.3	17.3	7	C	31.7	29.9	14.9	IFR components: Med-high to high Hydraulics: Med-high MED-HIGH
C	2	D	22	18.2	4.2	C	29	27.4	11.1	B	37.5	38.5	19.2	IFR components: Med-low (low flow), med-high (high flow). Hydraulics: High. MED-LOW (low flow), MED-High (high flow)
D		D	-	19.1	6.1	C	-	24.8	10.5	B	-	35.1	18	Low, extrapolated
E		C	-	25.4	10.1	B	-	35.3	18	-	-	-	-	Low, extrapolated
F	4 *1	B/C	29	28.4	12.4	B	31.8	31.8	14.7	-	-	-	-	IFR components: Med-high Hydraulics: Med-high MED-HIGH
G		D	-	18.94	-	C/D	-	22.1	9	B/C	-	30.8	14	Low, extrapolated
H	9	-	-	-	-	D	24.3	20.3	6.1	C	28.2	27.8	12	IFR components: Med-low Hydraulics: Med-high MED-HIGH*2
I	15	D	22.7	18.2	6.2	C	27	25.5	12.6	-	-	-	-	IFR components: Med-high Hydraulics: Low (low flow), med-high (high flow) LOW (low flow), MED-HIGH (high flow)
J	16	D	29.6	23.7	8.4	C/D	32.6	28.4	11.4	B/C	36	36.1	18	IFR components: Med (low flow), med- high (high flow) Hydraulics: Med (drought), med-high (rest) MED (low flow) MED-HIGH (high flow)

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
LITTLE THUKELA RIVER														
L		D				C				B				Low, extrapolated
M	3	D		18.6	6.1	C/D		24.7	11.1	B/C		42.8	21.4	IFR components: Med (low flow), med-high (high flow) Hydraulics: High MED (low flow), MED-HIGH (high flow)
BUSHMENS RIVER														
N		C/D	-	31.3	13.1	B/C	-	44.3	22	B	-	49.8	27.5	Low, extrapolated
O	5	C/D	37.5	32.7	13.3	B/C	47.4	45.4	22.4	-	-	-	-	IFR components: Med (low flow), med-high (high flow) Hydraulics: High MED (low flow), MED-HIGH (high flow)
P	6	C/D	-	32.1	13.1	B/C	-	44.7	22.2	-	-	-	-	Low, extrapolated
SUNDAYS RIVER														
Q	7	C/D	29.3	25.8	10.9	B/C	35.8	36.7	28.6	-	-	-	-	IFR components: Med Hydraulics: Med MED
R	8	-	-	-	-	D	24.1	19.6	6.8	C	29.5	28.7	13.1	IFR components: Med Hydraulics: High MED-HIGH (low flow), MED (high flow)
MOOI RIVER														
S	10	D	24.9	18.6	9	C	32.4	29.9	17.2	B	41.9	43.6	28.04	IFR components: Low-med to Med-high Hydraulics: Low (droughts), Med-high (low flow) LOW (droughts), MED (high flow)
T	11	C/D	27.2	23.5	12.4	B/C	35.4	36.3	22.1	B	39.5	42	27.7	IFR components: Med-high Hydraulics: Med-high MED-HIGH

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
	BUFFALO RIVER													
U	13	-	-	-	-	D	18.1	16	3.9	C	23.1	22.2	9.2	IFR components: Med-high Hydraulics: Low-med (low), med-high (intermediate 0 LOW-MEDIUM (low flow), MEDIUM (>1.8)
V	14	C/D	20	18.1	5	B/C	24.1	24.8	10.2	-	-	-	-	IFR components: Med-high Hydraulics: High MED-HIGH

*1 IFR 4: 3 scenarios were supplied, B (recommended), B/C (alternative and PES), C/D (lower than PES). Only the B and B/C scenario fit into the table and C/D information needs to be used within the design of additional scenarios if necessary.

C/D, LONG TERM % = 22.6

MAINTENANCE TOTAL % = 21.8

% LOW FLOWS = 8.8

*2 Even though the IFR component evaluation is med-low, flows should be managed from Spioenkop to cater for IFR 4 which is a higher ERC than IFR 9. IFR 9 should therefore get more flows than recommended and the confidence in achieving the ERC is therefore linked to the hydraulics, i.e. med-high.

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ACRONYMS AND ABBREVIATIONS

ASPT	Average Score Per Taxon
BBM	Building Block Methodology
DRIFT	Downstream Response to Imposed Flow Transformations
DTM	Digital Terrain Model
DWAF	Department of Water Affairs and Forestry
ERC	Ecological Reserve Category
FAII	Fish Assemblage Integrity Index
FS-R	Flow Stressor Response
HIS	Habitat Suitability Index
IFR	Instream Flow Requirement
Imp	Importance
MAR	Mean Annual Runoff
NWA	National Water Act
PES	Present Ecological State
PMT	Project Management Team
Q-C	Concentration discharge
RC	Reference condition
RDM	Resource Directed Measures
RU	Resource units
SASS	South African Scoring System
TDS	Total Dissolved Solids
TIN	Total Inorganic Nitrogen
Traj	Trajectory
TWPDSP	Thukela Water Project Decision Support Phase

1 INTRODUCTION

1.1 BACKGROUND

The Reserve Determination Module (Module 3 of 5 for the Thukela Water Project Decision Support Phase) is designed, *inter alia*, to meet the requirements of the *National Water Act No 36 of 1998*. As such the study has been guided by the following three major requirements:

- The objectives of Chapter 3 of the National Water Act No 36 of 1998 for a comprehensive Reserve Determination and the subsequent RDM protocols released by DWAF.
- The specific requirements of the Terms of Reference as supplied by Department of Water Affairs and Forestry (Tender WF7405).
- The needs of the Thukela Water Project and associated organs of the Department of Water Affairs and Forestry, which includes broad based planning required to meet overall water resource management objectives in the catchment.

The Reserve Determination module involves quantification of the water resource required to meet objectives for the Thukela system under a series of scenarios and will be defined during the course of the study. This need for a scenario based approach was mooted so as to enable recommendations regarding water resource planning based on a suite of alternatives with regard to the needs of the Reserve and stipulated management classes for the Thukela system. Out of the Reserve Determination study information will be made available in a manner that will allow the Project Management Team (PMT) of the TWPDSP to make informed recommendations and decisions for the way forward. The specific objectives of this Reserve Determination Module are, therefore:

- Develop scenarios and test these with the DWAF and stakeholders;
- recommend one of these scenarios to represent the Ecological Reserve for the quality, quantity components for the river and estuary;
- determine the impact of the recommended Reserve on the allocatable yield;
- determine whether it is possible to supply the Reserve from existing and proposed schemes;
- and to provide mitigation measures if it is not.

The work relevant to this report that has been undertaken at this stage is summarised as follows:

- Determine the Resource Units of the Thukela system (PBV000-00-10302)
- Determine the PES, the EIS and the ERC for each Resource Unit (PBV000-00-10303)
- Determine the Basic Human Needs Reserve (PBV000-00-10305)

The flow requirements/IFRs (quantity component of the Ecological Reserve) must now be quantified for each Resource Unit. This will provide the information to address those objectives (listed above) which have not been addressed in the reports already available.

1.2 PURPOSE OF THIS REPORT

The report consists of two sections as follows:

- Main report providing the results
- Appendix report providing all the specialist appendices.

The appendix report consists of all the specialists appendices generated as part of this task, as well as a summary of the results generated during this task.

The purpose of the main report is to:

- Document a summary of the methods followed. For the scientific detailed procedures, reference will have to be made to the relevant scientific papers.
- Provide the sequential actions undertaken during the specialist meetings to produce the results.
- Provide a detailed explanation of the format of the report chapters for each IFR site in which the results are provided.
- Provide all the results for each IFR site.
- Provide the confidence associated with the results generated per IFR site.

NOTE: From this point forward IFR 6 and 12 is not evaluated further.

- IFR 6
This is an old IFR site and has been irreversibly changed by the farmer. Access is limited and benchmarks destroyed. Due to the general lack of indicators present at the site additional work (to the previous work) would not have any purpose.
- IFR 12
This site could only be used if the benchmarks that have been vandalized would be reinstated by DWAF. These benchmarks were reinstated by DWAF after all site work was completed and could therefore not be used. However, this site can be used in future as a monitoring site.

1.3 STRUCTURE OF THE REPORT

This report combines the first 3 bullets into one chapter, i.e. chapter 2. Chapter 3 to Chapter 16 provides the results per IFR site. The main Thukela River is addressed first, i.e. IFR 1, 2, 4, 9, 15 and 16. The tributaries are addressed from the most upstream site to downstream. The last chapter provides a summary of the results and associated confidence.

Chapter 1: Introduction

This chapter.

Chapter 2: Approaches

This chapter provides a summary of the scientific methods used to determine the IFR. The sequential steps followed to provide the results prior to and during the specialist meetings are discussed. The outlay of the results chapters are also provided with an explanation of each section and the figures.

Chapter 3 to 16: IFR results

These chapters are presented in similar format and serve to produce the results for each IFR site. The chapters deal with the Thukela River first and then continue on to the most upstream tributary (Little Thukela) down to the Buffalo River.

Chapter 17: Summary

This chapter provides a summary of the results and provides the associated confidence.

2 APPROACHES FOLLOWED IN THIS STUDY

This chapter provides an explanation of the overall approach followed to quantify the Ecological Reserve (quantity component) for the Thukela Water Project. The Flow-Stress Response method (FS-R) was used to provide the low flows, and a method adjusted from the standard Building Block Methodology (BBM; King & Louw, 1998) and Downstream Response to Imposed Flow Transformation (DRIFT; Brown, C & King, J) approach was followed to set high flows. It is not the function of this report to provide the in-depth scientific rationale for these methods (which are available in scientific journals, as referenced), but rather to provide a simple summary of them.

The step-by-step method followed to provide the final flow recommendations for each IFR site is documented only in this chapter. The results for each site are then recorded on a chapter-by-chapter basis. The approach followed in producing the results is explained section-by-section. Chapter 3 is used as an example and the relevant section numbers are bracketed. Detailed specific changes for any IFR site are recorded in the relevant Chapters.

2.1 SEQUENTIAL PROCEDURE

The sequential procedure followed to determine an IFR (the quantity component of the Reserve) is summarised diagrammatically in Figure 2.1. The further steps in the process are then described from Section 2.3 onwards, following the section numbering used in the following (results) chapters. Reference will be made to the highlighted questions in Figure 2.1.

Fig 2.1 Sequential process to determine the IFR

1. What are the scenarios (ERCs) for which IFRs must be provided?	<table border="1"> <thead> <tr> <th>Scenario</th><th>PER</th><th>100</th><th>100</th><th>ERC</th><th>UP</th></tr> </thead> <tbody> <tr> <td>Scenario 1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr> <td>Scenario 2</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr> <td>Scenario 3</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr> <td>Scenario 4</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr> <td>Scenario 5</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr> <td>Scenario 6</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr> <td>Scenario 7</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr> <td>Scenario 8</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table>	Scenario	PER	100	100	ERC	UP	Scenario 1	0	0	0	0	0	Scenario 2	0	0	0	0	0	Scenario 3	0	0	0	0	0	Scenario 4	0	0	0	0	0	Scenario 5	0	0	0	0	0	Scenario 6	0	0	0	0	0	Scenario 7	0	0	0	0	0	Scenario 8	0	0	0	0	0
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Scenario 7	0	0	0	0	0																																																		
Scenario 8	0	0	0	0	0																																																		
Low flows 2. What are the stress indices for fish, inverts and veg?	<table border="1"> <thead> <tr> <th>Flow rate</th><th>3</th><th>1.5</th><th>2</th><th>0</th></tr> </thead> <tbody> <tr> <td>Reason</td><td>All life stages</td><td>All life stages</td><td>Critical cond</td><td>No survival</td></tr> <tr> <td>Stress</td><td>0</td><td>3</td><td>7</td><td>10</td></tr> </tbody> </table>	Flow rate	3	1.5	2	0	Reason	All life stages	All life stages	Critical cond	No survival	Stress	0	3	7	10																																							
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Reason	All life stages	All life stages	Critical cond	No survival																																																			
Stress	0	3	7	10																																																			
3. What would you expect under different river states (ERCs) for your components (flow related objectives / descriptions)?	Recommended C ERC - Maintain perennial flow - Maintain seasonal diversity - Operate to provide small to medium floods - Sufficient depth (30cm) to allow A nat to breed and feed in riffles for 70% of the time in wet season Alternative ERC B - Maintain perennial flow - Maintain seasonal diversity - Operate to provide small to medium floods - Sufficient depth (50cm) to allow A nat to breed and feed in riffles for 70%																																																						
4. What is the critical stress index? (compile critical curve)																																																							
5. Are the stress conditions under natural flow what you would expect? (refine stress indices)																																																							
6. What is the expected stress under maintenance & drought (wet & dry) conditions & at what % of time for the recommended ERC. How does this change for the alt ERCs?	Data base <table border="1"> <thead> <tr> <th rowspan="2">C/E</th><th colspan="2">Recommended ERC C</th><th colspan="2">ERC B</th></tr> <tr> <th>Requirement</th><th>Season</th><th>Requirement</th><th>Season</th></tr> </thead> <tbody> <tr> <td>3</td><td></td><td></td><td></td><td></td></tr> <tr> <td>4</td><td>Sufficient depth for breeding</td><td>Summer 70 %</td><td>Good breeding cond</td><td>Summer 70 %</td></tr> <tr> <td>5</td><td></td><td></td><td></td><td></td></tr> <tr> <td>7</td><td>Refuge areas maintained</td><td>Winter 70 %</td><td></td><td>10</td></tr> </tbody> </table> Complete grey blocks	C/E	Recommended ERC C		ERC B		Requirement	Season	Requirement	Season	3					4	Sufficient depth for breeding	Summer 70 %	Good breeding cond	Summer 70 %	5					7	Refuge areas maintained	Winter 70 %		10																									
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7	Refuge areas maintained	Winter 70 %		10																																																			
7. Which category does the flow scenarios represent. (express in stress)																																																							
High flows 8. Do the high flows as described in previous sp meeting occur under natural conditions. (adjust if necessary)	<table border="1"> <thead> <tr> <th colspan="4">FLOOD CLASS II: 5 - 9 m/s</th></tr> </thead> <tbody> <tr> <td>(what does it have to do)</td><td>(what is the flood characteristic that does that)</td><td></td><td></td></tr> <tr> <td>stimulus. Clean the spawning beds. Improve water quality. Remove algae build-up. Raise DO levels. Maintain</td><td>season.</td><td></td><td></td></tr> </tbody> </table>	FLOOD CLASS II: 5 - 9 m/s				(what does it have to do)	(what is the flood characteristic that does that)			stimulus. Clean the spawning beds. Improve water quality. Remove algae build-up. Raise DO levels. Maintain	season.																																												
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9. Are the number of events recommended for different scenarios realistic? (compared to hydrology) (adjust if necessary)	<table border="1"> <thead> <tr> <th colspan="4">FLOOD CLASS II: 5 - 9 m/s</th></tr> </thead> <tbody> <tr> <td>(what does it have to do)</td><td>(what is the flood characteristic that does that)</td><td>events</td><td></td></tr> <tr> <td>stimulus. Clean the spawning beds. Improve water quality. Remove algae build-up. Raise DO levels. Maintain</td><td>season.</td><td></td><td></td></tr> </tbody> </table>	FLOOD CLASS II: 5 - 9 m/s				(what does it have to do)	(what is the flood characteristic that does that)	events		stimulus. Clean the spawning beds. Improve water quality. Remove algae build-up. Raise DO levels. Maintain	season.																																												
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10. What are the final results/output for each scenario?	Flow duration table <table border="1"> <thead> <tr> <th></th><th>10%</th><th>20%</th><th>30%</th><th>40%</th><th>50%</th><th>etc</th></tr> </thead> <tbody> <tr> <td>Jan</td><td>1</td><td>1.5</td><td>2.7</td><td>3</td><td>3.2</td><td></td></tr> <tr> <td>Feb</td><td>3</td><td>3.7</td><td>3.6</td><td>4</td><td>4.6</td><td></td></tr> <tr> <td>Mar</td><td>3.5</td><td>3.7</td><td>3.9</td><td>4.1</td><td>4.2</td><td></td></tr> <tr> <td>etc</td><td></td><td></td><td></td><td></td><td></td><td></td></tr> </tbody> </table>		10%	20%	30%	40%	50%	etc	Jan	1	1.5	2.7	3	3.2		Feb	3	3.7	3.6	4	4.6		Mar	3.5	3.7	3.9	4.1	4.2		etc																									
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etc																																																							
11. Considering geomorph & H2O quality, will the objectives be achieved.	Provide qualitative reasoning.																																																						
12. What is your confidence in the results?	Numerical confidence evaluation.																																																						

The questions above which are specific to the FS-R method are questions 4, 5, 6 and 7.

2.2 THE FLOW-STRESS RESPONSE (FS-R) METHOD (FOR LOW FLOWS)

River processes and functions are naturally adapted to pre-impact or virgin flow patterns and a natural 'disturbance' regime (*sensu* Townsend 1989). These are two of the major drivers or causes of the biodiversity of a system. By requiring and using water resources, humans alter natural flow regimes, thus altering the natural disturbance patterns, i.e. by reducing flow in a river over time through damming or abstraction results in an increase in the low-flow disturbances to the system over time. The flow-on effects of this include a change in the natural biodiversity, in the goods and services which the ecosystem is capable of delivering, and in the stability and resilience of the system. Ecological health is reduced and the risk to the system is increased, resulting in the system becoming increasingly stressed (i.e. the natural stress paradigm is exceeded). Some of the indicators used in assessing the levels to which a river is stressed (either naturally or unnaturally) are fish, invertebrates and vegetation (O'Keeffe et al. 2002).

The Flow Stress-Response (FS-R) is a method (O'Keeffe et al. 2002) designed to guide the evaluation of the ecological consequences of modified flow regimes, based on the principles of ecological risk analysis (ERA) (Suter 1993), and using an index of flow-related stress. For the purposes of this method, the term 'stress' is used in a limited sense, to denote the discomfort/damage/undesirable changes experienced by the flow-dependent biota or other components/processes (e.g. water quality), as discharges are *artificially* altered. This definition excludes naturally-occurring stress, although this is recognised in the FS-R approach, as described in the following paragraph.

Natural flow regimes normally include low-flow episodes which cause natural stress to elements of the biota and changes to essential processes. These episodes are considered to be components of the natural 'disturbance' regime (Townsend 1989). Some level of low-flow stress is therefore considered necessary for the maintenance of the natural dynamic mosaic of species assemblages through space and time. Natural stress levels will vary from system to system, i.e. seasonal streams will have much higher natural stress levels than permanent streams. The desirability (or otherwise) of stresses in a system can only be judged in relation to the natural or reference stress regime.

A description of the Flow Stress-Response method

The Flow Stress-Response (FS-R) method is designed to be used within holistic Environmental Flow Recommendation (EFR) methodologies such as the BBM and DRIFT, as a way of consistently capturing specialist knowledge on the relationship between flow and hydraulic habitat, and the response of instream and riparian biota to adjustments in these. These relationships can then be directly translated into a 'stress profile'¹ for any flow regime, in terms of magnitude, frequency and duration. The FS-R method is independent of the level of biological and ecological knowledge available, although (as with other approaches) this will affect the degree of confidence in the flow recommendations.

The FS-R method is being used in the Thukela Project for assessing low flows, and focuses on water *quantity* requirements. The basis of the method is the application of a generic stress index describing the progressive consequences of flow reduction to the flow-dependent biota and river processes. Here, the **stressors** (e.g. flow), hydraulics and associated habitat changes are related to biotic **stress responses** in terms of abundance, life stages, and persistence. The generic stress index is adjusted for use to be specific to both sites and components (fish, aquatic invertebrates, riparian vegetation). Here, a detailed description of both ends of the stress index range (i.e. zero and the upper stress value) is

¹ Simplistically, the stress profile is created by linking relevant stress data to flow duration data, and generating a stress duration curve. The X axis of this graph is % Exceedence, and the Y axis is the Stress Index from 0 – 10.

important. The zero stress index relates to optimum and abundant habitat conditions under low flows. Stress 8 relates to a trickle, stress 9 to no flow (i.e. still pools present) and stress 10 to no surface water available. A copy of the generic stress index is illustrated in Table 2.1.

The FS-R process broadly consists of the following steps:

- A stress index of 0 – 10 is described for each element of the biota (fish, invertebrates, riparian vegetation), in relation to stresses experienced by specific flow-dependent organisms/processes under different flow conditions. Stress values (from 0 indicating no stress to 10 indicating very high stress) are attached to descriptions of the response of the organism to flow and habitat alterations.
- Each stress value at each river site is related to a specific flow at the site, via the hydraulic calibrations for the site. The hydraulic conditions are described for each of the pinpointed stress levels.
- The natural and altered low-flow time series are converted to stress time-series, and these in turn to stress duration curves and spell analyses. This information is used to evaluate any provided low-flow scenario.

2.3 THE DEVELOPMENT OF ECOLOGICAL RESERVE CATEGORY SCENARIOS

2.3.1 Summary of the ERC scenarios (Question 1; 3.3.1 in Chapter 3)

During November 2001, a specialist meeting was held during which reference conditions, the Present Ecological State (PES), and the recommended ecological category - the Ecological Reserve Category (ERC) - were determined for each IFR site (PBV000-00-10303). The ecological states (known as the Ecostatus) are an integration of the ERCs of each IFR component. The results are summarised in a figure, as shown in Figure 2.2, which provides the PES, indicating whether a negative trajectory is present and what the state would be in 20 years (time period chosen arbitrarily) if present, activities were to continue in the catchment. The recommended ERC is based on the PES and the importance of the river, and is modified according to the attainability of measures required to achieve the improvement. The red arrows at the top of the figure illustrate both recommended and alternative categories, for which Reserve scenarios will be provided.

To determine the alternative scenarios, each component ERC and the Ecostatus are increased or decreased by a category or half a category, according to the following rules (agreed on verbally and by email with the RDM Office):

PES or ERC	Increase	Decrease
A	N/a	B
A/B	N/a	B/C
B	N/a	C
B/C	B	C/D
C	B	D
C/D	B/C	D
D	C	N/a
E	D	N/a
E/F	D	N/a
F	D	N/a

Exceptions to these rules can be made if required and if stipulated.

Fig 2.2 Illustration of the PES, Trajectories of change, and ERC Scenarios



COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP
WATER QUALITY	B	0	B	EIS MODERATE SI LOW	B	
GEOMORPH	D	-	D/E		D	C
RIPARIAN VEGETATION	E	-	E/F		D	D
FISH	D	-	D		D	C
AQUATIC INVERTS	D	0	D		D	C
ECOSTATUS	D	-	E		D	C

2.3.2 Criteria for the various ERCs (Question 2; 3.1.2 in Chapter 3)

For each of the ERCs for which flow scenarios will be supplied, i.e. **the recommended and alternative ERCs**, the conditions to be achieved or maintained must be described. When the alternative scenarios are described, these are often required to be hypothetical as various combinations of non-flow and flow related situations could result in a specific Ecotatus. A hypothetical situation is therefore described for each alternative scenario per component category, and the intention is to provide flows to maintain these states.

Under “Criteria for the various ERCs”, the conditions and requirements to maintain the prescribed conditions are described for each component. This work is undertaken as part of the specialist preparatory work for the specialist meeting. .

2.4 STRESS INDEX FOR EACH IFR COMPONENT FOR LOW FLOWS (Question 3, 3.1.2 in Chapter 3)

2.4.1 Introduction

A site-specific index of zero (no stress) to 10 (maximum stress) was designed for fish, invertebrates and riparian vegetation. This work was undertaken at a separate specialist meeting dedicated to this task (20 to 24 May 2002). The following tools were used to determine the stress indices:

- Hydraulics
- Photos and videos of various flow conditions
- Habitat modelling
- Geomorphological and sediment transport information

- Fish survey results and historical information
- Aquatic invertebrate survey results and historical information
- Vegetation surveys on profile and habitat modelling cross-sections

The stress indices for each site are provided as Appendix G (see example table 2.1). The general approaches followed for each of the components are described in the following sections.

2.4.2 Fish (CJ Kleynhans)

AL Birkhead provided the hydraulic analysis specific to the fish approach. A description of which is included in this section.

The approach followed to assess the habitat-flow-response of fish to various low flows during the dry season (i.e. outside the breeding season) and during the wet season (breeding season) is explained here. This approach links with the Flow-Stress Response method of O'Keeffe, Hughes and Tharme (2002). It attempts to relate the stress response of fish species to altered flows, based on:

- The habitat and cover preferences of fish species. This is based on available literature, as well as expert knowledge.
- The responses of various broadly defined fish habitat attributes to different base-flows. This assessment is based on interpretation of hydraulic characteristics of the habitats at the site being investigated. This was done with the assistance and guidance of a hydraulician.
- Where habitat modelling is available, this information is used in conjunction with the hydraulics as an additional source of information that can lead to a more reliable interpretation of fish habitat conditions. This was done with the assistance and guidance of a hydraulician and the habitat modeller.

Habitat availability assessment

Habitat availability assessment is based on:

The availability of the following flow-depth categories at various flows:

- Slow-deep (SD): > 0.5 m deep; velocity < 0.3 m/s.
- Slow-shallow (SS): <0.5 m deep; velocity < 0.3 m/s.
- Fast-deep (FD): >0.3 m deep; velocity > 0.3 m/s.
- Fast-shallow (FS): < 0.3 m deep; velocity > 0.3 m/s.

Abundance of flow-depth classes were rated as follows:

- Very abundant = 5
- Abundant = 4
- Moderate = 3
- Sparse = 2
- Rare = 1
- None = 0

Availability of fish cover types

Fish cover types are the following:

- Overhanging vegetation: Thick vegetation overhanging the water by approximately 0.3m, and not more than 0.1m above the water surface (Wang *et al.* 1996).
- Substrate: The degree to which various substrate components (rocks, boulders, cobbles, gravel, sand, fine sediment and woody debris ("snags") provide cover for

fish is judged qualitatively. No detailed assessments of the stream substrate or estimation of the contribution of individual components are attempted.

- Bank undercut and root wads: Banks overhanging water by approximately 0.3m and not more than 0.1m above the water surface (Wang *et al.* 1996).
- Water column: This requirement relates specifically to open water.
- Aquatic macrophytes: Submerged and emergent plants were included, and a qualitative estimate made of the cover value for fish.

Table 2.1 An example of a site specific stress index for fish

FISH STRESS INDEX						RECOMMENDED ERC D SCENARIO EVALUATION			C SCENARIO EVALUATION		
Q m³/s	Habitat Response	SPECIES RESPONSES: HABITAT SUITABILITY FOR DIFFERENT LIFE-STAGE REQUIREMENTS (Breeding, Survival /Abundance, Survival, Health, Water Quality)		SI	Critical SI	FISH: D (PES D)			FISH: C (PES D)		
						Requirements	Season	Dur - % of time	Requirements	Season	Dur - % of time
				0							
7.5	FD=4 FS=2 SD=4 SS=3	Breeding = 4 Survival/Abundance = 4 Cover = 5 Health = 5 Water quality = 5	Breeding slightly impacted by silting of cobble and gravel beds.	1	1						
4.3	FD=3 FS=3 SD=4 SS=3	Breeding = 3 Survival/Abundance = 4 Cover = 4 Health = 5 Water quality = 5	Breeding moderately impacted, abundance slightly impacted by reduced cover due to reduction of deep-water areas.	2	3				Facilitate survival of abundant adult population in pools and shallows in summer.	Summer	70
				3	4.5						
2.1	FD=2 FS=2 SD=3 SS=3	Breeding = 1 Survival/Abundance = 3 Cover = 3 Health = 5 Water quality = 4	Breeding critically impacted by silting, abundance moderately impacted by lack of deep water and increased temperatures.	4	5.2	Maintain shallow slow-flow refuges for fish juveniles. (SI<4 2.1m³/s).	Summer	50	Maintain some areas of clean cobbles as <i>A. natalensis</i> refuge habitat to improve species diversity year round.	Winter	70
1.3	FD=1		The flow is greater than a 'trickle' providing at least a little cover in 'fast deep' habitat, improving abundance and health.	5	6	Perennial flow: Some surface flow during winter for 70% duration. SI: 5	Winter	70			
0.5	FD=0 FS=2 SD=2 SS=4	Breeding = 1 Survival/Abundance = 2 Cover = 1 Health = 4 Water quality = 2	Breeding critically impacted by silting, abundance and health impacted by lack of cover and raised temperatures.	6	9	Maintain moderate population of adult <i>L. natalensis</i> in pools and shallows. SI < 6. Limit impact of suspended silt (from Driel scour releases) on fish respiration and abundance of macroinvertebrate food organisms.	All year	100	Maintain moderate population of adult <i>L. natalensis</i> in pools and shallows. SI < 6. Limit impact of suspended silt (from Driel scour releases) on fish respiration and abundance of macroinvertebrate food organisms.	All year	100
0	FD=0 FS=0 SD=2 SS=4	Breeding = 0 Survival/Abundance = 1 Cover = 1 Health = 3 Water quality = 2	Breeding failure. Abundance and health seriously impacted by lack of habitat and increased temperatures.	7	9.7	Facilitate survival of minimum adult populations of <i>L. natalensis</i> in pools.	Winter	100	Facilitate survival of minimum adult populations of <i>L. natalensis</i> in pools.	Winter	100
				8	9.9						
				9	10						
0	FD=0 FS=0 SD=0 SS=0	Breeding = 0 Survival/Abundance = 0 Cover = 0 Health = 0 Water quality = 0	No survival.	10	10						

Abundance of cover types

Abundance of cover types for fish were scored as follows:

- Very abundant = 5
- Abundant = 4
- Moderate = 3
- Sparse = 2
- Rare = 1
- None = 0

Habitat suitability

Habitat suitabilities for a particular species (i.e. with reference to the preferences and requirements of the “target” species during different life-stages) were rated on the basis of expert knowledge, based on a simplified habitat suitability index (HSI) calculated as proposed by Stuber, Gebhart and Maughan (1982). This method makes use of the suitability of various habitat characteristics to fulfil the life-stage requirements of the “target” species. The suitability of the habitat (flow-depth class and cover) under various flow conditions were scored for each of the following:

- Breeding (B)
- Survival / abundance (S)
- Cover (C)
- Health (H)
- Water quality (only flow related aspects – temperature and oxygen concentration) (W)

Suitability scoring followed the following guidelines:

- Very high = 5
- High = 4
- Moderate = 3
- Low = 2
- Very low = 1
- None = 0

The habitat suitability index for a particular flow was calculated as follows:

$$HSI = (B+S+C+H+W)/5$$

Where assessment needs to be done outside the breeding season (dry season), the HSI can be calculated by excluding suitability for breeding requirements:

$$HSI = (S+C+H+W)/4$$

The average HSI score is expressed as a proportion of 10 and then transformed (reversed) to relate a high score out of 10 to a low suitability, and vice versa, e.g. 0 would indicate completely suitable conditions, while 10 would indicate completely unsuitable conditions. This procedure was followed to relate the average HSI score to the flow-stress rating table of O’Keeffe *et al.* (2002), shown in Table 2.2. It must be emphasised that Table 2.2 is generic in order to render it applicable to various biological groups. Some interpretation may be necessary to apply in specific situations.

The procedure for fish is specified in Table 2.3.

Table 2.2 A first attempt to describe a generic index of stress for flow-dependent instream fauna in terms of stressors (defined as reduction in base flow and reduction in habitat) and responses (defined as changes in the abundance of particular species; breakdown of particular life-stages; and reduced survival). (O’Keeffe et al. 2002)

Generic dimensionless index of base-flow stresses for instream biota					
Stress Index	Stressors		Responses		
	Flow*	Habitats	Species Abundance	Life Stages	Survival
0	Very Fast, very deep.	All very abundant.	All very abundant.	All healthy.	All species.
1	Fast, deep.	All abundant.	All abundant.	All healthy.	All species.
2	Fast, deep, but slightly reduced.	Critical habitats not abundant.	Slight reduction for rheophilic species.	All healthy in some areas.	All species.
3	Moderate, fairly deep.	Reduced critical habitat.	Reduction for rheophilic species.	All healthy in remnant areas.	All species.
4	Moderate, some deep areas.	Critical habitat limited.	Further reduction for rheophilic species.	Critical life-stages of sensitive species at risk.	All species.
5	Moderate/slow, few deep areas.	Critical habitat very reduced.	Remnant populations of all rheophilic species.	Critical life-stages of sensitive species Non-viable.	All species.
6	Moderate/slow, no deep areas.	Critical habitat residual.	Sensitive rheophilic species rare.	Critical life-stages of many species non-viable.	All species in the short-term.
7	Slow, shallow.	No critical habitat.	All rheophilic species rare.	All life-stages of sensitive species at risk or non-viable.	Sensitive species disappear.
8	Slow, trickle.	Flowing water habitats residual.	Only remnant populations of hardy rheophilic species.	All life-stages of all rheophilic species at risk or non-viable.	Most rheophilic species disappear.
9	No flow.	Stagnant habitats only.	Only pool dwellers.	All life-stages of all rheophilic species non-viable.	All rheophilic species disappear.
10	No surface water.	Sub-riverbed refugia only.	Only specialist survivors.	Virtually no development.	Only specialist survivors.

- Note: This does not imply that at 0 stress all species prefer deep fast flowing water. This does imply that at these conditions, **all** habitats should be abundant, i.e. slow shallow habitats.

Table 2.3 Example for data entry sheet to relate habitat-flow response to fish species response for various flows and the corresponding flow-stress response

Base flow responses for fish species						Flow-stress levels: Breed season	Flow-stress levels: outside breed season	Generic description of flow-stress response: Breed season	Generic description of flow-stress response: Outside breed season
Flow (m³/s)	Flow depth classes	Relative flow depth abundance rating	Cover types	Relative cover rating	Species responses: Habitat suitability for different life stage requirements (Breeding, Survival /Abundance, Cover, Health, WQ)				
	FD		Overhanging vegetation		Breeding	(Average score calculated, transformed and reversed to be expressed out of 10).	(Average score calculated, transformed and reversed to be expressed out of 10).	O'Keeffe et al. (2002). Table 2.2.	O'Keeffe et al. (2002). Table 2.2.
	FS		Substrate		Survival /Abundance				
	SD		Bank undercut root wads		Cover				
	SS		Water Column		Health				
			Aquatic macrophytes		WQ				

Where:

SD - Slow-deep: > 0.5 m deep; velocity < 0.3 m/s.

SS - Slow-shallow: <0.5 m deep; velocity < 0.3 m/s.

FD - Fast-deep: >0.3 m deep; velocity > 0.3 m/s.

FS - Fast-shallow: < 0.3 m deep; velocity > 0.3 m/s.

Relating discharge to habitat availability: approach used for assessing the response of fish to changes in discharge (AL Birkhead)

Four flow-depth categories (with flow defined here by velocity) were applied in defining habitat availability for fish (as described above), with relative abundance ratings specified according to the 0 to 5 scale.

Hydraulic analyses for the sites varied from single cross-sections through riffle/rapid type units, multiple cross-sections including pool type units, and sites for which a digital terrain model (DTM) was developed. From these analyses, the discharges corresponding to the critical depths (maximum and average) and velocities (average) defining the flow-depth categories were determined.

A matrix of discharge against habitat abundance (based on modelled depth and velocity) was developed (e.g. Table 2.4, an example from IFR Site 3 on the Little Thukela River). The depth and velocity threshold values corresponding to discharge values of 11.0, 3.1, 0.37 and 0.1 m³/s are shaded in Table 2.4. Note that the average velocity in the rapid unit is estimated to be half the maximum value (personal observation). It is for this reason that the average velocity of 0.15 m/s ($Q = 0.10 \text{ m}^3/\text{s}$) in the rapid is shaded - since this corresponds to the flow below which all fast flowing ($> 0.3 \text{ m/s}$) habitat is disappears.

For each of these flows, abundance ratings are estimated for the site for all four flow-depth categories. The slow-velocity categories are expected to disappear at high discharges, and the fast-velocity categories at low discharges. It is therefore expected that discharge-habitat type matrices (when given in the format of Table 2.4) will have higher abundance values on the diagonal. Other pertinent discharge values (corresponding to, for example, linear interpolations in flow depth or velocity) between these "threshold values" (e.g. 1.0 and 9.0 m³/s, and including the cessation of flow condition) are also included in the matrix and habitat abundance ratings estimated based on available hydraulic information.

Table 2.4 Example of the matrix of discharge against habitat abundance using IFR Site 3 on the Little Thukela River

Discharge $Q \text{ (m}^3/\text{s)}$	Rapid			Pool			Habitat type abundance			
	y	y_{av}	v	y	y_{av}	v	FD	FS	SD	SS
11.0	0.79	0.48	1.60	2.50	1.62	0.30	5	2	0	1
9.0	0.75	0.44	1.45	2.42	1.56	0.26	4	2	1	1
3.1	0.66	0.36	1.04	2.23	1.41	0.16	3	3	3	2
1.0	0.43	0.22	0.47	1.91	1.18	0.04	2	3	4	2
0.37	0.43	0.18	0.29	1.80	1.10	0.02	1	2	4	3
0.10	0.34	0.11	0.15	1.72	1.05	0.01	0	1	3	3
0.00	0.24	0.00	0.00	1.61	0.96	0.00	0	0	2	3

y = flow depth (m) y_{av} = average flow depth (m), v = average velocity (m/s)

2.4.2 Invertebrates (C Dickens)

This investigation has concentrated on flow-dependent taxa. Several of these are highly dependent on appropriate flows and are considered good indicators of river condition. Another group of organisms requiring consideration, but is not as dependent on flow, is that found in the marginal vegetation. This group has been included, as small reductions in water depth rapidly expose the marginal habitat and threaten its inhabitants. Many will nevertheless survive for short periods particularly in winter, on alternative substrates, though under threat.

The method for determining the stresses was as follows:

The marginal vegetation community was investigated by using the observed habitat during the day of the field visit as a reference point. The stress index of 0 was set so that there was abundant inundation of the bases of the marginal vegetation. Analyses were done making use of the hydraulic profiles and tables. The indices of greater stress were derived similarly, by measuring the reduction in water level that would leave only the bases of the marginal vegetation inundated. Note that this assessment for marginal vegetation communities applied only for the wet season, as during dry seasons the expectation would be that flows would recede from the vegetation.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over substrates in the rapid and run sections, and diverse biotope. Where banks provided habitat, it was important to maintain flow into the adjacent channel. The habitat model and hydraulic data were used to determine the depths and velocities that would produce minimal stress to rheophilic species. Higher stresses were determined by anticipating minimal depths and velocities at which only remnants of the required habitat would be provided. Stresses would be caused by reductions in velocity, with corresponding increases in temperature, sedimentation, diatom growth on stones, exposure to predators, and possibilities of decreased oxygen concentrations, especially at night. Reduced velocities would also cause stress to organisms that made use of flowing water to aid gaseous exchange. Slow velocities require the expenditure of energy to irrigate the gills, and this reduces the competitiveness of the insect.

A flow-dependent aquatic invertebrate stress index is provided below (Table 2.5) as an example.

Table 2.5 Flow Dependent invertebrate communities for IFR 3

Disch m³/s	Flow related hydraulics	Physical habitats	Abundance	Aquatic life stages	Persistence	Motivation	SI
1,75	Fast flow Wide WP: 14,6 m Max depth: 50 cm Ave depth 25 cm Width 11,8 m Ave vel. 0,6 m/s	Embedded stone habitat with clean stones and high velocity flows in the main channel.	All abundant.	All life stages healthy.	All species.	Fast flows and clean stone habitats supporting diverse rheophilic communities including Perlidae and Oligoneuridae.	0
0,49	Some areas of high velocity, WP moderately reduced 9,9m Max depth 36 cm Ave depth 19 cm Width 8,1 m Ave vel 0,32 m/s	Critical habitat of fast flow limited.	Rheophilic species reduced.	All viable, some life stages at risk.	All species.	Some good quality habitat for rheophilic species would remain although some like Oligoneuridae would become rare.	4
0,1	Slow trickle with very narrow WP 7,1 m Max depth 24 cm Ave depth 11 cm Width 6,3 m Ave vel 0,15 m/s	Flowing water habitat severely limited to a trickle in deep cracks.	Rheophilic species rare.	All life stages of most rheophilic species at risk or non- viable.	Most rheophilic species disappear.	Velocity of water will be insufficient to maintain many rheophilic populations. Oligoneuridae would have long since disappeared.	7

Where:

Q = Flow

WP = Wetted perimeter

Ave depth = Average depth

SI = Stress index

Max depth = Maximum depth

Ave vel = Average velocity

2.4.3 Riparian Vegetation (N Kemper)

Rationale

i. Low flows

The critical vegetation components were selected based on their life history characteristics and dependence on water. The components selected for the Thukela River differed from site to site and included:

Setaria sphaceolata: This occurs in distinct clumps at the rivers edge and on islands within the main channel. These occur in pockets of sediment deposited between rocks and on the marginal terraces. On careful investigation it was found that all clumps had direct contact with the river during the summer months. This contact is essential to ensure healthy growth temperature control and reproduction. Individual clumps are located at different vertical levels above the river. The clumps located higher up still maintain contact with the river by extended rooting characteristics. These individuals have an advantage over those located lower down in terms of their reproductive success and persistence during higher flows and freshes. Reproductive advantage is achieved due to the fact that the seeds from these clumps are able to fall on sediment on moist pockets which are less frequently inundated by river flows.

Juncus spp.: This occurs in large vegetative mats. The reproductive success is mainly achieved by vegetative growth achieved by the extension of the rhizome into viable marginal habitats. This strategy affords *Juncus* the ability to optimise its contact with the river as well as to locate itself in areas less disturbed by higher flows. *Juncus* also reproduces by seeds which are probably water borne.

Salix mucronata (subsp. *woodii*): Is a woody species, which frequently occurs on the edges of a river within the marginal, and lower riparian zones. It usually grows in areas frequently inundated during summer by elevated flows and are maintained by base flows during summer and winter. It is mainly spread by means of woolly seeds during late summer where they are distributed within the marginal and riparian zone by water during elevated flows and by wind. Little is known about its rooting characteristics, however, it is believed that these are restricted mainly to the marginal zone as they are not very tolerant of inundation for extended periods. *Salix mucronata* is mainly dependent on elevated flows for relief of moisture stress during summer and for the sake of seed distribution. Its low flow requirements are not well understood.

The stress levels of the critical components of both *Setaria* and *Juncus* were investigated in relation to a range of river flows and associated water levels.

Generic vegetation stress tables (Table 2.6) were compiled for stress levels from 0 (no stress) to 10 (maximum stress).

Table 2.6 Generic riparian vegetation stress table

Life history stages / characteristics		
Stress	Adults	Juveniles
0	Complete health and reproductive.	Germination and establishment of seedlings.
1		
2		
3	First signs of water stress.	Growth ceases.
4	Flower/fruit abortion.	Moderate wilting.
5	Leaf wilting or loss.	
6	Thinning or partial death of above-ground	Severe wilting.

Life history stages / characteristics		
Stress	Adults	Juveniles
	biomass.	
7	Loss or death of above-ground biomass, but rootstock remains viable.	
8	Complete death.	Desiccation/death.
9		
10	Stress levels of 10 were identified to occur when water levels fell below the maximum rooting depth of individuals. This would most likely occur during low flows in summer months when individuals are active and growing. Stress is less likely to occur during winter months as the individuals are dormant.	

Stress response tables were constructed for the critical components for various levels of stress corresponding with different river flows.

The relatively shallow maximum rooting depth of *Setaria* compared to that of *Juncus* which is much deeper indicates that it is more sensitive to reductions in river flow. *Setaria* is therefore more likely to stress in response to reductions in river flow, and is therefore more useful for applications with the Flow Stressor Response approach. This is demonstrated in Table 2.7, which illustrates that *Setaria* juveniles have a higher flow requirement than the other vegetation components. To derive this information, the generic vegetation stress table (Table 2.6) was applied to *Setaria* for adult individuals present and for juveniles recruiting in the marginal zone.

Table 2.7 Comparison of stresses and flow requirements between the different vegetation indicators.

Stress	<i>Setaria</i> adults	<i>Setaria</i> juveniles	<i>Cyperus</i> adults (bank)	<i>Cyperus</i> adults (island)
0	1.6 m ³ s ⁻¹	1.6 m ³ s ⁻¹	1.6 m ³ s ⁻¹	1.6 m ³ s ⁻¹
1				
2				
3	0.84 m ³ s ⁻¹		0.39 m ³ s ⁻¹	0.04 m ³ s ⁻¹
4				
5				
6		1.1 m ³ s ⁻¹		
7				
8	0.63 m ³ s ⁻¹	0.84 m ³ s ⁻¹	0.14 m ³ s ⁻¹	0 m ³ s ⁻¹
9				
10				

The generic vegetation index shown in Table 2.6 was also applied for *Juncus* adults occurring in the marginal zone and on islands within the active channel, also in a site specific manner. An example of the stress index is shown in Table 2.8.

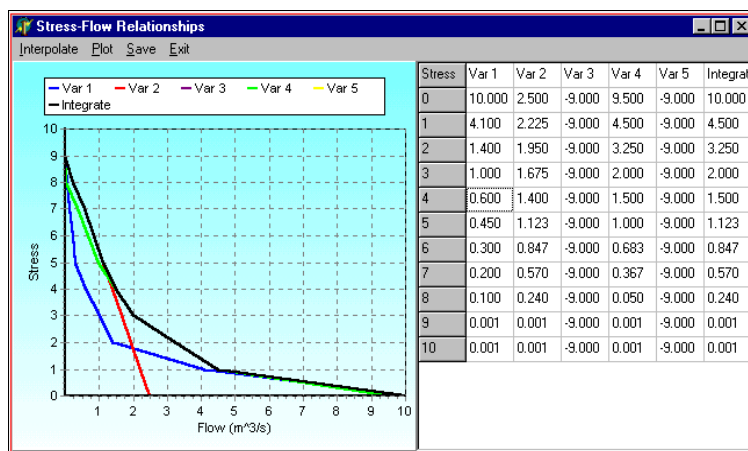
Table 2.8 An example of a vegetation stress index for *Juncus* adults

Flow	Depth/s	Response	Motivation	Stress
1	0.4	Complete health and reproductive	A stress of 0 would occur if water reached the base of the above- ground biomass. Most of roots located in saturated ground.	0
0.8	0.38	Good health and reproductive	Water levels well within rooting depth of individuals.	1
0.5	0.34	First signs of water stress	Large percentage of roots not in contact with water.	3
0.35	0.32	Leaf wilting or loss	Most of roots are exposed except for root tips.	5
0	0.1	Death of both above ground and below ground biomass.	Maximum stress levels occur when water levels are reduced below the maximum root depth of the adults would result in stress levels of 8 - 10. Roots no longer have contact with water.	8

2.5 FLOW STRESS RELATIONSHIP - IDENTIFICATION OF THE CRITICAL STRESS CURVE (Question 1; 3.2 in Chapter 3)

Once the stress indices (for low flows) have been identified for each component, the numbers are tabled and the unidentified flow stresses interpolated. At any one flow, the component with the highest stress point represents the critical curve. Figure 2.3 illustrates the interpolation and the critical curve. The black line represents the critical curve and the other lines the stress flow relationships for the various components. The critical curve in this case consists of the flow dependent invertebrates (red line) for the stress range 4 to 9, the vegetation (green line) for the stress range 4 to 1 and fish (blue line) the range of 1 to zero.

Fig 2.3 Component and critical stress curves



Var 1: Fish
Var 2: Flow Dependent Invertebrates
Var 3: Marginal Vegetation Invertebrates
Var 4: Riparian Vegetation 1
Var 5: Riparian Vegetation 2

From this point on, all conversions of flow to stress use the critical curve. Specialists refer back to their component stress index in order to convert any one critical stress value to their corresponding component stress value. The critical stress and corresponding component stresses are tabled in the spreadsheets (Appendix G).

The critical curve was compiled at the July and August 2002 specialist meetings, and the relationship between the different component stresses and the critical curve were completed on the spreadsheets during the same meetings.

2.6 STRESS DURATION CURVES (PROFILES)

2.6.1 Natural stress profile

(Question 5; 3.3.1 in Chapter 3)

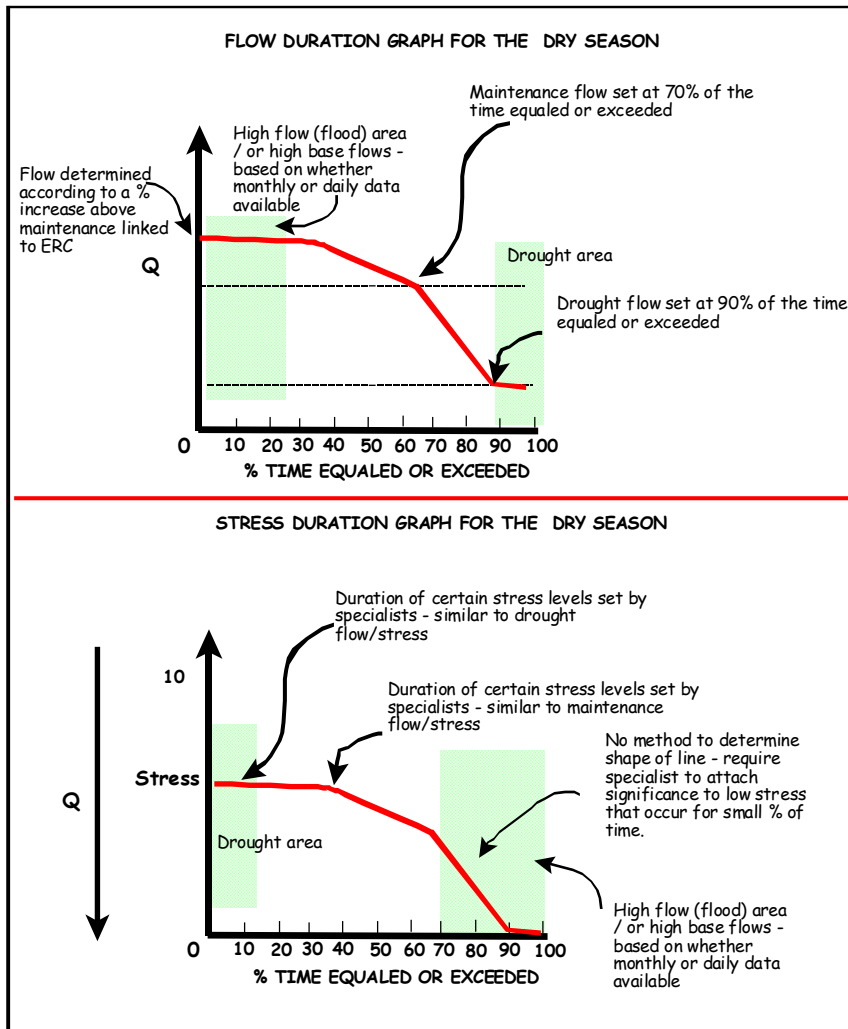
The modelled natural flow (either monthly or daily pending data availability) is converted to stress (using the critical stress profile) and the wet and dry season presented to specialists. Specialists then determine whether these represent the expected stress conditions under natural flow conditions. This, in essence, represents a hydrological check of the stress indices. The natural stress duration curve is represented as the blue line in the Figure 2.5 (dry season). This check took place during the July and August 2002 specialist meetings.

2.6.2 Recommended stress profile for each Reserve scenario (ERC)

(Question 6 and 7; 3.3.2 in Chapter 3)

The interpretation of stress durations is complex as the discharge values decrease up the y-axis, as opposed to the standard flow duration graphs, in which discharge values increase up the y-axis. This difference is accommodated for in the stepwise procedure as explained below. The relationship between flow duration graphs, as used during the determination of flows during the application of the BBM process, and the stress duration graph is illustrated in Figure 2.4.

Fig 2.4 A comparison between flow duration and stress duration graphs



The stepwise procedure for recommending the low-flow IFR is as follows:

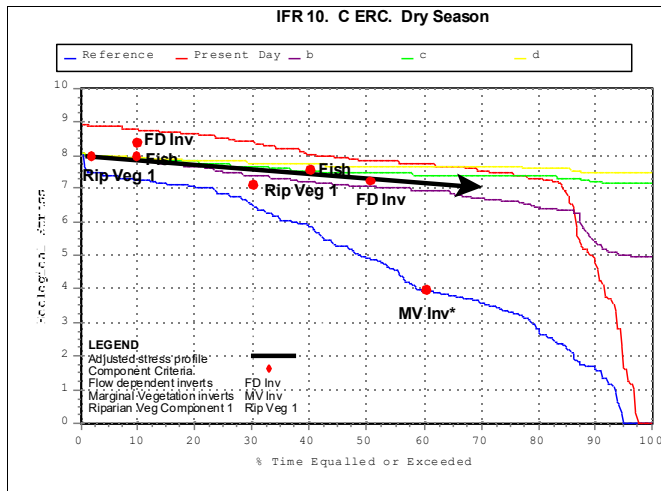
- Specialists determine the percentage time during which stress would be equalled or less for each different season. This is in contrast to flow duration, in which the calculation would be percentage time during which flow would be equalled or exceeded. The specialists are required to provide at least the maintenance stress (set according to assurances identified by the hydrologist) for both seasons, and the drought stress (at 10% assurance). Any additional points, which can provide more information regarding the shape of the curve, are useful. This work was undertaken in preparation for, and during, the July and August specialist meetings. The information is documented in the spreadsheets (Table 2.1, column 7 - 12). This information is required for each component, for each ERC for which a Reserve scenario must be generated. Specialists use the criteria set for the alternative ERCs

to determine whether the stress will change under these conditions, or whether the stress remains the same and the duration changes.

- The stress (critical values) for the wet and dry season at specific percentage points are provided to the facilitator who tables these on a flip chart and plots them on a blank stress profile.
- The stress profile is then overlain with the natural stress profile, a modelled present day hydrology (or preferably observed gauged data if at all possible), and desktop estimated Reserves for each relevant ERC.
- The natural and present day (or observed) hydrology is used to determine whether the points recommended by specialists are realistic. The following are basic rules to consider:
 - In a river where present flows are greater than natural (e.g. where the river is used as a conduit), recommendations can be greater than natural.
 - If specialists have identified the modified present flow regime as a problem for their component, and require a flow improvement for the component ecological condition, their points should fall between natural and present, i.e. closer to the natural than to the present flow.
 - If specialists have identified the modified present flow regime as a reason for the PES, but the present state must be maintained, and there is no negative trajectory, points should fall beyond both the natural and present lines. If however there is a negative trajectory, improvement will be required to MAINTAIN, and therefore points can again fall between natural and present flows.
 - If specialists have identified that all the causes of the PES are non-flow related, points should not reflect any improvement of the present flow regime.
 - In a river where present flows are greater than natural, it is highly likely that the points would fall between present and natural, i.e. representing more flow than natural, but less than present.
- In general, the points plotted for the components representing the lowest stress (see red dots on Figure 2.5) at any time guide the shape of the recommended low flow. Outliers are investigated and if confidence associated with these recommendations are very low, these points are not used to shape the curves.
- The curve is then drawn in by hand. This hand-drawn line represents a band (of flow /stress requirements). Figure 2.5 illustrates the process to the point at which the curve is drawn

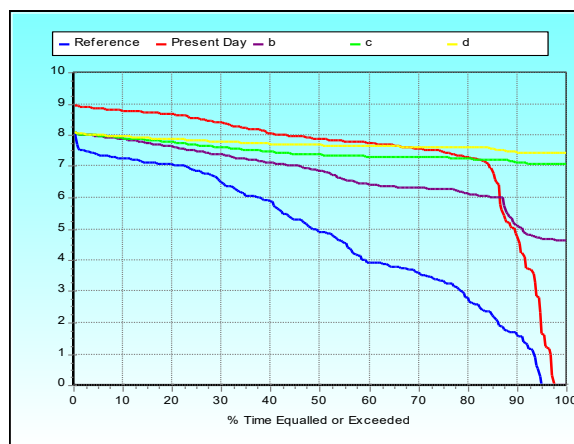
Fig 2.5 The hand-drawn line representing a band of flow/stress requirements from the individual specialists

Note: b,c and d refers to B, C and D ERC



- The hydrologist then investigates which Desktop-generated curve most closely represents the recommended curve, and adjusts the hydrology to fit the hand-drawn curve.
- This curve is presented to the specialists, who indicate whether further manipulation is required or whether the curve represents their requirements adequately.
- The final generated curve is then presented graphically (Figure 2.6) in the report.
- The hydrologist provides the changes required to adjust the Desktop (Hughes and Hannart, 2003) estimates and this is documented in the report.

Fig 2.6 The final curve



At this point the low flow recommendations for each Reserve scenario has been finalised and high flow recommendations are now required to enable the final Reserve scenarios to be provided.

2.7 APPROACH TO HIGH FLOWS

(Question 8 and 9; 3.4 in Chapter 3)

A FS-R approach is being developed for high flows but has not yet been used in a Reserve determination study. The approach used for high flows in this study has elements of both the BBM and the DRIFT methodologies. The fish, invertebrate and riparian vegetation specialists provide the functions of floods and identify the size of the events using the hydraulic cross-sections, photos and videos of known flows and interaction with the geomorphologists. The geomorphologists use the sediment transport modelling to determine the size of the events they require, as well as the number of events. This is further described in 2.7.1)

The stepwise approach to determining the high flows was as follows:

- Each specialist identified the range of high flows that will undertake similar functions. These were overlain and integrated to provide various classes of high flow events. Class 1 high flows are the smallest events - the freshes - and the larger the classes, the larger the size of the events. The largest class flood will represent flows with a return period of 1:2 or more. An example is provided below of the integrated floods to provide the size classes

Table 2.9 A summary of the flood class ranges, and the recommended high flow events for each component

Flood Classes m ³ /s	I	II	III	IV	V	VI
Fish	10-20	20-25 25-35				
Invertebrates	10-15	15-40		50-100		
Vegetation	8-15	15-40	40-80	80-180		
Geomorphology		20 - 39	64-106		106-236	236-500
Integrated	8-19	20- 39	40-79	80-105	106-235	236-500

- Specialists documented the functions and described the critical hydraulic parameters associated with each class of flood per component. This information is documented in the spreadsheets (Appendix G, column 2 to 6). An example of the spreadsheet is provided as Table 2.10

Table 2.10 High flows – Functions and associated critical hydraulic parameters

FLOOD CLASS II: 10 - 24 m³/s IFR 3				RECOMMENDED ERC C/D SCENARIO EVALUATION			B/C SCENARIO EVALUATION			D SCENARIO EVALUATION		
				Fish C, Inverts B/C, Geomorph C/D; Rip veg D (PES D/E)			Fish B (PES C); Inverts B (PES B/C), Geomorph B/C (PES C/D); Rip veg D (PES D/E)			Fish D (PES C); Inverts C/D (PES B/C), Geomorph D (PES C/D); Rip veg D (PES D/E)		
Com.	Function/s (what does it have to do)	Description (what is the flood characteristic that does that)	Season	No of events	Frequency	Reasoning	No of events	Frequency	Reasoning	No of events	Frequency	Reasoning
Inverts	To provide flow and thus habitat variability during summer in order to support a more diverse biodiversity. Short-term inundation of fresh habitats creates temporary opportunities for some pioneering species such as Baetids. These pioneering species are important for the reliance of the stream. Several life cycles will be stimulated by these events.	Sufficient flow to elevate the low flow water levels.	Spring / Summer	2	7:10	Maintain variability of flow.	4	7:10	Maintain variability of flow, closer to natural.	2	5:10	Maintain some variability but less reliable.
Fish	Facilitate peak midsummer breeding. Maintain longitudinal connectivity	Increased discharge when fish are mature. Moderate scouring flow.	Summer	2	8:10	To stimulate major spawning and migration by all species. Repeated floods required to maximise breeding success of serial spawners.	4	8:10	To stimulate major spawning and migration by all species. Repeated floods required to maximise breeding success of serial spawners.	4	6:10	To stimulate major spawning and migration by all species. Repeated floods required to maximise breeding success of serial spawners.
Rip Veg	To deposit sediments and nutrients, remove debris and provide water to the middle riparian terraces to establish nursery conditions for the germination, establishment and growth of seedlings of trees and shrubs in these areas. It is also important for re-distributing seeds in order to maintain the extent and distribution of riparian plants.	Needs to cover the lower riparian terraces and reach bases of riparian plants.	Summer	3	6:10	To maintain the existing distribution of <i>S. mucronata</i> in marginal areas and lower riparian terraces. Also to provide adequate habitat to promote establishment of other riparian species on lower riparian terraces. Achieve an overall improvement of the riparian vegetation in these areas. Three floods will provide sufficient water and deposition of nutrients and sediment to meet the requirements of marginal riparian vegetation in the lower terraces. These floods will ensure that the riparian and marginal substrates will remain sufficiently moist to promote germination of seedlings and their survival during the summer period. Fewer floods would result in these substrates drying out which would be detrimental to germination and growth of new seedlings.						
Geom.	Bed maintenance.	The discharge that maintains the transport of sand and gravel along the bed.		3	8:10	See Chapter 2.	4	8:10	See Chapter 2.	3	8:10	See Chapter 2.

- This work was undertaken during the May 2002 specialist meeting.
- The hydrologist checks the validity of these floods against naturalised daily hydrology, or in the absence of this, any observed hydrological data or by means of monthly volumes (as the last desirable option only).
- Where possible, the hydrologist provides the number of events which would occur under natural flow conditions for each of the flood classes. If any sort of daily hydrology is not available, an upstream reach of similar area and where information is available is used to provide some indication.
- The specialists then identify which of those numbers of events should occur for each of the Reserve scenarios (ERCs). The number of events should not exceed the natural and should only be similar to natural if the ERC being considered is high. The objectives and criteria set for the recommended and alternative ERCs must be kept in mind when motivating the number of events per ERC. Motivations linked to the number of events selected are supplied in the spreadsheets (Appendix G, column 7, Table 2.10).

At this stage the high flows are incorporated with the low flows already identified into a flow regime. The process followed and adjustments required to convert the instantaneous peaks provided by the specialists into the final results are provided by the hydrologists and documented in this report.

2.7.1 Geomorphological process for high flows (E Dollar and R Wadeson)

In determining high flows for geomorphology, hydraulic cross sections and look-up tables are essential for each site. Daily hydrology and sediment modelling are used wherever possible. Where the data are not available for certain sites, data are interpolated from known sites.

High flows are set as follows:

Using the sediment modelling data

Ranges of flows are determined for a number of flood classes (I – V), on the basis of the size and amount of material that they move. These flood class ranges are converted to a single value (calculated as the geometric mean of the range). This flow value is checked against the hydraulic cross sections and look-up tables, to determine whether it has any significance for geomorphology, i.e. does it inundate benches, the active channel, the macro channel etc. (Note: in all cases checked to date, these flood classes have coincided with a clear physical geomorphological cue on the cross section).

Using the data from the daily hydrology

A number of different methods are used to determine the number of events likely to occur per year within each flood class under natural conditions. Methods include:

- Looking at plots of daily flow data for a selection of dry and wet years and physically counting the number of events in each flow class.
- Ordering of daily data, counting the number of events and converting these results into frequency per year. The data are ranked from lowest daily flow event to highest. The number of events per flood class is counted to determine frequency of each flood class event for the total record. This is then converted to number of events per year. Where possible, real data are used to determine the average duration of each event to calculate the average number of events per year (natural).

The flood classes set for each site apply under any ERC. Only the *number of events* in each flood class changes with different categories. Determining the number of events is done as follows: a category A river is considered to have the full compliment of floods, which has been determined in an earlier step. As a general rule of thumb, a category D river is considered to have approximately half the number of floods that a category A river has within

a year. The number of floods for the in-between categories of B and C is interpolated from the category A and D data.

2.7.2 Generic objectives per site

Note that the specific objectives relating to each of the requirements tabulated here are dealt with in each chapter.

Bed maintenance – the discharge that maintains the transport of sand and gravel along the bed and maintains the physical diversity of bed forms. Roughly equivalent to the sediment maintenance flushing flow.
Bench maintenance - the discharge that overtops the in-channel bench, transports significant quantities of sand and gravel, and maintains the diversity of hydraulic habitats. Essentially a constructional flow event.
Channel maintenance - this flood is roughly equivalent to the effective discharge, is responsible for the maintenance of the active channel, and is the discharge that transports the most bed over the medium term (50-100 years).
Macro channel maintenance and bed mobilisation – this flood is responsible for floodplain or terrace maintenance (where present). The flood also mobilises the majority of the bed material.

These flow objectives are based on a number of assumptions:

1. That the amount of bed material entering the channel reach is roughly equivalent to the amount of bed material exiting the reach.
2. That the large flood events (≥ 20 -year return period) will move through the channel reach.
3. That between large re-set flood events, the channel will display a trajectory of change if the IFR flows are not met.
4. The time frames involved are between 50-100 years.

2.8 FINAL OUTPUT

(Question 10; 3.5 in Chapter 3)

The low flows and high flows have now been incorporated into an integrated flow regime. The final output, i.e. the IFR rules (presented as duration tables), is provided from either the Desktop Model or the IFR Model (Hughes *et al.*, 1997). The IFR rules are documented in the report, and also as Appendix H. Results are also provided as IFR tables (the .tab tables) and are presented both in the report and in Appendix H. These results describe the IFR rules as the Maintenance and Drought low flows and the high flows.

2.9 GEOMORPHOLOGICAL CONSEQUENCES OF THE RECOMMENDED RESERVE SCENARIOS

(Question 12; 3.7 in Chapter 3)

This section is a description by the geomorphologist of the consequences of different reserve scenarios on the geomorphology of the river.

2.10 CONFIDENCE EVALUATIONS OF THE RESULTS

(Question 13; 3.8 in Chapter 3)

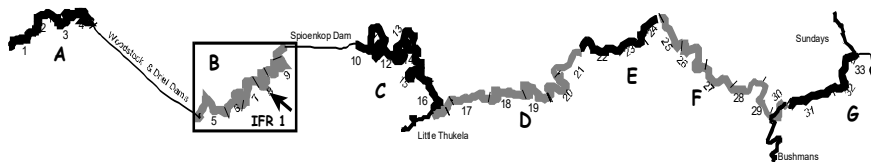
Each specialist provides a confidence evaluation on a scale of 0 (no confidence) to 5 (high confidence) for their component. The rationale for their evaluations is provided. The information is tabulated and documented at the end of each chapter. In the summary chapter, an overall confidence is provided in the results for each site. The overall confidence consists of the specialist component evaluation, modified where necessary by the hydraulic confidence. For example, if the biophysical component confidences were evaluated as high, and the hydraulic confidence as low, the overall confidence in the results would be low.

Further work to increase the confidence lies then in the hydraulics, not in the biophysical components.

2.11 EXTRAPOLATION TO RUs WITHOUT IFR SITES

The Desktop model was used to extrapolate the results generated at the closest and most relevant IFR site to the RUs that do not have IFR sites. The ERCs for these RUs were specified in order that the relevant ERC information needing to be extrapolated is available. No other ecological check is possible of the extrapolated flow as no hydraulic information is available.

3 RU B. IFR 1. BERGVILLE (Upper Thukela River)



3.1 ECOLOGICAL CATEGORIES

3.1.1 Summary of ERC Scenarios

Two Ecological Reserve scenarios were addressed for IFR 1. The recommended scenario is a D ERC. An alternative scenario of a C ERC was also evaluated.

Fig 3.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP
WATER QUALITY	B	0	B	MODERATE SI LOW	B	
GEOMORPH	D	-*	D/E		D	C
RIPARIAN VEGETATION	E	-	E/F		D	D
FISH	D	-	D		D	C
AQUATIC INVERTS	D	0	D		D	C
ECOSTATUS	D	-	E		D	C

-* Negative

3.1.2 Criteria for the Ecological Reserve Categories

Recommended scenario: D ERC

General

- Create a more natural seasonal diversity of flow.
- Maintain important habitats - riffle and marginal vegetation.

- Prevent irregular and unseasonal fluctuations in flow by appropriately operating Woodstock and Driel Dams.

Aquatic invertebrates (D)²

- Stones biotope: SASS >110 ASPT >6.5 (in winter), No of taxa 17. Vegetation biotope: SASS >25, ASPT >5.5 (in winter), No of taxa 4.
- Maintain presence of Baetidae in summer in stones biotope, and Leptoceridae in the marginal vegetation.

Fish (D)

- Limit impact of suspended silt (from scour releases from Driel barrage) on fish respiration and abundance of macrobenthic food organisms.
- Maintain existing *Labeo natalensis* population structure.
- Ensure moderate breeding success on clean gravel and cobble beds in spring.

Riparian vegetation (D)

- Ensure lower winter flows than in summer, marginal and riparian vegetation generally dormant during winter.
- Ensure higher flows in summer as vegetation is actively growing, reproducing and controlling the temperature.
- Maintain existing clumps of both *Setaria* and *Juncus* and to extend their distribution in the marginal areas on the river edge and on islands.
- Maintain *Salix mucronata* stands in marginal areas on river's edge and islands.
- Encourage and support the recovery and growth of other riparian species within the riparian zone.

Geomorphology (D)

- Maintain the river in its present state i.e. no further channel constriction or sediment accumulation and no increase in bed aggradation or embeddedness. There is a necessity for floods of a sufficient velocity and frequency to move the available sediment which is presently entering this system.

Alternative scenario: C ERC

Aquatic Invertebrates (C)

- Stones biotope: SASS > 120 ASPT > 6.5 (in winter). Vegetation biotope: SASS > 100 ASPT > 6.5 (in summer).
- Diverse mayfly communities must exist during summer.
- Provide for Heptageniidae and Elmidae in vegetations in summer, and Baetidae and other mayflies in summer in the stones biotope.

Fish (C)

- Reduce the impact of silt from the Driel barrage on the respiration and breeding of fish species.
- Siltation of cobble beds reduced and species diversity improved by the addition of small populations of *Amphilius natalensis*.

Riparian Vegetation (D)

- As for the D ERC.

Geomorphology (C)

- To change the present state from a D to a C, there is a need for reduced sediment accumulation i.e. increased sediment transport, together with an overall increase in sediment scour from the bed, banks and bars. Since the majority of sediment is

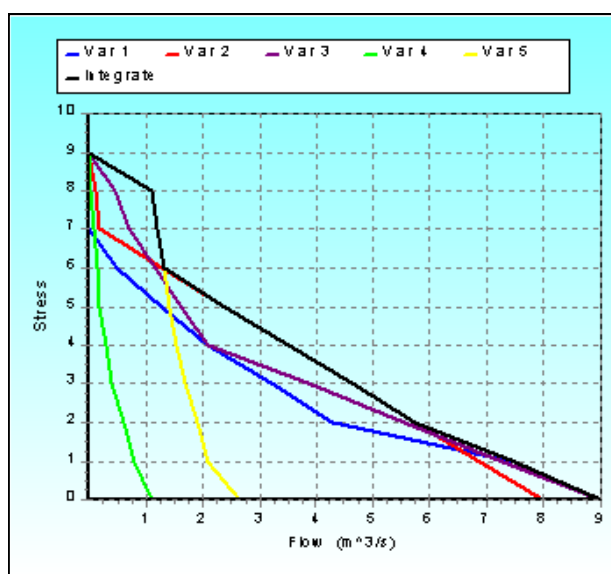
² Note that these refer to the component ERCs.

transported by flood events, an increase in the number of these events should achieve this objective.

3.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 1, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 3.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 3.2.

Fig 3.2 Critical Curve for IFR 1



Var 1: Fish

Var 3: Marginal Vegetation Invertebrates

Var 5: Riparian Vegetation 2

Var 2: Flow Dependent Invertebrates

Var 4: Riparian Vegetation 1

3.2.1 Invertebrates

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit (7.7m³/s) as a reference point. The no stress index was set so that there was abundant inundation of the bases of the marginal vegetation. Analysis was done making use of the hydraulic profile and tables. The indices of greater stress were derived similarly by measuring the reduction in water level that would leave just the bases of the reeds inundated. Note that this assessment for marginal vegetation communities applies only for the wet season, as during dry seasons it can be expected that flows will recede from the vegetation.

The flow dependent community investigation was dominated by the need to maintain high water velocities over quantities of small cobbles and diverse biotope. It was important to maintain flow into the channel on the left bank, which provided excellent habitat with small stones. The habitat model and hydraulic data were used to determine the depths and

velocities that would produce minimal stress to rheophilic species. Higher stresses were determined by anticipating minimal depths and velocities that would only provide remnants of the required habitat.

3.2.2 Riparian vegetation

Three components were selected, using elevations and discharges associated with the ecological transect for the hydraulic modelling.

- *Setaria* (adults) – applicable mainly to summer
Setaria adults were identified at the 0.4m water level. Root lengths of 0.28m were used, corresponding to water levels of 0.12m at the root bases.
- Fire Lily (adults) – applicable mainly to winter
Fire Lily individuals were estimated to occur at the 0.55m level. Critical water level were assessed to be approximately 0.15m below this level i.e. 0.40m.
- *Juncus* (adults) – applicable mainly to winter
Juncus adults were found on the banks as well as on the islands. The elevation was averaged at 0.5m level. The rooting depth of 0.40m was used which corresponded with a maximum rooting depth of 0.1m. It was felt that since *Juncus* is in contact with the water throughout the year and is not necessarily dormant during the winter that this curve can be incorporated in the critical curve.

3.3 STRESS DURATION CURVES (PROFILES)

3.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 3.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 1, stress indices as determined were accepted.

3.3.2 Recommended stress profiles for each reserve scenario

The C and D scenarios were estimated using the Desktop model and are shown in Figures 3.3 – 3.6 as purple and green lines respectively. The observed (historic) hydrology was converted into stress, as reflected by the red line in Figures 3.3 - 3.6 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are presented in Figures 3.3 - 3.6. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures 3.7 - 3.8). The adjusted scenarios were then checked with specialists to ensure that they were representative of their component requirements.

3.3.3 Process to adjust the Desktop output to fit specialist requirements

The Desktop-generated D scenario consisted of Maintenance Low Flows of 9.24 % MAR³, which were adjusted to 7.04 % MAR (see figure 3.5); and Drought Low Flows of 9.04 % MAR, which were adjusted to 6.34 % MAR (see figure 3.5). The Desktop-generated C scenario consisted of Maintenance Low Flows of 17.07% MAR, which were adjusted to 14.87 % MAR, and Drought Low Flows of 9.04 % MAR, which were adjusted to 6.34 % MAR. No change was made to seasonal distribution.

³ Note that “% MAR” refers to the % of virgin MAR and not the % of present day MAR.

Fig 3.3 IFR 1 - Stress duration curve for recommended scenario of a D ERC: Dry Season

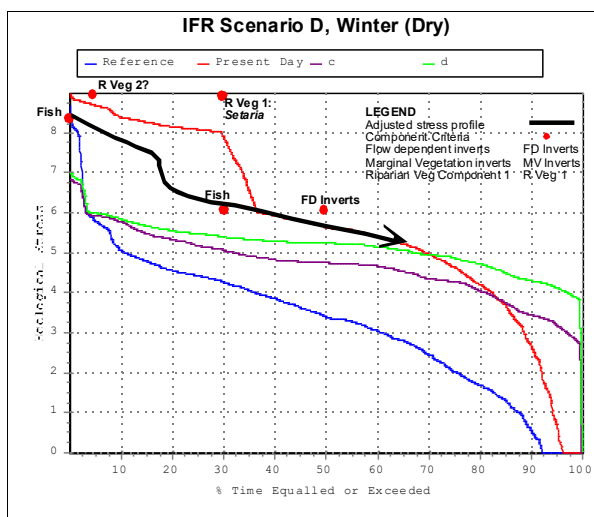


Fig 3.4 IFR 1 - Stress duration curve for recommended scenario of a D ERC: Wet Season

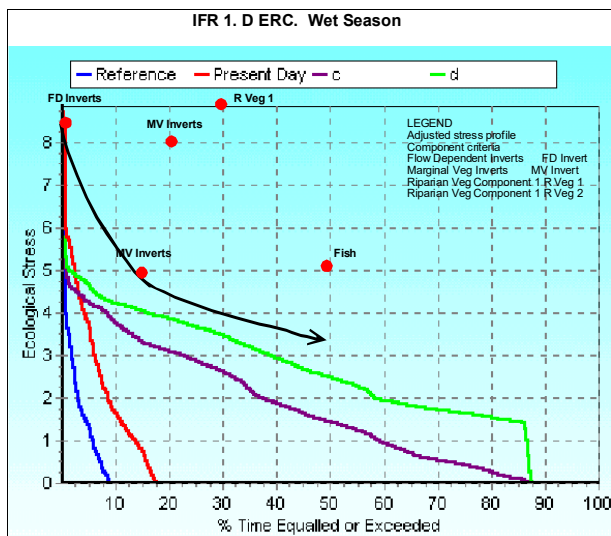


Fig 3.5 IFR 1 - Stress duration curve for alternative scenario of a C ERC: Dry Season

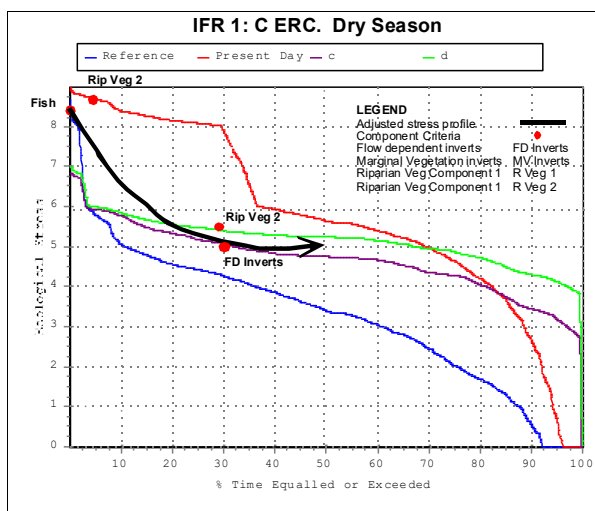
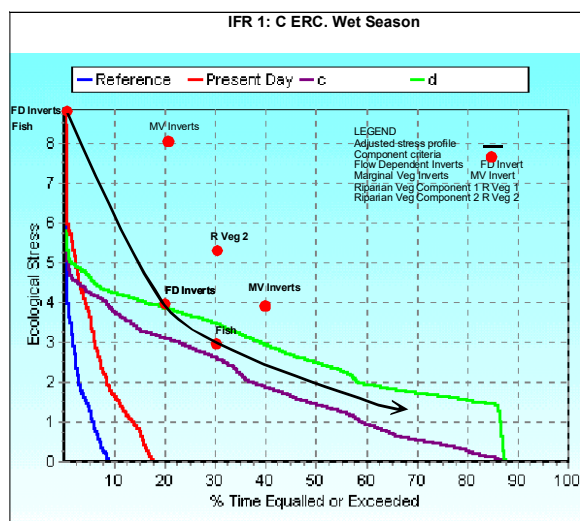


Fig 3.6 IFR 1 - Stress duration curve for alternative scenario of a C ERC: Wet Season



3.3.4 Final stress profiles for IFR 1

Fig 3.7 IFR 1 - Final stress profiles: Dry season

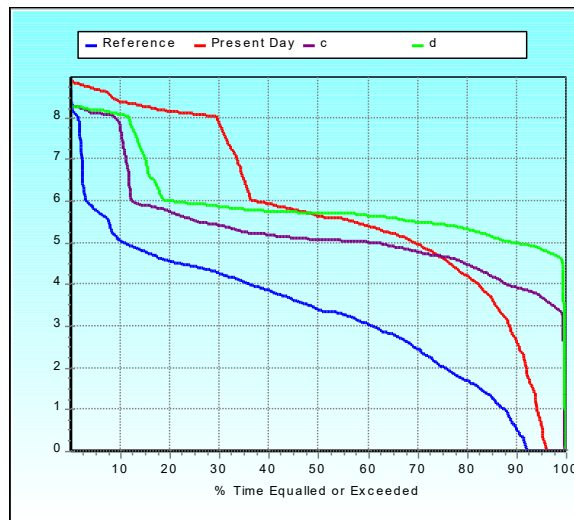
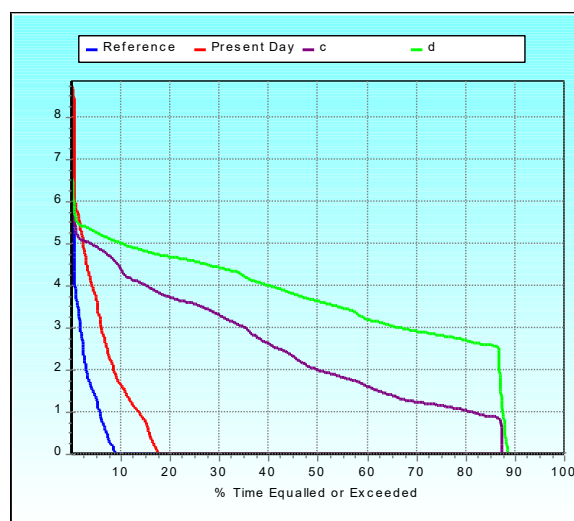


Fig 3.8 IFR 1 - Final stress profiles: Wet season



3.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 3.1. The number of events for each Flood Class required for an ERC of C and D are also summarised in Table 3.1.

Table 3.1 A summary of the flood class ranges, and the recommended high flow events for each scenario.

Component	Flood Classes m³/s					
	I	II	III	IV	V	VI
Fish	10-20	20-25 25-35				
Invertebrates	10-15	15-40		50-100		
Vegetation	8-15	15-40	40-80	80-180		
Geomorphology		20 - 39	64-106		106-236	236-500
Integrated	8-19	20- 39	40-79	80-105	106-235	236-500
Geometric Mean*		28	82 (Note that this is for Geomorphic Flow Classes III & IV)		158	340
Recommended Flood Events						
No of events for D ERC (Recommended scenario)	2 in spring 3 in summer	4	1	1	1	1 in 5 years
No of events for C ERC (Alternative scenario)	4 in spring 5 in summer	6	1	1	1	1 in 3 years

NOTE: No of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These high flow recommendations were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 300) were used within the IFR model (daily), but were reduced to the lower discharge values (e.g. 140) for the Desktop model (monthly), to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model. The floods provided in Table 3.1 are peak values. These have to be adjusted when used in the IFR model to present daily averages.

The adjustments as described above are illustrated in Tables 3.2 and 3.3.

Table 3.2 Adjusted flood sizes as used in the Desktop model for a D Category

Summer							
	Dec	Jan		Feb		Mar	
		Original	Adjusted	Original	Adjusted	Original	Adjusted
Flood size (m ³ /s)		300	>140	100	>50	36	>18
Duration (days)		8		5		4	
Freshet size (m ³ /s)	16	16		36	>18	16	
Duration (days)	4	4		5		4	
Spring							
	Oct	Nov					
Freshet size (m ³ /s)	16	16					
	4	4					

Table 3.3 Adjusted flood sizes as used in the Desktop model for a C Category

Summer						
	Dec	Jan		Feb		Mar
		Original	Adjusted	Original	Adjusted	
Flood size (m³/s)	16	300	>190	100	>65	36
Duration (days)	4	8		5		4
Freshet size (m³/s)	16	16		36		16
Duration (days)	4	4		5		4
Spring						
	Oct	Nov				
Flood size (m³/s)	16	16				
	4	4				
Freshet size (m³/s)	16	16				
	4	4				

3.5 FINAL RESULTS

3.5.1 IFR table for recommended scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR = 705.418
S.Dev. = 275.952
CV = 0.391
Q75 = 13.700
Q75/MMF = 0.233
BFI Index = 0.412
CV(JJA+JFM) Index = 1.066

Total IFR = 122.076 (17.31 %MAR)
Maint. Lowflow = 49.671 (7.04 %MAR)
Drought Lowflow = 44.729 (6.34 %MAR)
Maint. Highflow = 72.405 (10.26 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : D'berg

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	25.870	36.767	1.421	2.526	2.277	2.903	5.429
Nov	47.941	44.559	0.929	3.084	2.776	2.903	5.988
Dec	77.677	52.530	0.676	3.927	3.535	2.903	6.830
Jan	120.625	70.438	0.584	5.207	4.687	41.973	47.180
Feb	145.475	86.959	0.598	6.319	5.690	15.134	21.453
Mar	125.723	69.619	0.554	6.589	5.933	6.589	13.178
Apr	63.849	36.995	0.579	5.736	5.166	0.000	5.736
May	31.938	15.371	0.481	4.762	4.288	0.000	4.762
Jun	21.122	7.287	0.345	3.686	3.320	0.000	3.686
Jul	15.368	6.000	0.390	2.965	2.670	0.000	2.965
Aug	12.563	9.139	0.727	2.507	2.258	0.000	2.507
Sep	17.267	37.190	2.154	2.364	2.128	0.000	2.364

3.5.2 IFR table for alternative scenario: C ERC

Annual Flows (Mill. cu. m or index values):

MAR = 705.418
S.Dev. = 275.952
CV = 0.391
Q75 = 13.700
Q75/MMF = 0.233

BFI Index = 0.412
CV(JJA+JFM) Index = 1.066

Total IFR = 210.800 (29.88 %MAR)
Maint. Lowflow = 104.926 (14.87 %MAR)
Drought Lowflow = 44.729 (6.34 %MAR)
Maint. Highflow = 105.874 (15.01 %MAR)

Monthly Distributions (Mill. cu. m.)
Distribution Type : D'berg

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	25.870	36.767	1.421	5.092	2.277	5.806	10.898
Nov	47.941	44.559	0.929	6.353	2.776	5.806	12.159
Dec	77.677	52.530	0.676	8.263	3.535	5.806	14.069
Jan	120.625	70.438	0.584	11.161	4.687	55.927	67.088
Feb	145.475	86.959	0.598	13.681	5.690	22.254	35.935
Mar	125.723	69.619	0.554	14.289	5.933	10.275	24.564
Apr	63.849	36.995	0.579	12.361	5.166	0.000	12.361
May	31.938	15.371	0.481	10.156	4.288	0.000	10.156
Jun	21.122	7.287	0.345	7.719	3.320	0.000	7.719
Jul	15.368	6.000	0.390	6.083	2.670	0.000	6.083
Aug	12.563	9.139	0.727	5.046	2.258	0.000	5.046
Sep	17.267	37.190	2.154	4.723	2.128	0.000	4.723

3.5.3 IFR rule table for recommended scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	3.094	3.085	3.051	2.974	2.820	2.547	2.137	1.642	1.206	1.003
Nov	3.861	3.856	3.827	3.764	3.636	3.393	2.976	2.356	1.627	1.162
Dec	5.164	4.879	4.622	4.381	4.122	3.665	3.264	2.663	1.949	1.492
Jan	36.677	32.452	28.852	25.773	22.954	18.111	15.525	11.549	6.747	3.654
Feb	15.629	14.196	12.956	11.867	10.818	9.008	7.853	6.116	4.056	2.737
Mar	10.637	9.940	9.323	8.755	8.165	7.136	6.318	5.102	3.672	2.758
Apr	3.864	3.856	3.825	3.754	3.612	3.361	2.984	2.529	2.127	1.941
May	3.278	3.269	3.239	3.174	3.048	2.832	2.516	2.142	1.816	1.665
Jun	2.442	2.433	2.410	2.360	2.264	2.103	1.869	1.595	1.357	1.247
Jul	2.007	1.998	1.977	1.933	1.851	1.717	1.528	1.310	1.123	1.036
Aug	1.661	1.655	1.639	1.605	1.540	1.430	1.271	1.084	0.923	0.848
Sep	1.575	1.570	1.556	1.525	1.464	1.360	1.208	1.029	0.872	0.799

Reserve flows without High Flows

Oct	1.613	1.610	1.598	1.571	1.517	1.422	1.279	1.106	0.954	0.883
Nov	2.261	2.259	2.246	2.217	2.159	2.050	1.862	1.583	1.254	1.044
Dec	2.989	2.987	2.971	2.935	2.861	2.718	2.470	2.098	1.657	1.374
Jan	4.142	4.142	4.122	4.076	3.979	3.788	3.448	2.924	2.292	1.885
Feb	4.655	4.652	4.627	4.571	4.455	4.233	3.847	3.268	2.580	2.140
Mar	5.347	5.342	5.311	5.244	5.107	4.848	4.404	3.743	2.967	2.470
Apr	3.864	3.856	3.825	3.754	3.612	3.361	2.984	2.529	2.127	1.941
May	3.278	3.269	3.239	3.174	3.048	2.832	2.516	2.142	1.816	1.665
Jun	2.442	2.433	2.410	2.360	2.264	2.103	1.869	1.595	1.357	1.247
Jul	2.007	1.998	1.977	1.933	1.851	1.717	1.528	1.310	1.123	1.036
Aug	1.661	1.655	1.639	1.605	1.540	1.430	1.271	1.084	0.923	0.848
Sep	1.575	1.570	1.556	1.525	1.464	1.360	1.208	1.029	0.872	0.799

Natural Duration curves

Oct	20.772	16.034	10.336	7.064	4.691	3.665	2.944	2.265	1.794	1.512
Nov	34.237	26.818	22.935	18.104	14.057	10.069	7.620	5.052	2.983	1.579
Dec	56.667	43.113	37.002	33.005	30.123	25.185	18.600	10.822	5.725	1.821
Jan	86.466	68.207	63.290	54.793	44.057	37.360	30.105	24.389	15.860	8.034
Feb	106.399	80.223	63.012	58.673	46.640	40.886	33.147	26.762	24.384	7.699
Mar	93.998	72.441	59.516	54.039	50.298	41.014	36.367	30.208	20.126	10.127
Apr	40.024	29.798	27.042	24.167	20.411	18.989	16.700	15.054	12.336	8.464

May	17.816	15.181	13.183	11.948	11.269	10.320	9.622	8.638	7.631	5.629
Jun	11.705	10.144	8.494	7.822	7.310	6.784	6.414	5.865	5.115	3.864
Jul	8.279	7.203	6.435	5.934	5.529	4.938	4.715	4.371	3.762	2.998
Aug	6.761	5.694	4.846	4.301	4.014	3.745	3.297	3.114	2.860	2.248
Sep	9.121	5.149	4.062	3.472	3.091	2.972	2.774	2.244	2.053	1.665

3.5.4 IFR rule table for alternative scenario: C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	4.675	4.661	4.603	4.472	4.210	3.665	2.944	2.210	1.468	1.125
Nov	5.790	5.782	5.733	5.628	5.414	5.008	4.312	3.276	2.059	1.282
Dec	8.731	8.160	7.648	7.172	6.664	5.770	5.005	3.856	2.493	1.619
Jan	49.560	43.930	39.122	34.994	31.181	24.617	20.975	15.374	8.612	4.255
Feb	23.155	21.045	19.211	17.583	15.987	13.223	11.346	8.523	5.176	3.032
Mar	16.305	15.217	14.243	13.332	12.360	10.659	9.216	7.070	4.547	2.936
Apr	6.020	6.004	5.937	5.788	5.487	4.956	4.160	3.197	2.348	1.954
May	5.033	5.013	4.951	4.817	4.554	4.105	3.447	2.668	1.990	1.676
Jun	3.674	3.656	3.609	3.508	3.314	2.987	2.513	1.958	1.478	1.255
Jul	2.945	2.927	2.885	2.799	2.640	2.377	2.005	1.578	1.212	1.042
Aug	2.402	2.391	2.360	2.296	2.172	1.962	1.659	1.303	0.996	0.853
Sep	2.265	2.256	2.229	2.171	2.057	1.861	1.575	1.236	0.941	0.804

Reserve flows without High Flows										
Oct	2.270	2.264	2.242	2.191	2.089	1.908	1.637	1.310	1.021	0.887
Nov	3.236	3.232	3.208	3.157	3.053	2.857	2.519	2.017	1.427	1.050
Dec	4.380	4.377	4.346	4.280	4.142	3.877	3.417	2.727	1.908	1.383
Jan	6.209	6.209	6.170	6.083	5.898	5.533	4.883	3.883	2.676	1.898
Feb	7.018	7.012	6.963	6.855	6.631	6.201	5.456	4.335	3.006	2.155
Mar	8.057	8.047	7.987	7.857	7.592	7.091	6.231	4.952	3.448	2.487
Apr	6.020	6.004	5.937	5.788	5.487	4.956	4.160	3.197	2.348	1.954
May	5.033	5.013	4.951	4.817	4.554	4.105	3.447	2.668	1.990	1.676
Jun	3.674	3.656	3.609	3.508	3.314	2.987	2.513	1.958	1.478	1.255
Jul	2.945	2.927	2.885	2.799	2.640	2.377	2.005	1.578	1.212	1.042
Aug	2.402	2.391	2.360	2.296	2.172	1.962	1.659	1.303	0.996	0.853
Sep	2.265	2.256	2.229	2.171	2.057	1.861	1.575	1.236	0.941	0.804

3.6 GEOMORPHOLOGICAL CONSEQUENCES OF C AND D SCENARIOS

Bed maintenance

A C ERC means that although there will be the same size flood events, the reduced frequency means that there will be longer periods of sediment accumulation on the bed. This will result in a moderately modified morphology in the intermediate periods between the very large flood events (50 – 100yr return period).

A D ERC means that a further reduction in flood frequency will lead to even greater accumulations of sediment on the bed, resulting in a largely modified morphology. This is likely to keep the river in the same condition as its present state within the 20-year period being considered.

Bench maintenance

A C ERC means that the bench will not be overtopped as regularly as it would naturally. This will result in longer periods without sediment deposition and local scour, flushing etc. This will result in a moderately modified channel for the periods between large flood events.

A D ERC represents a further reduction in flood events. This will likely keep the channel in its presently largely modified condition for the long periods between very large flood events.

Channel maintenance

C and D ERCs mean that the number of events is halved from natural (A ERC). This is a very important geomorphological component and as such there is no difference in the number of events between the C and D ERCs. There will be some changes in channel

morphology (as represented by the present condition) but these conditions will be re-set by the large flood events.

Macro channel and bed mobilisation

C ERC requires these large flood events occur once every three years. This means that the bed will likely be quite stable for longer periods and may become embedded (temporarily).

D ERC requires the large flood event once in every five years, this simply means an even more stable bed with increased sedimentation, particularly of the large bed material. The bed is likely to be more embedded than in the C ERC.

Conclusion

If the geomorphological flood classes are met by the IFR, the trajectory of change would be slow enough to ensure that the river at this site remains within a D ERC in the 20-year period considered.

3.7 IFR CONFIDENCE EVALUATION

Confidence was evaluated in two ways, first according to a standard confidence evaluation scale of 0 (no confidence) to 5 (high confidence, Table 3.4) (The second evaluation was based on probability, and the method is described and results recorded in Appendix H). The standard confidence evaluation is only for the recommended D ERC. The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5.

Table 3.4 IFR confidence for a recommended D ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
1	Low flows	5	4	3	-
	High flows	5	4	4	4

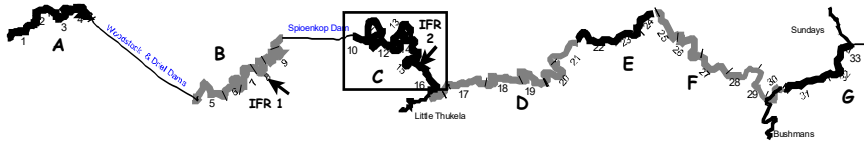
The confidence ranges from medium-to-high for low flows and medium-high to high for high flows.

Invertebrates: The high evaluation is due to the fact that the invertebrates are already in a D ERC and any improvement of the flows will definitely maintain the D ERC.

Fish: Medium-high confidence for fish is related to the good available habitat and survival opportunities for fish.

Riparian vegetation: The medium confidence at low flows is related to the fact that the marginal vegetation forms a wide band on the edge of the river, and that the knowledge of flow requirements for marginal riparian vegetation is limited.

4 RU C. IFR 2. SKIETDRIFT (Upper Thukela River)



4.1 ECOLOGICAL CATEGORIES

4.1.1 Summary of ERC scenarios

Three Ecological Reserve scenarios were addressed for IFR 2. The recommended scenario is a C ERC. The alternative scenarios of a B and a D ERC were also evaluated.

Fig 4.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP	DOWN
WATER QUALITY	B	0	B	MODERATE SI	B		
GEOMORPH	D	-	D/E		D	C	D
RIPARIAN VEGETATION	C	-	C/D		C	B	D
FISH	C	0	C		C	B	D
AQUATIC INVERTS	B/C	0	B/C		B/C	B	C/D
ECOSTATUS	C	-	C		C	B	D

4.1.2 Criteria for the Ecological Reserve Categories

Recommended scenario: C ERC

Aquatic invertebrates (B/C)

- Stone biotope: SASS > 120 ASPT > 6.5. Vegetation biotope: SASS > 60 ASPT > 6.5.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

- Recreate drought conditions as periodic conditioning is essentially based on natural cues.

Fish (C)

- Avoid the extinction of *A. natalensis*.
- Maintain minimal breeding success and abundance of *A. natalensis*.
- Species diversity are unchanged, but with reduced breeding success and abundances, particularly *A. natalensis*.

Riparian vegetation (C)

- Ensure lower winter flows than in summer, marginal and riparian vegetation is generally dormant during winter.
- Ensure higher flows in summer, as vegetation is actively growing, reproducing and controlling the temperature.
- Maintain mixed *Juncus* and *Setaria* clumps on islands and on the left bank as well as *Salix mucronata* stands in marginal areas of the left bank.
- Maintain existing stands of *Combretum erythrophyllum* and other riparian trees in the lower, main, and upper riparian zones.

Geomorphology (D)

- To change the present geomorphological state from a D to a C there is a need for reduced sediment accumulation i.e. increased sediment transport, together with an overall increase in sediment scour from the bed, banks and bars. Since the majority of sediment is transported by flood events, an increase in the number of these events should achieve this objective.

Alternative scenario: B ERC

Aquatic Invertebrates (B)

- Stone biotope: SASS > 140 ASPT > 7. No of taxa 20. Vegetation biotope: SASS > 70 ASPT > 6.5. No of taxa 10.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.
- Recreate drought conditions as periodic conditioning is essentially based on natural cues.

Fish (B)

- Maintain existing fish diversity.
- Maintain perennial flow, as *A. natalensis* is dependent on this.
- Ensure normal spawning success and survival of *A. natalensis*.

Riparian Vegetation (B)

- Ensure lower winter flows than in summer, as marginal and riparian vegetation generally is dormant during winter.
- Ensure higher flows in summer as vegetation is actively growing, reproducing and controlling the temperature.
- Ensure present distribution and extent of marginal and riparian zones are extended due to extended frequency and duration of low flows and elevated flows.
- Maintain and promote additional mixed *Juncus* and *Setaria* clumps on islands and on the left bank as well as *S. mucronata* stands in the marginal areas of the left bank.
- Maintain existing stands of *C. erythrophyllum* and other riparian trees in the lower, main, and upper riparian zones.

Geomorphology (C)

- The objective is to maintain the river in its present state i.e. no further sediment accumulation and no increase in bed aggradation or embeddedness. There is a need for floods which have a sufficient size and frequency to move the available sediment which is presently entering this system.

Alternative scenario: D ERC

Aquatic invertebrates (C/D)

- Stone biotope: SASS > 100 ASPT > 5.5. No of taxa 18. Vegetation biotope: SASS > 50 ASPT > 5.5. No of taxa 9.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.
- Recreate drought conditions as periodic conditioning is essentially based on natural cues.

Fish (D)

- Achieve the improved spawning and survival of *A. natalensis*.

Riparian Vegetation (D)

- Ensure lower winter flows than in summer, as marginal and riparian vegetation generally is dormant during winter.
- Ensure higher flows in summer as vegetation is actively growing, reproducing and controlling the temperature.
- Ensure reduced densities and recruitment rates of water dependant species in marginal areas of both banks with possible loss on islands. Maintain existing riparian trees and shrubs with slightly impaired recruitment rates and encroachment of terrestrial species.
- Maintain the majority of the existing mixed *Juncus* and *Setaria* clumps on islands and on the left bank as well as *S. mucronata* stands in the marginal areas of the left bank through the provision of adequate low flows during winter and summer.
- Maintain the majority of existing stands of *C. erythrophyllum* and other riparian trees in the lower, main, and upper riparian zones through the provision of adequate low flows during winter and summer.
- Maintain the majority of existing stands of *C. erythrophyllum* and other riparian trees in the lower, main, and upper riparian zones through the provision of elevated flows mainly during summer.

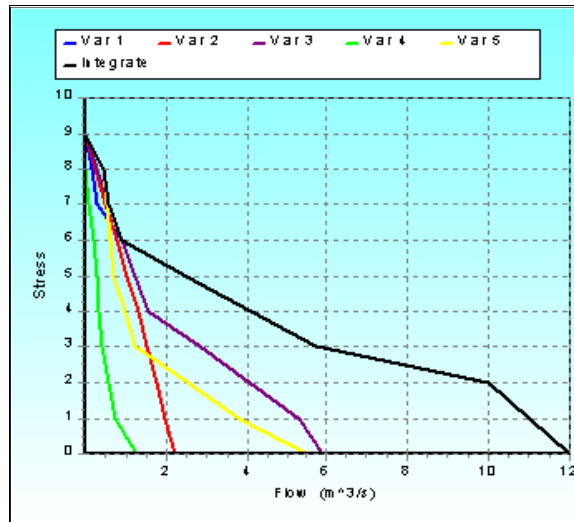
Geomorphology (D)

- As for the C ERC and D ERC - geomorphology.

4.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 2, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 4.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 4.2.

Fig 4.2 Critical Curve for IFR 2



Var 1: Fish

Var 2: Flow Dependent Invertebrates

Var 3: Marginal Vegetation Invertebrates

Var 4: Riparian Vegetation 1

Var 5: Riparian Vegetation 2

4.2.1 Invertebrates

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit (~1,6 m³/s) as a reference point. The stress index of 0 was set so that the *Juncus* on the islands and the *Phragmites* on the right bank were immersed with free flowing water of a depth of at least 0.1m. By measuring the reduction in water level that would leave just the bases of the *Juncus* inundated, the indices of greater stress were derived. Note that this assessment for marginal vegetation communities applies only for the wet season, as during dry seasons it can be expected that flows will recede from the vegetation.

Much of this investigation was based on the presence of families such as Oligoneuridae, Hydropsychidae, Perlidae and Elmidae, known to be present in 1960, and which require abundant clean, strong-flowing water over hard substrate.

4.2.2 Riparian vegetation

Two components were selected for IFR 2:

- Mixed individuals of *Setaria* and *Juncus* adults were identified for use in response to varying water levels.
- *Salix* adults (islands).

Elevations and discharges associated with the ecological transect were used. For this reason, where the habitat modelling depths were used, the depth was reduced by 0.38m. This provides the maximum depth on the cross section, for which the hydraulics has been modelled.

Adult stress levels for both mixed grasses and *Salix* individuals are most appropriate during the summer months when growth and survival is dependent on water levels. These grasses

are largely dormant during winter, and therefore less dependent on water. It is surmised that stress levels of 10 would only occur at much lower water levels than in summer.

4.3 STRESS DURATION CURVES (PROFILES)

4.3.1 Natural stress-duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 4.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 2, stress indices as determined were accepted.

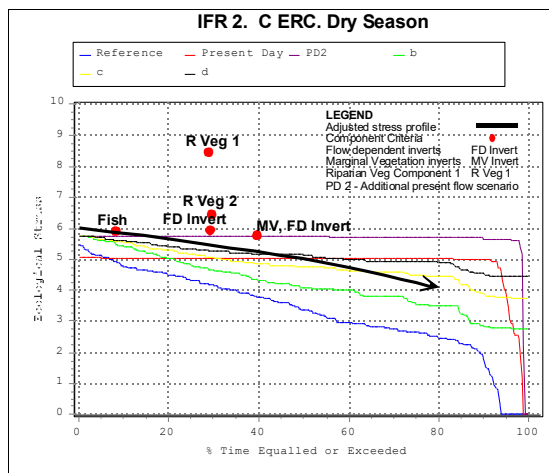
4.3.2 Recommended stress profiles for each Reserve scenario

The recommended C scenario and the alternative B and D scenarios were estimated using the Desktop model and are shown in Figures 4.3 – 4.8 as the yellow, green and black lines respectively. The observed (historical) hydrology, as converted into stress, is reflected by the red line in Figures 4.3 – 4.8 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 4.3 - 4.8. According to the specialists' evaluation, the Desktop generated scenarios were adjusted (see Figures 4.9 - 4.10). The adjusted scenarios were then checked with specialists to ensure that they were representative of their component requirements.

4.3.3 Process to adjust the Desktop output to fit specialist requirements

The Desktop generated B scenario consisted of Maintenance Low Flows of 28.3% MAR⁴, which were adjusted to 19.23% MAR, and Drought Low Flows of 8.6% MAR, which were adjusted to 4.24% MAR. The Desktop-generated C scenario consisted of Maintenance Low Flows of 16.4 % MAR, which were adjusted to 11.12 % MAR, and Drought Low Flows of 8.6% MAR, which were adjusted to 4.24% MAR. The Desktop-generated D scenario consisted of Maintenance Low Flows of 8.8% MAR, which were adjusted to 4.24% MAR, and Drought Low Flows of 8.6% MAR which were adjusted to 4.24% MAR.

Fig 4.3 IFR 2 - Stress duration curve for a recommended scenario of a C ERC: Dry Season



⁴ Note that "% MAR" refers to the % of virgin MAR.

Fig 4.4 IFR 2 - Stress duration curve for recommended scenario of a C ERC: Wet Season

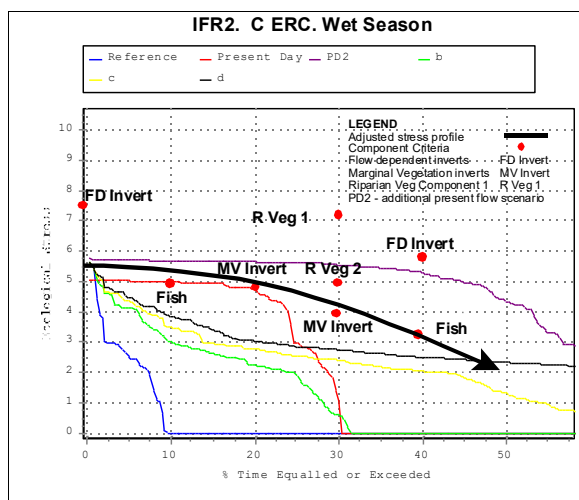


Fig 4.5 IFR 2 - Stress duration curve for alternative scenario of a B ERC: Dry Season

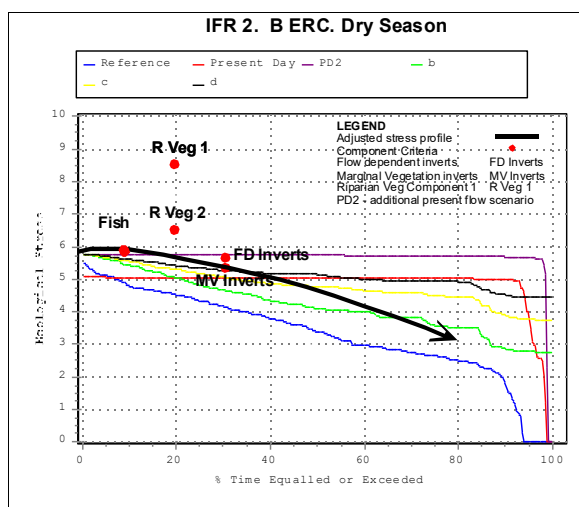


Fig 4.6 IFR 2 - Stress duration curve for alternative scenario of a B ERC: Wet Season

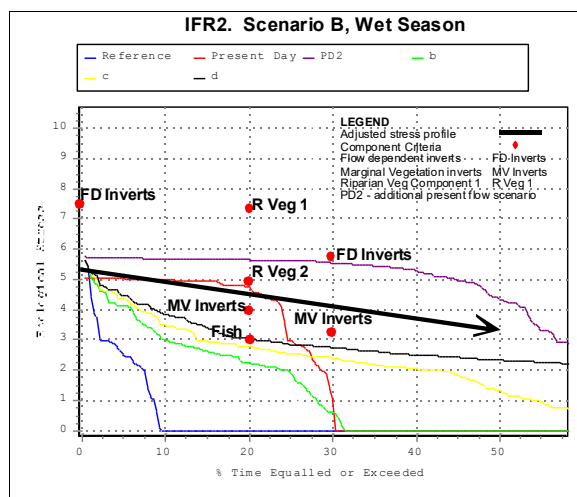


Fig 4.7 IFR 2 - Stress duration curve for alternative scenario of a D ERC: Dry Season

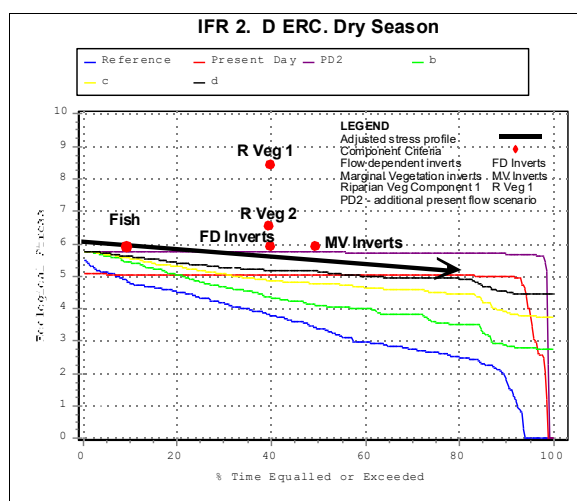
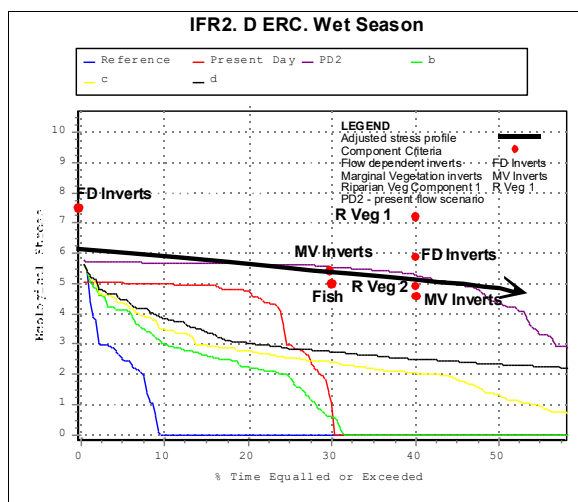


Fig 4.8 IFR 2 - Stress duration curve for alternative scenario of a D ERC: Wet Season



4.3.4 Final stress profiles for IFR 2

Fig 4.9 IFR 2 – Final stress profiles: Dry season

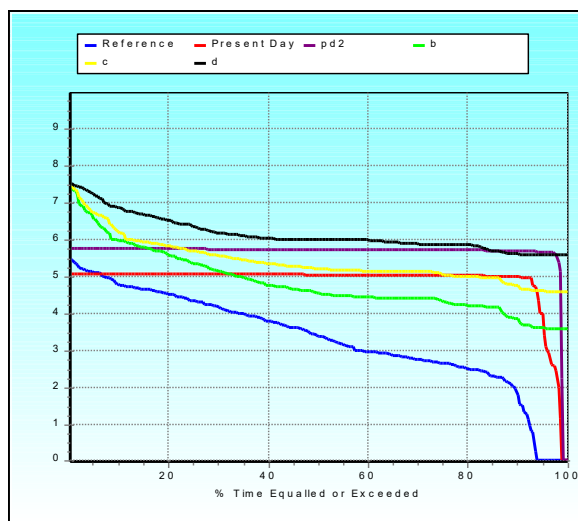
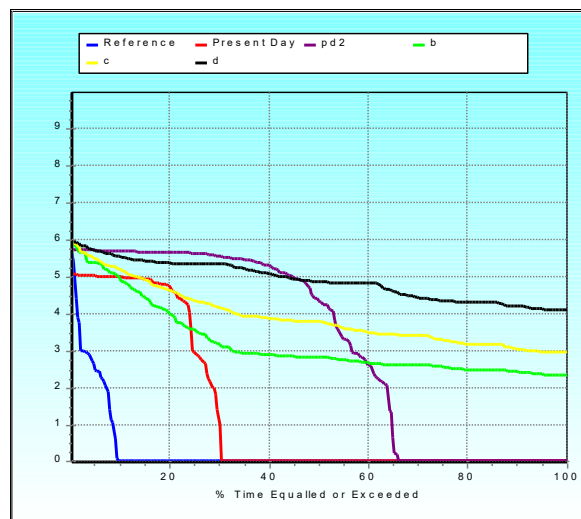


Fig 4.10 IFR 2 - Final stress profiles: Wet season



4.4 HIGH FLOWS

The functions for each flood class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 4.3. The number of events for each Flood Class required for an ERC of C and D are also summarised in Table 4.3.

Table 4.1 A summary of the Flood Class ranges, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s					
	I	II	III	IV	V	VI
Fish	5	20	30			
Invertebrates	5	11	20 - 50			
Vegetation	4.5 - 10		25 - 60	60 - 110		
Geomorphology			25 - 59	60 - 110	110 - 260	260-500
Integrated	5-9	10- 24	25- 59	60 - 109	110-259	260-500
Geometric Mean*			38	80	168	360
Recommended flood events						
No of events for C ERC (Recommended Scenario)	2 in spring 4 in summer	3	4	2	1	1 in 5 years
No of events for B ERC (Alternative scenario)	3 in spring 7 in summer	6	5	2	1	1 in 4 years
No of events for D ERC (Alternative scenario)	6 in spring	3	4	1	1	1 in 4 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 260 to 500) specified by the geomorphology specialist were reduced to the lower discharge values (e.g. 220) for the Desktop model (monthly) to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR (daily) model. The floods provided in Table 4.2 are peak values. These have to be adjusted when used in the IFR model to present daily averages.

The adjustments as described above are illustrated in Tables 4.4 and 4.5.

Table 4.2 Adjusted flood sizes as used in the Desktop model for a C Category

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood
Flood size (m³/s)	III	30	IV	80	VI, incl. V	200	IV	80		
Duration (days)	6		6		7		6			
Freshet size (m³/s)	I & II	7 + 14	I & II	7 + 14	III	30	III x 2	60	I	7
Duration (days)	5		5		5		5		3	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	7	I	7	I & II	7 + 14				
Duration (days)	3		3		5					

Table 4.3 Adjusted flood sizes as used in the Desktop Model for a B Category

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood
Flood size (m³/s)	III	30	IV	80	VI, incl. V	220	IV	80		
Duration (days)	5		6		7		6			
Freshet size (m³/s)	I, II & III	7 + 15 + 30	III & I x 4	30 + 7 + 8	III & II x 2	30 + 30	I, II & III + 30	7 + 15	II	15
Duration (days)	5		5		5		5		4	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	7	I	7	I x 2 & II	7 + 8 + 15				
Duration (days)	3		3		3					

Table 4.4 Adjusted flood sizes as used in the Desktop model for a D Category

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood	Flood Class	Flood
Flood size (m³/s)	III	30	IV	80	VI, incl. V	200	III	30		
Duration (days)	6		6		7		6			
Freshet size (m³/s)	I & II	7 + 14	I & II	7 + 14	III	30	III	30	I	7
Duration (days)	5		5		5		5		3	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	7	I	7	I & II	7 + 14				
Duration (days)	3		3		5					

4.5 FINAL RESULTS

4.5.1 IFR table for recommended scenario: C ERC

Annual Flows (Mill. cu. m or index values):

MAR = 798.396
S.Dev. = 322.968
CV = 0.405
Q75 = 14.290
Q75/MMF = 0.215
BFI Index = 0.400
CV (JJA+JFM) Index = 1.131

Total IFR = 218.492 (27.37 %MAR)
Maint. Lowflow = 88.819 (11.12 %MAR)
Drought Lowflow = 33.815 (4.24 %MAR)
Maint. Highflow = 129.673 (16.24 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : D'berg

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	29.242	44.070	1.507	4.821	1.500	1.089	5.910
Nov	53.440	51.573	0.965	5.702	1.944	4.914	10.617
Dec	87.327	63.108	0.723	8.571	2.678	11.057	19.628
Jan	140.476	88.394	0.629	9.642	3.750	23.231	32.873
Feb	169.976	107.403	0.632	10.161	4.838	56.601	66.761
Mar	143.309	83.784	0.585	10.714	4.955	30.603	41.316
Apr	70.432	44.167	0.627	9.850	4.147	1.089	10.938
May	33.808	17.531	0.519	8.035	3.214	0.000	8.035
Jun	21.864	7.726	0.353	6.480	2.333	0.000	6.480
Jul	15.871	6.337	0.399	5.357	1.741	0.000	5.357
Aug	13.163	10.458	0.794	4.821	1.393	0.000	4.821
Sep	19.488	47.027	2.413	4.666	1.322	1.089	5.754

4.5.2 IFR table for alternative scenario: B ERC

Annual Flows (Mill. cu. m or index values):

MAR = 798.396
S.Dev. = 322.968
CV = 0.405
Q75 = 14.290
Q75/MMF = 0.215

BFI Index = 0.400
CV(JJA+JFM) Index = 1.131

Total IFR = 307.237 (38.48 %MAR)
Maint. Lowflow = 153.524 (19.23 %MAR)
Drought Lowflow = 33.815 (4.24 %MAR)
Maint. Highflow = 153.713 (19.25 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : D'berg

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	29.242	44.070	1.507	8.303	1.500	1.089	9.392
Nov	53.440	51.573	0.965	9.850	1.944	4.666	14.515
Dec	87.327	63.108	0.723	14.731	2.678	16.791	31.522
Jan	140.476	88.394	0.629	16.606	3.750	30.603	47.209
Feb	169.976	107.403	0.632	17.660	4.838	67.789	85.450
Mar	143.309	83.784	0.585	18.481	4.955	28.965	47.446
Apr	70.432	44.167	0.627	17.107	4.147	2.722	19.829
May	33.808	17.531	0.519	13.928	3.214	0.000	13.928
Jun	21.864	7.726	0.353	11.146	2.333	0.000	11.146
Jul	15.871	6.337	0.399	9.374	1.741	0.000	9.374
Aug	13.163	10.458	0.794	8.303	1.393	0.000	8.303
Sep	19.488	47.027	2.413	8.035	1.322	1.089	9.124

4.5.3 IFR table for alternative scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR = 798.396
S.Dev. = 322.968
CV = 0.405
Q75 = 14.290
Q75/MMF = 0.215
BFI Index = 0.400
CV(JJA+JFM) Index = 1.131

Total IFR = 145.171 (18.18 %MAR)
Maint. Lowflow = 33.815 (4.24 %MAR)
Drought Lowflow = 33.815 (4.24 %MAR)
Maint. Highflow = 111.356 (13.95 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : D'berg

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	29.242	44.070	1.507	1.500	1.500	1.089	2.589
Nov	53.440	51.573	0.965	1.944	1.944	4.914	6.858
Dec	87.327	63.108	0.723	2.678	2.678	11.057	13.736
Jan	140.476	88.394	0.629	3.750	3.750	23.231	26.981
Feb	169.976	107.403	0.632	4.838	4.838	56.601	61.439
Mar	143.309	83.784	0.585	4.955	4.955	12.286	17.241
Apr	70.432	44.167	0.627	4.147	4.147	1.089	5.236
May	33.808	17.531	0.519	3.214	3.214	0.000	3.214
Jun	21.864	7.726	0.353	2.333	2.333	0.000	2.333
Jul	15.871	6.337	0.399	1.741	1.741	0.000	1.741
Aug	13.163	10.458	0.794	1.393	1.393	0.000	1.393
Sep	19.488	47.027	2.413	1.322	1.322	1.089	2.411

4.5.4 IFR rule table for recommended scenario: C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.907	2.898	2.861	2.777	2.609	2.313	1.867	1.329	0.855	0.635
Nov	5.065	5.057	5.013	4.917	4.720	4.349	3.711	2.762	1.648	0.935
Dec	12.826	11.742	10.790	9.933	9.067	7.561	6.446	4.768	2.780	1.506
Jan	23.371	21.032	19.017	17.260	15.588	12.688	10.866	8.064	4.680	2.500
Feb	46.256	40.901	36.327	32.387	28.740	22.505	19.106	13.998	7.940	4.059
Mar	30.611	27.393	24.625	22.208	19.912	15.982	13.633	10.140	6.033	3.409
Apr	5.264	5.249	5.189	5.055	4.785	4.308	3.593	2.728	1.965	1.612
May	3.982	3.965	3.915	3.806	3.593	3.228	2.694	2.062	1.512	1.257
Jun	3.083	3.067	3.024	2.932	2.756	2.459	2.028	1.524	1.087	0.885
Jul	2.592	2.574	2.532	2.446	2.286	2.022	1.650	1.221	0.854	0.684
Aug	2.293	2.280	2.246	2.172	2.031	1.792	1.448	1.043	0.693	0.531
Sep	2.699	2.686	2.646	2.560	2.392	2.104	1.682	1.184	0.749	0.548

Reserve flows without High Flows

Oct	2.425	2.418	2.388	2.320	2.184	1.945	1.585	1.151	0.768	0.590
Nov	2.903	2.899	2.876	2.825	2.723	2.528	2.194	1.697	1.113	0.739
Dec	4.541	4.537	4.502	4.424	4.264	3.956	3.421	2.618	1.665	1.055
Jan	5.363	5.363	5.329	5.251	5.086	4.761	4.181	3.290	2.214	1.521
Feb	5.214	5.210	5.175	5.100	4.944	4.645	4.126	3.346	2.420	1.828
Mar	6.042	6.035	5.992	5.899	5.711	5.354	4.741	3.829	2.758	2.073
Apr	4.797	4.784	4.731	4.612	4.374	3.952	3.320	2.555	1.881	1.569
May	3.982	3.965	3.915	3.806	3.593	3.228	2.694	2.062	1.512	1.257
Jun	3.083	3.067	3.024	2.932	2.756	2.459	2.028	1.524	1.087	0.885
Jul	2.592	2.574	2.532	2.446	2.286	2.022	1.650	1.221	0.854	0.684
Aug	2.293	2.280	2.246	2.172	2.031	1.792	1.448	1.043	0.693	0.531
Sep	2.236	2.226	2.194	2.124	1.989	1.757	1.418	1.016	0.667	0.504

Natural Duration curves

Oct	27.863	16.944	10.972	7.604	4.969	3.966	2.971	2.415	1.848	1.242
Nov	39.904	31.127	24.839	19.146	15.591	10.629	8.352	5.645	3.136	1.632
Dec	63.418	50.926	41.327	36.065	31.921	27.064	19.417	11.771	6.119	1.551
Jan	105.591	83.960	73.775	65.018	47.593	40.322	34.427	27.095	16.754	6.258
Feb	123.884	92.021	73.241	67.462	51.934	44.359	38.150	29.891	25.706	8.188
Mar	110.231	87.049	70.722	62.525	57.602	43.258	38.484	32.031	21.515	6.729
Apr	45.822	32.878	29.331	26.314	21.838	20.307	17.421	15.565	13.389	4.775
May	19.155	15.883	13.731	12.832	11.709	10.718	10.015	9.306	8.395	3.816
Jun	12.231	10.409	8.793	8.277	7.575	6.903	6.616	6.026	5.335	2.852
Jul	8.499	7.542	6.613	6.107	5.729	5.058	4.850	4.483	3.870	2.924
Aug	7.251	5.854	5.010	4.480	4.107	3.861	3.457	3.185	2.912	2.221
Sep	9.640	5.220	4.107	3.625	3.188	3.047	2.834	2.270	2.132	1.684

4.5.5 IFR rule table for alternative Scenario: B ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	4.113	4.099	4.043	3.915	3.658	3.205	2.525	1.703	0.978	0.643
Nov	6.159	6.150	6.094	5.972	5.723	5.253	4.446	3.245	1.834	0.933
Dec	19.252	17.605	16.157	14.847	13.519	11.205	9.463	6.846	3.741	1.753
Jan	31.634	28.554	25.887	23.547	21.287	17.356	14.757	10.761	5.936	2.826
Feb	56.899	50.483	44.986	40.226	35.773	28.143	23.790	17.246	9.487	4.516
Mar	32.148	29.097	26.445	24.086	21.768	17.774	15.080	11.074	6.364	3.355
Apr	8.395	8.368	8.258	8.012	7.516	6.641	5.328	3.740	2.341	1.692
May	6.042	6.013	5.924	5.733	5.361	4.722	3.787	2.680	1.717	1.270
Jun	4.637	4.610	4.537	4.381	4.081	3.574	2.842	1.983	1.240	0.895
Jul	3.958	3.926	3.855	3.708	3.434	2.982	2.345	1.611	0.984	0.692
Aug	3.453	3.433	3.376	3.254	3.020	2.626	2.055	1.386	0.807	0.538
Sep	3.802	3.783	3.723	3.592	3.188	2.904	2.268	1.514	0.859	0.555

Reserve flows without High Flows

Oct	3.664	3.652	3.602	3.489	3.262	2.862	2.261	1.535	0.895	0.598
Nov	4.280	4.274	4.236	4.153	3.985	3.667	3.122	2.311	1.357	0.748
Dec	6.671	6.664	6.607	6.483	6.225	5.730	4.871	3.580	2.049	1.069

Jan	7.913	7.913	7.856	7.727	7.453	6.913	5.951	4.473	2.687	1.537
Feb	7.743	7.736	7.676	7.545	7.273	6.752	5.848	4.489	2.876	1.844
Mar	8.895	8.882	8.809	8.650	8.327	7.715	6.664	5.101	3.264	2.091
Apr	7.309	7.286	7.192	6.982	6.558	5.811	4.689	3.334	2.138	1.584
May	6.042	6.013	5.924	5.733	5.361	4.722	3.787	2.680	1.717	1.270
Jun	4.637	4.610	4.537	4.381	4.081	3.574	2.842	1.983	1.240	0.895
Jul	3.958	3.926	3.855	3.708	3.434	2.982	2.345	1.611	0.984	0.692
Aug	3.453	3.433	3.376	3.254	3.020	2.626	2.055	1.386	0.807	0.538
Sep	3.372	3.354	3.302	3.187	2.964	2.581	2.020	1.357	0.779	0.512

4.5.6 IFR rule table for alternative Scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.631	1.627	1.611	1.574	1.499	1.368	1.172	0.934	0.724	0.627
Nov	4.134	4.128	4.094	4.019	3.867	3.578	3.083	2.347	1.482	0.929
Dec	10.325	9.244	8.317	7.515	6.764	5.477	4.743	3.638	2.329	1.490
Jan	20.991	18.653	16.658	14.950	13.379	10.679	9.214	6.960	4.238	2.485
Feb	44.608	39.255	34.698	30.794	27.222	21.132	17.984	13.253	7.643	4.049
Mar	13.886	12.593	11.479	10.499	9.560	7.949	6.949	5.462	3.714	2.597
Apr	3.362	3.355	3.327	3.262	3.131	2.901	2.556	2.139	1.771	1.600
May	2.213	2.208	2.190	2.151	2.075	1.946	1.756	1.532	1.337	1.246
Jun	1.546	1.541	1.528	1.500	1.446	1.356	1.224	1.070	0.937	0.875
Jul	1.179	1.174	1.163	1.140	1.098	1.028	0.930	0.817	0.720	0.675
Aug	0.923	0.920	0.912	0.896	0.864	0.809	0.731	0.639	0.559	0.523
Sep	1.445	1.439	1.423	1.386	1.316	1.194	1.017	0.807	0.625	0.540

Reserve flows without High Flows

Oct	1.044	1.043	1.035	1.018	0.984	0.923	0.833	0.723	0.626	0.582
Nov	1.425	1.424	1.417	1.400	1.367	1.305	1.197	1.038	0.850	0.730
Dec	2.040	2.038	2.028	2.006	1.960	1.872	1.718	1.488	1.215	1.040
Jan	2.984	2.984	2.971	2.941	2.877	2.752	2.529	2.186	1.773	1.506
Feb	3.566	3.564	3.546	3.507	3.427	3.272	3.004	2.601	2.123	1.817
Mar	4.023	4.019	3.998	3.952	3.859	3.682	3.379	2.929	2.399	2.061
Apr	2.795	2.790	2.769	2.724	2.632	2.471	2.228	1.935	1.676	1.556
May	2.213	2.208	2.190	2.151	2.075	1.946	1.756	1.532	1.337	1.246
Jun	1.546	1.541	1.528	1.500	1.446	1.356	1.224	1.070	0.937	0.875
Jul	1.179	1.174	1.163	1.140	1.098	1.028	0.930	0.817	0.720	0.675
Aug	0.923	0.920	0.912	0.896	0.864	0.809	0.731	0.639	0.559	0.523
Sep	0.881	0.879	0.872	0.856	0.826	0.775	0.699	0.610	0.532	0.496

4.6 GEOMORPHOLOGICAL CONSEQUENCES OF C AND D SCENARIOS

Bed maintenance

For the recommended scenario of a C ERC, although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be a longer bed material residence time compared to virgin conditions. This will result in a moderately modified bed for periods between large flood events (20 - 50 year return period).

For the alternative scenario of a D ERC, flows reflect further reductions in flood frequency, and consequently, there will be a longer bed material residence time compared to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Bench maintenance

For the recommended scenario of a C ERC, although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be less bench maintenance constructional flows relative to virgin conditions. This will result in a moderately modified bench for periods between large flood events (20 - 50 year return period). For the alternative scenario of a D ERC, flows reflect further reductions in flood frequency, and consequently, there will be less bench maintenance constructional flows relative to a C ERC river. This will result in a largely modified bench for the periods between

large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Channel maintenance

For the recommended scenario of a C ERC, although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer channel maintenance flows relative to virgin conditions. This will result in a moderately modified channel for periods between large flood events (20 - 50 year return period). For the alternative scenario of a D ERC, flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows relative to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Macro-channel and bed mobilisation

For the recommended scenario of a C ERC river, although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer macro-channel and bed mobilisation flows relative to virgin conditions. This will result in a moderately modified macro-channel and a less frequently mobilised bed for periods between large flood events (20 - 50 year return period). For the alternative scenario of a D ERC river, flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows, and further reductions in bed mobilisation relative to a C ERC river. This will result in a largely modified macro-channel and more stable bed for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

4.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 4.5 IFR confidence for a C ERC

IFR Site		IFR Component			
		Aquatic inverts	Fish	Riparian Vegetation	Geomorphology
2	Low flows	2	3	2	-
	High flows	5	4	4	4

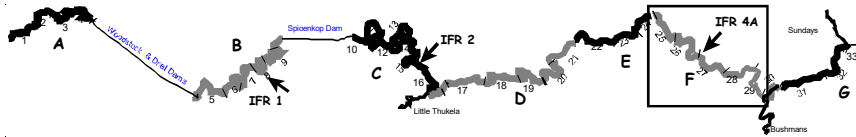
The confidence ranges from medium-to-low to medium for low flows, and medium to medium-to-high at high flows.

Invertebrates: The poor evaluation for aquatic invertebrates compared to that for IFR 1 is due to the poor habitats present at the site and the lack of a stones-in-current habitat specifically.

Fish: The medium evaluation for fish at low flows is due to the fact that the species, *A. natalensis*, was used as an indicator and that the site itself is unsuitable for this species.

Riparian vegetation: The low confidence for riparian vegetation at low flows is due to the lack of suitable low-flow indicator species.

5 RU F. IFR 4A. ZINGELA (Upper Thukela River)



5.1 ECOLOGICAL CATEGORIES

5.1.1 Summary of ERC scenarios

Three Ecological Reserve scenarios were addressed for IFR 4a. The recommended scenario is a B ERC. The alternative scenarios of a B/C and a C/D ERC were also evaluated.

Fig 5.1 Summary of the ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC (UP)	DOWN
WATER QUALITY	C	0	C	EIS H I G H S I G N I F I C A N T	B/C	
GEOMORPH	B/C	0	B/C		B/C	C/D
RIPARIAN VEGETATION	C	-	C/D		C	D
FISH	B	0	B		B	C
AQUATIC INVERTS	B/C	0	B/C		B	C/D
ECOSTATUS	B/C	0	B/C		B	C/D

5.1.2 Criteria for the Ecological Reserve Categories

Recommended scenario: B ERC

Aquatic invertebrates (B)

- Stones biotope: SASS > 130 ASPT > 7. Vegetation biotope: SASS > 110 ASPT > 7.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.

- Summer flows should be variable while winter flows should be more constant.

Fish (B)

- Maintain existing fish diversity.
- Maintain perennial flow.
- Freshes and floods needed to stimulate spawning especially of *A. natalensis*. Medium flows to provide backwater refuges for juveniles of all species and long-term migration opportunities for large-bodied species.

Riparian Vegetation (C)

- Ensure lower winter flows than in summer, marginal and riparian vegetation is generally dormant during winter.
- Ensure higher flows in summer as vegetation actively growing, reproducing and controlling the temperature.
- Maintain existing mixed *Juncus* and *Setaria* clumps on islands within the marginal zones on islands and on the edge of river through the provision of adequate low flows during winter and summer.
- Maintain existing stands of *Nuxia oppositifolia* and other riparian trees and shrubs in the lower, main, and upper riparian zone through the provision of adequate elevated flows, mainly during summer.
- Provide sufficient soil moisture to ensure successful recruitment of the majority of *Setaria* seedlings in marginal areas during autumn and early winter.
- Achieve thinning of weaker and older *Setaria* clumps during drought periods to improve the health and vigour of the *Setaria* population.
- Achieve limited failure of germination and survival of seedlings of *Setaria* to temper the resilience of the *Setaria* population.

Geomorphology (B/C)

- Maintain the river in its present state i.e. the continued re-formation of channel banks and benches. Floods need to occur which have a sufficient size and frequency to re-distribute the available sediment which is presently entering this system and continue to "re-set" the general channel morphology, particularly the bed and bank morphology. The number of events is less than that required for an A category as indicated in the above table.

Alternative Scenario: B/C ERC

Aquatic invertebrates (B/C)

- Stones biotope: SASS > 110 ASPT > 6.5. Vegetation biotope: SASS > 90, ASPT > 6.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (B)

- As for the B ERC.

Riparian Vegetation (C)

- As for the B ERC.

Geomorphology (B/C)

- As for the B ERC.

Alternative Scenario: C/D ERC

Aquatic invertebrates (C/D)

- Stones biotope: SASS > 100 ASPT > 6. Vegetation biotope: SASS > 80 ASPT > 6.

- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (C)

- Fish species diversity remains unchanged, but with reduced breeding success and abundance, particularly of *A. natalensis*.

Riparian Vegetation (D)

- Allow reduced densities and recruitment rates of water dependent species in the marginal areas of both banks, with possible loss on the islands. Maintain existing riparian trees and shrubs with slightly impaired recruitment rates and encroachment of terrestrial species.
- Ensure lower winter flows than in summer, as marginal and riparian vegetation is generally dormant during winter.
- Ensure higher flows in summer as the vegetation is actively growing, reproducing and the controlling temperature.
- Maintain some of the existing mixed *Juncus* and *Setaria* clumps on islands within marginal zones on the islands and edge of the river through the provision of adequate low flows during winter and summer.
- Maintain most of the existing stands of *Nuxia oppositifolia* and other riparian trees and shrubs in the lower, main, and upper riparian zone through the provision of adequate elevated flows, mainly during summer.
- Maintain most of the existing stands of *Nuxia oppositifolia* and other riparian trees and shrubs in lower, main, and upper riparian zone through the provision of adequate low flows during winter and summer.
- Provide sufficient soil moisture to ensure successful recruitment of the majority of *Setaria* seedlings in marginal areas during autumn and early winter.
- Achieve thinning of weaker and older *Setaria* clumps during drought periods to improve the health and vigour of the *Setaria* population.
- Achieve limited failure of germination and survival of seedlings of *Setaria* to temper the resilience of the *Setaria* population.

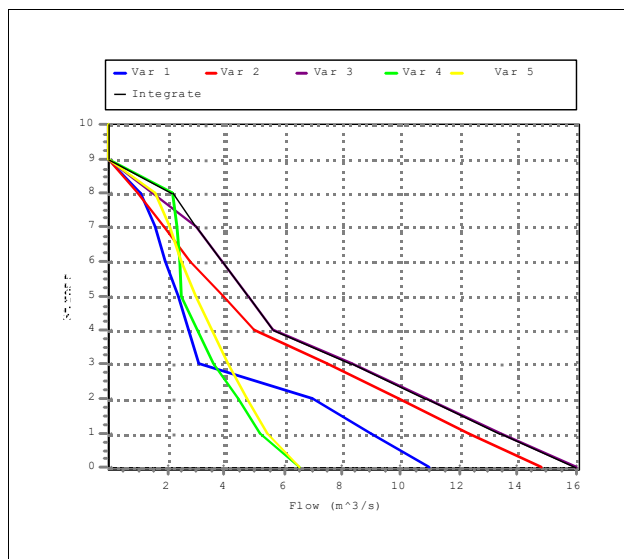
Geomorphology (C/D)

- To change the present state from a B/C to a C/D the transformation of the channel back towards some new form of dynamic equilibrium will occur considerably more slowly than would occur naturally. Also the reduced number of floods will likely lead to a slower re-formation of bed and banks whilst increasing the storage time of sediment on the bed. For this reason the number of requested flood events is less than that required for a B/C category.

5.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 4a, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 5.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 5.2.

Fig 5.2 Critical curve for IFR 4a



Var 1: Fish

Var 3: Marginal Vegetation Invertebrates

Var 5: Riparian Vegetation 2

Var 2: Flow Dependent Invertebrates

Var 4: Riparian Vegetation 1

5.2.1 Invertebrates

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit (5.2m³/s) as a reference point. The stress index of zero was set at approximately 0.2m higher than observed (so that the vegetation on the cobble bar on the left side of the river would be well inundated), as this would result in significant inundation of extra vegetation habitat (using the hydraulic profile and tables to derive the characteristics). The indices of greater stress were derived similarly, but measuring the reduction in water level that would leave just the bases of the *Juncus* inundated. Note that this assessment for marginal vegetation communities applies only for the wet season, as during dry seasons it can be expected that flows will recede from the vegetation.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of small cobbles and diverse biotope. The habitat model and hydraulic data were used to determine the depths and velocities that would produce minimal stress to mayflies. Higher stresses were determined by anticipating minimal depths and velocities that would only provide remnants of their required habitat. Much of this investigation was based on the families such as Oligoneuridae and Hydropsychidae that were known to be present in 1960 and which require abundant clean, strong flowing water over clean rocks.

5.2.2 Riparian Vegetation

Three components were selected, using elevations and discharges associated with the ecological transect.

- **Setaria adults**
Setaria adults were identified at the 0.85m water level. Since the site was not investigated for rooting depths of *Setaria*, mean maximum lengths were extrapolated from IFR 11. Root lengths of 0.20m were used, corresponding to water levels of 0.65m.
- **Setaria juveniles (seedlings)**
Setaria juveniles were estimated to occur at the same levels as that of the *Setaria* adults, i.e. 0.85m. Seedling stress levels are only applicable during the autumn and early winter when seedling recruitment is most prominent. Adult stress levels are most appropriate during the summer months when growth and survival is dependent on water levels. These grasses are largely dormant during winter and therefore less dependent on water. It is surmised that stress levels of 10 would only occur at much lower water levels than in summer.
- **Juncus spp.**
Juncus spp. occurs in mats which cover a reasonably large area of the marginal zone and are linked by rhizomes. Only the lower lying edges of these mats are crucial because the *Juncus* spp. would only attain maximum stress levels once water levels drop below the roots of these parts, i.e. at the 0.35m level. The *Juncus* spp. was found to be the less sensitive vegetation since its roots extended well below that of the *Setaria* adults and would therefore still remain relatively unstressed when the *Setaria* adults and seedlings have attained maximum stress.

5.3 STRESS DURATION CURVE

5.3.1 Natural stress duration curve

The natural flow regime was converted to a stress profile (see blue line, Figure 5.3 – 5.8), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 4a, stress indices as determined were accepted, and no changes were required.

5.3.2 Recommended stress profiles for each Reserve scenario

The recommended B scenario and the alternative B/C and C/D scenarios were estimated using the Desktop model and are shown in Figures 5.3 – 5.8 the purple, green, yellow and black lines respectively. The modelled present day hydrology as converted into stress, is reflected by the red line in Figures 5.3 – 5.8 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 5.3 - 5.8. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures 5.9 – 5.10). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

5.3.3 Process to adjust the Desktop output to fit specialist requirements

The B assurance rule was adjusted by increasing the control parameters that affect the maximum low flow at low assurance for the wet season. For all the scenarios B, B/C and C/D the B assurance rule was used. The generated recommended B scenario consisted of Maintenance Low Flows of 20.33% MAR, which were adjusted to 14.74% MAR. The generated B scenario consisted of Drought Low Flows of 7.09% MAR, which were adjusted to 6.85% MAR. The generated B/C scenario consisted of Maintenance Low Flows of 17.99 % MAR, which were adjusted to 12.39% MAR. The generated B/C scenario consisted of Drought Low Flows of 7.09% MAR, which were adjusted to 6.85% MAR. The generated C/D scenario consisted of Maintenance Low Flows of 11.22% MAR, which were adjusted to

8.76% MAR. The generated C/D scenario consisted of Drought Low Flows of 7.09% MAR, which were adjusted to 6.85% MAR. The seasonal distributions were changed to fit the specialists, requirements for stress patterns in a better way.

Fig 5.3 IFR 4a - Stress duration curve for recommended scenario of a B ERC: Dry Season

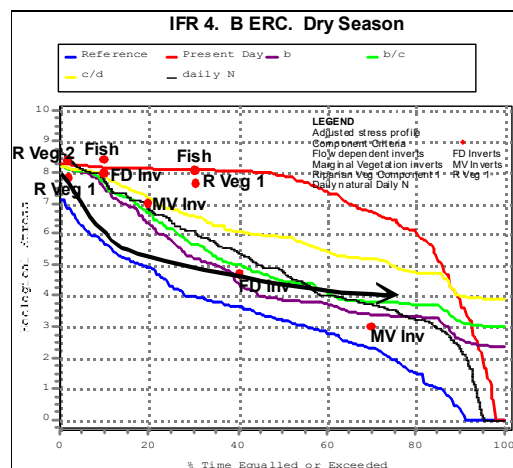


Fig 5.4 IFR 4a - Stress duration curve for recommended scenario of a B ERC: Wet Season

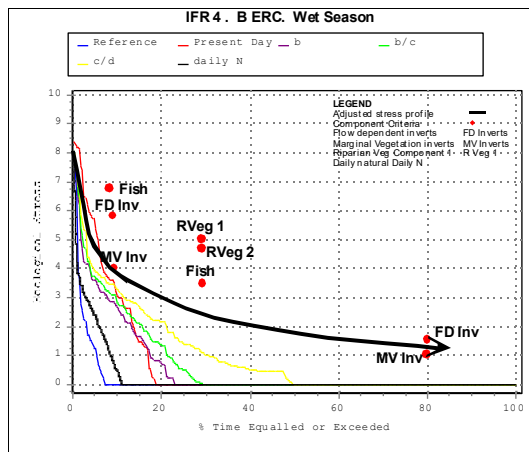


Fig 5.5 IFR 4a - Stress duration curve for alternative scenario of a B/C ERC: Dry Season

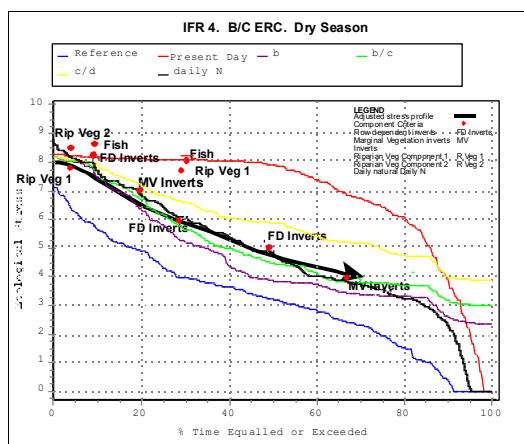


Fig 5.6 IFR 4a - Stress duration curve for alternative scenario of a B/C ERC: Wet Season

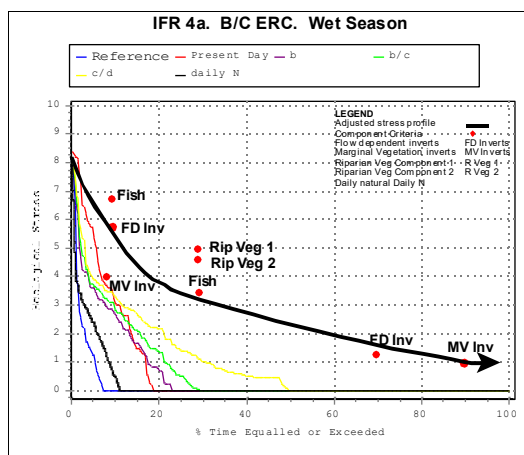


Fig 5.7 IFR 4a - Stress duration curve for alternative scenario of a C/D ERC: Dry Season

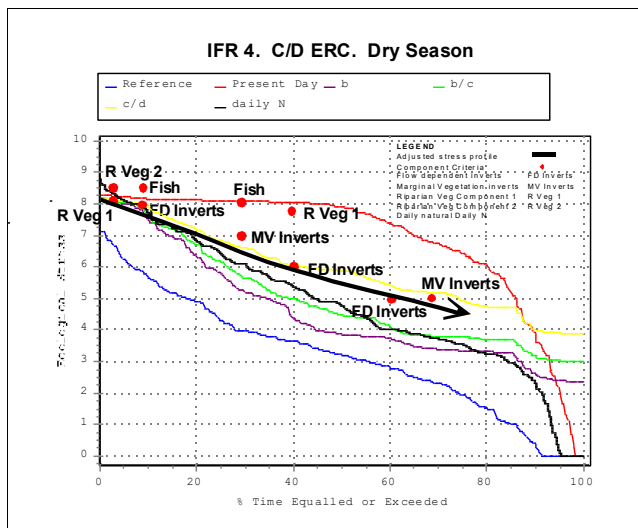
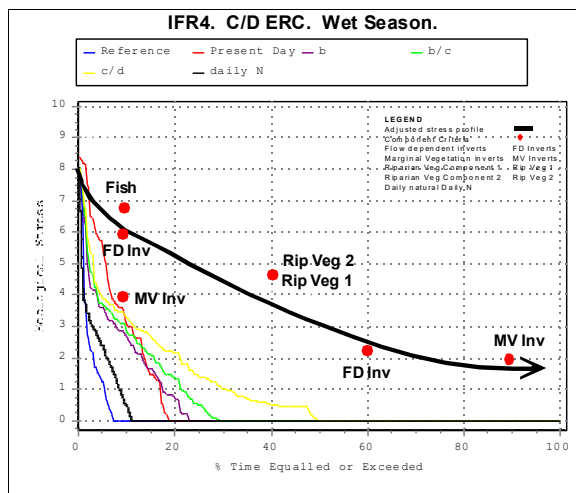


Fig. 5.1 IFR 4a - Stress duration curve for alternative scenario of a C/D ERC: Wet Season



5.3.4 Final stress profiles for IFR 4a

Fig 5.8 IFR 4a - Final stress profile: Dry Season

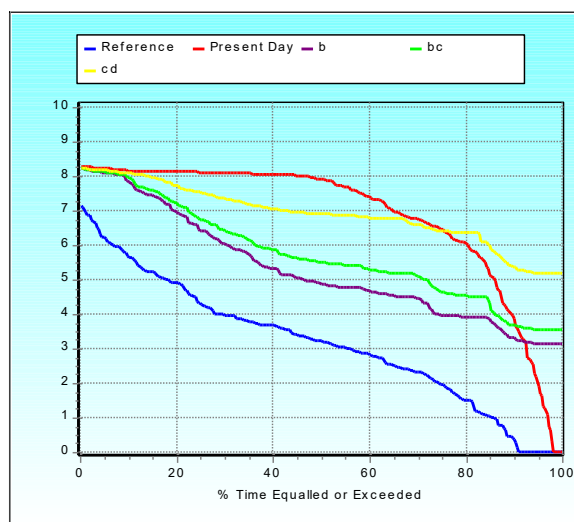
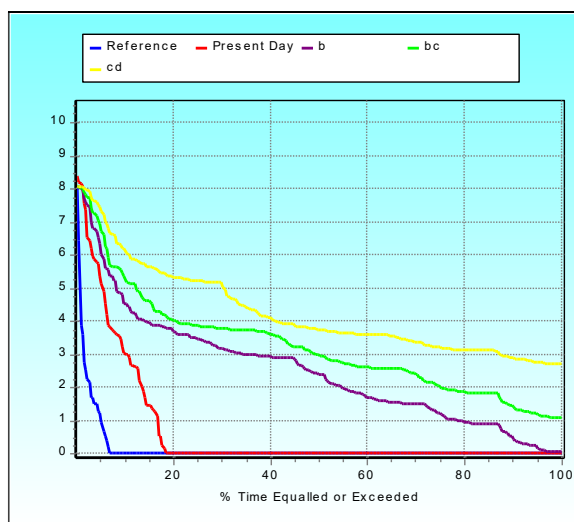


Fig 5.9 IFR 4a - Final stress profile: Wet Season



5.4 HIGH FLOWS

The functions for each flood class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 5.1. The number of events for each Flood Class required for an ERC of B, B/C, and C/D are also summarised in Table 5.1.

Table 5.1 A summary of the Flood Class ranges for IFR 4a, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s					
	I	II	III	IV	V	VI
Fish	10					
Invertebrates	10-25	Low+10		140		
Vegetation	10-25	20-60	60-140	140-220		
Geomorphology			60-139	140-233	233-241	441-510
Integrated	10-24	25-59	60-139	140-220	221-440	441-510
Geometric Mean*			92	175	320	474
Recommended Floods						
No of events for B ERC (Recommended scenario)	6	6	4	1	1	1 in 3 years
No of events for B/C ERC (Alternative scenario)	6	4	4	1	1	1 in 3 years
No of events for C/D ERC (Alternative scenario)	4	3	3	1	1	1 in 4 years

NOTE: No of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

Note that for Flood Class VII, it is important that the large, infrequent floods (1:20 year event) are allowed to pass through the system unimpeded.

These high flow recommendations were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 441 to 510) were reduced to lower discharge values (e.g. 250) for the Desktop model to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model. The floods provided in Table 5.1 are peak values. These have to be adjusted when used in the IFR model to present daily averages.

The adjustments as described above are illustrated in Tables 5.2 – 5.5.

Table 5.2 Adjusted flood sizes as used in the Desktop model for a B Category

Summer												
	Dec		Jan		Feb		Mar		Apr		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m ³ /s)	III	90	IV	120	VI, incl. V	250	III	90			III	90
Duration (days)	6		7		7		6				6	
Freshet size (m ³ /s)	I & II	15 + 40	III	90	I & II	15 + 40	II x2	15 + 15	I	15		
Duration (days)	4		6		4		4		4			
Spring												
	Sept		Oct		Nov							
	Class	Flood	Class	Flood	Class	Flood						
Freshet size (m ³ /s)	I	15	I & II	15 + 40	I & II	15 + 40						
Duration (days)	4		4		4							

Table 5.3 Adjusted flood sizes as used in the Desktop model for a B/C Category

Summer												
	Dec		Jan		Feb		Mar		Apr		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	90	IV	120	VI, incl. V	250	III	90			III	90
Duration (days)	6		7		7		6				6	
Freshet size (m³/s)	I & II	15 + 40	III	90	I & II	15 + 40	II	15	I	15		
Duration (days)	4		6		4		4		4			
Spring												
	Sept		Oct		Nov							
Freshet size (m³/s)	I	15	I	15	I & II	15 + 40						
Duration (days)	4		4		4							

Table 5.4 Adjusted flood sizes as used in the Desktop model for a C/D Category

Summer												
	Dec		Jan		Feb		Mar		Apr		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	90	IV	120	VI, incl. V	220	III	90			III	90
Duration (days)	6		7		8		6				6	
Freshet size (m³/s)	I & II	15 + 40	I	15	II	40	I	15				
Duration (days)	4		4		4		4					
Spring												
	Sept		Oct		Nov							
Freshet size (m³/s)			I	15	II	40						
Duration (days)			4		4							

Table 5.5 Adjusted flood sizes as used in the Desktop Model for a C Category

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	30	IV	80	VI, incl. V	200	IV	80		
Duration (days)	6		6		7		6			
Freshet size (m³/s)	I & II	7 + 14	I & II	7 + 14	III	30	III x 2	60	I	7
Duration (days)	5		5		5		5		3	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	7	I	7	I & II	7 + 14				
Duration (days)	3		3		5					

5.5 FINAL RESULTS

5.5.1 IFR table for recommended scenario: B ERC

Annual Flows (Mill. cu. m or index values):

MAR = 1423.828
 S.Dev. = 632.041
 CV = 0.444
 Q75 = 22.230
 Q75/MMF = 0.187
 BFI Index = 0.374
 CV(JJA+JFM) Index = 1.393

Total IFR = 452.252 (31.76 %MAR)
 Maint. Lowflow = 209.909 (14.74 %MAR)
 Drought Lowflow = 97.584 (6.85 %MAR)
 Maint. Highflow = 242.343 (17.02 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	53.199	79.775	1.500	12.856	5.089	9.979	22.836
Nov	96.743	98.158	1.015	13.738	4.925	30.586	44.323
Dec	157.320	129.274	0.822	15.803	5.357	30.586	46.388
Jan	263.929	188.163	0.713	21.695	11.249	50.881	72.576
Feb	315.884	211.074	0.668	25.644	14.031	79.747	105.391
Mar	249.980	149.462	0.598	25.445	14.463	35.122	60.566
Apr	117.914	81.130	0.688	22.032	12.442	2.722	24.754
May	52.757	31.989	0.606	19.284	9.107	0.000	19.284
Jun	32.240	12.298	0.381	17.366	6.480	0.000	17.366
Jul	23.725	10.614	0.447	13.392	5.223	0.000	13.392
Aug	22.438	30.791	1.372	11.249	4.553	0.000	11.249
Sep	37.699	103.165	2.737	11.405	4.666	2.722	14.126

5.5.2 IFR table for alternative scenario: B/C ERC

Annual Flows (Mill. cu. m or index values):

MAR = 1423.828
 S.Dev. = 632.041
 CV = 0.444
 Q75 = 22.230
 Q75/MMF = 0.187
 BFI Index = 0.374
 CV(JJA+JFM) Index = 1.393

Total IFR = 404.231 (28.39 %MAR)
 Maint. Lowflow = 176.403 (12.39 %MAR)
 Drought Lowflow = 97.584 (6.85 %MAR)
 Maint. Highflow = 227.828 (16.00 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	53.199	79.775	1.500	11.249	5.089	2.722	13.971
Nov	96.743	98.158	1.015	11.146	4.925	30.586	41.731

Dec	157.320	129.274	0.822	11.785	5.357	30.586	42.371
Jan	263.929	188.163	0.713	16.874	11.249	50.881	67.755
Feb	315.884	211.074	0.668	21.289	14.031	79.747	101.036
Mar	249.980	149.462	0.598	20.892	14.463	30.586	51.477
Apr	117.914	81.130	0.688	18.922	12.442	0.000	18.922
May	52.757	31.989	0.606	17.410	9.107	0.000	17.410
Jun	32.240	12.298	0.381	15.034	6.480	0.000	15.034
Jul	23.725	10.614	0.447	11.785	5.223	0.000	11.785
Aug	22.438	30.791	1.372	9.910	4.553	0.000	9.910
Sep	37.699	103.165	2.737	10.109	4.666	2.722	12.830

5.5.3 IFR table for alternative scenario: C/D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	1423.828
S.Dev.	=	632.041
CV	=	0.444
Q75	=	22.230
Q75/MMF	=	0.187
BFI Index	=	0.374
CV(JJA+JFM) Index	=	1.393

Total IFR	=	310.807	(21.83 %MAR)
Maint. Lowflow	=	124.658	(8.76 %MAR)
Drought Lowflow	=	94.733	(6.65 %MAR)
Maint. Highflow	=	186.149	(13.07 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High Flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	53.199	79.775	1.500	8.035	5.089	2.722	10.757
Nov	96.743	98.158	1.015	7.776	4.925	27.864	35.640
Dec	157.320	129.274	0.822	8.571	5.357	30.586	39.156
Jan	263.929	188.163	0.713	12.053	10.714	32.996	45.049
Feb	315.884	211.074	0.668	14.515	13.306	68.653	83.169
Mar	249.980	149.462	0.598	14.731	13.392	23.328	38.059
Apr	117.914	81.130	0.688	13.478	11.923	0.000	13.478
May	52.757	31.989	0.606	13.392	9.107	0.000	13.392
Jun	32.240	12.298	0.381	10.109	6.480	0.000	10.109
Jul	23.725	10.614	0.447	8.035	5.223	0.000	8.035
Aug	22.438	30.791	1.372	6.964	4.553	0.000	6.964
Sep	37.699	103.165	2.737	6.998	4.666	0.000	6.998

5.5.4 IFR rule table for recommended scenario: B ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	10.138	10.064	9.895	9.546	8.854	7.303	5.243	4.136	3.089	2.397
Nov	19.695	19.535	19.173	18.425	17.031	14.734	11.492	7.760	4.569	2.793
Dec	23.169	22.979	22.548	21.656	19.994	17.257	13.393	8.944	5.140	3.371
Jan	55.497	48.714	43.009	37.925	28.887	25.231	20.070	14.129	9.049	6.687
Feb	76.709	66.796	58.502	51.197	38.222	33.317	26.394	18.423	11.609	8.439
Mar	45.621	40.742	36.594	32.818	26.091	23.041	18.735	13.778	9.540	7.569
Apr	11.817	11.750	11.597	11.281	10.691	9.719	8.348	6.769	5.419	4.791
May	8.894	8.843	8.726	8.485	8.037	7.297	6.254	5.052	4.025	3.547
Jun	7.747	7.696	7.581	7.342	6.898	6.166	5.133	3.943	2.926	2.453
Jul	6.174	6.134	6.044	5.858	5.511	4.940	4.133	3.204	2.410	2.041
Aug	5.019	4.987	4.916	4.767	4.490	4.034	3.390	2.649	2.015	1.721
Sep	6.200	6.158	6.064	5.869	4.794	4.607	4.062	3.089	2.258	1.871

Reserve flows without High Flows

Oct	5.927	5.889	5.803	5.626	5.295	4.751	3.982	3.097	2.340	1.988
Nov	6.637	6.592	6.488	6.273	5.873	5.213	4.283	3.211	2.295	1.869
Dec	8.798	8.734	8.588	8.287	7.725	6.800	5.495	3.991	2.706	2.109
Jan	12.935	12.854	12.671	12.293	11.589	10.428	8.790	6.905	5.292	4.542
Feb	14.304	14.218	14.021	13.616	12.859	11.614	9.855	7.831	6.100	5.295
Mar	15.193	15.105	14.905	14.493	13.724	12.458	10.671	8.613	6.854	6.036
Apr	10.656	10.598	10.468	10.199	9.698	8.872	7.706	6.364	5.216	4.683
May	8.894	8.843	8.726	8.485	8.037	7.297	6.254	5.052	4.025	3.547
Jun	7.747	7.696	7.581	7.342	6.898	6.166	5.133	3.943	2.926	2.453
Jul	6.174	6.134	6.044	5.858	5.511	4.940	4.133	3.204	2.410	2.041
Aug	5.019	4.987	4.916	4.767	4.490	4.034	3.390	2.649	2.015	1.721
Sep	5.089	5.057	4.984	4.834	4.555	4.095	3.446	2.699	2.060	1.763

Natural Duration curves

Oct	47.388	30.100	17.747	14.776	8.854	7.303	5.243	4.136	3.422	2.577
Nov	98.656	51.684	40.039	33.363	25.246	17.507	15.009	10.827	5.212	2.793
Dec	116.011	90.953	75.891	64.495	48.264	43.588	34.240	18.372	10.810	3.611
Jan	200.946	178.025	141.403	103.093	83.421	70.211	56.905	42.916	26.461	14.500
Feb	230.858	184.192	137.362	117.832	94.702	86.708	73.253	47.159	37.840	20.598
Mar	187.475	160.160	124.198	110.764	94.845	78.700	63.806	56.031	33.945	20.961
Apr	74.238	59.558	50.183	44.892	34.745	32.508	28.495	24.111	20.359	12.929
May	32.072	24.398	20.999	19.201	18.075	17.068	14.834	13.376	12.076	8.148
Jun	19.217	14.583	12.896	11.862	11.029	10.230	9.532	8.554	7.672	5.582
Jul	14.707	11.173	10.000	9.167	8.113	7.643	6.809	6.250	5.598	4.892
Aug	12.194	8.695	7.770	6.661	6.231	5.742	5.279	4.626	4.230	3.693
Sep	19.258	9.498	7.359	5.940	4.794	4.607	4.204	3.801	3.203	2.830

5.5.5 IFR rule table for alternative scenario: B/C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	6.336	6.295	6.203	6.012	5.656	5.070	4.242	3.289	2.474	2.095
Nov	18.444	18.297	17.962	17.270	15.980	13.855	10.856	7.403	4.450	2.793
Dec	20.936	20.767	20.384	19.593	18.117	15.686	12.255	8.305	4.928	3.357
Jan	52.628	45.873	40.230	35.274	26.476	23.214	18.609	13.309	8.776	6.669
Feb	74.285	64.395	56.154	48.957	36.185	31.613	25.160	17.730	11.378	8.424
Mar	38.979	34.745	31.166	27.945	22.214	19.767	16.313	12.336	8.935	7.354
Apr	9.155	9.112	9.015	8.813	8.437	7.817	6.942	5.935	5.074	4.673
May	8.031	7.988	7.891	7.688	7.311	6.691	5.814	4.805	3.943	3.542
Jun	6.708	6.668	6.575	6.383	6.025	5.436	4.604	3.646	2.827	2.446
Jul	5.434	5.402	5.328	5.175	4.889	4.420	3.756	2.993	2.340	2.036
Aug	4.423	4.397	4.338	4.216	3.989	3.615	3.087	2.479	1.959	1.717
Sep	5.623	5.587	5.505	5.336	4.794	4.501	3.768	2.924	2.203	1.867

Reserve flows without High Flows

Oct	5.188	5.157	5.087	4.943	4.674	4.231	3.605	2.885	2.270	1.984
Nov	5.387	5.353	5.277	5.118	4.822	4.334	3.646	2.853	2.176	1.861
Dec	6.564	6.521	6.424	6.223	5.848	5.230	4.357	3.353	2.494	2.095
Jan	10.067	10.013	9.893	9.643	9.178	8.411	7.330	6.084	5.020	4.525
Feb	11.881	11.817	11.674	11.376	10.822	9.910	8.621	7.138	5.870	5.280
Mar	12.481	12.419	12.278	11.987	11.445	10.551	9.290	7.838	6.597	6.019
Apr	9.155	9.112	9.015	8.813	8.437	7.817	6.942	5.935	5.074	4.673
May	8.031	7.988	7.891	7.688	7.311	6.691	5.814	4.805	3.943	3.542
Jun	6.708	6.668	6.575	6.383	6.025	5.436	4.604	3.646	2.827	2.446
Jul	5.434	5.402	5.328	5.175	4.889	4.420	3.756	2.993	2.340	2.036
Aug	4.423	4.397	4.338	4.216	3.989	3.615	3.087	2.479	1.959	1.717
Sep	4.512	4.485	4.425	4.301	4.070	3.690	3.152	2.534	2.005	1.759

5.5.6 IFR Rule Table for Alternative Scenario: C/D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	4.857	4.831	4.770	4.646	4.413	4.030	3.489	2.866	2.333	2.086
Nov	15.657	15.535	15.259	14.687	13.621	11.865	9.387	6.533	4.093	2.793

Dec	19.149	18.998	18.653	17.942	16.615	14.430	11.345	7.794	4.758	3.346
Jan	34.798	30.424	26.780	23.597	17.949	15.929	13.078	9.796	6.990	5.685
Feb	61.833	53.343	46.304	40.224	29.443	25.861	20.805	14.985	10.008	7.694
Mar	29.020	25.806	23.113	20.732	16.501	14.866	12.559	9.902	7.631	6.574
Apr	6.529	6.509	6.464	6.371	6.198	5.912	5.509	5.046	4.649	4.465
May	6.183	6.158	6.100	5.980	5.758	5.391	4.873	4.277	3.767	3.530
Jun	4.516	4.496	4.450	4.357	4.182	3.894	3.487	3.019	2.619	2.432
Jul	3.709	3.693	3.656	3.581	3.439	3.206	2.878	2.500	2.176	2.026
Aug	3.111	3.098	3.067	3.004	2.886	2.692	2.419	2.104	1.834	1.709
Sep	3.127	3.114	3.084	3.022	2.906	2.716	2.447	2.138	1.874	1.751

Reserve flows without High Flows

Oct	3.709	3.692	3.655	3.576	3.431	3.191	2.852	2.463	2.129	1.974
Nov	3.762	3.744	3.702	3.616	3.456	3.191	2.818	2.389	2.022	1.851
Dec	4.778	4.752	4.693	4.572	4.346	3.973	3.447	2.842	2.324	2.084
Jan	7.197	7.169	7.106	6.975	6.732	6.330	5.764	5.111	4.553	4.294
Feb	8.109	8.079	8.011	7.871	7.609	7.177	6.568	5.866	5.266	4.987
Mar	8.809	8.778	8.707	8.560	8.287	7.837	7.203	6.472	5.847	5.556
Apr	6.529	6.509	6.464	6.371	6.198	5.912	5.509	5.046	4.649	4.465
May	6.183	6.158	6.100	5.980	5.758	5.391	4.873	4.277	3.767	3.530
Jun	4.516	4.496	4.450	4.357	4.182	3.894	3.487	3.019	2.619	2.432
Jul	3.709	3.693	3.656	3.581	3.439	3.206	2.878	2.500	2.176	2.026
Aug	3.111	3.098	3.067	3.004	2.886	2.692	2.419	2.104	1.834	1.709
Sep	3.127	3.114	3.084	3.022	2.906	2.716	2.447	2.138	1.874	1.788

5.6 GEOMORPHOLOGICAL CONSEQUENCES OF B/C AND C/D SCENARIOS

Bed maintenance

B/C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be a longer bed material residence time compared to virgin conditions. This will result in a slightly modified bed for periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be a longer bed material residence time compared to a B/C ERC river. This will result in a moderately modified channel for the periods between large flood events (20 - 50 year return period).

Bench maintenance

B/C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be less bench maintenance constructional flows relative to virgin conditions. This will result in a slightly modified bench for periods between large flood events (20 - 50 year return period). C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be less bench maintenance constructional flows relative to a B/C ERC river. This will result in a largely modified bench for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Channel maintenance

B/C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer channel maintenance flows relative to virgin conditions. This will result in a moderately modified channel for periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events). C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows relative to a B/C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period).

Macro Channel and bed mobilisation

B/C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer macro-channel and bed mobilization flows relative to virgin conditions. This will result in a moderately modified macro-channel and a less frequently mobilized bed for periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events). C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows, and further reductions in bed mobilization relative to a B/C ERC river. This will result in a largely modified macro-channel and more stable bed for the periods between large flood events (20 - 50 year return period).

Conclusion

IFR 4 (Zingela) is a site that is in a phase of re-building its banks. The focus for the flood requirements has been on the bench maintenance to ensure the geomorphology stays in the ecological state which it is presently in. For this reason requirements remain very similar for both C/D and B/C ERC. If the flood requirements are met, there is reasonable confidence that the morphology will remain within the present class for the 20-year period considered.

5.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 5.6 IFR confidence table for a B ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
4a	Low flows	4	4	4	-
	High flows	4	4	4	4

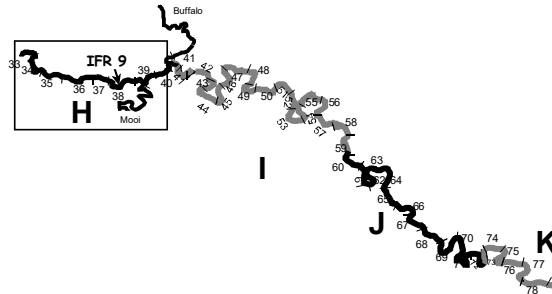
The confidence is medium-high.

Fish: The medium-high confidence for fish reflects the presence of adequate habitat for *A. natalensis*. The confidence in whether *A. natalensis* still occurs there is however low.

Riparian vegetation: The riparian vegetation evaluation is linked to the presence of low-flow indicators which occur consistently at interpretable levels. The high-flow indicators such as *Nuxia oppositifolia* allow for the medium-high confidence.

Geomorphology: Evaluation was aided by the sediment transport modelled results that allow for higher confidence than at sites where these are not available.

6 RU H. IFR 9. THUKELA FERRY (Upper Thukela River)



6.1 ECOLOGICAL CATEGORIES

6.1.1 Summary of ERC scenarios

Two Ecological Reserve Scenarios were addressed for IFR 9. The recommended scenario is a D ERC. The alternative scenario of a C ERC was also evaluated.

Fig 6.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP
WATER QUALITY	B	-	B/C	EIS	B	
GEOMORPH	D	-	D/E	M	D	C
RIPARIAN VEGETATION	E	-	E/F	O	D	D
FISH	B	-	C	D	B	B
AQUATIC INVERTS	C	0	C	E	C	B
ECOSTATUS	D	-	D/E	S	D	C

6.1.2 Criteria for the Ecological Reserve Categories

Recommended scenario: D ERC

Aquatic invertebrates (C)

- Stones biotope: SASS >120 ASPT > 6.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (B)

- Maintain existing fish diversity and abundances.

Geomorphology (D)

- This part of the Thukela River appears to be very resilient to change. To maintain the river in its present state, there is a requirement for floods which have a sufficient size and frequency to move the available sediment which is presently entering this system, particularly the sand and gravel components. For this reason the number of events to maintain the bed, bench and channel do not change very much between categories A and D. The return period for the larger floods is extended, which means that bed material is turned over less frequently.

Alternative scenario: C ERC

Aquatic invertebrates (B)

- Stones biotope: SASS > 130 ASPT > 6.5.
- Improved flows support flow dependent taxa although limited by excess turbidity of the water.

Fish (B)

- As for the D ERC.

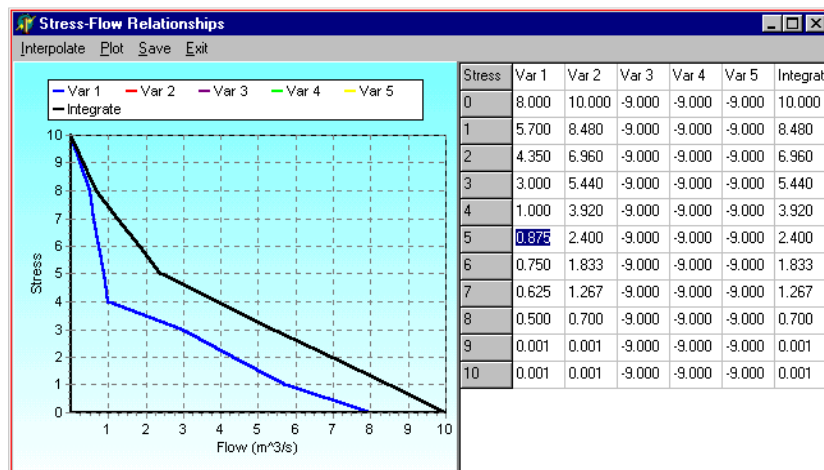
Geomorphology (C)

- To change the present state from a D ERC to a C ERC, there is a need for reduced sediment accumulation i.e. increased sediment transport, together with an overall increase in sediment scour from the bed, banks and bars. Since the majority of sediment is transported by flood events, an increase in the number of these events or their return period should achieve this objective.

6.2 FLOW STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 9, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 6.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 6.2.

Fig 6.2 Critical curve for IFR 9



Var 1: Fish

Var 2: Flow Dependent Invertebrates

Var 3: Marginal Vegetation Invertebrates

Var 4: Riparian Vegetation 1

Var 5: Riparian Vegetation 2

6.2.1 Invertebrates

Marginal vegetation was not present at the site and was therefore not investigated.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of stones biotope which was limited by being dominated by large embedded stones. The hydraulic data was used to determine the depths and velocities that would produce minimal stress to rheophilic species including *Elassoneuria* (Oligoneuridae), and *Centroptiloides* (Baetidae). Higher stresses were determined by anticipating minimal velocities that would only provide remnants of their required habitat. Stresses would be caused by reductions in velocity, with corresponding increased temperatures, sedimentation and diatom growth on stones, exposure to predators, with possibilities of decreased oxygen concentrations especially at night. Reduced velocities also cause stress to organisms that make use of flowing water to aid gaseous exchange – slow velocities require the expenditure of energy to irrigate the gills, thus reducing the competitiveness of the insect

6.2.2 Riparian Vegetation

This site has been devastated from a vegetation perspective by a variety of non-flow related disturbances. Grazing and browsing by cattle and goats and the removal of vegetation for building materials, fuel and muti have left this site completely devoid of both marginal and riparian vegetation. It is also surmised that the impact of large and frequent floods has also lead to the absence of suitable habitat for the re-colonisation and subsequent recovery of marginal vegetation.

Since no water-dependant vegetation such as *Juncus*, *Setaria* or *Salix* were present, it was not possible to provide stress curves for any vegetation components in response to low flows.

The absence of suitable riparian vegetation on the banks also made it impossible to provide high flow recommendations.

6.3 STRESS DURATION CURVES (PROFILES)

6.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 6.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 9, stress indices as determined were accepted, no changes were required.

6.3.2 Desktop-generated scenarios and evaluation

The recommended scenario of a D and the alternative scenario of a C were estimated using the Desktop model and are shown in Figures 6.3 – 6.6 as the green and purple lines respectively. The modelled present day hydrology, as converted into stress, is reflected by the red line in Figures 6.3 – 6.6 (described as Present Day). Specialists evaluated the generated scenarios for winter (Dry) and summer (Wet). The results of this evaluation are overlaid as points and bold black lines in Figures 6.3 - 6.6. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures 6.7 – 6.8). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

6.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated D scenario consisted of Maintenance Low Flows of 7.22 % MAR, which were adjusted to 6.1% MAR, and of Drought Low Flows of 7% MAR, which were adjusted to 3.4% MAR (see Figure 7.3). The generated C scenario consisted of Maintenance Low Flows of 13.97% MAR, which were adjusted to 12% MAR, and of Drought Low Flows of 7% MAR, which were adjusted to 3.4% MAR (see Figure 7.3). The seasonal distributions were flattened from the original distribution to better fit the specialists' requirements for stress patterns.

Fig 6.3 IFR 9 - Stress-duration curve for a recommended scenario of a D ERC: Dry Season

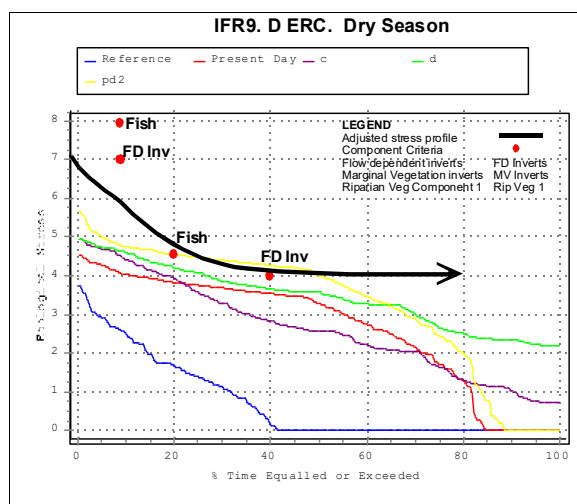


Fig 6.4 IFR 9 - Stress-duration curve for a recommended scenario of a D ERC: Wet Season

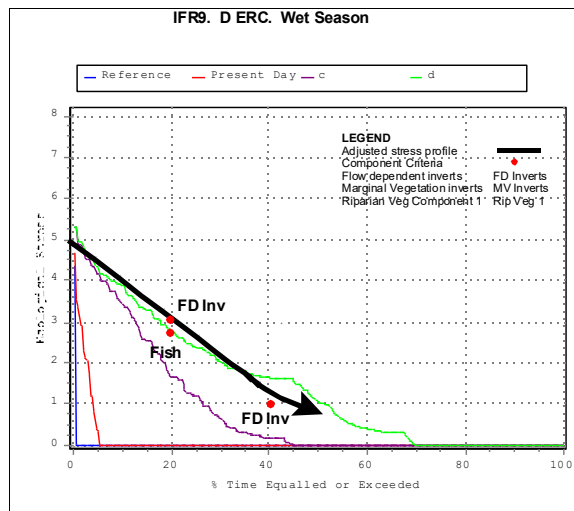


Fig 6.5 IFR 9 - Stress-duration curve for a recommended scenario of a C ERC: Dry Season

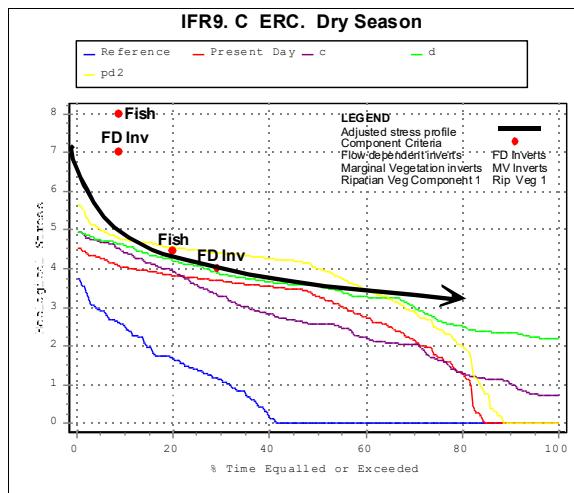
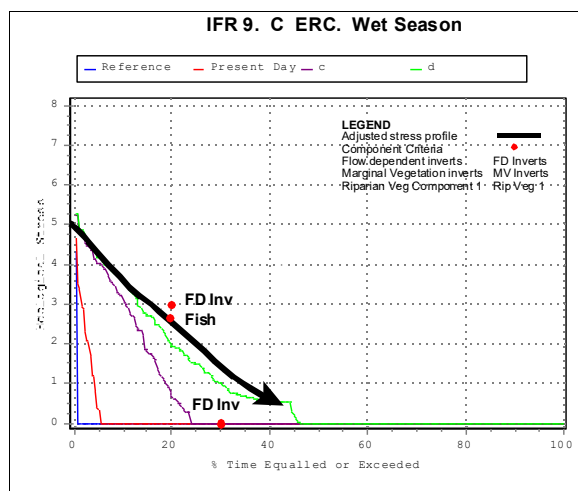


Fig 6.6 IFR 9 - Stress-duration curve for a recommended scenario of a C ERC: Wet Season



6.3.4 Final stress profiles for IFR 9

Fig 6.7 IFR 9 - Final stress profiles: Dry Season

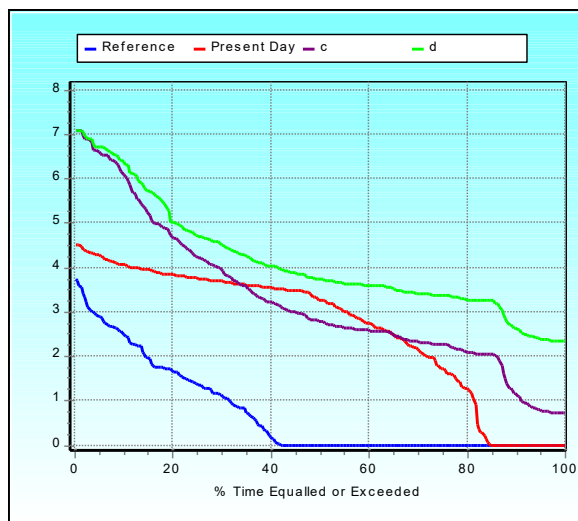
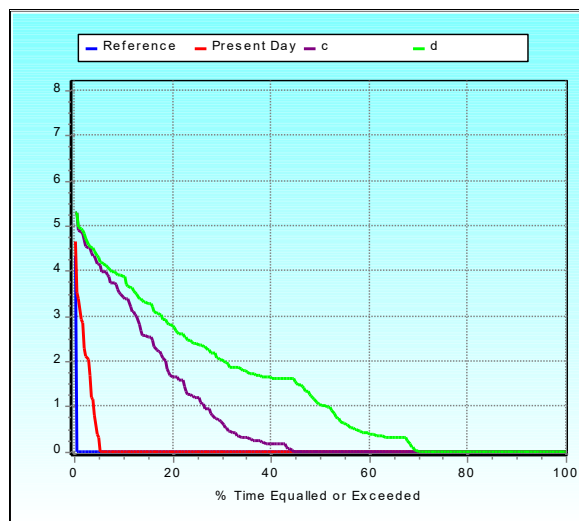


Fig 6.8 Final stress profiles for IFR 9: Wet Season



6.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 6.1. The number of events for each Flood Class required for an ERC of D and C are also summarised in Table 6.1.

Table 6.1 A summary of the Flood Class ranges for IFR 9, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s					
	I	II	III	IV	V	VI
Fish	10-15	15-20	50			
Invertebrates	10-15	20-40				
Vegetation	7-20	20-50	50-110	110-249		
Geomorphology			50-110	175 - 244	250 - 362	362 - 546
Integrated	7-19	20-49	50-110	111 - 249	250 - 361	362 - 546
Geometric Mean*			74	166	300	445
Recommended Flood events						
No of Events for a D Scenario (Recommended scenario)	6	5	2	2	2	1 in 4 years
No of Events for a C Scenario (Alternative scenario)	6	7	3	2	2	1 in 3 years

NOTE: Geomorphology is extrapolated from IFR 11 based on monthly data: 76% of the total load is mobilised by 10% of the flows

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

For geomorphology Flood Class VII, it is important that the large, infrequent floods (1:20 year events) are allowed to pass through the system unimpeded.

These high flow recommendations were checked with hydrology and found to be acceptable.

To incorporate high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 362 to 546) specified by the geomorphology specialist were reduced to the lower discharge values (e.g. 270) for the Desktop model (monthly) to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model (daily). The floods provided in Table 6.1 are peak values. These have to be adjusted when used in the IFR model to present daily averages.

The adjustments as described above are illustrated in Tables 6.2 and 6.3.

Table 6.2 Adjusted flood sizes as used in the Desktop model for a D ERC

Summer												
	Dec		Jan		Feb		Mar		Apr		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	IV	170	V	180	VI incl. 1- V	250	IV	170				
Duration (days)	7		7		8		7					
Freshet size (m³/s)	I & III	15 + 80	II	35	II	35	I & III	15 +80	I & II	15 + 35		
Duration (days)	5		5		5		5		5			
Spring												
	Sept		Oct		Nov							
Freshet size (m³/s)	I	15	I & II	15 + 35	I & II	15 + 35						
Duration (days)	4		5		5							

Table 6.3 Adjusted flood sizes as used in the Desktop model for a C ERC

Summer												
	Dec		Jan		Feb		Mar		Apr		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	IV	170	V	180	VI incl. 1- V	270	IV	170			III	80
Duration (days)	7		7		8		7				5	
Freshet size (m³/s)	I & II & III	15 + 35 +80	II	35	II	35	I &II & III	15 +35 +80	I & II	15 + 35		
Duration (days)	5		5		5		5		5			
Spring												
	Sept				Oct		Nov					
Freshet size (m³/s)	I	15			I & II	15 + 35	I & II	15 + 35				
Duration (days)	4				5		5					

6.5 FINAL RESULTS

6.5.1 IFR Table for recommended scenario: D ERC

Annual Flows (Mill. cu. m or index values):
MAR = 2050.762
S.Dev. = 921.651

CV = 0.449
 Q75 = 33.340
 Q75/MMF = 0.195
 BFI Index = 0.389
 CV(JJA+JFM) Index = 1.605

Total IFR = 415.403 (20.26 %MAR)
 Maint. Lowflow = 125.168 (6.10 %MAR)
 Drought Lowflow = 69.552 (3.39 %MAR)
 Maint. Highflow = 290.235 (14.15 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	87.892	135.759	1.545	7.500	3.750	10.238	17.738
Nov	149.276	146.769	0.983	9.072	4.406	10.238	19.310
Dec	235.287	187.723	0.798	10.178	5.892	62.342	72.520
Jan	386.097	269.381	0.698	12.856	8.303	52.579	65.435
Feb	433.826	280.910	0.648	14.999	9.677	79.536	94.535
Mar	335.635	197.032	0.587	15.535	9.642	62.342	77.877
Apr	166.704	116.264	0.697	12.701	8.294	10.238	22.939
May	75.824	52.254	0.689	12.588	5.892	0.000	12.588
Jun	46.105	19.858	0.431	9.072	3.888	0.000	9.072
Jul	34.844	19.531	0.561	7.366	3.482	0.000	7.366
Aug	36.478	68.975	1.891	6.562	3.214	0.000	6.562
Sep	62.794	178.601	2.844	6.739	3.110	2.722	9.461

6.5.2 IFR Table for recommended scenario: C ERC

Annual Flows (Mill. cu. m or index values):

MAR = 2050.762
 S.Dev. = 921.651
 CV = 0.449
 Q75 = 33.340
 Q75/MMF = 0.195
 BFI Index = 0.389
 CV(JJA+JFM) Index = 1.605

Total IFR = 569.929 (27.79 %MAR)
 Maint. Lowflow = 245.998 (12.00 %MAR)
 Drought Lowflow = 69.552 (3.39 %MAR)
 Maint. Highflow = 323.931 (15.80 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	87.892	135.759	1.545	13.928	3.750	10.238	24.166
Nov	149.276	146.769	0.983	16.848	4.406	26.620	43.468
Dec	235.287	187.723	0.798	18.749	5.892	69.509	88.258
Jan	386.097	269.381	0.698	26.784	8.303	52.579	79.363
Feb	433.826	280.910	0.648	33.869	9.677	82.516	116.385
Mar	335.635	197.032	0.587	32.141	9.642	69.509	101.650
Apr	166.704	116.264	0.697	25.920	8.294	10.238	36.158
May	75.824	52.254	0.689	22.766	5.892	0.000	22.766
Jun	46.105	19.858	0.431	17.107	3.888	0.000	17.107
Jul	34.844	19.531	0.561	13.392	3.482	0.000	13.392
Aug	36.478	68.975	1.891	12.053	3.214	0.000	12.053

Sep 62.794 178.601 2.844 12.442 3.110 2.722 15.163

6.5.3 IFR rule table for recommended scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	10.972	10.885	10.688	10.279	9.517	8.263	6.492	4.453	2.709	1.899
Nov	12.442	12.365	12.204	11.885	11.287	10.244	8.585	6.279	3.709	2.093
Dec	43.685	43.395	42.791	41.596	39.359	35.451	29.237	20.602	10.978	4.923
Jan	50.974	45.491	40.776	36.567	32.485	25.665	21.576	15.893	9.558	5.573
Feb	68.826	61.083	54.445	48.557	42.909	33.482	28.051	20.503	12.089	6.796
Mar	62.837	56.101	50.305	45.127	40.095	31.689	26.615	19.565	11.706	6.762
Apr	14.219	14.116	13.884	13.403	12.507	11.031	8.948	6.550	4.500	3.546
May	8.991	8.927	8.781	8.481	7.920	6.997	5.694	4.194	2.912	2.315
Jun	6.270	6.224	6.119	5.904	5.502	4.840	3.905	2.829	1.910	1.482
Jul	5.261	5.223	5.139	4.963	4.636	4.098	3.338	2.464	1.716	1.368
Aug	4.536	4.504	4.432	4.283	4.004	3.546	2.899	2.154	1.517	1.221
Sep	6.103	6.056	5.952	5.735	5.331	4.666	3.728	2.647	1.723	1.293

Reserve flows without High Flows

Oct	5.357	5.320	5.235	5.060	4.734	4.196	3.438	2.565	1.818	1.471
Nov	6.742	6.704	6.625	6.469	6.177	5.666	4.854	3.726	2.468	1.677
Dec	7.818	7.777	7.691	7.521	7.203	6.648	5.765	4.537	3.169	2.308
Jan	10.219	10.167	10.060	9.849	9.453	8.761	7.661	6.133	4.429	3.357
Feb	11.152	11.096	10.980	10.749	10.316	9.561	8.360	6.691	4.831	3.660
Mar	12.787	12.722	12.586	12.316	11.811	10.929	9.527	7.579	5.407	4.041
Apr	8.784	8.730	8.607	8.352	7.878	7.096	5.993	4.723	3.637	3.132
May	8.991	8.927	8.781	8.481	7.920	6.997	5.694	4.194	2.912	2.315
Jun	6.270	6.224	6.119	5.904	5.502	4.840	3.905	2.829	1.910	1.482
Jul	5.261	5.223	5.139	4.963	4.636	4.098	3.338	2.464	1.716	1.368
Aug	4.536	4.504	4.432	4.283	4.004	3.546	2.899	2.154	1.517	1.221
Sep	4.658	4.625	4.549	4.392	4.101	3.620	2.942	2.161	1.494	1.183

Natural Duration curves

Oct	89.140	44.001	32.091	22.326	17.141	11.971	9.788	6.713	6.046	3.843
Nov	137.698	87.806	60.473	48.424	37.433	30.231	25.090	16.047	9.494	5.048
Dec	174.182	137.218	118.403	95.266	70.949	59.522	50.490	27.905	19.622	13.183
Jan	321.085	256.577	202.415	148.539	121.320	99.529	85.301	72.685	44.764	22.282
Feb	316.334	251.561	185.715	155.014	137.493	118.007	99.044	67.608	51.243	29.316
Mar	248.657	207.143	161.405	146.073	123.694	107.635	89.637	70.465	48.929	27.381
Apr	101.090	85.853	69.202	60.447	54.988	45.363	37.944	33.490	27.367	17.305
May	47.998	34.591	31.084	28.052	25.583	24.005	20.077	18.530	16.659	11.211
Jun	25.422	21.005	18.332	16.906	15.756	14.729	12.929	11.768	10.596	7.855
Jul	21.049	16.802	14.225	12.936	11.624	10.741	10.054	8.688	8.256	7.519
Aug	19.560	13.941	12.325	9.521	8.886	8.225	7.799	6.900	5.992	5.518
Sep	30.093	14.807	11.764	9.957	7.366	7.094	6.366	5.940	5.122	4.238

6.5.4 IFR rule table for alternative scenario: C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	11.905	11.809	11.591	11.141	10.301	8.919	6.967	4.719	2.798	1.905
Nov	20.620	20.486	20.208	19.657	18.625	16.824	13.960	9.979	5.543	2.752
Dec	42.073	41.797	41.222	40.085	37.956	34.237	28.324	20.108	10.950	5.187
Jan	55.648	50.130	45.343	40.991	36.640	29.353	24.518	17.801	10.313	5.602
Feb	77.450	69.371	62.388	56.091	49.876	39.477	32.857	23.658	13.405	6.954
Mar	74.312	66.766	60.231	54.313	48.434	38.588	32.181	23.278	13.354	7.111
Apr	17.583	17.448	17.143	16.512	15.335	13.397	10.662	7.512	4.819	3.567
May	11.885	11.793	11.585	11.155	10.353	9.032	7.168	5.022	3.187	2.333
Jun	8.641	8.573	8.417	8.095	7.495	6.507	5.113	3.508	2.135	1.497
Jul	6.991	6.937	6.815	6.562	6.091	5.315	4.219	2.958	1.880	1.379
Aug	6.089	6.043	5.937	5.718	5.310	4.638	3.690	2.598	1.665	1.231
Sep	7.477	7.418	7.283	7.005	6.487	5.633	4.428	3.040	1.854	1.302

Reserve flows without High Flows

Oct	7.271	7.215	7.089	6.829	6.343	5.542	4.413	3.112	2.000	1.483
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Nov	8.762	8.709	8.599	8.381	7.972	7.259	6.126	4.550	2.794	1.690
Dec	10.077	10.019	9.899	9.660	9.212	8.430	7.187	5.459	3.534	2.322
Jan	14.893	14.806	14.627	14.273	13.608	12.448	10.604	8.041	5.184	3.386
Feb	17.615	17.511	17.294	16.865	16.062	14.659	12.429	9.329	5.874	3.701
Mar	18.508	18.401	18.176	17.731	16.898	15.443	13.129	9.914	6.331	4.077
Apr	13.098	13.003	12.786	12.339	11.504	10.130	8.190	5.957	4.047	3.159
May	11.885	11.793	11.585	11.155	10.353	9.032	7.168	5.022	3.187	2.333
Jun	8.641	8.573	8.417	8.095	7.495	6.507	5.113	3.508	2.135	1.497
Jul	6.991	6.937	6.815	6.562	6.091	5.315	4.219	2.958	1.880	1.379
Aug	6.089	6.043	5.937	5.718	5.310	4.638	3.690	2.598	1.665	1.231
Sep	6.285	6.236	6.125	5.896	5.469	4.764	3.771	2.626	1.648	1.193

6.6 GEOMORPHOLOGICAL CONSEQUENCES OF C AND D SCENARIOS

Bed maintenance

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be a longer bed material residence time compared to virgin conditions. This will result in a moderately modified bed for periods between large flood events (20 - 50 year return period).

D ERC flows reflect further reductions in flood frequency, and consequently, there will be a longer bed material residence time compared to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Bench maintenance

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be less bench maintenance constructional flows relative to virgin conditions. This will result in a moderately modified bench for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be less bench maintenance constructional flows relative to a C ERC river. This will result in a largely modified bench for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Channel maintenance

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer channel maintenance flows relative to virgin conditions. This will result in a moderately modified channel for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows relative to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Macro channel and bed mobilisation

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer macro-channel and bed mobilisation flows relative to virgin conditions. This will result in a moderately modified macro-channel and a less frequently mobilised bed for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows, and further reductions in bed mobilisation relative to a C ERC river. This will result in a largely modified macro-channel and more stable bed for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Conclusions

This site is quite resilient in terms of morphology. It occurs within a locally steepened and incised section of the river. The river has historically experienced very large floods which act to mobilise the entire bed (which consists of very coarse material). The focus of flood requirements for this site has been on the channel maintenance and macro-channel maintenance. If the required floods are met the site will remain within a D category for geomorphology with periods of sediment accumulation interspersed with larger re-set events.

6.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 6.4 IFR confidence table: DRC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
9	Low flows	2	3	-	-
	High flows	3	4	2	2

The confidence ranges from low-medium to medium-high.

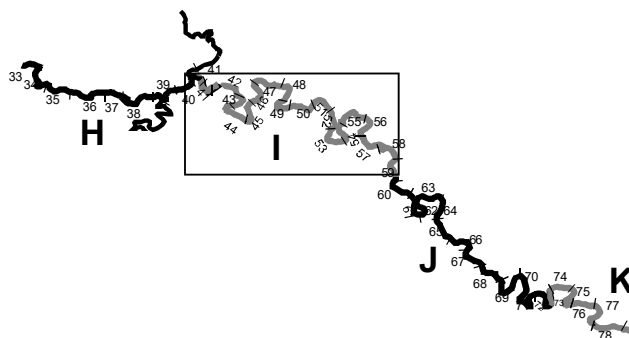
Invertebrates: The aquatic invertebrates are low-medium as no survey information is available, the historical records are contradictory and the available habitats are not suitable for invertebrates.

Fish: The fish is evaluated as medium (for low flows), as the cobbles are being silted and it is unsure whether under low-flow conditions the flows will be sufficient to create suitable habitats.

Riparian vegetation: The low-medium evaluation for vegetation is due to the large floods that will occur and will prevent recolonisation of riparian vegetation.

Geomorphology: The evaluation is medium-low, as no daily hydrology is available.

7 RU I. IFR 15. JAMESON'S DRIFT (Lower Thukela)



7.1 ECOLOGICAL CATEGORIES

7.1.1 Summary of ERC scenarios

Fig 7.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP	DOWN
WATER QUALITY	B	-	B/C	EIS H I G H S I H I G H	B		
GEOMORPH	D	-	D/E		D	C	D
RIPARIAN VEGETATION (gorge)	C	0	C		C	B	D
RIPARIAN VEGETATION (rest)	E	-	E/F		D	D	D
FISH	C	0	C		C	B	D
AQUATIC INVERTS	B	0	B		B	B	C
ECOSTATUS	C	-	C/D		C	B	D

↓ : Note that for IFR 15, the PES as well as the recommended ERC is a C. However, aquatic invertebrates are in a B PES and ERC. It was initially decided to provide flow regimes for a

C, B and D scenario. In both the C and B Ecstatus scenarios, aquatic invertebrates are in a B state. The B Ecstatus ERC also included fish and riparian vegetation in the gorge in a B state, however fish and riparian vegetation requirements were not higher than the invertebrate B requirements. This meant that the flow regime for the C would in effect also cater for a B ERC. Described differently, insufficient information was available to determine the B ERC, which drove the C Ecstatus requirements.

7.1.2 Criteria for the Ecological Reserve Categories

Recommended scenario: C ERC

Aquatic invertebrates (B)

- Stones biotope: SASS > 120 ASPT > 6.5.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (C)

- Maintain existing fish diversity.
- Maintain clear cobble beds to ensure breeding success of *L. natalensis* and *L. rubromaculatus*.
- Maintain inundation marginal sedges/grasses to enable spawning by *Clarias* spp.

Riparian Vegetation (D)

- Ensure lower winter flows than in summer, as the marginal and riparian vegetation generally are dormant during winter.
- Higher flows in summer as vegetation is actively growing, reproducing and controlling the temperature.
- Maintain existing *Juncus* mats within the marginal zones on the edge of river and encourage additional mats through the provision of adequate low flows during winter and summer.
- Maintain the few existing individuals of riparian trees and shrubs and encourage recovery of new individuals within the lower, main, and upper riparian zone through the provision of adequate elevated flows, mainly during summer.

Geomorphology (D)

- This part of the Thukela River appears to undergo regular change. To maintain the river in its present state floods need to occur which have a sufficient size and frequency to move the available sediment which is presently entering this system.

Alternative Scenario: D ERC

Aquatic invertebrates (C)

- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (D)

- Maintain close to the existing fish diversity.
- Maintain clear cobble beds to allow for reduced breeding success of *L. natalensis* and *L. rubromaculatus*.

Riparian Vegetation: (D)

- As for the C ERC.

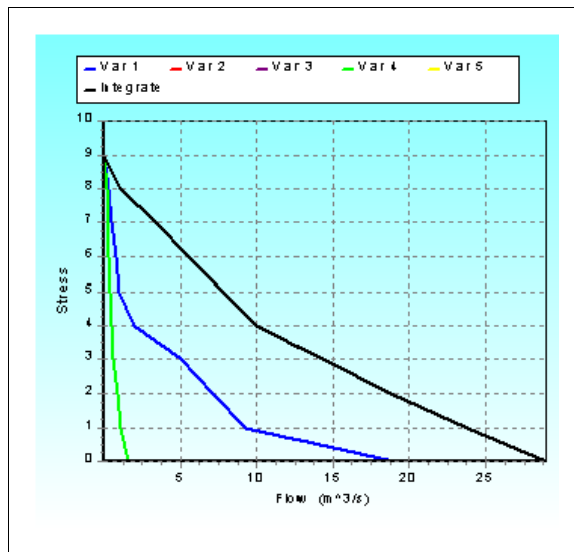
Geomorphology (D)

- As for the C ERC.

7.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 15, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 7.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 7.2.

Fig 7.2 Critical curve for IFR 15



Var 1: Fish

Var 2: Flow Dependent Invertebrates (covered by the integrated line)

Var 3: Marginal Vegetation Invertebrates

Var 4: Riparian Vegetation 1

Var 5: Riparian Vegetation 2

7.2.1 Riparian Vegetation

Only one component was selected, using elevations and discharges associated with the ecological transect. A rooting depth of 0.3m was used to estimate the stress level of 8, based on the generic stress table.

- *Juncus* spp.
Juncus spp. occurs in mats which would cover a reasonably large area of the marginal zone. Currently *Juncus* spp. are only sparsely present due to grazing pressure from local livestock. It is surmised that extensive mats of *Juncus* spp. would be present on the edges of the active channels adjacent to both banks under more natural grazing pressure. Only the lower edges of these mats are crucial because the maximum stress levels of these mats would only occur once the water levels drop below the roots in these areas, i.e. at the 0.19m level.

Juncus was found to be quite insensitive since its roots extended well into the level of the main channel, and would therefore still remain relatively unstressed until the river has almost stopped flowing.

7.3 STRESS DURATION CURVES (PROFILES)

7.3.1 Natural stress duration profiles

The natural flow regime was converted to a stress profile (see blue line, Figure 7.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 15, stress indices as determined were accepted and no changes were required.

7.3.2 Desktop-generated scenarios and evaluation

The C and D scenarios were estimated using the Desktop Model and are shown in Figures 7.3 – 7.6. The present day hydrology as converted into stress, is shown by the red line in Figures 7.3 - 7.6 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are presented in Figures 7.3 – 7.6. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures 7.7 – 7.8). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

7.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated C scenario consisted of Maintenance Low Flows of 13.34 % MAR⁵, which were adjusted to 12.6% MAR. The generated C scenario consisted of Drought Low Flows of 6.61% MAR, which were adjusted to 5.13% MAR (see Figure 7.3). The generated D scenario consisted of Maintenance Low Flows of 6.80 % MAR, which were adjusted to 6.17% MAR (see Figure 7.3). The generated D scenario consisted of Drought Low Flows of 6.61% MAR, which were adjusted to 5.13% MAR. The maintenance and drought low flows were manually changed to better fit the specialists' requirements for stress patterns.

⁵ Note that "% MAR" refers to the % virgin MAR and not % of the present day MAR.

Fig 7.3 IFR 15 - Stress duration curve for recommended Scenario of a C ERC: Dry Season

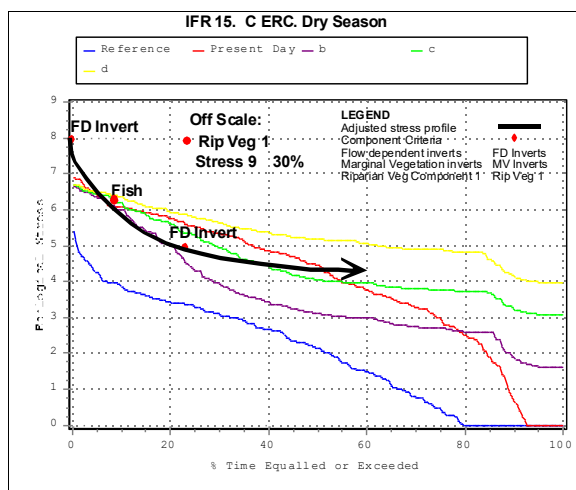


Fig 7.4 IFR 15 - Stress duration curve for recommended scenario of a C ERC: Wet Season

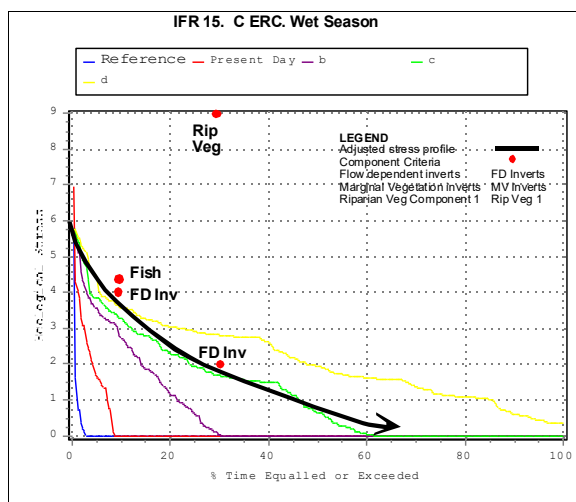


Fig 7.5 IFR 15 - Stress duration curve for alternative scenario of a D ERC: Dry Season

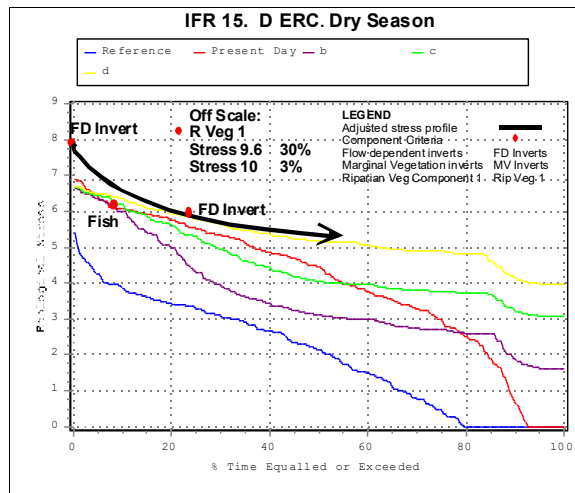
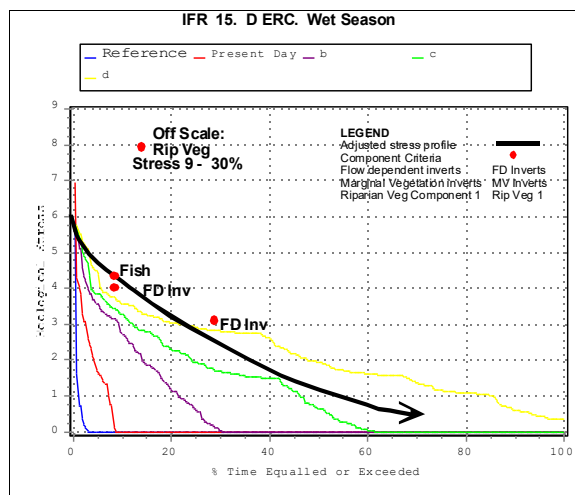


Fig 7.6 IFR 15 - Stress duration curve for recommended scenario of a D ERC: Wet Season



7.3.4 Final stress profiles for IFR 15

Fig 7.7 IFR 15 - Final stress profiles: Dry season

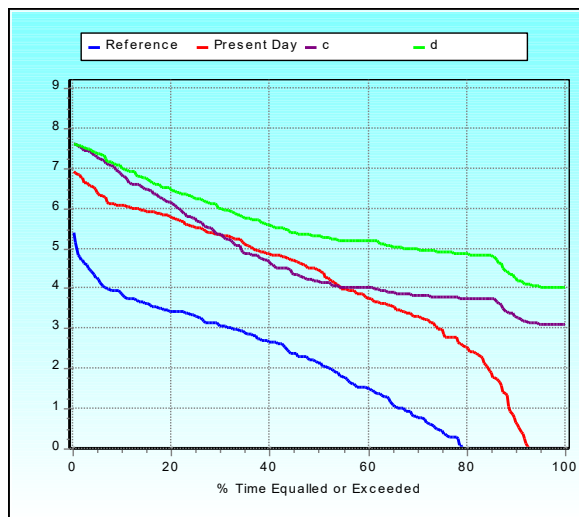
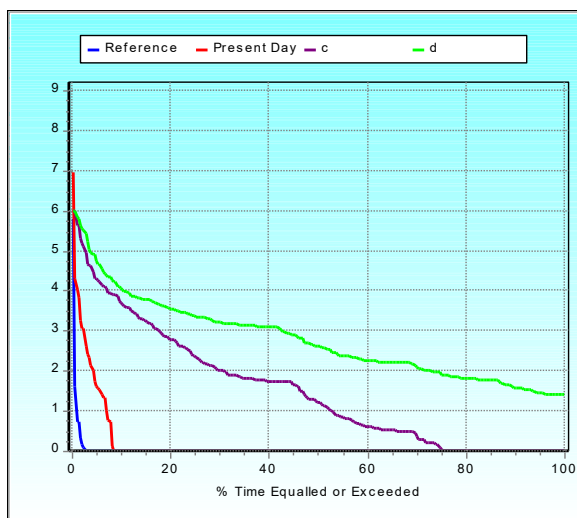


Fig 7.8 IFR 15 - Final stress profiles: Wet season



7.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 7.1. The number of events for each Flood Class required for an ERC of C and D are also summarised in Table 7.1.

Table 7.1 A summary of Flood Class ranges for IFR 15, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s						
	I	II	III	IV	V	VI	VII
Fish		40-50 50-60	60-110				
Invertebrates	20-30	30-60		105			
Vegetation	15-40	30-105		105-220	250-300		
Geomorph				105- 220	220-344	344-807	807-1844
Integrated	15-29	30-59	60-104	105-219	220-343	344-806	807-1844
Geometric Mean*				150	275	525	1220
Recommended Flood Events							
No of events for C ERC (Recommended scenario)	6	6	1	2	1	1	1 in 4 years
No of events for D ERC (Alternative scenario)	4	4	1	2	1	1	1 in 4 years

NOTE: Geomorphology is extrapolated from IFR4a based on daily data. 76% of the total load is mobilised by 10% of the flows specific.

NOTE: The vegetation class function is relevant for both Classes II and III.

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 807 to 1844) specified by the geomorphology specialist were reduced to the lower discharge values (e.g. 920) for the Desktop model (monthly) to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model (daily).

The adjustments as described above are illustrated in Tables 7.2 and 7.3.

Table 7.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a C ERC

Summer									
	Dec		Jan		Feb		Mar		Apr
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class Flood
Flood size (m ³ /s)	VI	150	IV	110	VII incl. 1- VI	920	IV	110	
Duration (days)	7		6		8		6		
Freshet size (m ³ /s)	II x 2	45 + 45	I & II	22 + 45	I & II	22 + 45	II & III	45 + 80	I 22
Duration (days)	5		5		5		6		5
Spring									
	Sept		Oct		Nov				
Freshet size (m ³ /s)	I	22	I	22	I & II	22 + 45			

Table 7.3 Adjusted flood sizes as used in the Desktop model for the alternative scenario of a D ERC

Summer									
	Dec		Jan		Feb		Mar		Apr
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class Flood
Flood size (m³/s)	VI	150	IV	110	VII incl. 1- VI	920	IV	110	
Duration (days)	7		6		8		6		
Freshet size (m³/s)	II	45	I & II	22 + 45	II	45	III	80	I 22
Duration (days)	5		5		5		6		5
Spring									
	Sept		Oct		Nov				
Freshet size (m³/s)	I	22	I	22	I & I	22 + 45			
Duration (days)	5		5		5				

7.5 FINAL RESULTS

7.5.1 IFR table for recommended scenario: C ERC

Annual Flows (Mill. cu. m or index values):

MAR = 3466.939
S.Dev. = 1544.455
CV = 0.445
Q75 = 56.890
Q75/MMF = 0.197
BFI Index = 0.381
CV(JJA+JFM) Index = 1.749

Total IFR = 883.616 (25.49 %MAR)
Maint. Lowflow = 436.933 (12.60 %MAR)
Drought Lowflow = 177.716 (5.13 %MAR)
Maint. Highflow = 446.683 (12.88 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	164.310	261.596	1.592	24.373	8.571	4.505	28.878
Nov	273.370	253.086	0.926	27.216	11.664	13.719	40.935
Dec	424.799	350.079	0.824	38.837	14.731	56.272	95.109
Jan	658.083	449.877	0.684	50.890	22.766	38.905	89.795
Feb	716.768	458.690	0.640	60.480	25.402	270.466	330.946
Mar	527.358	294.238	0.558	57.586	24.641	53.806	111.391
Apr	262.655	190.191	0.724	49.248	22.810	4.505	53.753
May	126.626	100.905	0.797	38.301	17.410	0.000	38.301
Jun	75.946	43.218	0.569	26.957	10.886	0.000	26.957
Jul	62.132	53.596	0.863	22.231	8.035	0.000	22.231
Aug	64.918	125.531	1.934	19.820	5.357	0.000	19.820
Sep	109.975	317.268	2.885	20.995	5.443	4.505	25.500

7.5.2 IFR table for alternative scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR = 3466.939
S.Dev. = 1544.455
CV = 0.445
Q75 = 56.890

Q75/MMF = 0.197
 BFI Index = 0.381
 CV(JJA+JFM) Index = 1.749

 Total IFR = 632.038 (18.23 %MAR)
 Maint. Lowflow = 213.883 (6.17 %MAR)
 Drought Lowflow = 177.984 (5.13 %MAR)
 Maint. Highflow = 418.155 (12.06 %MAR)

Monthly Distributions (Mill. cu. m.)
 Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	164.310	261.596	1.592	12.856	8.839	4.505	17.361
Nov	273.370	253.086	0.926	14.256	11.664	13.719	27.975
Dec	424.799	350.079	0.824	18.749	14.731	47.058	65.807
Jan	658.083	449.877	0.684	24.106	22.766	38.905	63.011
Feb	716.768	458.690	0.640	26.611	25.402	265.961	292.572
Mar	527.358	294.238	0.558	26.784	24.641	43.502	70.286
Apr	262.655	190.191	0.724	23.328	22.810	4.505	27.833
May	126.626	100.905	0.797	19.552	17.410	0.000	19.552
Jun	75.946	43.218	0.569	13.997	10.886	0.000	13.997
Jul	62.132	53.596	0.863	11.785	8.035	0.000	11.785
Aug	64.918	125.531	1.934	10.714	5.357	0.000	10.714
Sep	109.975	317.268	2.885	11.146	5.443	0.000	11.146

7.5.3 IFR rule table for recommended scenario: C ERC

Data are given in m³/s mean monthly flow

% Points										
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	14.768	14.661	14.416	13.911	12.969	11.418	9.229	6.708	4.553	3.551
Nov	20.275	20.161	19.922	19.450	18.566	17.023	14.568	11.157	7.356	4.963
Dec	46.783	46.494	45.891	44.699	42.465	38.566	32.364	23.747	14.141	8.098
Jan	58.470	54.308	50.600	47.054	43.223	36.763	31.488	24.157	15.987	10.846
Feb	227.597	201.295	178.777	158.868	139.869	108.179	90.289	65.429	37.719	20.285
Mar	76.376	70.448	65.208	60.267	55.041	46.243	39.411	29.918	19.336	12.678
Apr	26.876	26.703	26.309	25.495	23.977	21.477	17.949	13.887	10.413	8.798
May	20.012	19.886	19.598	19.003	17.893	16.067	13.488	10.519	7.980	6.800
Jun	13.627	13.536	13.329	12.901	12.103	10.789	8.935	6.799	4.973	4.124
Jul	11.611	11.529	11.345	10.964	10.254	9.085	7.434	5.534	3.909	3.153
Aug	10.013	9.937	9.764	9.405	8.736	7.635	6.081	4.292	2.762	2.050
Sep	12.580	12.481	12.256	11.792	10.926	9.500	7.486	5.169	3.187	2.265

Reserve flows without High Flows

Oct	12.729	12.639	12.435	12.014	11.227	9.933	8.105	6.001	4.202	3.366
Nov	14.164	14.091	13.939	13.639	13.076	12.093	10.531	8.359	5.939	4.416
Dec	20.881	20.768	20.533	20.067	19.195	17.673	15.252	11.888	8.138	5.778
Jan	28.313	28.170	27.873	27.284	26.181	24.255	21.192	16.935	12.191	9.207
Feb	31.474	31.311	30.970	30.297	29.035	26.832	23.329	18.461	13.035	9.621
Mar	33.180	33.009	32.653	31.949	30.630	28.326	24.663	19.573	13.899	10.330
Apr	24.903	24.747	24.392	23.659	22.291	20.040	16.861	13.202	10.074	8.619
May	20.012	19.886	19.598	19.003	17.893	16.067	13.488	10.519	7.980	6.800
Jun	13.627	13.536	13.329	12.901	12.103	10.789	8.935	6.799	4.973	4.124
Jul	11.611	11.529	11.345	10.964	10.254	9.085	7.434	5.534	3.909	3.153
Aug	10.013	9.937	9.764	9.405	8.736	7.635	6.081	4.292	2.762	2.050
Sep	10.607	10.525	10.339	9.955	9.240	8.062	6.399	4.484	2.847	2.086

Natural Duration curves

Oct	137.488	80.691	54.171	39.394	28.426	22.353	17.141	14.171	11.632	7.330
Nov	283.150	189.001	106.022	77.296	66.734	55.813	48.805	38.250	20.034	11.522
Dec	346.053	252.766	197.292	173.333	123.877	97.076	80.826	68.156	30.502	21.566
Jan	523.432	403.792	308.637	269.225	234.746	192.082	151.541	121.847	70.877	39.998
Feb	544.247	419.336	336.779	245.068	228.237	203.543	151.086	126.781	82.867	42.652
Mar	376.856	325.331	270.470	236.764	200.091	167.249	143.390	113.628	84.553	45.490
Apr	153.875	127.793	113.482	97.581	85.226	72.767	63.807	53.226	43.421	27.184
May	76.624	57.909	51.080	44.641	41.624	36.250	32.793	29.186	24.066	18.708
Jun	41.738	34.547	29.249	26.717	25.351	23.439	20.721	17.962	15.580	13.769
Jul	36.462	27.631	23.256	20.509	18.403	17.770	16.123	14.309	12.481	11.177
Aug	32.389	25.788	20.878	16.047	14.699	13.385	12.653	11.466	10.155	8.595
Sep	54.204	31.007	21.711	17.040	13.351	12.175	11.309	9.901	8.968	7.202

7.5.4 IFR rule table for alternative scenario: D ERC

Data are given in m³/s mean monthly flow

% Points										
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	11.660	11.583	11.408	11.047	10.373	9.263	7.697	5.893	4.351	3.634
Nov	18.244	18.145	17.938	17.528	16.761	15.420	13.289	10.328	7.027	4.951
Dec	41.485	41.232	40.706	39.665	37.715	34.311	28.897	21.373	12.988	7.711
Jan	49.335	45.240	41.674	38.407	35.101	29.556	25.736	20.428	14.512	10.789
Feb	212.662	186.882	164.914	145.683	127.649	97.618	81.827	59.883	35.423	20.034
Mar	56.993	52.250	48.116	44.327	40.487	34.045	29.591	23.400	16.500	12.159
Apr	18.543	18.449	18.235	17.794	16.972	15.617	13.705	11.504	9.621	8.746
May	13.985	13.915	13.758	13.433	12.826	11.828	10.418	8.795	7.407	6.762
Jun	9.685	9.631	9.509	9.258	8.789	8.017	6.927	5.672	4.599	4.100
Jul	8.423	8.372	8.257	8.019	7.575	6.843	5.811	4.622	3.606	3.133
Aug	7.406	7.354	7.237	6.995	6.544	5.802	4.753	3.546	2.514	2.034
Sep	7.704	7.650	7.527	7.273	6.800	6.021	4.921	3.654	2.571	2.068

Reserve flows without High Flows

Oct	9.189	9.134	9.009	8.750	8.268	7.474	6.353	5.063	3.959	3.446
-----	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Nov	10.606	10.559	10.463	10.271	9.912	9.286	8.290	6.907	5.364	4.394
Dec	14.412	14.347	14.212	13.944	13.444	12.569	11.179	9.247	7.093	5.738
Jan	19.178	19.103	18.947	18.637	18.058	17.047	15.440	13.206	10.716	9.149
Feb	19.806	19.729	19.569	19.253	18.661	17.627	15.983	13.698	11.151	9.548
Mar	22.068	21.980	21.796	21.432	20.750	19.560	17.667	15.037	12.105	10.260
Apr	16.152	16.079	15.914	15.572	14.935	13.886	12.405	10.700	9.242	8.564
May	13.985	13.915	13.758	13.433	12.826	11.828	10.418	8.795	7.407	6.762
Jun	9.685	9.631	9.509	9.258	8.789	8.017	6.927	5.672	4.599	4.100
Jul	8.423	8.372	8.257	8.019	7.575	6.843	5.811	4.622	3.606	3.133
Aug	7.406	7.354	7.237	6.995	6.544	5.802	4.753	3.546	2.514	2.034
Sep	7.704	7.650	7.527	7.273	6.800	6.021	4.921	3.654	2.571	2.068

7.6 GEOMORPHOLOGICAL CONSEQUENCES

Bed maintenance

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be a longer bed material residence time compared to virgin conditions. This will result in a moderately modified bed for periods between large flood events (20 - 50 year return period).

D ERC flows reflect further reductions in flood frequency, and consequently, there will be a longer bed material residence time compared to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Bench maintenance

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be less bench maintenance constructional flows relative to virgin conditions. This will result in a moderately modified bench for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be less bench maintenance constructional flows relative to a C ERC river. This will result in a largely modified bench for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Channel maintenance

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer channel maintenance flows relative to virgin conditions. This will result in a moderately modified channel for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows relative to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Macro Channel and bed mobilisation

C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer macro-channel and bed mobilization flows relative to virgin conditions. This will result in a moderately modified macro-channel and a less frequently mobilized bed for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows, and further reductions in bed mobilization relative to a C ERC river. This will result in a largely modified macro-channel and more stable bed for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Conclusion

This is a stable site geomorphologically with evidence of continual expansion and contraction of bars (particularly the sand fraction). Recommended floods have accounted for the movement of smaller bed material with occasional large events to mobilise the coarse material on the bed. The main difference between classes is the residence time of material within the channel

7.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 7.4 IFR result confidence table: C ERC

IFR site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
15	Low flows	4	4	2	-
	High flows	5	5	3	4

The confidence ranges from low-medium (one value only) to high.

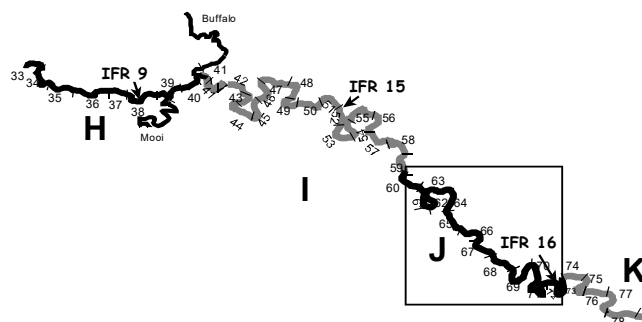
Invertebrates: The medium-high to high evaluation is due to much experience of the site and the varied habitats which will be maintained with a range of flows.

Fish: The fish is of the same order - however the confidence evaluation is based on the fact that the invertebrate requirements are higher than the fish requirements, which should then be more than satisfied.

Riparian vegetation: The lower riparian vegetation evaluation is due to the lack of cues for both low and high flows. The higher (than the previous site's evaluation) is due to the availability of daily data.

Hydraulics: The low confidence in hydraulics will influence the confidence in the flow requirements irrespective of the reasonable high ecological confidence.

8 RU J. IFR 16. MANDINI (Lower Thukela River)



8.1 ECOLOGICAL CATEGORIES

8.1.1 Summary of ERC scenarios

Three Ecological Reserve Scenarios were addressed for IFR 16. The recommended scenario is a C/D ERC. The alternative scenarios of a B/C and a D ERC were also evaluated.

Fig 8.1 Summary of ERC Scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP	DOWN
WATER QUALITY	B	-	B/C	EIS MODERATE SI H MODERATE E	B		
GEOMORPH	C/D	-	D		C/D	B/C	D
RIPARIAN VEGETATION	D	-	D/E		D	C	D
FISH	C	0	C		C	B	D
AQUATIC INVERTS	C	-	C/D		C	B	D
ECOSTATUS	C/D	-	D		C/D	B/C	D

8.1.2 Criteria for the Ecological Reserve Categories

Recommended Scenario: C/D ERC

Aquatic invertebrates (C)

- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (C)

- Maintain existing fish diversity.
- Maintain perennial flow.
- Provide ample migration stimuli to move fish populations to suitable breeding sites and permit migration of elvers to inland (living) areas.
- Provide adequate breeding stimuli, with water levels that inundate abundant shallows and backwaters as refuges for juveniles and breeding sites for smaller species.

Geomorphology (C/D)

- This part of the Thukela River is a sediment sink zone and is an alluvial sand bed river. To maintain the river in its present state floods need to occur which have a sufficient size and frequency to move the available sediment which is presently entering this system, in this case large quantities of sand and gravel.

Alternative scenario: B/C ERC

Aquatic invertebrates (B)

- Stones biotope: SASS >110 ASPT > 6.5. Vegetation biotope: SASS >90 ASPT > 6.
- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (B)

- Reduced incidence of alien fish species. Recurrence of *A. natalensis* through increase in clean bed habitat.
- Frequent inundation of marginal shallows and backwaters resulting in improved spawning and survival of all species.

Geomorphology (B/C)

- To change the present state from a C/D to a B/C there is a need for reduced sediment accumulation i.e. increased sediment transport together with an overall increase in sediment scour from the bed, banks and bars. Since the majority of sediment is transported by flood events, an increase in the number of these events or their return period (as indicated in the above table) should achieve this objective.

Alternative scenario: D ERC

Aquatic invertebrates (D)

- Maintain higher flows in summer than in winter - i.e. seasonal diversity.
- Summer flows should be variable while winter flows should be more constant.

Fish (D)

- Reduced abundance of large-bodied fish species, without loss of species diversity.

Geomorphology (D)

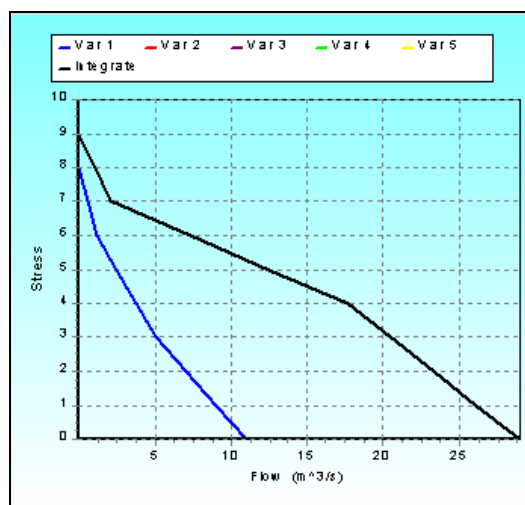
- To change the present state from a C/D category to a D category there is an understanding that increased sediment accumulation can occur. More braiding may

occur in the dry season. The resident time of material is increased as a response to increased time between flood events.

8.2 FLOW STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 16, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 8.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 8.2.

Fig 8.2 Critical curve for IFR 16



Var 1: Fish

Var 2: Flow Dependent Invertebrates

Var 3: Marginal Vegetation Invertebrates

Var 4: Riparian Vegetation 1

Var 5: Riparian Vegetation 2

8.2.1 Invertebrates

This investigation has concentrated on taxa dependent on marginal vegetation, as the in-channel habitat and the bedrock in the main channel are highly unreliable habitats and were found to be almost devoid of life.

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit (~11 m³/s) as a reference point. The stress index of 0 was set so that ~0.20m of water flooded into the *Phragmites* zone. The indices of greater stress were derived, by measuring the reduction in water level that would leave just the bases of the *Phragmites* reeds inundated. Note that this assessment for marginal vegetation communities applies to both dry and wet seasons as this is the only available and reliable habitat and the relevant species would not survive well on the alluvial sand.

8.2.2 Riparian Vegetation

A number of vegetation components present at this site are clearly dependant on low flows. These being *Ficus sycomorus*, *Ficus capreifolia*, *Phoenix reclinata* and *Nuxia oppositifolia*.

However, little is known about the rooting characteristics of these species relative to discharge, particularly at this site. It is assumed that while these plants are located on the banks and on the island, they are well rooted in the water and are able to grow and reproduce at a wide range of discharges. It is surmised that these trees will probably survive for extended periods of no surface flow as sub-surface flows will maintain their requirements except during periods of severe and extended drought.

No perennial grass clumps or *Juncus* mats were present which have been used at the other sites for low flow requirements. It was therefore not possible to provide stress curves for any vegetation components in response to low flows.

8.3 STRESS DURATION CURVES (PROFILES)

8.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 8.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 16, stress indices as determined were accepted, no changes were required.

8.3.2 Recommended stress profiles for each reserve scenario

The C/D, B/C and D scenarios were estimated using the Desktop model and are shown in Figures 8.3 – 8.8. The present day hydrology, as converted into stress, is reflected by the red line in Figures 8.3 - 8.8 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are presented in Figures 8.3 – 8.8. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures. 8.9 - 8.10). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

8.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated B/C scenario consisted of Maintenance Low Flows of 17.96 % MAR⁶, which required only a minor adjustment to 17.95% MAR and of Drought Low Flows of 6.53% MAR, which were adjusted to 6.51% MAR (see Figure 8.3). The generated C/D scenario consisted of Maintenance Low Flows of 9.2 % MAR, which were adjusted to 11.4% MAR, and of Drought Low Flows of 6.53% MAR, which were adjusted to 6.51% MAR (see Figure 8.3). The generated D scenario consisted of Maintenance Low Flows of 6.58 % MAR, which were adjusted to 8.37% MAR, and of Drought Low Flows of 6.53% MAR, which were adjusted to 6.51% MAR. The maintenance and drought low flows were manually changed to better fit the specialists' requirements for stress patterns.

⁶ % MAR refers to a % of virgin flows and not present day flows

Fig 8.3 IFR 16 – Stress duration curve for recommended scenario of a C/D ERC: Dry Season

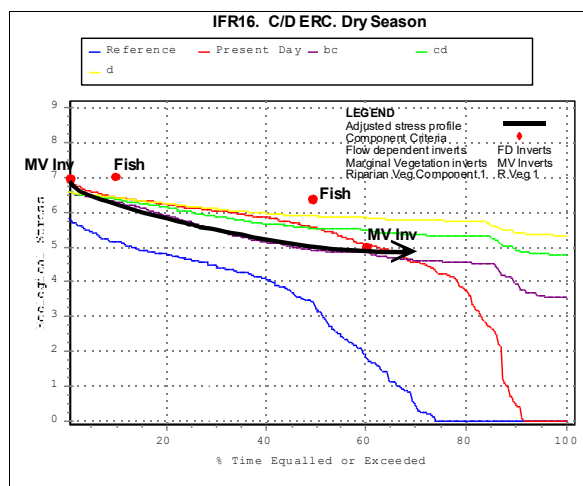


Fig 8.4 IFR 16 – Stress duration curve for recommended scenario of a C/D ERC: Wet Season

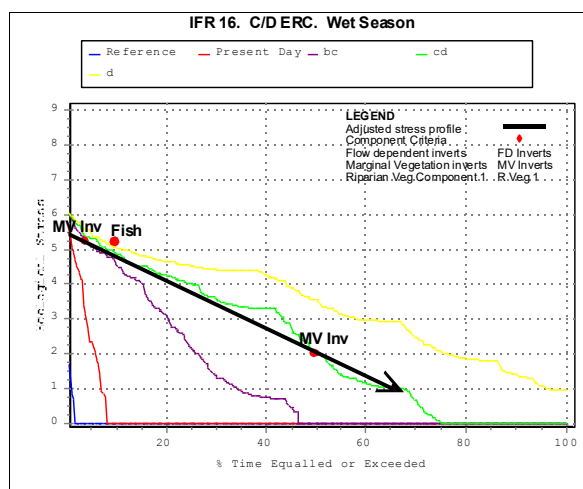


Fig 8.5 IFR 16 – Stress duration curve for alternative scenario B/C: Dry season

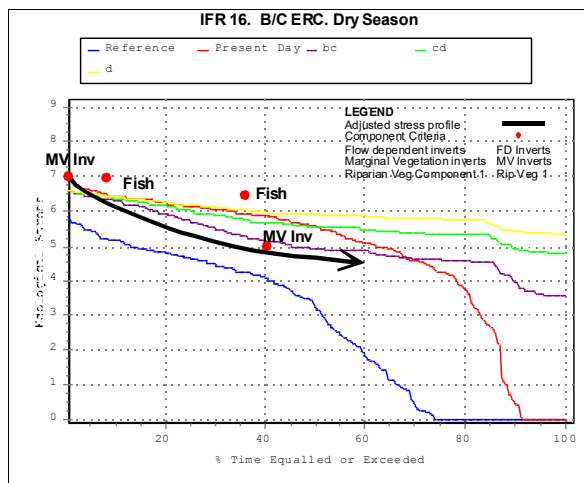


Fig 8.6 IFR 16 – Stress duration curve for alternative scenario B/C: Wet Season

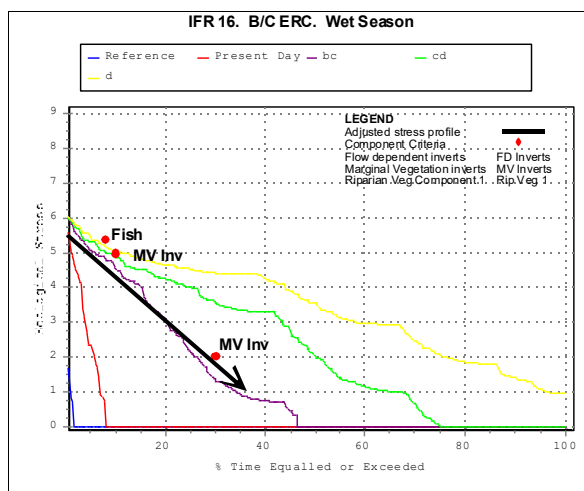


Fig 8.7 IFR 16 – Stress duration curve for alternative scenario D: Dry Season

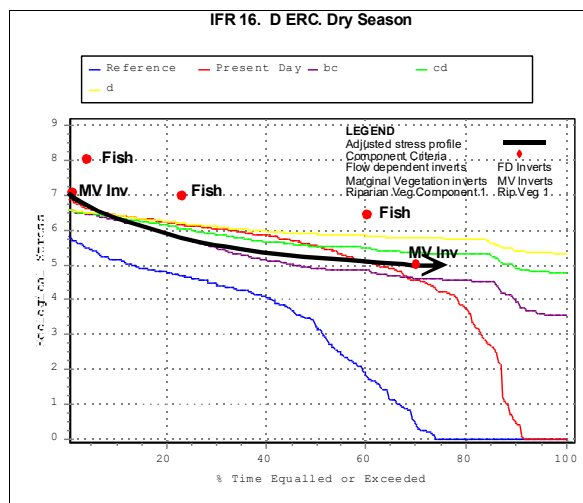
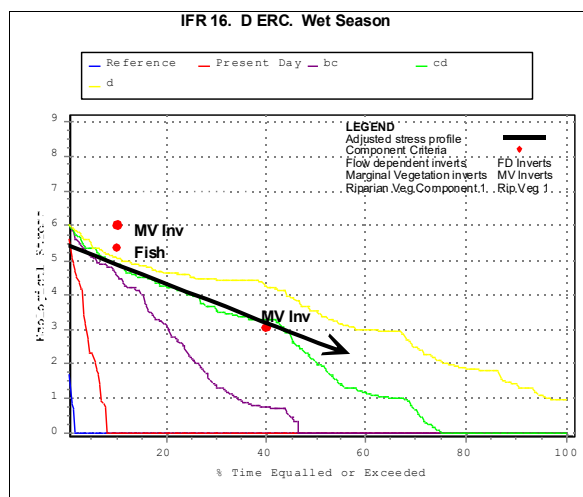


Fig 8.8 IFR 16 – Stress duration curve for alternative scenario D: Wet Season



8.3.4 Final stress profiles for IFR16

Fig 8.9 IFR 16 - Final stress profile: Dry Season

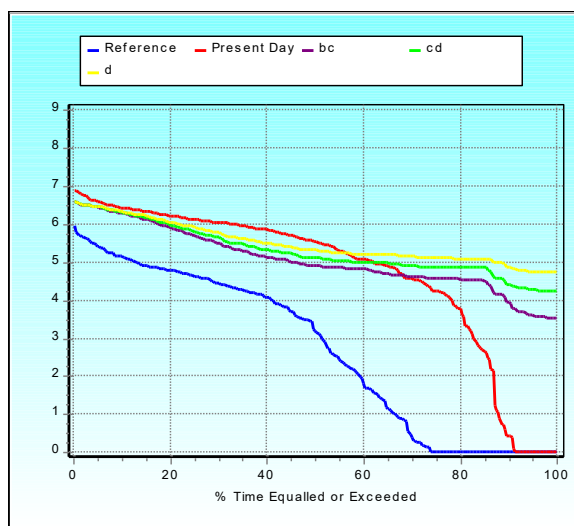
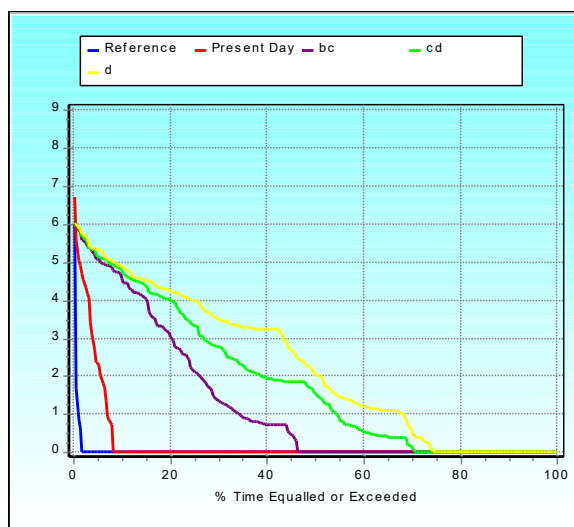


Fig 8.10 IFR 16 - Final stress profile: Wet Season



8.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 8.1. The number of events for each Flood Class required for a C/D, B/C and D ERC are also summarised in Table 8.1.

Table 8.1 A summary of the Flood Class ranges for IFR 16, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s						
	I	II	III	IV	V	VI	VII
Fish	30-80	80-100	100-150				
Invertebrates	30-60		100-150				
Vegetation	17-80	80-160	160-400	400-1100			
Geomorph.				400-1100	280-460	460-1050	1050-2260
Integrated	30-79	80-99	100-159	160-279	280-460	460-1099	1100-2260
Geometric Mean*				210	360	710	1575
Recommended Floods							
No of events for Scenario B/C (Recommended scenario)	6		2	4	1	2	1 in 3 Years
No of events for Scenario C/D (Alternative scenario)	5		2	3	1	2	1 in years
No of events for D ERC (Alternative scenario))	4		1	2	1	2	1 in 5 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 1110 to 2260) specified by the geomorphology specialist were reduced to the lower discharge values (e.g. 1000) for the Desktop model (monthly), to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances, and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model (daily).

The adjustments as described above are illustrated in Tables 8.2 – 8.4.

Table 8.2 Adjusted flood sizes as used in the Desktop model for a C/D ERC

Summer												
	Dec		Jan		Feb		Mar		Apr		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	VI	500	V	180	VII, incl. VI	980	IV	110			IV	110
Duration (days)	8		8		8		6				6	
Freshet size (m³/s)	IV	110	I & III	55 + 80	III	80	I	55	I	55		
Duration (days)	6		5		6		5		5			
Spring												
	Sept		Oct		Nov							
Freshet size (m³/s)			I	55	I	55						
Duration (days)			5		5							
Duration (days)			5		5							

Table 8.3 Adjusted flood sizes as used in the Desktop model for a B/C ERC

Summer													
	Dec		Jan		Feb		Mar		Apr		Nov		
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	
Flood size m ³ /s	VI	500	V	180	VII, incl. VI	1000	IV & I	110 + 55			IV	110	
Duration (days)	8		8		8		6				6		
Freshet size (m ³ /s)	IV	110	I & III	55 + 80	III	80	IV	110	I	55			
Duration (days)	6		5		6		6		5				
Spring													
	Sept		Oct		Nov								
Freshet size (m ³ /s)	I	55	I	55	I	55							
Duration (days)	5		5		5								

Table 8.4 Adjusted flood sizes as used in the Desktop model for a D ERC

Summer													
	Dec		Jan		Feb		Mar		Apr		Nov		
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood	
Flood size (m ³ /s)	VI	500	V	180	VII, incl. VI	960	IV	110			IV	110	
Duration (days)	8		8		8		6				6		
Freshet size (m ³ /s)			III	80	I	55	I	55					
Duration (days)	6		6		5		5						
Spring													
	Sept		Oct		Nov								
Freshet size (m ³ /s)			I	55	I	55							

8.5 FINAL RESULTS

8.5.1 IFR table for recommended scenario: C/D ERC

Annual Flows (Mill. cu. m or index values):

MAR = 3722.905
 S.Dev. = 1656.375
 CV = 0.445
 Q75 = 62.290
 Q75/MMF = 0.201
 BFI Index = 0.370
 CV(JJA+JFM) Index = 1.796
 Total IFR = 1058.525 (28.43 %MAR)
 Maint. Lowflow = 425.434 (11.43 %MAR)
 Drought Lowflow = 242.404 (6.51 %MAR)
 Maint. Highflow = 633.092 (17.01 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : N.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	190.120	300.633	1.581	24.106	13.928	11.262	35.368
Nov	301.650	274.226	0.909	31.104	16.848	36.448	67.552
Dec	456.110	379.313	0.832	38.837	19.284	164.722	203.558
Jan	690.284	470.624	0.682	45.533	28.123	81.143	126.675
Feb	754.673	486.025	0.644	50.803	32.659	291.807	342.611

Mar	560.244	319.843	0.571	53.568	32.141	36.448	90.016
Apr	280.015	202.950	0.725	50.544	27.734	11.262	61.806
May	139.090	116.800	0.840	37.498	20.624	0.000	37.498
Jun	84.031	57.890	0.689	27.216	15.034	0.000	27.216
Jul	67.569	59.457	0.880	22.766	12.588	0.000	22.766
Aug	71.845	138.082	1.922	21.427	11.517	0.000	21.427
Sep	127.272	375.009	2.947	22.032	11.923	0.000	22.032

8.5.2 IFR table for alternative scenario: B/C ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	3722.905	
S.Dev.	=	1656.375	
CV	=	0.445	
Q75	=	62.290	
Q75/MMF	=	0.201	
BFI Index	=	0.370	
CV(JJA+JFM) Index	=	1.796	
Total IFR	=	1344.695	(36.12 %MAR)
Maint. Lowflow	=	668.244	(17.95 %MAR)
Drought Lowflow	=	242.404	(6.51 %MAR)
Maint. Highflow	=	676.452	(18.17 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : N.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	190.120	300.633	1.581	35.891	13.928	11.262	47.153
Nov	301.650	274.226	0.909	44.842	16.848	36.448	81.289
Dec	456.110	379.313	0.832	58.121	19.284	164.722	222.843
Jan	690.284	470.624	0.682	78.745	28.123	81.143	159.888
Feb	754.673	486.025	0.644	92.413	32.659	297.389	389.802
Mar	560.244	319.843	0.571	91.601	32.141	62.964	154.565
Apr	280.015	202.950	0.725	78.019	27.734	11.262	89.281
May	139.090	116.800	0.840	56.514	20.624	0.000	56.514
Jun	84.031	57.890	0.689	39.917	15.034	0.000	39.917
Jul	67.569	59.457	0.880	32.409	12.588	0.000	32.409
Aug	71.845	138.082	1.922	28.927	11.517	0.000	28.927
Sep	127.272	375.009	2.947	30.845	11.923	11.262	42.107

8.5.3 IFR table for alternative scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	3722.905	
S.Dev.	=	1656.375	
CV	=	0.445	
Q75	=	62.290	
Q75/MMF	=	0.201	
BFI Index	=	0.370	
CV(JJA+JFM) Index	=	1.796	
Total IFR	=	883.164	(23.72 %MAR)
Maint. Lowflow	=	311.748	(8.37 %MAR)
Drought Lowflow	=	242.404	(6.51 %MAR)
Maint. Highflow	=	571.415	(15.35 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : N.Natal

Month	Natural Flows			Modified Flows (IFR)			
				Low flows		High Flows	Total Flows

	Mean	SD	CV	Maint.	Drought	Maint.	Maint.
Oct	190.120	300.633	1.581	18.749	13.928	11.262	30.011
Nov	301.650	274.226	0.909	20.736	16.848	36.448	57.184
Dec	456.110	379.313	0.832	26.784	19.284	139.536	166.320
Jan	690.284	470.624	0.682	34.819	28.123	68.550	103.369
Feb	754.673	486.025	0.644	42.336	32.659	279.171	321.507
Mar	560.244	319.843	0.571	40.176	32.141	36.448	76.624
Apr	280.015	202.950	0.725	32.400	27.734	0.000	32.400
May	139.090	116.800	0.840	25.445	20.624	0.000	25.445
Jun	84.031	57.890	0.689	19.440	15.034	0.000	19.440
Jul	67.569	59.457	0.880	17.410	12.588	0.000	17.410
Aug	71.845	138.082	1.922	16.606	11.517	0.000	16.606
Sep	127.272	375.009	2.947	16.848	11.923	0.000	16.848

8.5.4 IFR rule table for recommended scenario: C/D ERC

Data are given in m³/s mean monthly flow

Month	% Points								
	10%	20%	30%	40%	50%	60%	70%	85%	99%
Oct	20.094	19.958	19.649	19.009	17.817	15.854	13.083	8.405	5.897
Nov	37.007	36.789	36.334	35.435	33.751	30.810	26.134	15.968	7.835
Dec	148.040	131.463	117.240	104.608	92.461	72.183	60.393	34.764	14.258
Jan	92.764	84.242	76.841	70.102	63.344	52.019	44.436	27.951	14.760
Feb	242.775	214.433	190.211	168.877	148.651	114.935	96.389	56.074	23.817
Mar	56.237	55.929	55.287	54.018	51.640	47.488	40.886	26.535	15.052
Apr	34.879	34.649	34.127	33.048	31.037	27.725	23.050	15.158	10.926
May	22.620	22.480	22.163	21.507	20.283	18.268	15.424	10.623	8.048
Jun	15.888	15.790	15.568	15.108	14.251	12.839	10.846	7.481	5.677
Jul	13.734	13.649	13.457	13.060	12.319	11.099	9.377	6.471	4.912
Aug	12.508	12.430	12.252	11.885	11.200	10.072	8.480	5.792	4.351
Sep	12.861	12.781	12.599	12.223	11.521	10.366	8.734	5.981	4.504

Reserve flows without High Flows

Oct	14.543	14.456	14.257	13.847	13.082	11.822	10.043	7.041	6.245	5.431
Nov	19.081	18.986	18.788	18.396	17.662	16.381	14.343	9.914	8.356	6.370
Dec	24.614	24.487	24.221	23.695	22.709	20.989	18.253	12.306	10.214	7.547
Jan	29.867	29.728	29.440	28.869	27.799	25.932	22.962	16.506	14.235	11.341
Feb	31.177	31.036	30.742	30.161	29.072	27.170	24.146	17.572	15.259	12.312
Mar	36.390	36.218	35.861	35.153	33.827	31.513	27.832	19.832	17.017	13.430
Apr	29.507	29.324	28.909	28.052	26.454	23.823	20.108	13.837	12.175	10.475
May	22.620	22.480	22.163	21.507	20.283	18.268	15.424	10.623	9.350	8.048
Jun	15.888	15.790	15.568	15.108	14.251	12.839	10.846	7.481	6.589	5.677
Jul	13.734	13.649	13.457	13.060	12.319	11.099	9.377	6.471	5.700	4.912
Aug	12.508	12.430	12.252	11.885	11.200	10.072	8.480	5.792	5.080	4.351
Sep	12.861	12.781	12.599	12.223	11.521	10.366	8.734	5.981	5.251	4.504

Natural Duration curves

Oct	144.120	94.035	60.255	45.779	34.610	25.417	19.853	14.722	13.287	8.341
Nov	298.185	200.347	121.513	87.059	73.622	63.572	53.416	27.580	21.472	15.782
Dec	376.910	276.925	208.302	182.330	132.253	110.779	85.602	46.165	33.831	25.093
Jan	557.036	415.916	322.565	280.408	249.501	204.913	155.727	94.013	74.637	45.993
Feb	571.647	441.405	349.156	263.306	235.891	209.606	165.102	93.126	85.133	43.664
Mar	405.382	337.603	289.463	242.179	206.841	175.810	148.404	94.089	90.518	46.511
Apr	159.524	136.305	121.886	106.201	91.984	76.198	67.958	51.191	45.165	28.349
May	88.677	54.911	47.936	43.735	38.380	35.274	30.328	24.660	21.389	19.753
Jun	44.948	36.428	31.104	28.364	27.389	24.985	22.652	17.641	16.599	14.266
Jul	40.247	30.529	25.378	22.859	19.672	18.758	17.130	13.823	13.391	11.640
Aug	38.474	29.204	22.726	18.168	16.346	14.677	13.818	11.705	10.872	9.248
Sep	68.257	34.360	24.884	19.486	15.334	13.878	13.011	10.827	10.013	8.027

8.5.5 IFR rule table for alternative scenario: B/C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	21.935	21.781	21.432	20.710	19.364	17.149	14.021	10.419	7.341	5.909

Nov	36.058	35.846	35.407	34.536	32.907	30.061	25.536	19.248	12.239	7.829
Dec	151.326	134.724	120.450	107.718	95.382	74.775	62.461	45.351	26.279	14.279
Jan	102.005	93.415	85.871	78.849	71.561	59.310	50.254	37.670	23.644	14.818
Feb	258.581	229.611	204.750	182.659	161.393	125.890	105.173	76.386	44.299	24.110
Mar	76.230	75.782	74.848	72.999	69.537	63.492	53.880	40.522	25.634	16.266
Apr	40.641	40.356	39.710	38.373	35.881	31.778	25.985	19.316	13.614	10.962
May	26.917	26.736	26.325	25.477	23.895	21.290	17.612	13.378	9.759	8.075
Jun	18.399	18.277	18.001	17.428	16.362	14.605	12.125	9.269	6.828	5.693
Jul	15.437	15.336	15.107	14.634	13.751	12.297	10.245	7.882	5.862	4.923
Aug	13.335	13.249	13.053	12.649	11.895	10.654	8.901	6.884	5.159	4.357
Sep	18.901	18.767	18.463	17.836	15.334	13.878	12.016	8.884	6.205	4.960

Reserve flows without High Flows

Oct	17.096	16.984	16.730	16.206	15.228	13.617	11.343	8.726	6.487	5.447
Nov	20.836	20.728	20.502	20.057	19.222	17.765	15.448	12.228	8.639	6.381
Dec	27.900	27.748	27.431	26.805	25.631	23.581	20.322	15.793	10.744	7.568
Jan	39.109	38.901	38.470	37.616	36.016	33.222	28.780	22.608	15.728	11.399
Feb	42.935	42.707	42.231	41.289	39.526	36.446	31.549	24.744	17.158	12.386
Mar	47.117	46.866	46.342	45.306	43.365	39.975	34.586	27.097	18.750	13.497
Apr	35.958	35.714	35.160	34.014	31.878	28.360	23.394	17.676	12.788	10.515
May	26.917	26.736	26.325	25.477	23.895	21.290	17.612	13.378	9.759	8.075
Jun	18.399	18.277	18.001	17.428	16.362	14.605	12.125	9.269	6.828	5.693
Jul	15.437	15.336	15.107	14.634	13.751	12.297	10.245	7.882	5.862	4.923
Aug	13.335	13.249	13.053	12.649	11.895	10.654	8.901	6.884	5.159	4.357
Sep	14.218	14.125	13.914	13.477	12.662	11.320	9.425	7.245	5.380	4.513

8.5.6 IFR rule table for alternative scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	19.580	19.449	19.151	18.535	17.386	15.493	12.822	9.746	7.117	5.894
Nov	35.719	35.510	35.076	34.216	32.606	29.794	25.323	19.110	12.184	7.827
Dec	125.138	111.106	99.079	88.422	78.212	61.176	51.412	37.844	22.722	13.207
Jan	80.825	73.621	67.357	61.641	55.891	46.253	39.732	30.671	20.571	14.216
Feb	233.927	206.803	183.613	163.167	143.752	111.382	93.458	68.551	40.788	23.321
Mar	55.557	55.253	54.622	53.374	51.035	46.951	40.458	31.434	21.376	15.047
Apr	22.424	22.309	22.047	21.507	20.500	18.842	16.501	13.806	11.502	10.430
May	18.194	18.097	17.875	17.417	16.563	15.156	13.170	10.884	8.930	8.021
Jun	13.451	13.376	13.206	12.855	12.201	11.125	9.604	7.854	6.358	5.662
Jul	12.445	12.373	12.208	11.869	11.236	10.193	8.721	7.027	5.578	4.904
Aug	11.487	11.418	11.263	10.941	10.341	9.354	7.960	6.355	4.983	4.345
Sep	11.655	11.586	11.430	11.108	10.507	9.517	8.120	6.511	5.136	4.497

Reserve flows without High Flows

Oct	13.403	13.327	13.153	12.794	12.124	11.020	9.463	7.670	6.137	5.424
Nov	15.426	15.358	15.217	14.937	14.413	13.498	12.042	10.020	7.766	6.347
Dec	20.584	20.486	20.283	19.880	19.126	17.809	15.715	12.806	9.563	7.522
Jan	27.689	27.567	27.312	26.808	25.863	24.214	21.591	17.946	13.883	11.327
Feb	31.491	31.348	31.049	30.458	29.351	27.418	24.343	20.072	15.310	12.314
Mar	33.090	32.942	32.636	32.029	30.893	28.909	25.754	21.370	16.484	13.410
Apr	22.424	22.309	22.047	21.507	20.500	18.842	16.501	13.806	11.502	10.430
May	18.194	18.097	17.875	17.417	16.563	15.156	13.170	10.884	8.930	8.021
Jun	13.451	13.376	13.206	12.855	12.201	11.125	9.604	7.854	6.358	5.662
Jul	12.445	12.373	12.208	11.869	11.236	10.193	8.721	7.027	5.578	4.904
Aug	11.487	11.418	11.263	10.941	10.341	9.354	7.960	6.355	4.983	4.345
Sep	11.655	11.586	11.430	11.108	10.507	9.517	8.120	6.511	5.136	4.497

8.6 GEOMORPHOLOGICAL CONSEQUENCES OF C AND D SCENARIOS

Bed maintenance

A C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be a longer bed material residence time compared to virgin conditions. This will result in a moderately modified bed for periods between large flood events (20 - 50 year return period).

For a D ERC, flows reflect further reductions in flood frequency, and consequently, there will be a longer bed material residence time compared to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Bench maintenance

A C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be less bench maintenance constructional flows relative to virgin conditions. This will result in a moderately modified bench for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be less bench maintenance constructional flows relative to a C ERC river. This will result in a largely modified bench for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Channel maintenance

A C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer channel maintenance flows relative to virgin conditions. This will result in a moderately modified channel for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows relative to a C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Macro Channel and bed mobilisation

A C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer macro-channel and bed mobilisation flows relative to virgin conditions. This will result in a moderately modified macro-channel and a less frequently mobilised bed for periods between large flood events (20 - 50 year return period). D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows, and further reductions in bed mobilisation relative to a C ERC river. This will result in a largely modified macro-channel and more stable bed for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Conclusion

Alluvial sediments dominate the channel, the reduction in the number of flood events for different geomorphological purposes simply means that there is likely to be a long-term accumulation of sediments in this segment of the river. This will result in a concomitant change in bed morphology i.e. bars and islands may become more permanent and stable features.

8.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 8.5 IFR confidence table for a C ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
16	Low flows	2	4	-	-
	High flows	4	5	4	4

The confidence ranges from low-to-medium (one value only) to high.

Invertebrates: The low - medium evaluation is due to the uncertainty of depth requirements for invertebrates as well as to an understanding that any change in depth impacts severely on volume.

Fish: Is of higher confidence, based on the fact that the invertebrate requirements are higher than the fish requirements.

Riparian Vegetation: The information is based on the cues that are available on the lower terrace of the right bank - there is therefore more confidence in the smaller floods than in the larger. The confidence for the geomorphology results is linked to the fact that there is daily hydrology available as well as sediment modelling.

9 RU M. IFR 3. LITTLE THUKELA (Little Thukela River)

9.1 ECOLOGICAL CATEGORIES

9.1.1 Summary of ERC scenarios

Three Ecological Reserve Scenarios were addressed for IFR 3. The recommended scenario is a C/D ERC. The alternative scenarios of a B/C and a D ERC were also evaluated.

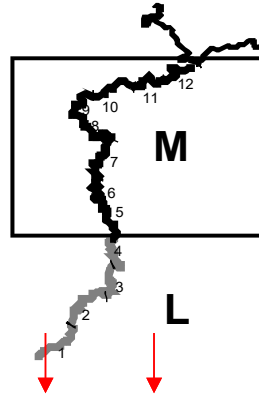


Fig 9.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP	DOWN
WATER QUALITY	C	-	C	EIS MODERATE SI H MODERATE	C		
GEOMORPH	C/D	-	D		C/D	B/C	D
RIPARIAN VEGETATION	D/E	-	E		D	D	D
FISH	C	0	C		C	B	D
AQUATIC INVERTS	B/C	-	C		B/C	B	C/D
ECOSTATUS	C/D	-	D		C/D	B/C	D

9.1.2 Criteria for the Ecological Reserve Categories

Recommended Scenario: C/D ERC

Aquatic invertebrates (B/C)

- Marginal vegetation species:
Maintain populations as indicated by SASS results during summer and over the winter.
Monitor the presence of Heptageniidae and Elmidae. These would need to be maintained even in the dry season when they would naturally move onto alternative substrates.
Marginal vegetation as a habitat would not be essential during winter and drought flows.

- Flow-dependent species:
Maintain flow-dependent families, with Heptageniidae as the dominant family.

Fish (C)

- Maintain existing species diversity by providing adequate breeding and refuge facilities for *Amphilius natalensis*.

Riparian Vegetation (D)

- Maintain and possibly extend the existing distribution and abundances of the mesic zone on both banks and islands.
- Maintain the existing distribution and abundances of *Salix mucronata* on the marginal and lower terraces.
- Promote the establishment of other natural riparian species on the lower riparian areas to achieve an overall improvement in the status of riparian vegetation in these areas.

Geomorphology (C/D)

- Maintain the river in its present state i.e. no further channel constriction or sediment accumulation, and no increase in bed aggradation or embeddedness. Floods of a sufficient size and frequency to move the available sediment presently entering this system are needed.

Alternative scenario: B/C ERC

Aquatic invertebrates (B)

- Marginal vegetation species:
Heptageniidae and Elmidae families must be present.
The SASS scores (as indicated in Appendix G) should be appropriate for a B/C category, i.e. higher than the C/D category.
Ensure vegetation is inundated to a greater depth and more often.
- Flow-dependent species:
Maintain flow-dependent families with Heptageniidae the dominant, but also with Perlidae present. Perlidae were found upstream in a more diverse site.
Achieve good SASS scores (as indicated in Appendix G).
Ensure greater velocities, with more suitable habitat of clean stones.

Fish (B)

- Maintain existing species diversity, with increased abundances of *A. natalensis*.
- Ensure improved spawning success and abundance of *A. natalensis*, *Labeobarbus natalensis* and *L. rubromaculatus*.
- Maintain existing species diversity, with improved breeding and survival of all species, by providing increased cobble-bed coverage and improved water quality during summer breeding season.

Riparian Vegetation (D)

- As for the ecostatus C/D ERC.

Geomorphology (B/C)

- In order to change the present state from a C/D to a B/C, there is a need for reduced sediment accumulation, i.e. increased sediment transport together with an overall increase in sediment scour from the bed, banks and bars. Since the majority of sediment is transported by flood events, an increase in the number of these events from that of the C/D should achieve this objective.

Alternative scenario: D ERC

Aquatic invertebrates (C/D)

- Marginal vegetation species:
Lower SASS scores achieved less often with Heptageniidae and Elmidae becoming uncommon.
Marginal vegetation should be well inundated for 50% of summer.
- Flow-dependent species:
SASS scores decrease with Heptageniidae occurring infrequently.
Flow velocities and as is the quantity of habitat are reduced.

Fish (D)

DESCRIPTION

- Maintain existing species diversity, but with reduced abundances of *A. natalensis*, *L. natalensis* and *L. rubromaculatus*.
- Facilitate moderate breeding success and consequent abundance of *L. natalensis* and *L. rubromaculatus*.
- Maintain existing species diversity and prevent extinction of *Amphilius* by facilitating minimal breeding success during summer and survival during winter.

Riparian Vegetation (D)

- As for the ecostatus C/D ERC.

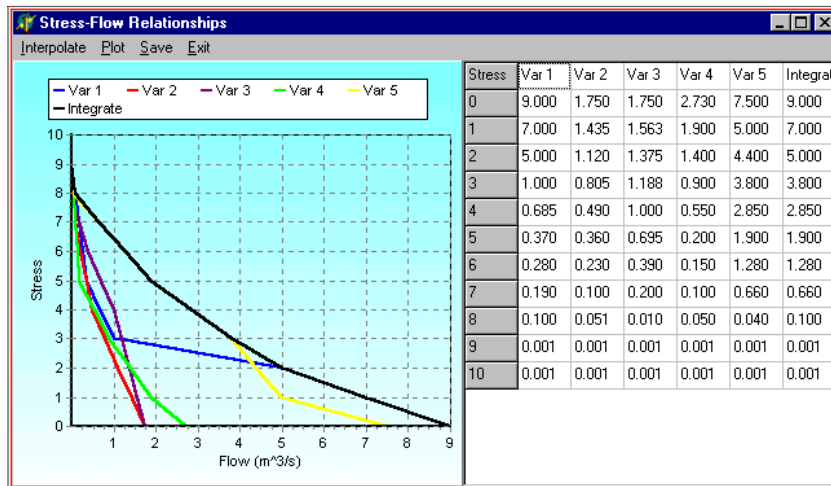
Geomorphology (D)

- In order to change the present state from a C/D to a D, there is an allowance for long-term accumulation of sediments. Flood events for the maintenance of bed and bench remain the same. The occurrence of larger events becomes less frequent. The assurance of the occurrence of the very large re-set event is also lower.

9.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining flow-stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The flow-stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 3, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 9.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 9.2.

Fig 9.2 Critical curve for IFR 3



Var 1: Fish

Var 2: Flow Dependent Invertebrates

Var 3: Marginal Vegetation Invertebrates

Var 4: Riparian Vegetation 1

Var 5: Riparian Vegetation 2

9.2.1 Invertebrates

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit ($0.36\text{m}^3/\text{s}$) as a reference point. The stress index of 0 was set so that approximately 0.2m of water would enter the marginal vegetation. The indices of greater stress were derived similarly, by measuring the reduction in water level that would leave just the bases of the *Juncus* inundated. Maximum stress was set where the only marginal vegetation would be found, in the pool downstream. Note that this assessment for marginal vegetation communities applies only for the wet season, as during dry seasons it can be expected that flows will recede from the vegetation.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of the stone biotope, which is extensively impacted and of poor quality. Much of this investigation was based on the known presence of families such as Oligoneuridae and Perlidae, which require abundant clean, strong flowing water over clean rocks.

9.2.2 Riparian Vegetation

Two components were selected, using elevations and discharges associated with the ecological transect for the hydraulic modelling.

- **Mixed grasses (adults)** - applicable throughout the year
The mean elevation for individuals was assessed at the 0.56m water level. Root lengths of 0.25m were used, corresponding to water levels of 0.24m at the root bases.
- **Salix (adults)** - applicable throughout the year
Salix adults were identified at the 0.78m level. Critical water levels (below maximum rooting depth) were assessed to be approximately 0.6m below this level, i.e. 0.03m.

9.3 STRESS DURATION CURVES (PROFILES)

9.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 9.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 3, stress indices as determined were accepted and no changes were required.

9.3.2 Recommended stress profiles for each Reserve scenario

The recommended C/D scenario and the alternative B/C and D scenarios were estimated using the Desktop Model and are shown in Figures 9.3 – 9.8 as the green, purple and yellow lines respectively. The modelled present day hydrology, as converted into stress, is reflected by the red line in Figures 9.3 – 9.8 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 9.3 - 9.8. According to the specialists' evaluations, the Desktop-generated scenarios were adjusted (see Figures 9.9 - 9.10). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

Note that the adjusted line was not drawn in to coincide with Riparian vegetation 2. The Riparian Vegetation 2 point is below the natural or reference line. The confidence in the evaluation is low as marginal vegetation responds quickly to flow changes. Taking this into account, the point was seen as an outlier and ignored.

9.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated C/D scenario consisted of Maintenance Low Flows of 11.3 % MAR, which were adjusted to 11.11% MAR, and Drought Low Flows of 7.36% MAR, which were adjusted to 6.39% MAR (see Figure 9.3). The generated B/C scenario consisted of Maintenance Low Flows of 20.23% MAR, which were adjusted to 21.40% MAR, and Drought Low Flows of 7.36% MAR, which were adjusted to 7.37% MAR (see Figure 9.3). The generated D scenario consisted of Maintenance Low Flows of 7.69% MAR, which were adjusted to 6.14% MAR, and Drought Low Flows of 7.36% MAR, which were adjusted to 5.03% MAR. The Maintenance and Drought Low Flows were manually changed to better fit the specialists' requirements for stress patterns.

Fig 9.3 IFR 3 – Stress duration curve for recommended scenario of a C/D ERC: Dry Season

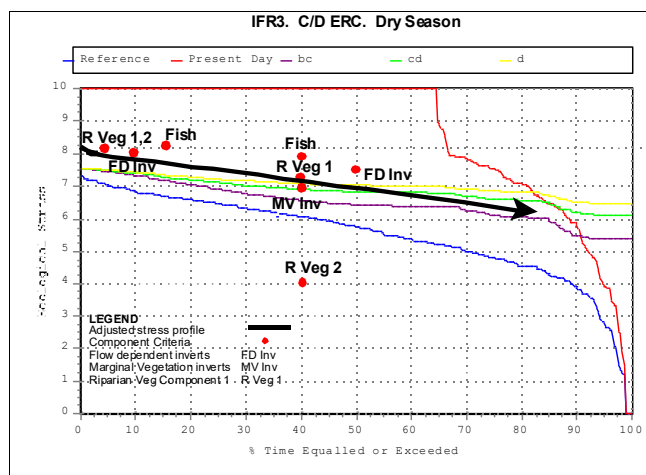
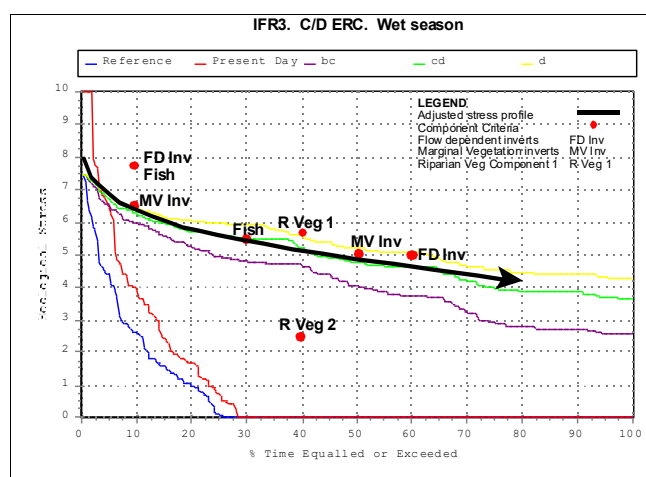


Fig 9.4 IFR 3 – Stress duration curve for recommended scenario of a C/D ERC: Wet Season



NOTE (above): A fish stress of 2 = a critical stress of 2. A fish stress of 3 = a critical stress of 6.3. A recommendation was made for a stress of 6.3 for 30% of the time for fish, for a C/D evaluation. The desktop generated C/D line lies in 5.5 for 10% of the time. The sensitivity of the fish range of stress and flow is such that there would be no impact to use the desktop stress of 5.5 at 10% duration rather than 6.3 at 10% duration.

Fig 9.5 IFR 3 – Stress duration curve for alternative scenario of a B/C ERC: Dry Season

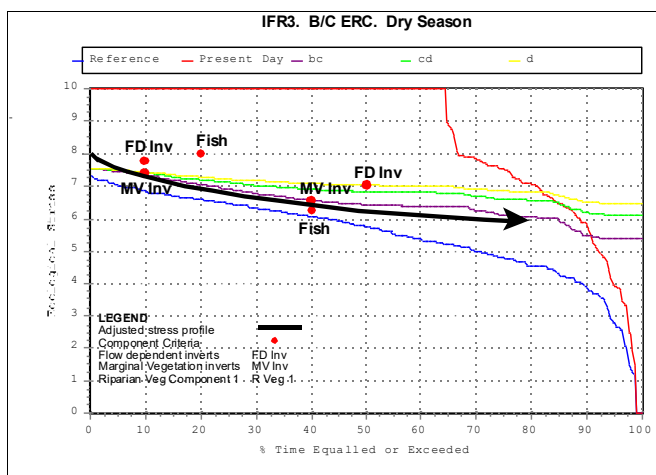


Fig 9.6 IFR 3 – Stress duration curve for alternative scenario of a B/C ERC: Wet Season

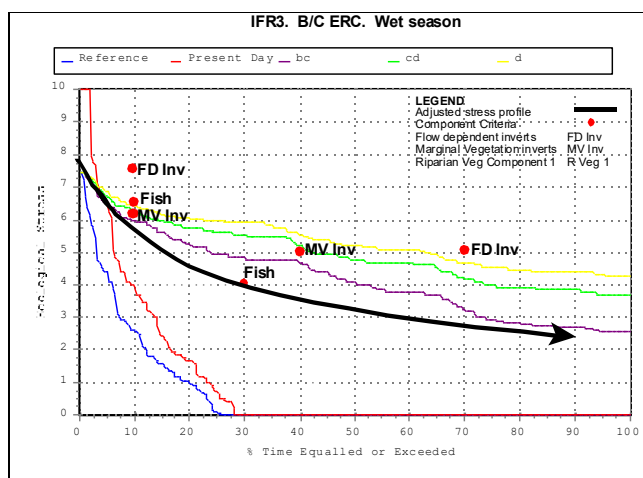


Fig 9.7 IFR 3 – Stress duration curve for alternative scenario of a D ERC: Dry Season

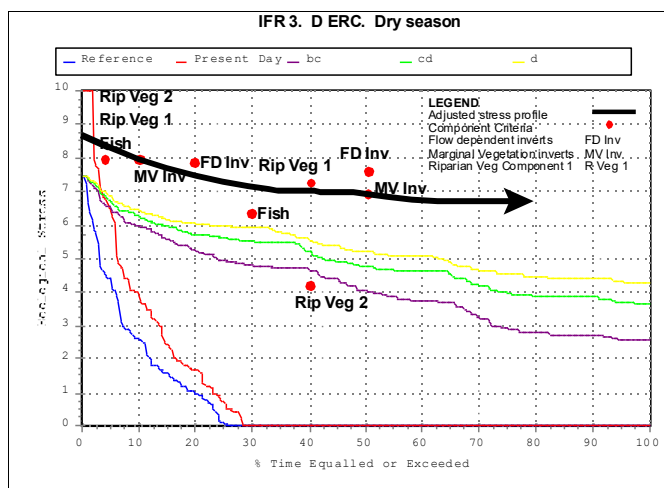
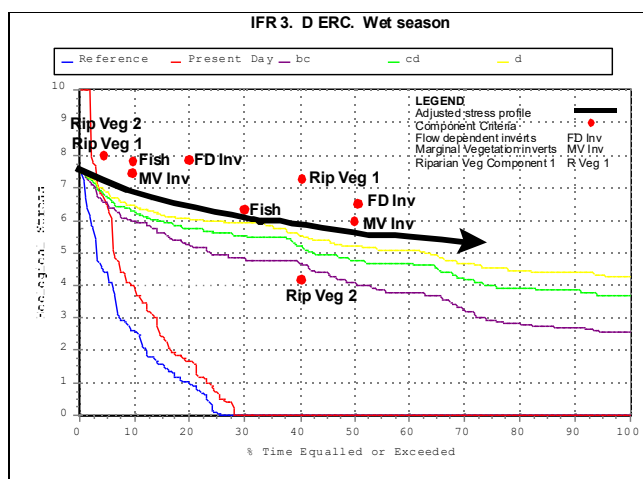


Fig 9.8 IFR 3 – Stress duration curve for alternative scenario of a D ERC: Wet Season



NOTE (above): Riparian vegetation points often lie at the lower stress than natural, (i.e. below the natural curve) meaning a higher flow requirement than natural. Considering the low confidence in the vegetation stress estimates, these points were not used to define the line (requirements).

9.3.4 Final stress profiles for IFR 3

Fig 9.9 IFR 3 - Final stress profiles: Dry Season

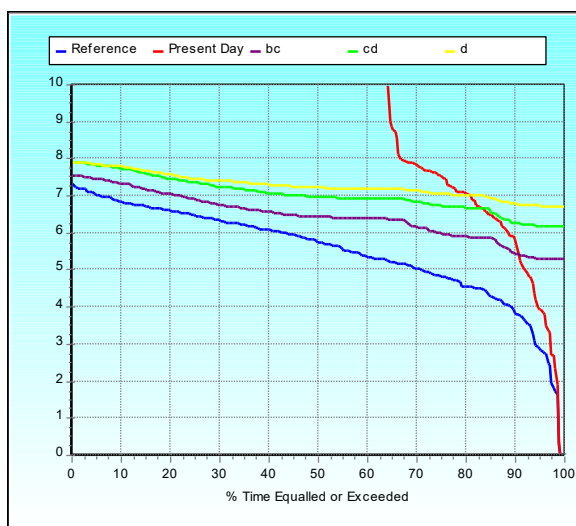
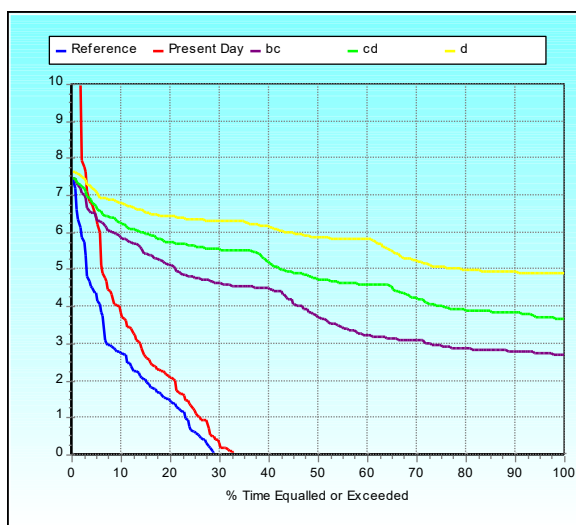


Fig 9.10 IFR 3 - Final stress profiles: Wet Season



9.4 HIGH FLOWS

The functions for each Flood Class are described in Appendix G. A summary of the flood class ranges is provided in Table 9.1. The number of events for each Flood Class required for a recommended ERC of C/D and alternative scenarios of B/C and D are also summarised in Table 9.1.

Table 9.1 A summary of the Flood Class ranges for IFR 3, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s				
	I	II	III	IV	V
Fish	2-5	10-15 15-25			
Invertebrates	1-2	5-15	20-30		
Vegetation		10-25	25-60	60-125	125-250
Geomorphology			23-38	38-90	90-207
Integrated	1-5	10-24	25-39	40-124	125-250
Geometric Mean*		15	32	70	177
Recommended Flood Events					
No of events for C/D ERC (Recommended scenario)	3 spring 5 summer	3	2	1	1 in 4 years
No of events for B/C ERC (Alternative scenario)	4 spring 8 summer	4	3	2	1 in 3 years
No of events for D ERC (Alternative scenario)	2 spring 3 summer	3	2	1:2	1 in 5 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher values (e.g. 125 to 250) specified by the geomorphologist were reduced to the lower values (e.g. 100) for the Desktop model to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 9.2 – 9.4.

Table 9.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a C/D ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	II	15	III	32	V incl. 1-IV	100	III	32		
Duration (days)	2		3		5		3			
Freshet size (m³/s)	I	3	I + II	3 + 15	I	3	I + II	3 + 15	I	3
Duration (days)	2		2		2		2		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	3	I	3	I	3				
Duration (days)	2		2		2					

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Table 9.3 Adjusted flood sizes as used in the Desktop (monthly) model for the alternative scenario of a B/C ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	32	IV	70	V incl. 1-IV	100	III	32		
Duration (days)	3		4		5		3			
Freshet size (m³/s)	I + II	3 + 15	I*2 + III	3*2 + 32	I + II	3 + 15	I*2+ II	3*2 + 15	I*2	3*2
Duration (days)	2		3		2		2		2	
Spring										
	Sept		Oct		Nov					
	I	3	I + II	3 + 15	I*2	3*2				
	2		2		2					

Table 9.4 Adjusted flood sizes as used in the Desktop model for scenario of a D ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	II	15	III	32	V incl. 1-IV	90	III	32		
Duration (days)	2		3		5		3			
Freshet size (m³/s)			II	15	I	3	I + II	15 + 3	I	3
Duration (days)			2		2		2		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)			I	3	I	3				
Duration (days)			2		2					

9.5 FINAL RESULTS

9.5.1 IFR table for recommended scenario: C/D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	285.197
S.Dev.	=	138.725
CV	=	0.486
Q75	=	4.040
Q75/MMF	=	0.170
BFI Index	=	0.361
CV (JJA+JFM) Index	=	1.327
Total IFR	=	70.474 (24.71 %MAR)
Maint. Lowflow	=	31.698 (11.11 %MAR)
Drought Lowflow	=	18.223 (6.39 %MAR)
Maint. Highflow	=	38.776 (13.60 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	9.038	13.914	1.539	1.366	0.536	0.363	1.729
Nov	17.881	20.886	1.168	1.814	0.778	0.363	2.177
Dec	31.993	30.894	0.966	2.598	1.071	2.177	4.775

Jan	50.956	35.325	0.693	3.750	2.491	7.154	10.904
Feb	62.672	42.287	0.675	4.645	3.145	20.840	25.485
Mar	55.559	35.442	0.638	4.901	3.294	7.154	12.055
Apr	25.952	19.073	0.735	3.888	2.670	0.363	4.251
May	10.477	7.218	0.689	2.946	1.875	0.000	2.946
Jun	6.169	2.593	0.420	1.944	1.037	0.000	1.944
Jul	4.518	2.291	0.507	1.473	0.536	0.000	1.473
Aug	3.953	4.142	1.048	1.205	0.402	0.000	1.205
Sep	6.031	15.219	2.524	1.166	0.389	0.363	1.529

9.5.2 IFR table for alternative scenario: B/C ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	285.197
S.Dev.	=	138.725
CV	=	0.486
Q75	=	4.040
Q75/MMF	=	0.170
BFI Index	=	0.361
CV(JJA+JFM) Index	=	1.327
Total IFR	=	122.027 (42.79 %MAR)
Maint. Lowflow	=	61.029 (21.40 %MAR)
Drought Lowflow	=	21.024 (7.37 %MAR)
Maint. Highflow	=	60.998 (21.39 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : S.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	9.038	13.914	1.539	2.678	0.991	0.363	3.041
Nov	17.881	20.886	1.168	3.629	1.037	2.540	6.169
Dec	31.993	30.894	0.966	5.089	1.071	10.040	15.129
Jan	50.956	35.325	0.693	8.035	2.491	16.796	24.831
Feb	62.672	42.287	0.675	8.588	3.145	22.654	31.242
Mar	55.559	35.442	0.638	9.107	3.294	7.517	16.623
Apr	25.952	19.073	0.735	7.517	2.696	0.726	8.243
May	10.477	7.218	0.689	5.357	1.982	0.000	5.357
Jun	6.169	2.593	0.420	3.629	1.374	0.000	3.629
Jul	4.518	2.291	0.507	2.946	1.098	0.000	2.946
Aug	3.953	4.142	1.048	2.277	0.937	0.000	2.277
Sep	6.031	15.219	2.524	2.177	0.907	0.363	2.540

9.5.3 IFR table for alternative scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	285.197
S.Dev.	=	138.725
CV	=	0.486
Q75	=	4.040
Q75/MMF	=	0.170
BFI Index	=	0.361
CV(JJA+JFM) Index	=	1.327
Total IFR	=	53.162 (18.64 %MAR)
Maint. Lowflow	=	17.522 (6.14 %MAR)
Drought Lowflow	=	14.347 (5.03 %MAR)
Maint. Highflow	=	35.640 (12.50 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
				Low flows		High Flows	Total Flows

	Mean	SD	CV	Maint.	Drought	Maint.	Maint.
Oct	9.038	13.914	1.539	0.937	0.536	0.363	1.300
Nov	17.881	20.886	1.168	1.166	0.518	0.363	1.529
Dec	31.993	30.894	0.966	1.473	0.804	1.814	3.288
Jan	50.956	35.325	0.693	1.875	1.875	6.791	8.666
Feb	62.672	42.287	0.675	2.419	2.419	18.792	21.211
Mar	55.559	35.442	0.638	2.678	2.678	7.154	9.832
Apr	25.952	19.073	0.735	1.814	1.814	0.363	2.177
May	10.477	7.218	0.689	1.473	1.339	0.000	1.473
Jun	6.169	2.593	0.420	1.166	1.037	0.000	1.166
Jul	4.518	2.291	0.507	0.937	0.536	0.000	0.937
Aug	3.953	4.142	1.048	0.804	0.402	0.000	0.804
Sep	6.031	15.219	2.524	0.778	0.389	0.000	0.778

9.5.4 IFR rule table for recommended scenario: C/D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.002	0.995	0.978	0.943	0.878	0.770	0.619	0.444	0.295	0.226
Nov	1.291	1.284	1.268	1.238	1.182	1.083	0.925	0.707	0.463	0.310
Dec	2.753	2.736	2.701	2.632	2.502	2.277	1.917	1.418	0.862	0.511
Jan	8.005	7.255	6.606	6.017	5.431	4.451	3.810	2.921	1.929	1.305
Feb	17.962	15.936	14.201	12.668	11.205	8.765	7.389	5.478	3.347	2.006
Mar	9.074	8.294	7.614	6.990	6.358	5.297	4.562	3.541	2.403	1.686
Apr	2.444	2.430	2.399	2.335	2.216	2.019	1.740	1.420	1.147	1.019
May	1.778	1.768	1.745	1.698	1.610	1.465	1.260	1.025	0.824	0.730
Jun	1.135	1.128	1.111	1.078	1.016	0.913	0.768	0.601	0.458	0.392
Jul	0.888	0.881	0.867	0.836	0.779	0.686	0.554	0.401	0.271	0.211
Aug	0.703	0.698	0.686	0.661	0.615	0.539	0.432	0.308	0.203	0.153
Sep	0.853	0.847	0.832	0.801	0.743	0.647	0.513	0.357	0.225	0.163
Reserve flows without High Flows										
Oct	0.823	0.818	0.804	0.777	0.725	0.640	0.521	0.383	0.265	0.211
Nov	1.113	1.106	1.094	1.069	1.021	0.939	0.808	0.626	0.423	0.295
Dec	1.646	1.637	1.618	1.580	1.509	1.386	1.189	0.917	0.612	0.421
Jan	2.460	2.449	2.426	2.382	2.297	2.151	1.917	1.593	1.231	1.003
Feb	2.851	2.838	2.812	2.761	2.665	2.497	2.230	1.859	1.445	1.185
Mar	3.331	3.316	3.286	3.225	3.112	2.915	2.601	2.166	1.680	1.374
Apr	2.271	2.259	2.231	2.174	2.068	1.893	1.646	1.361	1.118	1.005
May	1.778	1.768	1.745	1.698	1.610	1.465	1.260	1.025	0.824	0.730
Jun	1.135	1.128	1.111	1.078	1.016	0.913	0.768	0.601	0.458	0.392
Jul	0.888	0.881	0.867	0.836	0.779	0.686	0.554	0.401	0.271	0.211
Aug	0.703	0.698	0.686	0.661	0.615	0.539	0.432	0.308	0.203	0.153
Sep	0.680	0.675	0.664	0.640	0.595	0.522	0.418	0.298	0.196	0.149
Natural Duration curves										
Oct	8.083	4.541	3.160	2.022	1.609	1.215	0.853	0.733	0.610	0.444
Nov	13.949	9.524	7.557	5.679	4.865	3.636	2.132	1.314	0.818	0.508
Dec	25.664	16.597	14.051	11.732	9.645	7.427	5.525	3.106	1.725	0.567
Jan	41.483	34.519	23.264	20.626	18.008	13.035	11.658	7.539	5.783	3.955
Feb	48.499	32.053	28.271	22.924	19.082	17.503	15.072	10.984	6.795	4.051
Mar	43.552	32.804	26.443	23.189	19.196	16.319	14.749	12.318	8.234	3.443
Apr	18.563	13.127	10.734	8.934	7.833	6.896	5.865	4.495	3.920	2.431
May	6.281	4.680	4.271	3.754	3.437	3.171	2.739	2.492	2.160	1.678
Jun	3.905	3.009	2.520	2.266	2.113	1.904	1.684	1.591	1.408	1.135
Jul	2.770	2.137	1.860	1.744	1.555	1.381	1.289	1.161	1.049	0.880
Aug	2.397	1.773	1.415	1.254	1.172	1.057	0.915	0.840	0.780	0.676
Sep	3.771	1.829	1.344	1.023	0.930	0.851	0.743	0.642	0.545	0.504

9.5.5 IFR rule table for alternative scenario: B/C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.432	1.422	1.399	1.353	1.267	1.124	0.853	0.692	0.495	0.403
Nov	2.746	2.729	2.694	2.625	2.495	2.268	1.908	1.314	0.818	0.496
Dec	6.774	6.730	6.637	6.454	6.111	5.513	4.562	3.106	1.725	0.567
Jan	17.009	15.252	13.733	12.364	11.015	8.757	7.325	5.335	3.117	1.721
Feb	20.417	18.207	16.306	14.609	12.961	10.209	8.556	6.258	3.696	2.085
Mar	10.719	9.890	9.156	8.463	7.726	6.486	5.514	4.163	2.658	1.711

Apr	3.766	3.740	3.681	3.559	3.331	2.955	2.425	1.815	1.293	1.051
May	2.551	2.534	2.496	2.416	2.267	2.021	1.675	1.276	0.934	0.776
Jun	1.673	1.662	1.637	1.585	1.488	1.328	1.104	0.845	0.623	0.520
Jul	1.403	1.394	1.373	1.329	1.247	1.113	0.923	0.704	0.517	0.430
Aug	1.050	1.043	1.028	0.996	0.938	0.842	0.706	0.550	0.416	0.354
Sep	1.155	1.147	1.130	1.023	0.930	0.851	0.743	0.582	0.429	0.357

Reserve flows without High Flows

Oct	1.276	1.267	1.248	1.208	1.133	1.011	0.837	0.638	0.467	0.388
Nov	1.685	1.676	1.656	1.616	1.541	1.411	1.204	0.917	0.597	0.395
Dec	2.441	2.426	2.395	2.333	2.216	2.013	1.690	1.241	0.741	0.426
Jan	3.990	3.967	3.921	3.829	3.657	3.357	2.880	2.217	1.478	1.013
Feb	3.990	3.969	3.926	3.840	3.678	3.396	2.947	2.324	1.629	1.192
Mar	4.684	4.660	4.608	4.507	4.316	3.983	3.454	2.718	1.898	1.383
Apr	3.464	3.441	3.388	3.278	3.073	2.735	2.258	1.709	1.240	1.022
May	2.551	2.534	2.496	2.416	2.267	2.021	1.675	1.276	0.934	0.776
Jun	1.673	1.662	1.637	1.585	1.488	1.328	1.104	0.845	0.623	0.520
Jul	1.403	1.394	1.373	1.329	1.247	1.113	0.923	0.704	0.517	0.430
Aug	1.050	1.043	1.028	0.996	0.938	0.842	0.706	0.550	0.416	0.354
Sep	1.004	0.997	0.983	0.953	0.898	0.806	0.677	0.529	0.402	0.343

9.5.6 IFR rule table for alternative scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.869	0.863	0.849	0.820	0.766	0.676	0.551	0.406	0.282	0.225
Nov	1.069	1.062	1.049	1.023	0.973	0.887	0.750	0.559	0.346	0.212
Dec	2.175	2.162	2.134	2.079	1.976	1.796	1.510	1.113	0.670	0.391
Jan	6.756	6.049	5.442	4.903	4.384	3.518	3.014	2.312	1.531	1.039
Feb	15.427	13.605	12.050	10.686	9.402	7.263	6.121	4.533	2.763	1.650
Mar	7.951	7.177	6.511	5.914	5.331	4.357	3.761	2.932	2.008	1.426
Apr	1.449	1.442	1.425	1.391	1.328	1.224	1.077	0.908	0.763	0.696
May	1.054	1.049	1.037	1.013	0.968	0.894	0.790	0.670	0.568	0.520
Jun	0.807	0.803	0.794	0.775	0.740	0.683	0.601	0.507	0.427	0.390
Jul	0.670	0.665	0.655	0.635	0.596	0.532	0.443	0.339	0.251	0.210
Aug	0.555	0.552	0.543	0.525	0.491	0.435	0.356	0.266	0.189	0.153
Sep	0.538	0.534	0.525	0.508	0.475	0.421	0.345	0.257	0.182	0.148

Reserve flows without High Flows

Oct	0.670	0.665	0.655	0.635	0.596	0.532	0.443	0.339	0.251	0.210
Nov	0.867	0.862	0.851	0.831	0.792	0.725	0.617	0.468	0.302	0.198
Dec	1.131	1.125	1.113	1.088	1.040	0.958	0.827	0.645	0.443	0.315
Jan	1.492	1.486	1.475	1.452	1.409	1.335	1.216	1.052	0.868	0.753
Feb	1.801	1.794	1.780	1.753	1.701	1.611	1.468	1.270	1.048	0.909
Mar	2.207	2.199	2.182	2.148	2.085	1.975	1.800	1.556	1.285	1.114
Apr	1.256	1.251	1.238	1.212	1.164	1.085	0.972	0.843	0.732	0.681
May	1.054	1.049	1.037	1.013	0.968	0.894	0.790	0.670	0.568	0.520
Jun	0.807	0.803	0.794	0.775	0.740	0.683	0.601	0.507	0.427	0.390
Jul	0.670	0.665	0.655	0.635	0.596	0.532	0.443	0.339	0.251	0.210
Aug	0.555	0.552	0.543	0.525	0.491	0.435	0.356	0.266	0.189	0.153
Sep	0.538	0.534	0.525	0.508	0.475	0.421	0.345	0.257	0.182	0.148

9.6 GEOMORPHOLOGICAL CONSEQUENCES OF A C/D, B/C AND D SCENARIO

Bed maintenance

B/C flood events allow longer periods of sediment accumulation on the bed. This will lead to some sediment fining, particularly in lee areas. The degree of accumulation should not allow irreversible embedding within a 20-year record.

The number of C/D and D category flood events are the same. This will lead to longer periods of sediment accumulation, and the loss of some interstitial habitat, particularly on channel margins and behind obstructions. This will be re-set by large floods.

Bench maintenance

B/C flood events will result in longer periods without sediment deposition and local scour, flushing etc. This will result in a partially modified channel bench for the periods between large flood events.

The number of C/D and D category flood events are the same. This will likely keep the channel in its presently modified condition for the long periods between very large flood events. The channel bench is overtopped twice a year but there is likely to be some vegetation encroachment (perhaps terrestrial).

Channel maintenance

B/C category floods allow for longer periods than natural between the mobilisation of coarse sediments on the bed and the scour of channel banks. This may result in some sediment fining and the accumulation of algae and other deposits on gravels and cobbles.

C/D category floods allow for longer periods of sediment accumulation on the bed, and as bars on the channel margins. This may encourage some vegetation encroachment. This must not be allowed to continue for too long, as sediment scouring will become more and more difficult.

D category floods allow for a significant change in channel condition. Bed and banks are likely to become quite stable.

Macro-channel and bed mobilisation

B/C flood events allow for periods of stability between large re-set events. The bed may become temporarily embedded.

C/D flood events simply mean an even, more stable bed with increased sedimentation, particularly of the larger bed material. The bed is likely to be more embedded than in the B/C category.

D category floods allow long periods of stability (5 years). This will lead to increased vegetation encroachment on banks, bars and islands.

Conclusion

B/C category floods allow for a greater time between events, (than would occur naturally) and therefore allows for the temporary storage of sediment on the channel bed and banks. This may result in temporary loss of habitat and some vegetation encroachment.

C/D category floods occur even less regularly than B/C category. This is likely to allow a more permanent storage of sediment and some long-term changes in channel morphology and in-stream habitat.

D category floods assume a long-term change in channel morphology as bars, islands and banks are built up by sediment deposition and are well stabilised by encroaching vegetation.

9.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set, based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 9.5 IFR confidence table for recommended scenario of a C/D ERC

IFR Site		IFR Component			
		Aquatic Inverts	FISH	Riparian Vegetation	Geomorphology
3	Low flows	3	3	3	-
	High flows	4	4	4	3

The confidence is medium for low flows, and mostly medium-to-high for high flows.

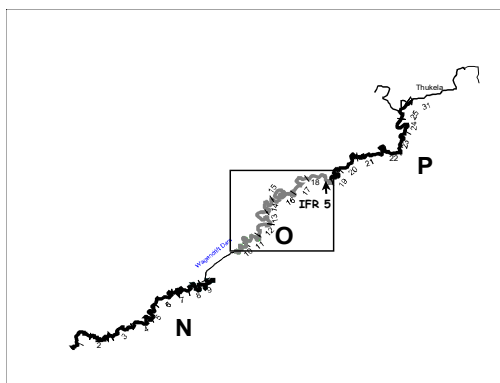
Invertebrates: The medium evaluation for invertebrates is due to a limited information database.

Fish: The medium evaluation for fish is linked to some uncertainty regarding the use of *Amphilius natalensis*, as it is uncertain whether this species occurs at the site.

Riparian vegetation: The medium to high riparian vegetation evaluation is linked to the presence of clear terraces and a reasonable number of indicator species.

Geomorphology: The medium evaluation for high flows for geomorphology is due to the lack of sediment transport modelling, and the uncertainty regarding the base flow separation techniques.

10 RU O. IFR 5. WEENEN NATURE RESERVE (Bushman's River)



10.1 ECOLOGICAL CATEGORIES

10.1.1 Summary of ERC scenarios

Two Ecological Reserve scenarios were addressed for IFR 5. The recommended scenario is a B/C ERC. The alternative scenario of a C/D ERC was evaluated.

Fig 10.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	DOWN
WATER QUALITY	B/C	+	B/C	MODERATE SI MODERATE	B/C	
GEOMORPH	B/C	-	C		B/C	C/D
RIPARIAN VEGETATION	B/C	-	C		B/C	C/D
FISH	C	0	D		C	D
AQUATIC INVERTS	C	-	C/D		C	D
ECOSTATUS	B/C	-	C		B/C	C/D

+* Positive

The hydrology in the IFR 5 area is confusing as it illustrates elevated flows in winter. At the specific IFR site however, elevated flows might not be as much of an issue as some of the elevated flow is being abstracted into a canal just upstream of the site. The marginal vegetation has adjusted to the remaining flows and if this had to be considered for setting the IFRs, one would recommend flows less than present and more towards natural. The aquatic invertebrates and fish do however not show the same tendency. This could either be because the elevated flows do not impact to the same degree on the in-stream biota as on the vegetation, or that the site does not reflect elevated flows to the same degree as other sections of the river, due to the immediate upstream abstraction.

It was decided that based on the aquatic invertebrates and the fish, the standard approach would be followed, i.e. that comprising recommendations which are less than natural. However, it must be noted that any proposed management of the system towards less flow will be better for some sections of the river (where elevated flow is presently a problem). Any scenario evaluation or future decisions on scenarios must be evaluated considering these issues. The marginal vegetation information should also be considered at this stage.

10.1.2 Criteria for Ecological Reserve Categories

Recommended scenario: B/C ERC

Aquatic invertebrates (C)

- Stones biotope: SASS>100 ASPT>6.0 (winter).

Fish (C)

- Maintain existing fish diversity.
- Ensure fairly large wetted perimeter over large cobbles for *L. natalensis* breeding and eel habitat.
- Ensure inundated backwaters for *B. anoplus* breeding and habitat.

Riparian Vegetation (B/C)

- The vegetation at this site has become adapted to an elevated and artificial flow regime. Consequently the vegetation, particularly the marginal vegetation, is very dense and lush and is in a very good state. This is an artificial state which is better than would be present in the natural state. The application of the recommended B/C flow scenario will result in this condition changing to one which is more natural. Thinning and reduction in the density of this vegetation will therefore take place with time. The change will even be more significant with the provision of the recommended C/D flow scenario leading to extensive thinning of marginal vegetation.
- Ensure lower winter flows than in summer, as marginal and riparian vegetation are generally dormant during winter.
- Ensure higher flows in summer as vegetation activity is growing, reproducing and controlling the temperature.

Geomorphology (B/C)

- Maintain the river in its present state i.e. ensure channel dimensions remain as at present, no further narrowing or excessive sediment accumulation as has occurred in the past 50 years. Floods need to occur which have a sufficient size and frequency to re-distribute the available sediment which is presently entering this system.

Alternative scenario: C/D ERC

Aquatic invertebrates (D)

- Stones biotope: SASS>120 ASPT>6.5 (in winter).
- Stones biotope: SASS>80 ASPT>5 (in winter).

- Vegetation biotope: SASS>80 ASPT>5 (in winter).

Fish (D)

- Reduce fish species abundances but no loss of diversity.
- Limit the adverse impacts of alien fish (catfish and carp).

Riparian Vegetation (C/D)

- Reduced densities and recruitment of water dependant species in the marginal areas of the left bank and island. Maintain the existing riparian trees and shrubs with slightly impaired recruitment rates and encroachment of terrestrial species particularly in the upper riparian zone.
- Ensure lower winter flows than in summer, marginal and riparian vegetation generally dormant during winter.
- Higher flows in summer as vegetation is actively growing and controlling the temperature.

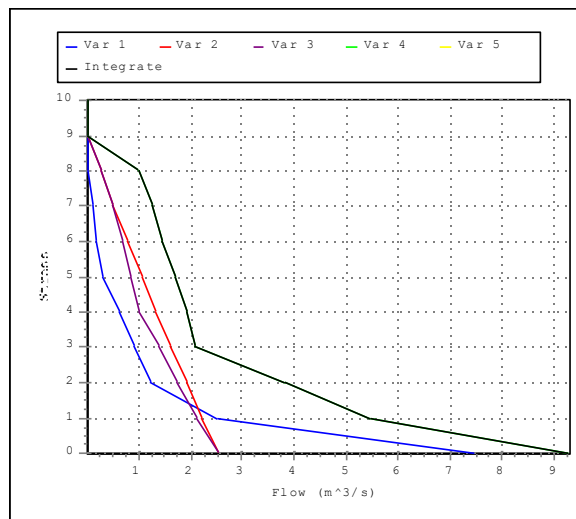
Geomorphology (C/D)

- To change the present state from a B/C to a C/D there is an allowance for some sediment accumulation both on the channel margins and within the channel itself. The reduced number of floods will lead to a longer retention time of sediment within the zone between intermediate events and between the large re-set events. For this reason the number of requested flood events is less than that required for a B/C category.

10.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 5, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 10.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 10.2.

Fig 10.2 Critical curve for IFR 5



Var 1: Fish **Var 2: Flow Dependent Invertebrates**
Var 3: Marginal Vegetation Invertebrates
Var 4: Riparian Vegetation 1 (covered by integrated line)
Var 5: Riparian Vegetation 2

10.2.1 Invertebrates

This investigation has concentrated on flow-dependent taxa. Several of these species are highly dependent on good flows and good indicators of river condition. Another group of organisms that requires consideration, but is not so dependent on flow, is that found in the marginal vegetation. Small reductions in water depth rapidly expose this habitat and threaten its inhabitants. Many of these inhabitants will nevertheless survive for short periods particularly in winter, on alternative substrates, but will be under threat.

Historical data for this site was very poor and furthermore the site was not surveyed during this investigation. The marginal vegetation community was investigated by using comprehensive photographic records and the DTM (habitat modelling). The 0 stress index was set at a level where the vegetation was well inundated. The indices of greater stress were derived by measuring the reduction in water level that would leave just the bases of the vegetation inundated, although even at a stress of 7 some vegetation was still in the water. Note that this assessment for marginal vegetation communities applies only for the wet season, as during dry seasons it can be expected that flows will recede from the vegetation.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of small cobbles and diverse biotope. The habitat model and hydraulic data were used to determine the depths and velocities that would produce minimal stress to rheophilic species. Higher stresses were determined by anticipating minimal depths and velocities that would only provide remnants of their required habitat. At this site, stresses would be dominated by a loss in velocity, as at minimal velocities there would still be abundant standing water. Low velocities would cause increased temperatures, sedimentation, diatom growth on stones, exposure to predators, and possibilities of decreased oxygen concentrations especially at night. Reduced velocities also cause stress to organisms that make use of flowing water to aid gaseous exchange. Slow velocities

require the expenditure of energy to irrigate the gills, thus reducing the competitiveness of the insect.

10.2.2 Riparian Vegetation

Two components were selected, using elevations and discharges associated with the ecological transect (i.e. 0.13m below the habitat modelling elevation). The habitat modelling provided the average root base depths and stem base depths, which made it possible to determine associated discharges (water levels), based on Transect 5a of the hydraulic model.

- *Setaria* (adults) - applicable mainly to summer
Setaria adults were identified at the 0.83m water level. Since the site was not investigated for rooting depths of *Setaria*, mean maximum lengths were extrapolated from IFR 11. Root lengths of 0.27m were used, corresponding to water levels of 0.56m at the root bases.

It is important to bear in mind that seedling stress levels are only applicable during the autumn and early winter when seedling recruitment is most prominent. The use of adult stress levels are most appropriate during the summer months when growth and survival is dependent on water levels. These grasses are largely dormant during winter and therefore less dependent on water. It is surmised that stress levels of 10 would only occur at much lower water levels than in summer.

- *Setaria* juveniles (seedlings) – applicable mainly to autumn
Setaria juveniles were estimated to occur at the same water levels as *Setaria* adults, i.e. 0.83m. Critical water levels were assessed to be approximately 0.15m below this level, i.e. 0.68m.

10.3 STRESS DURATION CURVES (PROFILES)

10.3.1 Natural stress duration profile

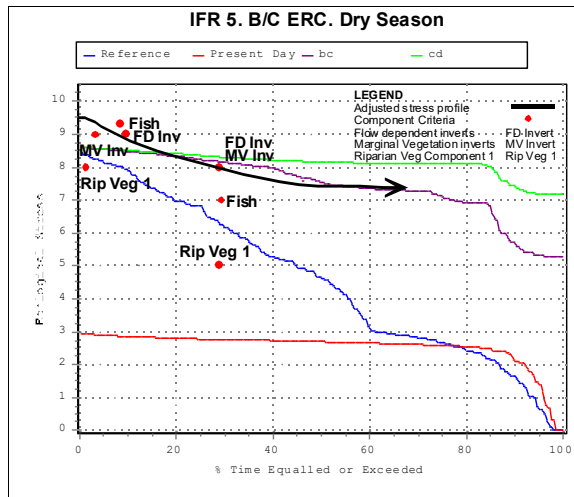
The B/C and C/D scenarios were estimated using the Desktop Model and are shown in Figures 10.3 – 10.6. The modelled present hydrology as converted into stress, is reflected by the red line in Figures 10.3 – 10.6 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are presented in Figures 10.3 – 10.6. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures 10.7 - 10.8). These scenarios were then checked with specialists to ensure that they were representative of their component requirements.

10.3.2 Process to adjust the Desktop output to fit specialist requirements

The C assurance rule was used for the B/C category. The generated B/C scenario consisted of Maintenance Low Flows of 20.10 % MAR⁷, which were adjusted to 22.4% MAR, and of Drought Low Flows of 7.59% MAR, which were adjusted to 7.02% MAR (see Figure 10.3). The C/D Assurance Rule was used for the C/D category. The generated C/D scenario consisted of Maintenance Low Flows of 11.22 % MAR, which were adjusted to 13.31% MAR, and of Drought Low Flows of 7.59 % MAR, which were adjusted to 6.93% MAR. The maintenance and drought low flows were manually changed to better fit the specialists' requirements for stress patterns.

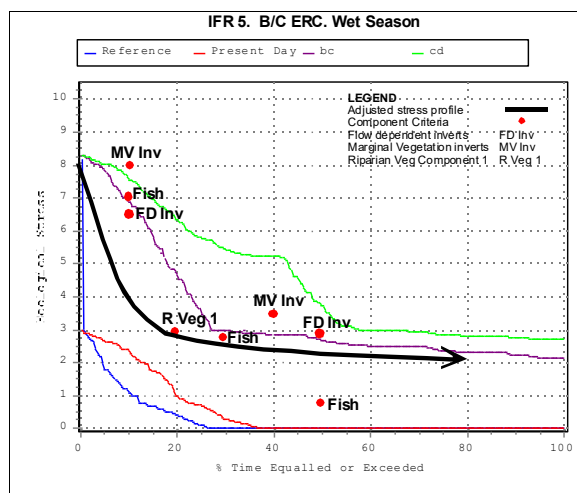
⁷ % MAR refers to a % of virgin flows and not present day flows

Fig 10.3 IFR 5 - Stress-duration curve for recommended scenario of a B/C ERC: Dry Season



The vegetation at this site has become adapted to an elevated and artificial flow regime. Consequently the vegetation, particularly the marginal vegetation, is very dense and lush and is in a very good state. This is an artificial state which is better than would be present in the natural state. The application of the B/C flow scenario will result in this condition changing to one which is more natural. Thinning and reduction in the density of this vegetation will therefore take place in with time. This change will be even more significant with the provision of the recommended C/D flow scenario leading to extensive thinning of marginal vegetation. A stress of 2 falls somewhere between a flow of 0.4 and 0.75m³/s. Interpolation will be required to reach appropriate flow. When stress profiles were compiled, stresses were identified on a range between 0 - 10 at certain points. (i.e. 0,1,3,5,8) It is uncertain what occurs with the vegetation in between these points. It is also uncertain what flows coincided with these unknown effects. These Riparian vegetation points were therefore not used to define the line and set the points.

Fig 10.4 IFR 5 - Stress-duration curve for recommended scenario of a B/C ERC: Wet Season



The fish point at stress 0.7 and 50% exceedence (Figure 10.4) is an outlier due to some mis-interpretation of the fish signals. It was therefore not included.

Fig 10.5 IFR 5 - Stress-duration curve for alternative scenario of a C/D ERC: Dry Season

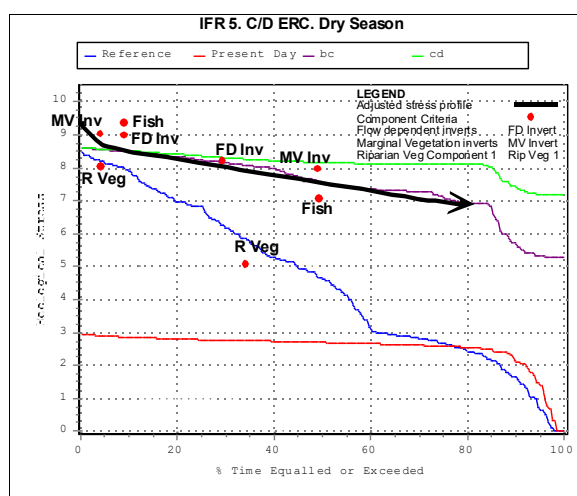
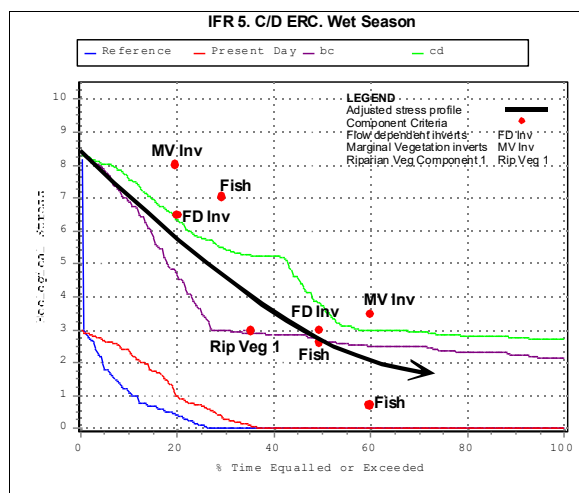


Fig 10.6 IFR 5 - Stress-duration curve for alternative scenario of a C/D ERC: Wet Season



10.3.3 Final stress profiles for IFR 5

Fig 10.7 IFR 5 – Final stress profiles: Dry season

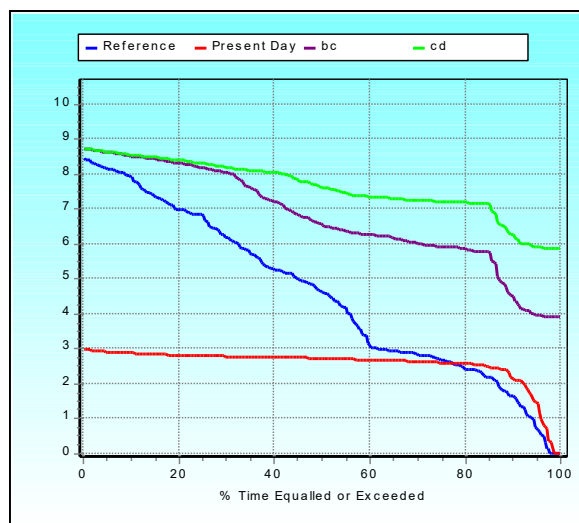
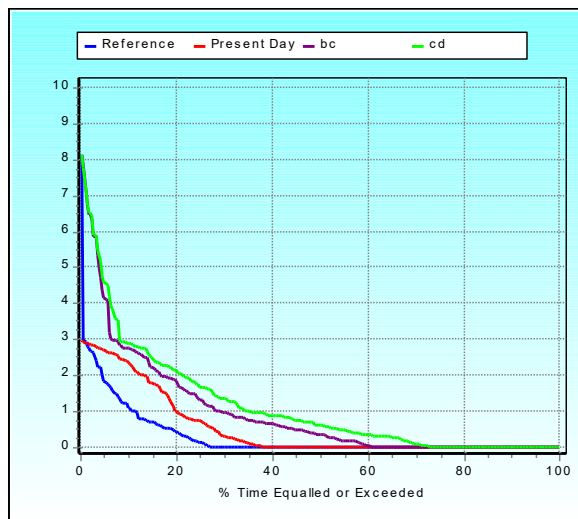


Fig 10.8 IFR 5 – Final stress profiles: Wet season



10.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 10.1. The number of events for each Flood Class required for an ERC of B/C and C/D are also summarised in Table 10.1.

Table 10.1 A summary of the Flood Class ranges for IFR 5, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s						
	I	II	III	IV	V	VI	VII
Fish	2-10	10-15	10-25				
Invertebrates	3-5	10-15	20-30				
Vegetation	5-15		15-60		40-90	90-200	
Geomorphology				30-59	60-83	83-114	114-138
Integrated	3-9	10-14	15-29	30-59	60-89	90-113	114-200
Geometric mean*				42	73	100	150
Recommended Floods							
No of events for B/C ERC (Recommended scenario)	4	4	1	4	1	1	1 in 2 yrs
No of events for C/D ERC (Alternative scenario)	3	3	1	3	1	1	1 in 3 yrs

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 114 to 200) specified by the geomorphology specialist were reduced to the lower discharge values (e.g. 90) for the Desktop model (monthly) to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 10.2 and 10.3.

Table 10.2 Adjusted flood sizes as used in the Desktop model for a B/C Category

Summer										
	Dec		Jan		Feb		Mar		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	IV	35	IV	35	VII, incl. VI	90	V	45	IV	35
Duration (days)	4		4		6		5		4	
Freshet size (m³/s)	I & II	6 + 10	IV	35	II & III	10 + 18	I & II	6 + 10		
Duration (days)	3		4		4		3			
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)			I	6	I & II	6 + 10				
Duration (days)			3		3					

Table 10.3 Adjusted flood sizes as used in the Desktop model for a C/D Category

Summer										
	Dec		Jan		Feb		Mar		Nov	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	IV	35	IV	35	VII, incl. VI	80	V	45		
Duration (days)	4		4		6		5			
Freshet size (m³/s)	III	18	IV	35	I & II	6 + 10	I & II	6 + 10		
Duration (days)	4		4		3		3			
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)			I	6	I & II	6 + 10				
Duration (days)			3		3					

10.5 FINAL RESULTS

10.5.1 IFR table for recommended scenario: B/C ERC

Annual Flows (Mill. cu. m or index values):

MAR = 281.449
S.Dev. = 117.492
CV = 0.417
Q75 = 5.380
Q75/MMF = 0.229
BFI Index = 0.411
CV(JJA+JFM) Index = 1.530

IFR Management Class = C

Total IFR = 127.643 (45.35 %MAR)
Maint. Lowflow = 62.934 (22.36 %MAR)
Drought Lowflow = 19.751 (7.02 %MAR)
Maint. Highflow = 64.709 (22.99 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : D'berg

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High Flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	15.226	21.525	1.414	3.482	1.071	0.933	4.415
Nov	23.117	18.774	0.812	4.147	1.296	7.932	12.079
Dec	35.722	23.892	0.669	5.625	1.875	7.932	13.556
Jan	48.516	31.015	0.639	7.500	2.411	10.886	18.386
Feb	48.663	29.839	0.613	8.225	2.661	25.324	33.549
Mar	41.972	26.094	0.622	8.303	2.678	11.703	20.006
Apr	27.036	18.885	0.699	6.998	2.203	0.000	6.998
May	12.499	10.980	0.878	5.625	1.607	0.000	5.625
Jun	7.748	4.905	0.633	3.888	1.296	0.000	3.888
Jul	5.642	3.430	0.608	3.214	1.071	0.000	3.214
Aug	5.983	8.826	1.475	2.946	0.804	0.000	2.946
Sep	9.324	18.887	2.026	2.981	0.778	0.000	2.981

10.5.2 IFR table for alternative scenario: C/D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	281.449
S.Dev.	=	117.492
CV	=	0.417
Q75	=	5.380
Q75/MMF	=	0.229
BFI Index	=	0.411
CV(JJA+JFM) Index	=	1.530
Total IFR	=	92.046 (32.70 %MAR)
Maint. Lowflow	=	37.454 (13.31 %MAR)
Drought Lowflow	=	19.509 (6.93 %MAR)
Maint. Highflow	=	54.592 (19.40 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : D'berg

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High Flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	15.226	21.525	1.414	2.411	1.071	0.000	2.411
Nov	23.117	18.774	0.812	2.722	1.296	2.488	5.210
Dec	35.722	23.892	0.669	3.214	1.875	8.709	11.923
Jan	48.516	31.015	0.639	4.018	2.411	10.886	14.904
Feb	48.663	29.839	0.613	4.355	2.419	20.805	25.160
Mar	41.972	26.094	0.622	4.553	2.678	11.703	16.256
Apr	27.036	18.885	0.699	4.018	2.203	0.000	4.018
May	12.499	10.980	0.878	3.214	1.607	0.000	3.214
Jun	7.748	4.905	0.633	2.592	1.296	0.000	2.592
Jul	5.642	3.430	0.608	2.143	1.071	0.000	2.143
Aug	5.983	8.826	1.475	2.143	0.804	0.000	2.143
Sep	9.324	18.887	2.026	2.074	0.778	0.000	2.074

10.5.3 IFR rule table for recommended scenario: B/C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.165	2.158	2.130	2.067	1.941	1.719	1.385	0.981	0.625	0.460
Nov	5.600	5.591	5.540	5.428	5.200	4.769	4.029	2.419	1.636	0.810
Dec	8.923	8.146	7.466	6.856	6.247	5.190	4.429	3.285	1.929	1.061

Jan	12.609	11.513	10.556	9.705	8.862	7.385	6.322	4.687	2.713	1.441
Feb	22.581	20.183	18.119	16.319	14.609	11.670	9.891	7.216	4.044	2.012
Mar	14.075	12.841	11.760	10.789	9.814	8.128	6.916	5.113	2.994	1.640
Apr	3.407	3.396	3.354	3.260	3.070	2.735	2.232	1.623	1.087	0.839
May	2.786	2.773	2.733	2.647	2.479	2.190	1.769	1.270	0.835	0.634
Jun	1.849	1.840	1.813	1.757	1.648	1.464	1.198	0.887	0.618	0.492
Jul	1.555	1.544	1.520	1.468	1.373	1.216	0.995	0.740	0.522	0.420
Aug	1.401	1.393	1.372	1.326	1.239	1.090	0.876	0.625	0.408	0.307
Sep	1.428	1.422	1.401	1.355	1.267	1.116	0.894	0.632	0.403	0.297

Reserve flows without High Flows

Oct	1.751	1.746	1.724	1.675	1.577	1.403	1.143	0.828	0.550	0.422
Nov	2.111	2.108	2.091	2.053	1.976	1.831	1.581	1.210	0.773	0.494
Dec	2.980	2.978	2.955	2.905	2.802	2.604	2.260	1.743	1.130	0.737
Jan	4.170	4.170	4.142	4.077	3.940	3.670	3.189	2.450	1.557	0.982
Feb	4.218	4.214	4.181	4.110	3.963	3.680	3.188	2.450	1.575	1.014
Mar	4.680	4.673	4.635	4.552	4.383	4.064	3.515	2.700	1.742	1.129
Apr	3.407	3.396	3.354	3.260	3.070	2.735	2.232	1.623	1.087	0.839
May	2.786	2.773	2.733	2.647	2.479	2.190	1.769	1.270	0.835	0.634
Jun	1.849	1.840	1.813	1.757	1.648	1.464	1.198	0.887	0.618	0.492
Jul	1.555	1.544	1.520	1.468	1.373	1.216	0.995	0.740	0.522	0.420
Aug	1.401	1.393	1.372	1.326	1.239	1.090	0.876	0.625	0.408	0.307
Sep	1.428	1.422	1.401	1.355	1.267	1.116	0.894	0.632	0.403	0.297

Natural Duration curves

Oct	13.715	8.457	6.204	3.750	2.909	2.446	1.563	1.246	1.022	0.613
Nov	18.302	12.575	10.458	9.099	7.049	6.220	4.962	2.419	1.721	0.814
Dec	28.306	20.347	17.566	14.317	12.226	10.394	7.585	6.547	3.584	2.211
Jan	40.757	30.919	22.941	17.648	15.769	12.684	11.542	9.982	7.830	4.442
Feb	36.492	30.851	21.703	17.936	14.789	12.989	10.644	8.994	7.389	4.674
Mar	34.007	24.186	20.424	19.296	16.249	12.533	10.723	8.147	5.365	2.939
Apr	20.344	15.252	12.519	10.189	7.844	6.560	5.585	4.439	3.442	2.154
May	7.627	6.231	5.598	4.198	3.796	3.275	2.917	2.573	2.188	1.632
Jun	4.917	3.431	3.084	2.651	2.367	2.124	2.001	1.740	1.557	1.146
Jul	3.275	2.558	2.292	1.921	1.821	1.682	1.543	1.439	1.215	0.910
Aug	4.126	2.531	1.964	1.680	1.605	1.363	1.236	1.131	0.982	0.683
Sep	7.172	3.584	2.255	1.661	1.467	1.228	1.165	1.064	0.795	0.586

10.5.4 IFR rule table for alternative scenario: C/D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.407	1.403	1.387	1.351	1.278	1.149	0.955	0.721	0.515	0.420
Nov	2.849	2.845	2.820	2.768	2.660	2.457	2.108	1.590	0.980	0.591
Dec	8.539	7.686	6.952	6.309	5.694	4.638	3.983	3.000	1.833	1.086
Jan	11.074	9.978	9.035	8.214	7.437	6.089	5.256	3.975	2.428	1.431
Feb	17.726	15.756	14.070	12.611	11.248	8.914	7.591	5.603	3.245	1.734
Mar	12.432	11.201	10.138	9.205	8.308	6.769	5.809	4.381	2.702	1.630
Apr	2.271	2.265	2.242	2.189	2.082	1.894	1.612	1.271	0.971	0.832
May	1.852	1.845	1.822	1.773	1.678	1.514	1.274	0.990	0.742	0.628
Jun	1.436	1.429	1.411	1.371	1.295	1.167	0.982	0.765	0.577	0.490
Jul	1.210	1.203	1.185	1.150	1.083	0.974	0.819	0.641	0.489	0.418
Aug	1.186	1.180	1.163	1.126	1.056	0.936	0.764	0.562	0.387	0.306
Sep	1.156	1.151	1.135	1.100	1.033	0.918	0.749	0.550	0.376	0.296

Reserve flows without High Flows

Oct	1.407	1.403	1.387	1.351	1.278	1.149	0.955	0.721	0.515	0.420
Nov	1.639	1.637	1.624	1.598	1.543	1.440	1.263	0.999	0.689	0.491
Dec	2.013	2.012	1.999	1.970	1.911	1.798	1.601	1.306	0.956	0.731
Jan	2.635	2.635	2.620	2.587	2.515	2.374	2.124	1.738	1.273	0.973
Feb	2.639	2.637	2.620	2.581	2.502	2.349	2.085	1.687	1.216	0.914
Mar	3.037	3.033	3.013	2.968	2.877	2.704	2.408	1.968	1.450	1.119
Apr	2.271	2.265	2.242	2.189	2.082	1.894	1.612	1.271	0.971	0.832
May	1.852	1.845	1.822	1.773	1.678	1.514	1.274	0.990	0.742	0.628
Jun	1.436	1.429	1.411	1.371	1.295	1.167	0.982	0.765	0.577	0.490
Jul	1.210	1.203	1.185	1.150	1.083	0.974	0.819	0.641	0.489	0.418
Aug	1.186	1.180	1.163	1.126	1.056	0.936	0.764	0.562	0.387	0.306
Sep	1.156	1.151	1.135	1.100	1.033	0.918	0.749	0.550	0.376	0.296

10.6 GEOMORPHOLOGICAL CONSEQUENCES OF A B/C AND C/D SCENARIO

Bed maintenance

For a B/C ERC, although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be a longer bed material residence time compared to virgin conditions. This will result in a slightly modified bed for periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be a longer bed material residence time compared to a B/C ERC river. This will result in a moderately modified channel for the periods between large flood events (20 - 50 year return period).

Bench maintenance

A B/C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be less bench maintenance constructional flows relative to virgin conditions. This will result in a slightly modified bench for periods between large flood events (20 - 50 year return period). C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be less bench maintenance constructional flows relative to a B/C ERC river. This will result in a largely modified bench for the periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events).

Channel maintenance

A B/C ERC means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer channel maintenance flows relative to virgin conditions. This will result in a moderately modified channel for periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events). C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows relative to a B/C ERC river. This will result in a largely modified channel for the periods between large flood events (20 - 50 year return period).

Macro Channel and bed mobilisation

A B/C category means that although the same-sized flood events will occur relative to virgin conditions, these will occur less frequently, and consequently, there will be fewer macro-channel and bed mobilisation flows relative to virgin conditions. This will result in a moderately modified macro-channel and a less frequently mobilised bed for periods between large flood events (20 - 50 year return period). These flows are likely to maintain the site in the same condition as it is presently (between large re-set flood events). C/D ERC flows reflect further reductions in flood frequency, and consequently, there will be fewer channel maintenance flows, and further reductions in bed mobilisation relative to a B/C ERC river. This will result in a largely modified macro-channel and more stable bed for the periods between large flood events (20 - 50 year return period).

Conclusion

Recommended flows for a B/C category are very similar to the natural requirements. The slight reduction in events will lead to some temporary changes in channel morphology. Requirements for a C/D category allow more permanent changes in channel morphology. The large flood events will not re-set morphology as easily as with the B/C category, particularly if vegetation has allowed to become well established.

10.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 10.4 IFR table for C ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
5	Low flows	2	3	4	-
	High flows	4	4	4	3

The confidence ranges from low-medium (one value only) to medium-high.

Invertebrates: The confidence level relates to the lack of data at this site, the conflicting vegetation signals and uncertainty with regard to water quality conditions.

Fish: The fish information relates to the lack of data and the fact that that surveys are based on historical information only.

Geomorphology: The confidence relates to the lack of daily data for sediment transport modelling.

11 RU Q. IFR 7. UPPER SUNDAYS (Sunday River)

11.1 ECOLOGICAL CATEGORIES

11.1.1 Summary of ERC scenarios

Two Ecological Reserve Scenarios were addressed for IFR 7. The recommended scenario is a B/C ERC. The alternative scenario of a C/D was also evaluated.

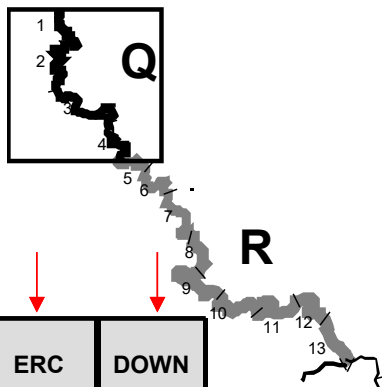


Fig 11.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	DOWN
WATER QUALITY	B/C	0	B/C	EIS	B/C	
GEOMORPH	B/C	-	C	M O D E R A T E	B/C	C/D
RIPARIAN VEGETATION	B/C	-	?	S I	B/C	C/D
FISH	B	0	B	M O D E R A T E	B	C
AQUATIC INVERTS	C	0	C		C	D
ECOSTATUS	B/C	-	C		B/C	C/D

11.1.2 Criteria for Ecological Reserve Categories

Recommended Scenario: B/C ERC

Aquatic invertebrates (C)

- Marginal vegetation species
The objective is to maintain a diverse population in the fine-leaved vegetation at the top of the riffles over summer during dry years, and also during normal winter months.
- Flow-dependent species:
Good SASS scores should be maintained (as indicated) and families should include the diverse assemblage of mayflies, Hydropsychidae, Elmidae and Perlidae.

Fish (B)

- Maintain species diversity by providing ample breeding and refuge conditions for *L. natalensis*.

Riparian Vegetation (B/C)

- Maintain existing distribution and abundance of *Setaria* clumps in the marginal zone on both banks and on islands.

Geomorphology (B/C)

- Maintain the river in its present state i.e. relatively narrow with good hydraulic diversity and occasional vegetated islands. No further channel constriction or excessive sediment accumulation and no increase in bed aggradation or embeddedness. Floods which have a sufficient size and frequency to move the available sediment presently entering this system are required.

Alternative scenario: C/D ERC**Aquatic invertebrates (D)**

- Marginal vegetation species:
Marginal vegetation becomes a less important habitat, supporting a reduced SASS score.
- Water reaches the base of the marginal vegetation, thus only just supporting the invertebrate population.
- Flow dependent species:
In a D scenario the monthly assemblage may reduce in diversity and Perlidae may be lost.
- Flow velocities are reduced, thus less clean stone habitat is available.

Fish (C)

- Maintain existing species diversity whilst permitting reduced abundances of all species.
- Prevent the extinction of *L. natalensis* by facilitating minimal breeding success during summer, and survival during winter.
- Maintain existing species diversity with reduced abundances.

Riparian Vegetation (C/D)

- Allow a slight reduction in abundances along with a narrower distribution of *Salix* grass clumps in the marginal areas of both banks and islands.
- Maintain the majority of existing *Setaria* grass clumps within the marginal zone of both banks and islands, while maintaining the existing distribution and allowing a slight reduction in overall abundance.

Geomorphology (C/D)

- In order to change the present state from a B/C ERC to a C/D ERC, there is an allowance for increased sediment accumulation within the channel, in the form of bars and islands. Since the majority of sediment is transported by flood events, a decrease in the number of these events should achieve this objective.

11.2 FLOW-STRESS RELATIONSHIPS

SITE 7: PROBLEMS WITH RECONCILING THE SPECIALISTS' RECOMMENDATIONS WITH THE HYDROLOGY

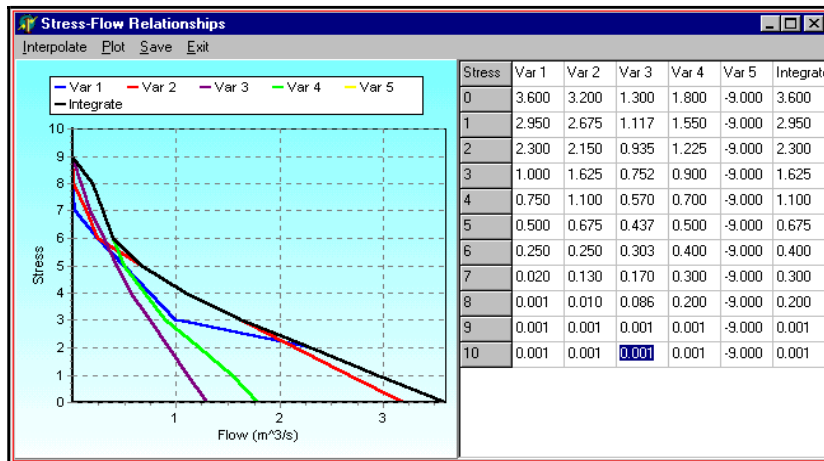
All the specialists initially recommended flows (stress levels) which were a substantial improvement on the levels suggested by the Desktop model scenarios. In particular, the low stress levels were recommended for substantial durations during the wet season, whereas the flow scenarios (for low flows only) were not indicating any duration for stresses less than 4, even in the wet season. The rationale for these mismatched recommendations included the need to maintain marginal habitats for substantial periods during the wet season. A stress of 5 is equivalent to flows which fail to inundate any of the marginal habitats other than in pools. The rationale for recommending long durations of low stress in the wet season was therefore well motivated, but there remained the necessity to reconcile the mismatch between the hydrological indicators and the specialist recommendations.

This site proved difficult for the specialists to interpret, due to the wide flat nature of the channel, which is relatively insensitive to flow changes. The hydraulic analysis was also problematic. A possible explanation for the mismatch is that the specialists were interpreting the habitat requirements in relation to the full range of flows (including floods), rather than just the low flows. The higher flows and floods decrease the duration of medium and low stresses which are indicated by the flow scenarios (which only include low flows).

It was decided to simulate low flow duration curves for categories B/C and C/D, which ignored the low stress extreme of the specialist recommendations. The high flow recommendations were then added in to the resulting flow scenarios. This had the anticipated effect of reducing the medium and low stresses in the scenarios so that the specialist recommendations were met. For example, with the high flows included, the C/D scenario provided stresses of less than 5 for 80% of the time during the wet season, indicating that marginal habitats would be inundated for extended periods – the original motivation for the recommendations.

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The flow-stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 7, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 11.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 11.2.

Fig 11.2 Critical curve for IFR 7



Var 1: Fish

Var 2: Flow Dependent Invertebrates

Var 3: Marginal Vegetation Invertebrates

Var 4: Riparian Vegetation 1

Var 5: Riparian Vegetation 2

11.2.1 Invertebrates

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit ($0.25\text{m}^3/\text{s}$) as a reference point. The stress index of zero was set at approximately 0.2m higher than observed, so that the vegetation would be well inundated. Note that the *Phragmites* reeds would be inundated even at zero flow but provide a poor habitat, as the stems are large and covered with sediment. The hydraulic profile and tables were used to derive the associated habitat characteristics. The indices of greater stress were derived by measuring the reduction in water level that would leave only the bases of the grass inundated. At maximum stress no grass bases would be inundated.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of stones, even though much of this habitat was embedded. The hydraulic data were used to determine the depths and velocities that would produce minimal stress to rheophilic species. Higher stresses were determined by anticipating minimal depths and velocities that would only provide remnants of their required habitat. Much of this investigation was based on the presence of families such as Oligoneuridae, Perlidae and Hydropsychidae, which require abundant clean, strong flowing water over clean rocks.

11.2.2 Riparian Vegetation

One component was selected, using elevations and discharges associated with the ecological transect for the hydraulic modelling.

- *Setaria* (adults) - applicable mainly to summer
Setaria adult individuals were identified at the 0.9m mean water level on the islands and on both banks. Maximum root lengths of 0.60m were used, corresponding to water levels of 0.6m at the root bases.

11.3 STRESS DURATION CURVES (PROFILES)

11.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 11.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 7, stress indices as determined were accepted, no changes were required.

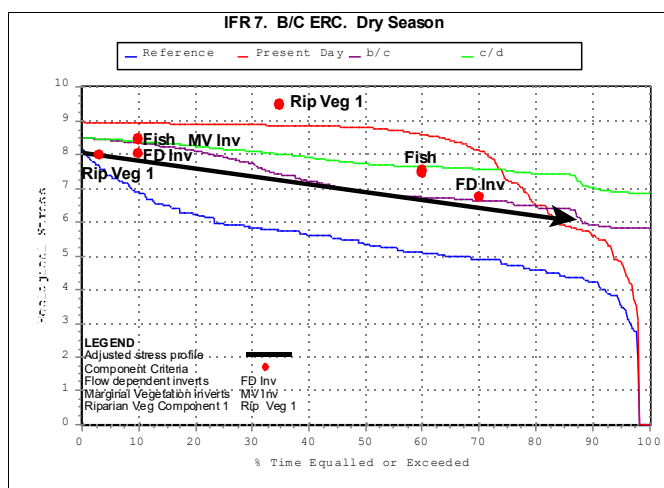
11.3.2 Recommended stress profiles for each Reserve scenario

The recommended B/C scenario and the alternative C/D scenarios were estimated using the Desktop model and are shown in Figures 11.3 – 11.6 as the purple and green lines respectively. The observed (historic) hydrology as converted into stress, is reflected by the red line in Figures 11.3 – 11.6 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 11.3 - 11.6. According to the specialists' evaluations, the Desktop-generated scenarios were adjusted (see Figures 11.7 - 11.8). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

11.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated B/C scenario consisted of Maintenance Low Flows of 15.99% MAR⁸, which were adjusted to 18.59% MAR, and of Drought Low Flows of 5.45% MAR, which were adjusted to 5.69% MAR (see Figure 11.3). The generated C/D scenario consisted of Maintenance Low Flows of 8.68% MAR, which were adjusted to 10.89% MAR, and of Drought Low Flows of 5.45% MAR, which were adjusted to 5.69% MAR (see Figure 11.3). The Maintenance and Drought Low Flows were manually changed to better fit the specialists' requirements for stress patterns.

Fig 11.3 IFR 7 – Stress duration curve for recommended scenario of a B/C ERC: Dry Season



⁸ Note that "% MAR" refers to the % of virgin MAR and not the % of present day MAR.

Fig 11.4 IFR 7 – Stress duration curve for recommended scenario of a B/C ERC: Wet Season

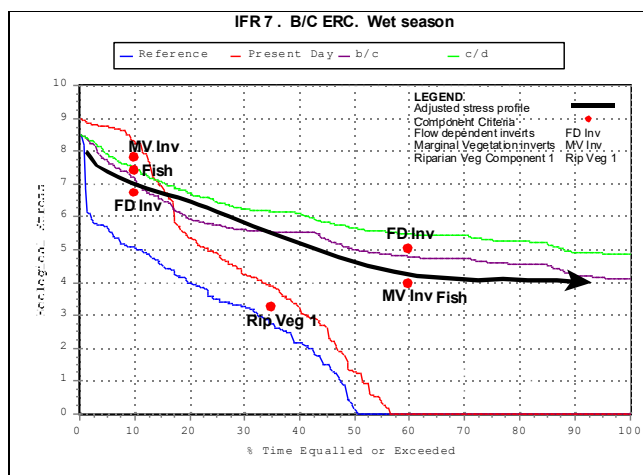


Fig 11.5 IFR 7 – Stress duration curve for alternative scenario of a C/D ERC: Dry Season

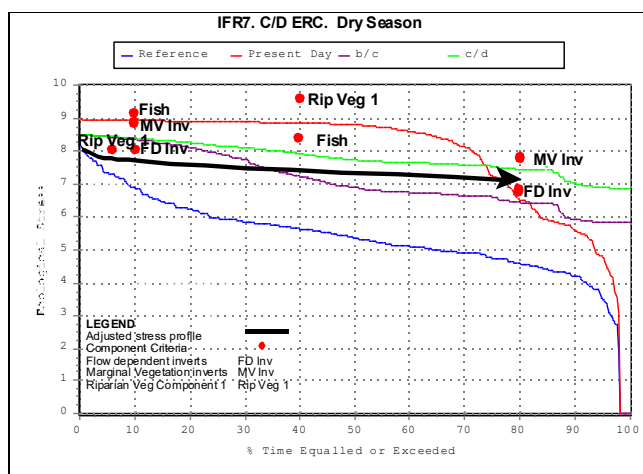
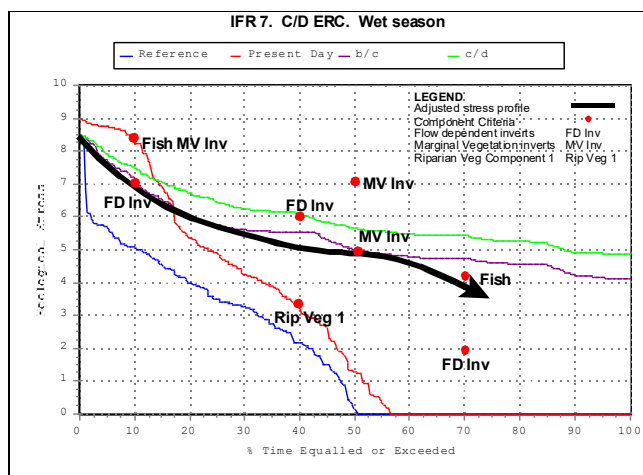


Fig 11.6 IFR 7 – Stress duration curve for alternative scenario of a C/D ERC: Wet Season



11.3.4 Final stress profiles for IFR 7

Fig 11.7 IFR 7 - Final stress profiles: Dry Season

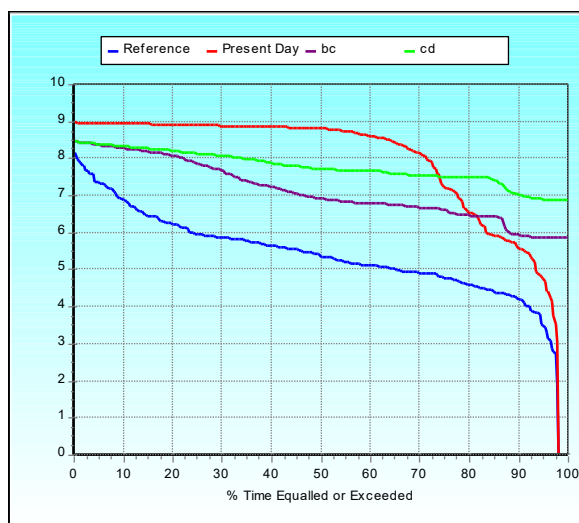
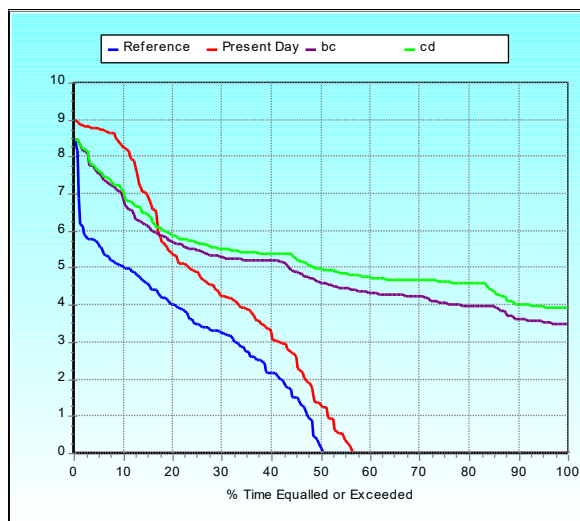


Fig 11.8 IFR 7 - Final stress profiles: Wet Season



11.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 11.1. The number of events for each flood class required for an ERC of B/C and C/D are also summarised in Table 11.1.

Table 11.1 A summary of the Flood Class ranges for IFR 7, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s				
	I	II	III	IV	V
Fish	1-2		8-12 12-20		
Invertebrates	1-2	3-5	15-20		
Vegetation		2-5	5-20	20-40	40-80
Geomorphology			7-14	14-41	41-86
Integrated	1-2	2-5	6-19	20-39	40-86
Geometric Mean*		3	11	28	59
Recommended high flow events					
No of events for B/C ERC (Recommended scenario)	2 Spring 3 Summer	4	3	1 in 2 years	1 in 3 years
No of events for C/D ERC (Alternative scenario)	1 Spring 2 Summer	3	2	1 in 2 years	1 in 4 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 40 to 86) specified by the geomorphologist were reduced to the lower discharge values (e.g. 40) for the Desktop model, to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 11.2 and 11.3.

Table 11.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a B/C ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)			III	14	V incl. 1-IV	40	III	14		
Duration (days)			3		4		3			
Freshet size (m³/s)	II	3.5			II	3.5	II	3.5	I	1.5
Duration (days)	2				2		2		2	
Spring										
	Sept		Oct		Nov					
			I	1.5	II	3.5				
			2		2					

Table 11.3 Adjusted flood sizes as used in the Desktop model for a C/D Category

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	14	III	14	V incl. 1- IV	40	III	14		
Duration (days)	3		3		4		3			
Freshet size (m³/s)	II	3.5	I	1.5	I + II	1.5 + 3.5	I + II	1.5 + 3.5		
Duration (days)	2		2		2		2			
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	1.5	I	1.5	II	3.5				
Duration (days)	2		2		2					

11.5 FINAL RESULTS

11.5.1 IFR table for recommended scenario: B/C ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	90.282
S.Dev.	=	57.784
CV	=	0.640
Q75	=	1.430
Q75/MMF	=	0.190
BFI Index	=	0.380
CV (JJA+JFM) Index	=	2.432
Total IFR	=	33.173 (36.74 %MAR)
Maint. Lowflow	=	16.783 (18.59 %MAR)
Drought Lowflow	=	5.139 (5.69 %MAR)
Maint. Highflow	=	16.390 (18.15 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : N.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High Flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	4.109	6.881	1.675	0.804	0.321	0.181	0.985
Nov	8.181	12.047	1.472	1.166	0.363	0.423	1.590
Dec	9.128	9.874	1.082	1.339	0.281	2.601	3.940
Jan	18.177	18.782	1.033	2.143	0.589	2.359	4.501
Feb	20.417	18.236	0.893	2.661	0.677	7.862	10.524
Mar	12.056	10.574	0.877	2.411	0.643	2.782	5.193
Apr	5.745	4.991	0.869	1.814	0.544	0.000	1.814
May	3.212	2.081	0.648	1.339	0.429	0.000	1.339
Jun	2.170	0.934	0.431	0.933	0.363	0.000	0.933
Jul	1.889	2.072	1.097	0.777	0.321	0.000	0.777
Aug	2.168	6.427	2.964	0.696	0.321	0.000	0.696
Sep	3.030	8.063	2.661	0.700	0.285	0.181	0.881

11.5.2 IFR table for alternative scenario: C/D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	90.282
S.Dev.	=	57.784
CV	=	0.640
Q75	=	1.430
Q75/MMF	=	0.190
BFI Index	=	0.380
CV(JJA+JFM) Index	=	2.432
Total IFR	=	23.261 (25.76 %MAR)
Maint. Lowflow	=	9.834 (10.89 %MAR)
Drought Lowflow	=	5.139 (5.69 %MAR)
Maint. Highflow	=	13.427 (14.87 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High Flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	4.109	6.881	1.675	0.482	0.321	0.181	0.664
Nov	8.181	12.047	1.472	0.622	0.363	0.181	0.804
Dec	9.128	9.874	1.082	0.937	0.281	0.423	1.361
Jan	18.177	18.782	1.033	1.339	0.589	2.177	3.516
Feb	20.417	18.236	0.893	1.693	0.677	7.681	9.374
Mar	12.056	10.574	0.877	1.393	0.643	2.601	3.993
Apr	5.745	4.991	0.869	0.907	0.544	0.181	1.089
May	3.212	2.081	0.648	0.696	0.429	0.000	0.696
Jun	2.170	0.934	0.431	0.518	0.363	0.000	0.518
Jul	1.889	2.072	1.097	0.429	0.321	0.000	0.429
Aug	2.168	6.427	2.964	0.402	0.321	0.000	0.402
Sep	3.030	8.063	2.661	0.415	0.285	0.000	0.415

11.5.3 IFR rule table for recommended scenario: B/C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.461	0.458	0.450	0.436	0.408	0.363	0.299	0.225	0.162	0.133
Nov	0.719	0.714	0.706	0.688	0.656	0.599	0.508	0.383	0.243	0.155
Dec	2.591	2.327	2.099	1.891	1.574	1.289	0.860	0.691	0.440	0.174
Jan	2.892	2.642	2.423	2.218	2.005	1.647	1.381	1.011	0.599	0.340
Feb	6.937	6.170	5.510	4.921	4.349	3.393	2.524	1.613	0.795	0.433
Mar	2.526	2.510	2.477	2.411	2.288	2.073	1.731	1.256	0.727	0.394
Apr	0.836	0.830	0.816	0.788	0.735	0.648	0.525	0.384	0.263	0.207
May	0.638	0.633	0.623	0.602	0.562	0.498	0.406	0.300	0.210	0.168
Jun	0.430	0.427	0.421	0.408	0.383	0.343	0.286	0.220	0.163	0.137

Jul	0.370	0.368	0.362	0.351	0.331	0.297	0.249	0.194	0.147	0.126
Aug	0.321	0.319	0.315	0.306	0.289	0.261	0.222	0.178	0.139	0.121
Sep	0.398	0.395	0.389	0.376	0.353	0.314	0.258	0.195	0.140	0.115

Reserve flows without High Flows

Oct	0.383	0.380	0.375	0.363	0.342	0.306	0.256	0.198	0.149	0.126
Nov	0.542	0.539	0.532	0.520	0.497	0.456	0.391	0.301	0.201	0.138
Dec	0.642	0.638	0.630	0.614	0.583	0.530	0.445	0.326	0.195	0.112
Jan	1.064	1.058	1.045	1.019	0.972	0.889	0.757	0.573	0.369	0.240
Feb	1.236	1.228	1.213	1.183	1.127	1.028	0.872	0.654	0.412	0.259
Mar	1.239	1.232	1.217	1.187	1.131	1.034	0.879	0.663	0.423	0.272
Apr	0.836	0.830	0.816	0.788	0.735	0.648	0.525	0.384	0.263	0.207
May	0.638	0.633	0.623	0.602	0.562	0.498	0.406	0.300	0.210	0.168
Jun	0.430	0.427	0.421	0.408	0.383	0.343	0.286	0.220	0.163	0.137
Jul	0.370	0.368	0.362	0.351	0.331	0.297	0.249	0.194	0.147	0.126
Aug	0.321	0.319	0.315	0.306	0.289	0.261	0.222	0.178	0.139	0.121
Sep	0.323	0.321	0.316	0.306	0.288	0.258	0.217	0.168	0.127	0.108

Natural Duration curves

Oct	5.837	1.779	1.019	0.741	0.517	0.467	0.374	0.351	0.313	0.204
Nov	11.190	4.555	2.117	1.411	0.896	0.777	0.541	0.455	0.302	0.194
Dec	9.321	7.064	4.699	2.720	1.574	1.289	0.860	0.691	0.540	0.174
Jan	20.163	14.647	9.926	5.867	3.875	2.351	1.692	1.249	0.954	0.475
Feb	15.868	12.825	10.719	7.579	5.544	4.439	2.524	1.613	0.795	0.433
Mar	11.723	7.796	6.370	4.824	3.212	2.724	1.901	1.620	1.141	0.690
Apr	4.320	2.711	2.199	1.859	1.587	1.411	1.198	0.922	0.810	0.556
May	1.948	1.478	1.339	1.262	1.080	0.984	0.887	0.737	0.594	0.475
Jun	1.154	0.982	0.911	0.862	0.765	0.680	0.631	0.586	0.448	0.340
Jul	0.992	0.806	0.741	0.671	0.660	0.567	0.513	0.455	0.382	0.274
Aug	0.848	0.665	0.605	0.545	0.511	0.452	0.388	0.370	0.291	0.213
Sep	1.299	0.680	0.560	0.459	0.418	0.396	0.343	0.302	0.261	0.213

11.5.4 IFR rule table for alternative scenario: C/D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.380	0.378	0.373	0.361	0.341	0.306	0.258	0.202	0.155	0.133
Nov	0.471	0.468	0.463	0.453	0.434	0.402	0.349	0.276	0.195	0.144
Dec	0.911	0.865	0.822	0.776	0.719	0.623	0.522	0.383	0.227	0.129
Jan	2.566	2.336	2.135	1.950	1.760	1.442	1.216	0.902	0.551	0.331
Feb	6.608	5.860	5.218	4.648	4.099	3.183	2.524	1.613	0.795	0.433
Mar	2.362	2.347	2.316	2.255	2.141	1.942	1.625	1.185	0.694	0.386
Apr	0.616	0.612	0.604	0.585	0.552	0.496	0.417	0.326	0.249	0.213
May	0.420	0.418	0.412	0.401	0.380	0.345	0.295	0.238	0.190	0.167
Jun	0.303	0.301	0.298	0.290	0.276	0.253	0.221	0.183	0.151	0.137
Jul	0.259	0.257	0.255	0.248	0.237	0.219	0.193	0.163	0.137	0.125
Aug	0.235	0.234	0.231	0.226	0.216	0.201	0.178	0.153	0.131	0.121
Sep	0.242	0.241	0.238	0.232	0.221	0.202	0.176	0.145	0.119	0.107

Reserve flows without High Flows

Oct	0.291	0.289	0.286	0.278	0.264	0.241	0.209	0.172	0.140	0.125
Nov	0.382	0.380	0.376	0.368	0.354	0.330	0.290	0.236	0.175	0.137
Dec	0.594	0.590	0.583	0.568	0.540	0.491	0.414	0.307	0.187	0.112
Jan	0.878	0.873	0.863	0.843	0.807	0.742	0.640	0.498	0.339	0.239
Feb	1.038	1.032	1.020	0.996	0.951	0.872	0.747	0.574	0.380	0.258
Mar	0.946	0.941	0.930	0.909	0.870	0.802	0.694	0.543	0.376	0.270
Apr	0.530	0.527	0.520	0.505	0.478	0.433	0.369	0.297	0.234	0.205
May	0.420	0.418	0.412	0.401	0.380	0.345	0.295	0.238	0.190	0.167
Jun	0.303	0.301	0.298	0.290	0.276	0.253	0.221	0.183	0.151	0.137
Jul	0.259	0.257	0.255	0.248	0.237	0.219	0.193	0.163	0.137	0.125
Aug	0.235	0.234	0.231	0.226	0.216	0.201	0.178	0.153	0.131	0.121
Sep	0.242	0.241	0.238	0.232	0.221	0.202	0.176	0.145	0.119	0.107

11.6 GEOMORPHOLOGICAL CONSEQUENCES OF A B/C AND C/D SCENARIO

Bed maintenance

B/C category flood events will allow longer periods of sediment accumulation on the bed, particularly on the channel margins. This will also lead to some sediment fining behind large obstructions. The number of C/D flood events is slightly smaller than for the B/C condition. This will lead to longer periods of sediment accumulation and the loss of some interstitial habitat, particularly on channel margins and behind obstructions. This will be re-set by large floods.

Bench maintenance

B/C category flood events will result in longer periods without sediment deposition and local scour, flushing etc on the benches. This will result in a partially modified channel bench for the periods between large flood events. The number of C/D category flood events is slightly smaller than for a B/C. This will likely keep the channel in a modified condition for the long periods between very large flood events. The channel bench is overtopped twice a year, and there is likely to be some vegetation encroachment (perhaps terrestrial).

Channel maintenance

B/C category floods allow for longer periods than natural between the mobilisation of coarse sediments on the bed and the scour of channel banks. This will result in some sediment fining and the accumulation of algae and other deposits on gravels and cobbles. C/D category floods allow for longer periods of sediment accumulation on the bed and as bars on the channel margins. This may encourage some vegetation encroachment. This must not be allowed to continue for an extended period as sediment scour will become more and more difficult.

Macro-channel and bed mobilisation

B/C flood events allow for periods of stability between large re-set events. The bed may become temporarily embedded. C/D category flood events simply mean an even more stable bed with increased sedimentation, particularly of the large bed material. The bed is likely to be more embedded than in the B/C category.

Conclusion

If the four geomorphological flood classes were met by the IFR the trajectory of change would be gradual enough to ensure that the river at this site remained within a B/C category in the 20-year period considered. The reasoning for this is that the site is quite resistant to change because it consists of a bedrock bed together with coarse substrate, and is incised within the landscape.

11.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 11.4 IFR confidence table for a recommended B/C ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
7	Low flows	3	4	2	-
	High flows	3	4	3	3

The confidences are low-to-medium to medium-to-high for low flows, and medium to medium-high for high flows. The reasons for this are as follows:

Invertebrates: The medium evaluation is due to uncertainty regarding the depth of inundation linked to marginal flows.

Fish: The high evaluation is linked a good understanding of the requirements of *Labeobarbus natalensis*.

Riparian vegetation: The low evaluation is due to the lack of poor low-flow cues and confusing high-flow cues.

Geomorphology: The low evaluation is linked to the lack of a sediment transport model to interpret high-flow requirements, and problems regarding the base flow separation

12 RU R. IFR 8. LOWER SUNDAYS (Sundays River)

12.1 ECOLOGICAL CATEGORIES

12.1.1 Summary of ERC scenarios

Two Ecological Reserve Scenarios were addressed for IFR 8. The recommended scenario is a D ERC. The alternative scenario of a C was also evaluated.

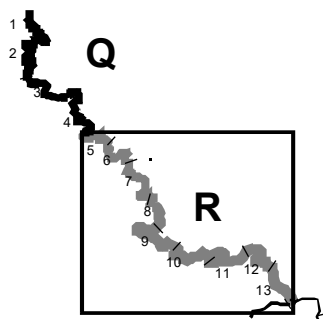


Fig 12.1 Summary of ERC Scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP
WATER QUALITY	B/C	0	B/C	EIS MODERATE SI MODERATE	B/C	
GEOMORPH	D	-	D		D	C
RIPARIAN VEGETATION	E	-	E/F		D	D
FISH	C	0	C		C	B
AQUATIC INVERTS	B/C	0	B/C		B/C	B
ECOSTATUS	D	-	D/E		D	C

12.1.2 Criteria for the Ecological Reserve Categories

Recommended scenario: D ERC

Aquatic invertebrates (B/C)

- Flow-dependent species:
Great emphasis has been placed on ensuring the continuation of the diverse family structure of the Ephemeroptera that occur at this site (which is most suited for these organisms). This has been coupled to the achievement of SASS scores as supplied for the PES.

Fish (C)

- Maintain species diversity by providing adequate breeding and refuge conditions for *L. natalensis*.

Riparian Vegetation (D)

- Maintain existing, and promote additional grass and sedge clumps within the marginal areas on both banks and on the island. The problems at this site are largely non flow related and consequently will not be improved by the provision of additional flows. Improvement in the condition of this site will most likely involve the removal of grazing and utilisation pressures.
- Provide both low and elevated river flows which will encourage the establishment and recovery of marginal and riparian vegetation appropriate to the ERC and PES, provided that non flow related activities are adequately controlled.

Geomorphology (D)

- Maintain the river in its present state i.e. as a wide channel with slowly developing channel banks (following the last large flood), with a bed dominated by coarse bed material interspersed with sand and gravel.

Alternative scenario: C ERC

Aquatic invertebrates (B)

- Flow dependent species:
The B/C SASS scores and Ephemeroptera must be maintained for a greater percentage of the season.
The same stress levels for a D category must be maintained for a greater percentage of the season.

Fish (B)

- Maintain species diversity with greater abundances (than the D) of all species.
- Maintain species diversity and improve *L. natalensis* breeding conditions.
- Maintain existing species diversity. Provide increased wetted perimeter and greater extent of fast-shallow habitat over cobble beds in summer to improve abundance.

Riparian Vegetation (D)

- As for the D ERC.

Geomorphology (C)

- To change the present state from a D to a C there is a need for increased sediment movement and re-distribution. Of particular importance at this site are the flows which act on the macro channel. The number of events for bench maintenance remains the same (D and C) as this event is an important component in allowing stabilisation of channel margins.

12.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The flow-stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 8, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 12.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 12.2.

12.2.1 Invertebrates

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit (0,31 m³/s) as a reference point. The stress index of zero was set so that water would inundate the vegetation at the sides of the river to a depth of approximately 15 cm. Some plants in the river channel would be inundated to a greater depth, in particular the roots of *Juncus*. The hydraulic profile and tables were used to derive the characteristics. The indices of greater stress were derived similarly, by measuring the reduction in water level that would leave just the bases of the *Juncus* and ultimately just the exposed roots inundated.

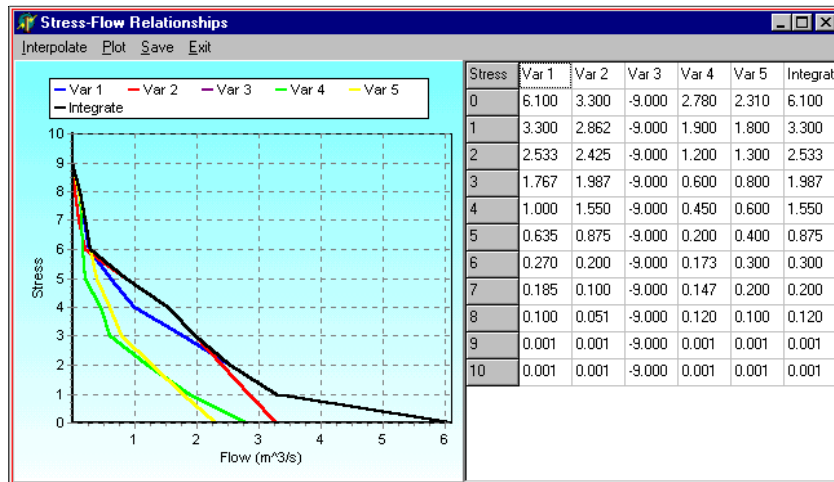
The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of small cobbles. The hydraulic data were used to determine the depths and velocities that would produce minimal stress to rheophilic species. Higher stresses were determined by anticipating minimal depths and velocities that would only provide remnants of their required habitat. Much of this investigation was based on the known presence of families such as Oligoneuridae and Hydropsychidae which require abundant clean, strong flowing water over clean rocks.

12.2.2 Riparian Vegetation

Two components were selected, using elevations and discharges associated with the ecological transect.

- *Juncus* spp.
Juncus spp. occurs in mats which cover a reasonably large area of the marginal zone on the left bank and islands. Only the edges of these mats, which are located adjacent to the river's edge, are crucial because the maximum stress levels of the entire mat would only occur once the water levels dropped below the roots in these areas, i.e. at the 0.10 m level. The *Juncus* was found to be quite insensitive since its roots extended well into the level of the main channel, and would therefore still remain relatively unstressed until the river had almost stopped flowing.
- *Setaria* (adults) – applicable in summer only
Setaria individuals were identified on the left hand bank and on islands. These corresponded with the 0.48m level. A maximum rooting depth of 0.25m was used to assess the maximum stress level at the 0.22m level.

Fig 12.2 Critical curve for IFR 8



Var 1: Fish

Var 3: Marginal Vegetation Invertebrates

Var 5: Riparian Vegetation 2

Var 2: Flow Dependent Invertebrates

Var 4: Riparian Vegetation 1

12.3 STRESS DURATION CURVES (PROFILES)

12.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 12.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 8, stress indices as determined were accepted, no changes were required.

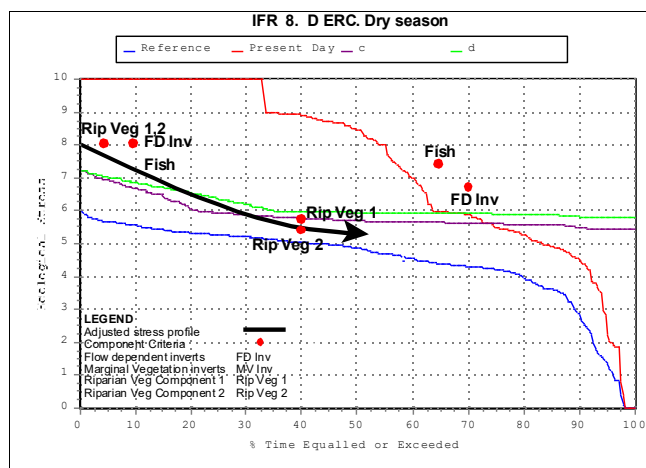
12.3.2 Recommended stress profiles for each Reserve scenario

The recommended D scenario and the alternative C scenario were estimated using the Desktop Model and are shown in Figures 12.3 – 12.6 as the green and purple lines respectively. The modelled present day hydrology as converted into stress, is reflected by the red line in Figures 12.3 – 12.6 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 12.3 - 12.6. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures 12.7 - 12.8). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

12.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated C scenario consisted of Maintenance Low Flows of 10.88% MAR, which were adjusted to 13.1% MAR, and of Drought Low Flows of 4.85% MAR, which were adjusted to 4.56% MAR (see Figure 12.3). The generated D scenario consisted of Maintenance Low Flows of 5.12% MAR, which were adjusted to 6.75% MAR, and of Drought Low Flows of 4.85% MAR, which were adjusted to 4.56% MAR (see Figure 12.3). The maintenance and drought low flows were manually changed to better fit the specialists' requirements for stress patterns.

Fig 12.3 IFR 8 – Stress duration curve for recommended scenario of a D ERC: Dry Season



Rationale for dry season duration curves

Vegetation: Vegetation presently has a category E PES due to catchment land use problems. The ERC for vegetation must therefore show an improvement to a D. This improvement cannot be achieved by manipulating flows, only by addressing catchment management problems. If these problems are addressed and vegetation is re-established, the flows are set to maintain the re-established vegetation. Vegetation is a D ERC for both the recommended D ERC and the alternative scenario of a C ERC. On the stress duration curves (for both C and D, dry season) (Figures 12.3 and 12.5), the vegetation point was the critical point (i.e. the lowest stress requirement) that guided the D scenario curve. The same vegetation point was also valid for the C scenario, as this point was below any of the other C requirements. This explains the proximity of the adjusted D and C lines to one another. [THIS PROXIMITY WILL NOT BE OBVIOUS FROM THE GRAPHS AS THEY ARE GRAPHED SEPARATELY].

Fig 12.4 IFR 8 - Stress-duration curve for recommended scenario of a D ERC: Wet Season

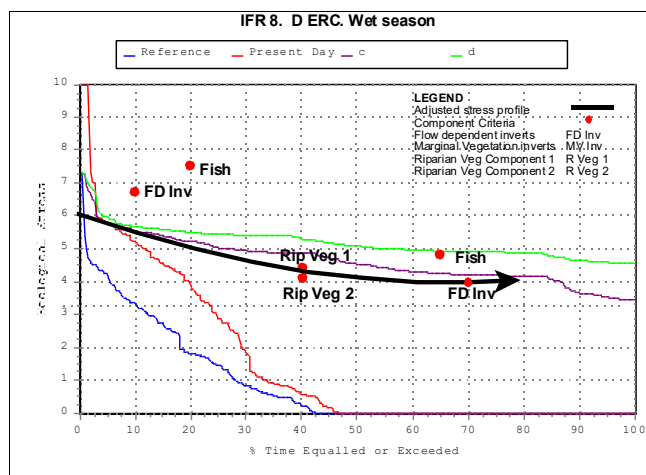


Fig 12.5 IFR 8 – Stress duration curve for alternative scenario of a C ERC: Dry Season (Refer to notes following Figure 12.3)

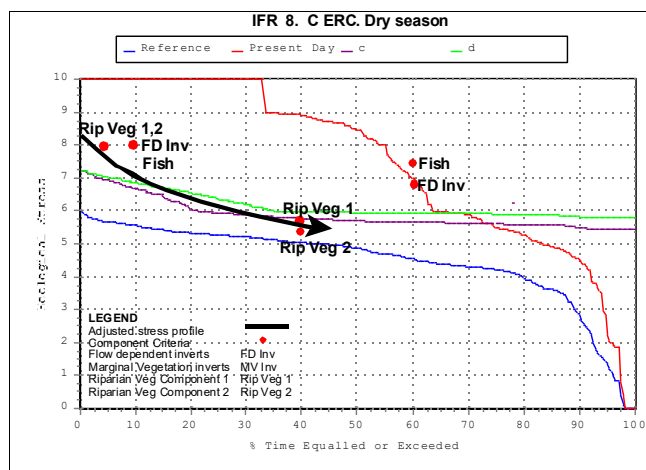
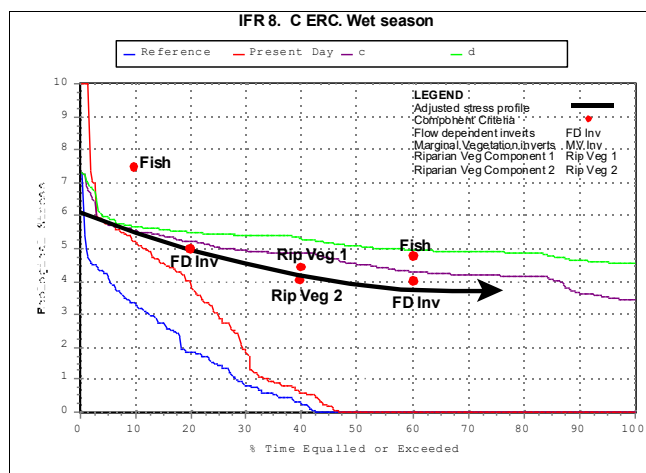


Fig 12.6 IFR 8 – Stress duration curve for alternative scenario of a C ERC: Wet Season



12.3.4 Final stress profiles for IFR 8

Fig. 12.1 IFR 8 - Final stress profiles: Dry Season

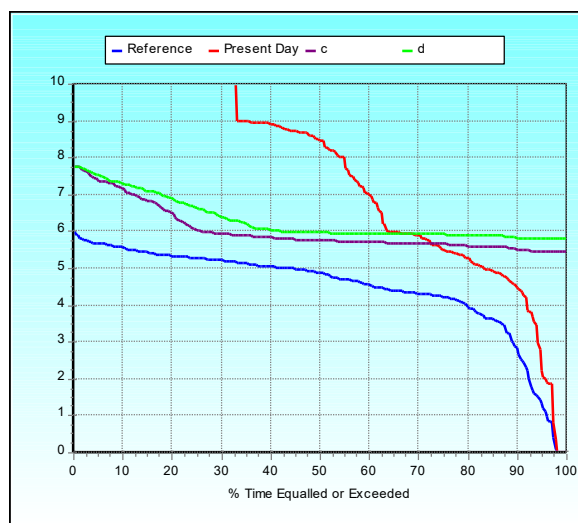
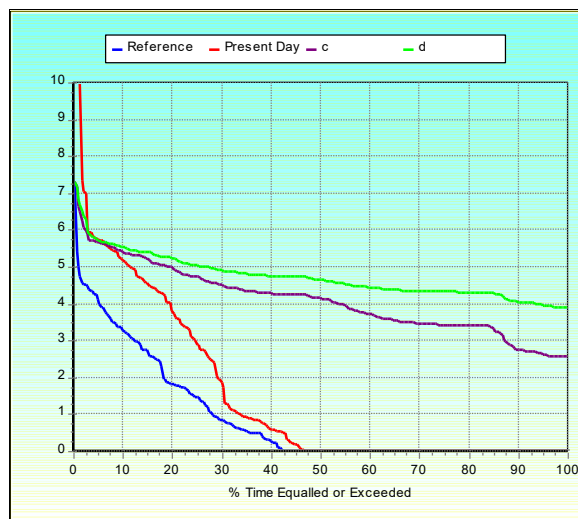


Fig. 12.2 IFR 8 - Final stress profiles: Wet Season



12.5 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 12.1. The number of events for each Flood Class required for a C and a D ERC are also summarised in Table 12.1.

Table 12.1 A summary of the Flood Class ranges, and the recommended high flow events for each scenario.

Component	Flood Classes m ³ /s				
	I	II	III	IV	V
Fish	3-5 5-10	10-20			
Invertebrates	1-2	10-15			50-100
Vegetation	2-10	10-21	21-38	38-58	
Geomorphology			18-28	28-50	50-70
Integrated	2-9	10-19	20-37	38-57	58-100
Geometric mean *		14	28	47	76
Recommended Floods					
No of events for D ERC (Recommended scenario)	2 spring 3 summer	3	1	1	1 in 4 years
No of events for C/D ERC (Alternative scenario)	2 spring 4 summer	5	1	1	1 in 3 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These requirements were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 58 to 100) specified by the geomorphology specialist were reduced to the lower discharge values (e.g. 50) for the Desktop model to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 12.2 and 12.3.

Table 12.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a D ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	II	15	II	15	V incl. 1-IV	50	III	28		
Duration (days)	3		3		5		3			
Freshet size (m³/s)			I	6	I*2	6	II	15	II	15
Duration (days)			2		2		3		3	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	6	I	6	I	6				
Duration (days)	2		2		2					

Table 12.3 Adjusted flood sizes as used in the Desktop model for the alternative scenario of a C ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	II	15	II	15	V incl. 1 - IV	50	III	28		
Duration (days)	3		34		5		3			
Freshet size (m³/s)			I	6	I	6	I	6	II	15
Duration (days)			2		2		2		3	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)			I	6	I	6				
Duration (days)			2		2					

12.4 FINAL RESULTS

12.4.1 IFR table for recommended scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	197.034
S.Dev.	=	122.758
CV	=	0.623
Q75	=	2.990
Q75/MMF	=	0.182
BFI Index	=	0.355
CV (JJA+JFM) Index	=	2.613
Total IFR	=	38.522 (19.55 %MAR)
Maint. Lowflow	=	13.302 (6.75 %MAR)
Drought Lowflow	=	8.975 (4.56 %MAR)
Maint. Highflow	=	25.220 (12.80 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	10.755	18.437	1.714	0.589	0.536	0.726	1.315
Nov	18.952	27.007	1.425	1.037	0.648	0.726	1.763
Dec	22.661	24.375	1.076	1.420	0.482	2.333	3.752
Jan	41.306	43.096	1.043	1.795	1.259	3.059	4.853
Feb	41.705	36.696	0.880	1.935	1.427	10.964	12.900
Mar	24.439	20.962	0.858	1.821	1.286	5.080	6.902
Apr	11.512	9.745	0.847	1.555	1.037	2.333	3.888
May	6.068	4.618	0.761	1.045	0.670	0.000	1.045
Jun	3.830	2.277	0.595	0.596	0.441	0.000	0.596
Jul	3.415	3.853	1.128	0.509	0.375	0.000	0.509
Aug	4.586	15.296	3.335	0.482	0.375	0.000	0.482
Sep	7.806	25.451	3.260	0.518	0.441	0.000	0.518

12.4.2 IFR table for alternative scenario: C ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	197.034
S.Dev.	=	122.758
CV	=	0.623
Q75	=	2.990
Q75/MMF	=	0.182
BFI Index	=	0.355
CV (JJA+JFM) Index	=	2.613
Total IFR	=	56.614 (28.73 %MAR)
Maint. Lowflow	=	25.796 (13.09 %MAR)
Drought Lowflow	=	8.975 (4.56 %MAR)
Maint. Highflow	=	30.819 (15.64 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	10.755	18.437	1.714	1.607	0.536	0.726	2.333
Nov	18.952	27.007	1.425	1.944	0.648	0.726	2.670
Dec	22.661	24.375	1.076	2.678	0.482	2.333	5.011
Jan	41.306	43.096	1.043	3.482	1.259	5.599	9.081
Feb	41.705	36.696	0.880	3.871	1.427	11.690	15.561
Mar	24.439	20.962	0.858	3.482	1.286	6.687	10.169
Apr	11.512	9.745	0.847	2.592	1.037	2.333	4.925
May	6.068	4.618	0.761	2.009	0.670	0.000	2.009
Jun	3.830	2.277	0.595	1.192	0.441	0.000	1.192
Jul	3.415	3.853	1.128	0.911	0.375	0.000	0.911
Aug	4.586	15.296	3.335	0.991	0.375	0.000	0.991
Sep	7.806	25.451	3.260	1.037	0.441	0.726	1.763

12.4.3 IFR rule table for recommended scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.820	0.814	0.801	0.775	0.726	0.646	0.533	0.402	0.290	0.238
Nov	1.175	1.168	1.154	1.126	1.074	0.984	0.839	0.639	0.415	0.275
Dec	2.838	2.598	2.386	2.187	1.977	1.624	1.352	0.974	0.552	0.287
Jan	3.797	3.475	3.192	2.931	2.664	2.215	1.894	1.447	0.950	0.637
Feb	9.390	8.324	7.410	6.603	5.832	4.546	3.818	2.807	1.680	0.971
Mar	4.631	4.602	4.542	4.423	4.200	3.810	3.190	2.329	1.370	0.766
Apr	2.314	2.296	2.256	2.174	2.021	1.768	1.411	1.000	0.649	0.486
May	0.746	0.742	0.731	0.709	0.669	0.602	0.507	0.398	0.305	0.261

Jun	0.412	0.410	0.405	0.394	0.373	0.339	0.291	0.235	0.188	0.166
Jul	0.364	0.362	0.357	0.347	0.329	0.299	0.256	0.207	0.165	0.146
Aug	0.334	0.332	0.328	0.319	0.303	0.276	0.239	0.195	0.158	0.141
Sep	0.359	0.357	0.353	0.344	0.328	0.301	0.263	0.220	0.183	0.166

Natural Duration curves

Oct	13.762	4.622	2.994	1.833	1.578	1.269	1.061	0.791	0.602	0.413
Nov	20.893	11.249	6.243	3.629	2.968	2.236	1.785	1.243	0.777	0.437
Dec	21.076	15.652	10.517	8.175	4.880	2.986	2.319	2.014	1.651	0.671
Jan	44.780	31.777	18.487	13.689	9.183	8.070	4.314	3.205	2.155	1.309
Feb	37.511	24.369	22.088	15.222	12.003	8.490	5.929	3.681	2.053	1.262
Mar	22.561	15.865	12.045	10.028	7.068	5.477	4.861	3.249	2.517	1.629
Apr	10.301	5.268	4.197	3.693	2.994	2.628	2.416	2.076	1.695	1.206
May	4.564	2.643	2.350	2.076	1.933	1.759	1.485	1.308	1.150	0.841
Jun	2.005	1.684	1.456	1.344	1.288	1.191	1.042	0.892	0.825	0.534
Jul	1.848	1.493	1.343	1.165	0.984	0.895	0.791	0.741	0.679	0.451
Aug	1.882	1.415	1.146	0.911	0.848	0.780	0.732	0.624	0.519	0.448
Sep	3.121	1.617	1.206	1.042	0.780	0.709	0.661	0.590	0.489	0.399

12.4.4 IFR rule table for alternative scenario: C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.168	1.159	1.139	1.097	1.019	0.891	0.710	0.501	0.323	0.241
Nov	1.335	1.327	1.310	1.278	1.216	1.110	0.940	0.704	0.441	0.276
Dec	3.187	2.944	2.727	2.518	2.288	1.899	1.572	1.116	0.608	0.289
Jan	6.276	5.687	5.174	4.705	4.230	3.434	2.887	2.127	1.280	0.747
Feb	10.491	9.350	8.368	7.492	6.640	5.217	4.359	3.168	1.839	1.003
Mar	5.304	5.270	5.201	5.063	4.805	4.355	3.639	2.643	1.534	0.836
Apr	2.332	2.314	2.274	2.191	2.036	1.781	1.420	1.005	0.651	0.486
May	1.049	1.041	1.024	0.989	0.923	0.814	0.661	0.484	0.333	0.263
Jun	0.603	0.598	0.589	0.569	0.533	0.473	0.388	0.290	0.206	0.167
Jul	0.476	0.473	0.465	0.451	0.423	0.377	0.313	0.239	0.176	0.147
Aug	0.501	0.497	0.490	0.474	0.443	0.394	0.324	0.243	0.174	0.142
Sep	0.842	0.836	0.822	0.793	0.738	0.649	0.523	0.378	0.253	0.196

12.5 GEOMORPHOLOGICAL CONSEQUENCES OF D AND C SCENARIOS

Bed maintenance

C category flood events are more frequent than D category. This allows for more frequent movement and re-distribution of finer bed material. It also prevents the accumulation of sand bars and islands, and maintains good hydraulic diversity. There are also fewer flood events for the D than for the C category. This will lead to longer periods of sediment accumulation and the loss of some interstitial habitat, particularly on channel margins and behind obstructions. This will be re-set by large floods.

Bench maintenance

C and D category flood events occur at the same frequency. The reason for this is that continual re-building of channel margins needs to continue post the last large flood event. These benches will likely be vegetated and stabilised over time.

Channel maintenance

C and D category flood events occur at the same frequency. The bed needs to be mobilised often, in order to prevent long-term sediment accumulation, loss of habitat etc. This will lead to failure of the larger events to achieve their geomorphological objectives.

Macro channel and bed mobilisation

C category flood events occur slightly more frequently than D category events. This will lead to an improved channel condition i.e. more frequently clean substrate on the bed, better habitat for some periods of time as interstitial spaces are available. D Class Flood events should maintain the river in its present state within the 20-year period. The accumulation of sediment, temporary loss of habitat, and bar accumulation is likely to be relatively short-lived until the large re-set events pass through the system.

Conclusion

If the four geomorphological flood classes are met by the IFR, the trajectory of change would be gradual enough to ensure that the river at this site remains within a D category in the 20-year period considered. The reasoning for this is that the site is quite resistant to change because it consists of coarse substrates and is incised within the landscape.

12.6 IFR RESULT CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 12.4 IFR confidence for a D ERC

IFR Site		IFR Component			
		Aquatic Inverts	FISH	Riparian Vegetation	Geomorphology
8	Low flows	3	4	3	-
	High flows	4	4	3	3

The confidences are medium to medium-to-high for low and high flows.

Invertebrates: The medium evaluation is due to uncertainty about microhabitat velocities.

Riparian Vegetation: The low evaluation is due to the lack of poor flow cues available and also the lack of riparian vegetation.

Geomorphology: The medium evaluation is linked to the lack of a sediment transport model to interpret high flow requirements, and to problems regarding the base flow separation.

13 RU S. IFR 10. CARAVAN PARK (Mooi River)

13.1 ECOLOGICAL CATEGORIES

13.1.1 Summary of Reserve scenarios

Three Ecological Reserve Scenarios were addressed for IFR10. The recommended scenario is a C ERC. The alternative scenarios of a B and a D ERC were also evaluated.

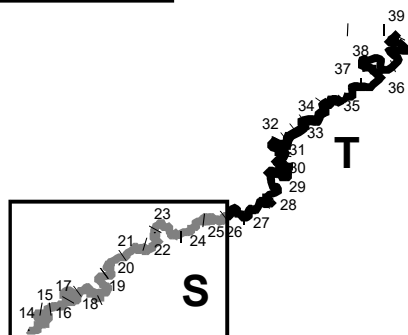


Fig. 13.1 Summary of ERC scenarios

COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP	DOWN
WATER QUALITY	B/C	-	B/C	E I S H I G H S I H I G H	B		
GEOMORPH	C	-	C		C	B	D
RIPARIAN VEGETATION	C/D	-	C/D		C/D	B/C	D
FISH	C	0	C		C	B	D
AQUATIC INVERTS	B/C	0	B/C		B/C	B	C/D
ECOSTATUS	C	-	C		C	B	D

13.1.2 Criteria for the Ecological Reserve Categories

Recommended scenario: C ERC

Aquatic invertebrates (B/C)

- Marginal vegetation species:
Some emphasis has been placed on protection of Ephemeroptera, but this is mainly reflected in the provision of the SASS score. In drought winters, inundation of the marginal vegetation will not be necessary.
- Flow-dependent species:
Because of the importance of Ephemeroptera in this river, their presence and diversity has been made a requirement. This is captured in the number of families required, and in the SASS scores.

Fish (C)

- To maintain species diversity and high abundances of species.

Riparian Vegetation (C/D)

- To maintain existing abundances and distribution of mixed grasses and sedges on both banks and islands.

Geomorphology (C)

- To maintain the river in its present state we need to keep the fine material moving through the bedrock rapids/riffles. Channel banks and floodplains must be maintained with regular overbank topping.

Alternative scenario: B ERC**Aquatic invertebrates (B)**

- Marginal vegetation species:
Diversity of Ephemeroptera is more secure.
Maintain stress levels the same but with greater assurance.
- Flow-dependent species:
Oligoneuridae found regularly.
Diverse and dominant mayfly populations are present.
Ensure reduced stress with emphasis on depth in fast flowing chutes. This will cater for Oligoneuridae.

Fish (B)

- All species are present with increased breeding success of *L. natalensis* and decreased breeding success of bass species.
- Maintain species diversity. Improve breeding and juvenile habitat for *L. natalensis* and disturb nesting behaviour of bass.
- Maintain existing species diversity. Provide increased wetted perimeter and extent of fast-shallow habitat over cobble beds and increased inundation of backwaters as habitat for *L. natalensis* juveniles in summer.

Riparian Vegetation (B/C)

- Extended distribution and abundance of marginal vegetation (mixed grasses and sedges) on both banks and islands on the right bank.
- To encourage an increased abundance and distribution of mixed grasses and sedges on both the banks and islands by the provision of larger flows and more frequent floods.

Geomorphology (B)

- To improve the state of the river from a C to a B category, there is a need to reinstate a more "natural" hydrology. In this case this means an increase in the number of flood events as outlined above. Further improvements relate to changes in catchment condition and are not flow related.

Alternative scenario: D ERC

Aquatic invertebrates (C/D)

- Marginal vegetation species:
Ephemeroptera remain diverse.
Less depth, with a decreased quantity of marginal vegetation habitat. The available habitat must be maintained.
- Flow-dependent species:
Allow increased stress (this will result from less depth in deep chutes).

Fish (D)

- All species present, with a decreased abundance of *L. natalensis*
- Maintain existing species diversity. Prevent the extinction of *L. natalensis* by maintaining fast-shallow habitat over small areas of cobble beds in summer.

Riparian Vegetation (D)

- A broad band of mixed grasses and sedges in the marginal areas on both banks and on islands on the right bank.
- Riparian vegetation is composed of *Salix mucronata* and alien trees and shrubs, mainly *S. babylonica*.
- Maintain the existing abundance and distribution of mixed grasses and sedges on both banks and islands on the right bank.

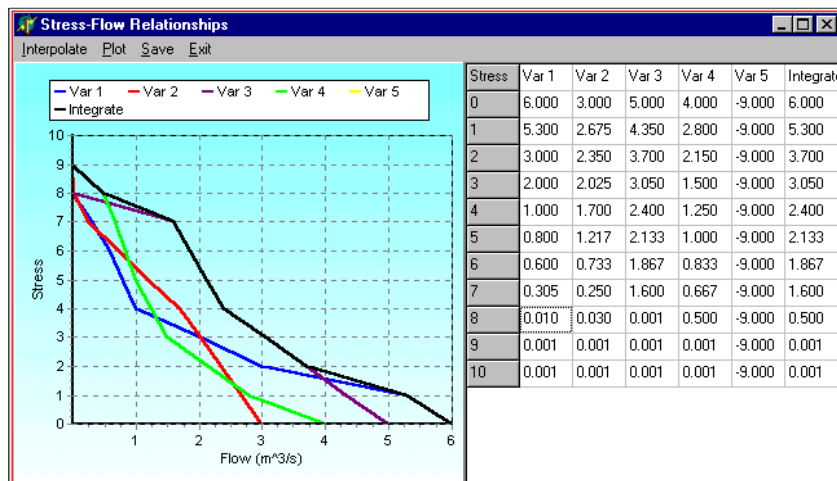
Geomorphology (D)

- The removal of some flood events will lead to a change from a C to a D category. This will lead to the temporary accumulation of instream sediments and may lead to bar and island development.

13.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 10, which is presented in Appendix G. The numerical flow-stress relationships are provided in Figure 13.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 13.2.

Fig. 13.2 Critical curve for IFR 10



Var 1: Fish
 Var 2: Flow Dependent Invertebrates
 Var 3: Marginal Vegetation Invertebrates
 Var 4: Riparian Vegetation 1
 Var 5: Riparian Vegetation 2

13.2.1 Invertebrates

The marginal vegetation community was investigated by using cross-sectional data and photographs. The stress index of zero was set so that approximately 0.2m of water depth inundated the marginal vegetation.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of cobbles and bedrock. The hydraulic data were used to determine the depths and velocities that would produce minimal stress to mayflies in particular but also giving consideration to other rheophilic species. Higher stresses were determined by anticipating the reduction of quantities of stone habitat that would only provide remnants of the required habitat.

13.2.2 Riparian Vegetation

Only one component was selected, using elevations and discharges associated with the ecological transect. A maximum rooting depth of 0.27m was used to estimate the stress level of 8, based on the generic stress table.

- Mixed sedges and grasses:
 Mixed sedges and grasses cover a reasonably large area of the marginal zone on both banks. Only the lower edges of these mats are crucial because the maximum stress levels of these mats would only occur once the water levels drop below the roots in these areas, i.e. at the 0.26m level at less than 0.5m³/s.

13.3 STRESS DURATION CURVES (PROFILES)

13.3.1 Stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 13.3), and evaluated to determine whether or not it was representative of the expected stress under

natural flow conditions. For IFR 10, stress indices were as determined and no changes were required.

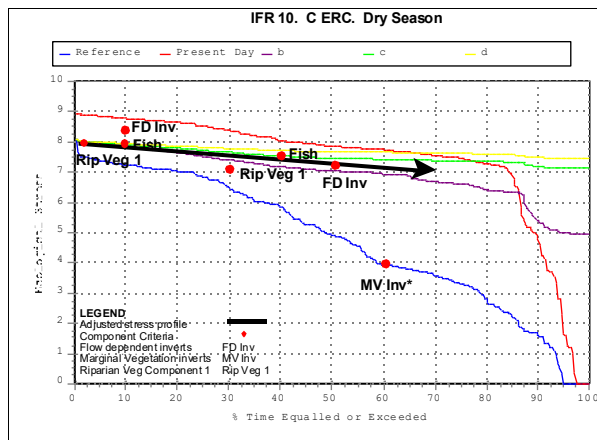
13.3.2 Recommended stress profiles for each Reserve scenario

The recommended C scenario and the alternative B and D scenarios were estimated using the Desktop model and are shown in Figures 13.3 – 13.8 as the purple, green and yellow lines respectively. The observed (historical) hydrology as converted into stress, is reflected by the red line in Figures 13.3 – 13.8 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 13.3 - 13.8. According to the specialists' evaluations, the Desktop generated scenarios were adjusted (see Figures 13.9 - 13.10). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

13.3.3 Process to adjust the Desktop output to fit specialist requirements

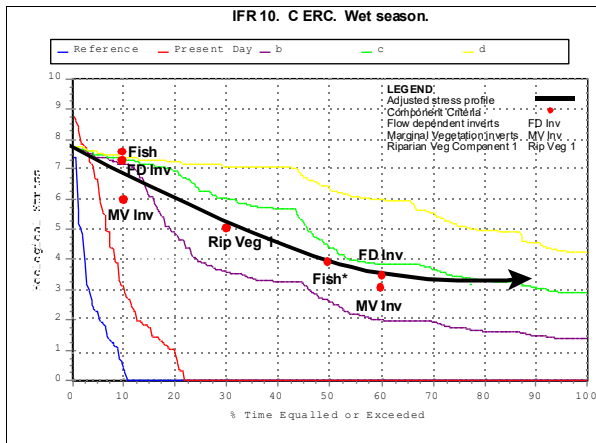
The generated C scenario consisted of Maintenance Low Flows of 16% MAR, which were adjusted to 17.2% MAR, and of Drought Low Flows of 8.5% MAR, which remained unchanged (see Figure 13.3). The generated B scenario consisted of Maintenance Low Flows of 27.5% MAR, which were adjusted to 29% MAR, and of Drought Low Flows of 8.5% MAR, which remained unchanged (see Figure 13.3). The generated D scenario consisted of Maintenance Low Flows of 8.54% MAR, which were adjusted to 9% MAR, and of Drought Low Flows of 8.5% MAR, which remained unchanged. The maintenance and drought low flows were manually changed mainly in the wet season to better fit the specialists' requirements for stress patterns.

Fig. 13.3 IFR 10 – Stress duration curve for recommended scenario of a C ERC: Dry Season



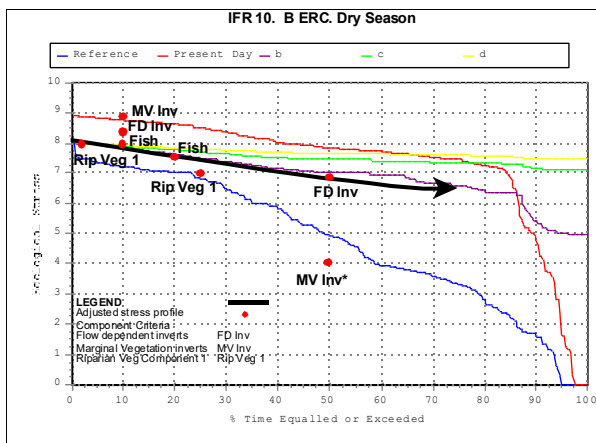
* The MV Inv. stress of 4 at a percentage of 60 is an outlier. This is possibly due to the lack of knowledge of the inundation levels of the marginal vegetation.

Fig. 13.4 IFR10 – Stress duration curve for recommended scenario of a C ERC: Wet Season



* A fish stress of 2 relates to a critical stress of 3. A fish stress of 3 relates to a critical stress of 5. The fish specialist provided the regime for a critical stress of 3. The critical stress of 4 lies between the fish stress of 2 and 3. It is therefore assumed that the fish requirement of a critical stress of 3 would also be valid for a critical stress of 4 as this point falls in the line created by the other points.

Fig. 13.5 IFR10 – Stress duration curve for alternative scenario of a B ERC: Dry Season



* See note below Figure 13.3.

Fig. 13.6 IFR10 – Stress duration curve for alternative scenario of a B ERC: Wet Season

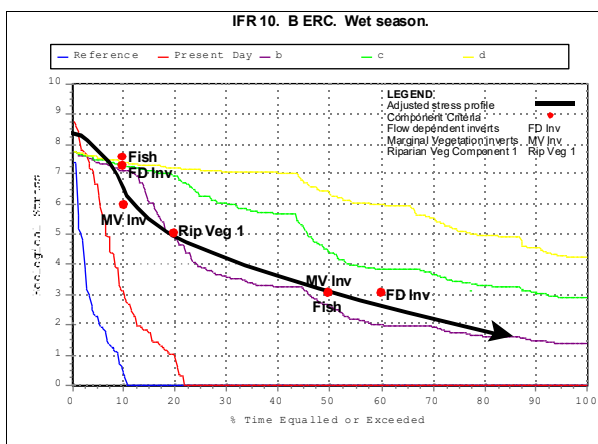


Fig. 13.7 IFR10 – Stress duration curve for alternative scenario of a D ERC: Dry Season

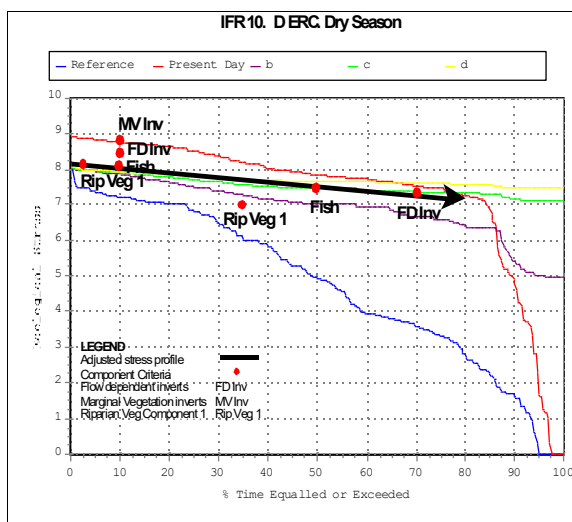
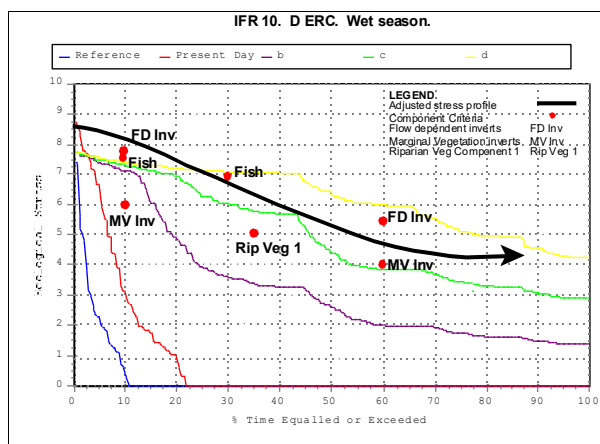


Fig. 13.8 IFR10 Stress duration curve for alternative scenario of a D ERC: Wet Season



13.3.4 Final stress profiles for IFR10

Fig. 13.9 IFR 10 - Final stress profiles: Dry Season

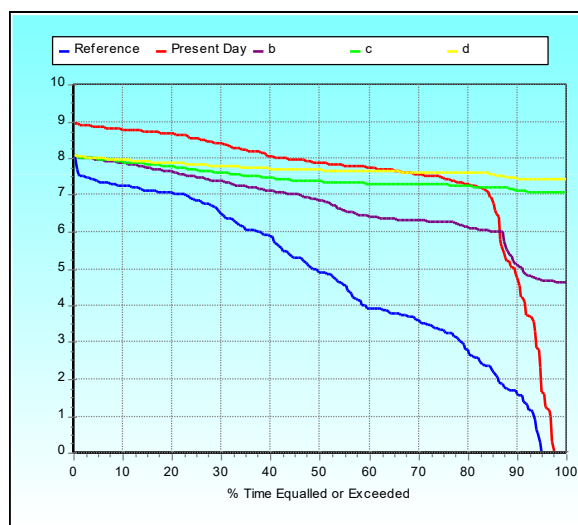
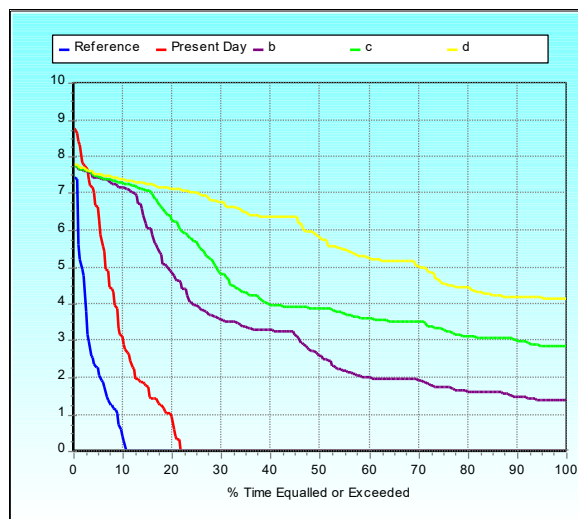


Fig. 13.10 IFR 10 - Final Stress Profiles: Wet Season



13.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 13.1. The number of events for each Flood Class required for C, B and D ERCs also summarised in Table 13.1.

Table 13.1 A summary of the Flood Class ranges, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s					
	I	II	III	IV	V	VI
Fish		8-10	10-20	20-30		
Invertebrates	2-4	7-15				
Vegetation		5-10	10-30		30-60	60-100
Geomorphology				19-29	29-60	60-155
Integrated	2-4	5-9	10-19	20-29	30-59	60-155
Geometric mean *			14	24	42	96
Recommended high flow events						
No of events for C ERC (Recommended scenario)	2 spring 1 autumn	4	3	2	1	1 in 3 years
No of events for B ERC (Alternative scenario)	2 spring 1 autumn	5	4	3	1	1 in 2 years
No of events for D ERC (Alternative scenario)	1 spring	4	2	1	1	1 in 5 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 60 - 155) specified by the geomorphologist were reduced to the lower discharge values (e.g. 80) for the Desktop model to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 13.2 and 13.3.

B - High flow maintenance was 9%, increased to 15.6%.

C - High flow maintenance was 7.8%, increased to 12.7%.

D - High flow maintenance was 6.8%, increased to 9.6%.

Table 13.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a C ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m ³ /s)	III	15	IV	25	VI incl. 1- V	80	IV	25		
Duration (days)	3		3		5		3			
Freshet size (m ³ /s)	II	7	III	15	II *2	7 + 7	III	15	I	2.5
Duration (days)	2		3		2		3		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m ³ /s)	I	2.5	I	2.5	II	7				
Duration (days)	2		2		2					

Table 13.3 Adjusted flood sizes as used in the Desktop Model for the alternative scenario of a B ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m ³ /s)	IV	25	IV	25	VI incl. 1- V	80	IV	25		
Duration (days)	3		3		5		3			
Freshet size (m ³ /s)	II	7	II & III	7 + 15	II & III	7 + 15	II & III	7 + 15	I	2.5
Duration (days)	2		3		3		3		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m ³ /s)	I	2.5	I	2.5	II	7				
Duration (days)	2		2		2					

Table 13.4 Adjusted flood sizes as used in the Desktop (monthly) model for the alternative scenario of a D ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	15	III	15	VI incl. 1- V	70	IV	25		
Duration (days)	3		3		5		3			
Freshet size (m³/s)	II	7	II	7	II	7	II	7		
Duration (days)	2		2		2		2			
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)					I	2.5				
Duration (days)					2					

13.5 FINAL RESULTS

13.5.1 IFR table for recommended scenario: C ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	278.075
S.Dev.	=	123.643
CV	=	0.445
Q75	=	6.080
Q75/MMF	=	0.262
BFI Index	=	0.439
CV(JJA+JFM) Index	=	1.323
Total IFR	=	83.241 (29.93 %MAR)
Maint. Lowflow	=	47.791 (17.19 %MAR)
Drought Lowflow	=	23.560 (8.47 %MAR)
Maint. Highflow	=	35.450 (12.75 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	11.824	13.995	1.184	2.812	1.393	0.302	3.115
Nov	19.010	15.838	0.833	3.110	1.607	0.847	3.957
Dec	33.647	25.686	0.763	4.821	2.036	3.180	8.001
Jan	48.084	31.537	0.656	5.223	2.518	6.221	11.444
Feb	52.202	36.365	0.697	5.564	2.855	18.075	23.639
Mar	44.535	28.093	0.631	5.892	2.946	6.221	12.113
Apr	25.707	17.009	0.662	5.184	2.644	0.302	5.486
May	13.032	11.737	0.901	3.857	2.062	0.000	3.857
Jun	7.984	4.371	0.548	3.110	1.607	0.000	3.110
Jul	6.665	3.879	0.582	2.946	1.259	0.000	2.946
Aug	6.341	5.429	0.856	2.678	1.312	0.000	2.678
Sep	9.045	17.423	1.926	2.592	1.322	0.302	2.894

13.5.2 IFR table for alternative scenario: B ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	278.075
S.Dev.	=	123.643
CV	=	0.445
Q75	=	6.080
Q75/MMF	=	0.262
BFI Index	=	0.439
CV(JJA+JFM) Index	=	1.323

Total IFR = 121.303 (43.62 %MAR)
 Maint. Lowflow = 77.973 (28.04 %MAR)
 Drought Lowflow = 23.560 (8.47 %MAR)
 Maint. Highflow = 43.330 (15.58 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	11.824	13.995	1.184	4.553	1.393	0.302	4.856
Nov	19.010	15.838	0.833	4.977	1.607	0.847	5.823
Dec	33.647	25.686	0.763	6.562	2.036	4.735	11.297
Jan	48.084	31.537	0.656	8.437	2.518	7.309	15.746
Feb	52.202	36.365	0.697	9.725	2.855	19.803	29.528
Mar	44.535	28.093	0.631	9.990	2.946	7.309	17.300
Apr	25.707	17.009	0.662	8.916	2.644	2.722	11.638
May	13.032	11.737	0.901	6.642	2.062	0.000	6.642
Jun	7.984	4.371	0.548	5.184	1.607	0.000	5.184
Jul	6.665	3.879	0.582	4.553	1.259	0.000	4.553
Aug	6.341	5.429	0.856	4.285	1.312	0.000	4.285
Sep	9.045	17.423	1.926	4.147	1.322	0.302	4.450

13.5.3 IFR table for alternative scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR = 278.075
 S.Dev. = 123.643
 CV = 0.445
 Q75 = 6.080
 Q75/MMF = 0.262
 BFI Index = 0.439
 CV(JJA+JFM) Index = 1.323
 Total IFR = 51.701 (18.59 %MAR)
 Maint. Lowflow = 25.124 (9.04 %MAR)
 Drought Lowflow = 23.560 (8.47 %MAR)
 Maint. Highflow = 26.577 (9.56 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	11.824	13.995	1.184	1.473	1.393	0.000	1.473
Nov	19.010	15.838	0.833	1.607	1.607	0.302	1.909
Dec	33.647	25.686	0.763	2.411	2.036	3.180	5.590
Jan	48.084	31.537	0.656	2.812	2.518	3.180	5.992
Feb	52.202	36.365	0.697	2.903	2.855	15.180	18.084
Mar	44.535	28.093	0.631	3.214	2.946	4.735	7.949
Apr	25.707	17.009	0.662	2.851	2.644	0.000	2.851
May	13.032	11.737	0.901	2.062	2.062	0.000	2.062
Jun	7.984	4.371	0.548	1.685	1.607	0.000	1.685
Jul	6.665	3.879	0.582	1.339	1.259	0.000	1.339
Aug	6.341	5.429	0.856	1.393	1.312	0.000	1.393
Sep	9.045	17.423	1.926	1.374	1.322	0.000	1.374

13.5.4 IFR rule table for recommended scenario: C ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.550	1.546	1.529	1.493	1.419	1.290	1.095	0.859	0.651	0.555
Nov	1.957	1.955	1.941	1.910	1.847	1.729	1.525	1.223	0.867	0.640

Dec	4.938	4.625	4.344	4.081	3.797	3.297	2.860	2.203	1.425	0.926
Jan	7.728	7.102	6.555	6.067	5.582	4.733	4.115	3.165	2.018	1.279
Feb	15.962	14.251	12.784	11.510	10.313	8.260	7.068	5.276	3.151	1.790
Mar	8.318	7.661	7.085	6.564	6.036	5.121	4.445	3.440	2.258	1.503
Apr	2.655	2.649	2.622	2.561	2.440	2.224	1.902	1.512	1.168	1.009
May	1.912	1.906	1.885	1.841	1.754	1.605	1.388	1.131	0.907	0.803
Jun	1.481	1.475	1.457	1.421	1.351	1.232	1.061	0.860	0.686	0.606
Jul	1.426	1.417	1.397	1.355	1.276	1.147	0.965	0.755	0.575	0.492
Aug	1.275	1.269	1.254	1.222	1.159	1.053	0.901	0.722	0.567	0.495
Sep	1.372	1.367	1.351	1.317	1.249	1.134	0.965	0.765	0.591	0.510

Reserve flows without High Flows

Oct	1.416	1.412	1.398	1.366	1.301	1.187	1.016	0.810	0.627	0.543
Nov	1.585	1.583	1.572	1.550	1.503	1.415	1.264	1.039	0.775	0.606
Dec	2.556	2.554	2.536	2.497	2.416	2.260	1.991	1.585	1.104	0.796
Jan	2.906	2.906	2.889	2.851	2.770	2.610	2.325	1.887	1.358	1.017
Feb	2.856	2.853	2.835	2.796	2.714	2.557	2.284	1.874	1.388	1.077
Mar	3.324	3.320	3.297	3.249	3.149	2.961	2.637	2.157	1.592	1.231
Apr	2.526	2.520	2.495	2.438	2.325	2.126	1.826	1.464	1.145	0.997
May	1.912	1.906	1.885	1.841	1.754	1.605	1.388	1.131	0.907	0.803
Jun	1.481	1.475	1.457	1.421	1.351	1.232	1.061	0.860	0.686	0.606
Jul	1.426	1.417	1.397	1.355	1.276	1.147	0.965	0.755	0.575	0.492
Aug	1.275	1.269	1.254	1.222	1.159	1.053	0.901	0.722	0.567	0.495
Sep	1.244	1.239	1.225	1.196	1.137	1.037	0.891	0.719	0.568	0.498

Natural Duration curves

Oct	9.880	6.447	4.491	3.461	2.905	1.960	1.728	1.489	1.254	0.992
Nov	14.210	9.987	8.610	6.847	5.014	4.503	3.629	3.032	1.986	0.982
Dec	29.977	17.762	14.460	13.152	10.891	9.510	7.095	4.888	3.175	1.246
Jan	34.339	30.747	22.789	19.963	16.264	14.268	11.526	8.289	5.887	3.915
Feb	41.797	29.716	21.532	18.272	15.267	11.820	10.895	9.244	6.579	5.406
Mar	30.973	24.611	20.333	17.973	15.274	13.434	12.128	10.760	8.470	5.680
Apr	16.118	13.105	10.839	9.476	8.221	7.333	6.254	5.518	4.219	2.520
May	7.010	5.980	5.069	3.985	3.827	3.704	3.441	2.948	2.770	1.767
Jun	4.872	3.368	3.207	2.740	2.580	2.419	2.218	1.990	1.800	1.415
Jul	3.792	2.978	2.662	2.527	2.184	2.079	1.917	1.725	1.578	1.146
Aug	4.219	2.610	2.348	2.158	1.882	1.714	1.587	1.471	1.314	1.169
Sep	5.623	3.734	2.494	2.080	1.717	1.613	1.437	1.307	1.109	1.016

13.5.5 IFR rule table for alternative scenario: B ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.136	2.129	2.103	2.045	1.929	1.723	1.414	1.041	0.711	0.559
Nov	2.505	2.502	2.482	2.438	2.350	2.182	1.895	1.467	0.964	0.643
Dec	6.521	6.056	5.642	5.259	4.857	4.152	3.570	2.695	1.657	0.992
Jan	9.688	8.952	8.302	7.713	7.110	6.046	5.203	3.906	2.341	1.332
Feb	18.624	16.748	15.128	13.705	12.337	9.979	8.485	6.238	3.573	1.867
Mar	10.677	9.904	9.215	8.576	7.903	6.729	5.763	4.327	2.638	1.559
Apr	4.897	4.881	4.820	4.680	4.401	3.906	3.165	2.269	1.479	1.113
May	2.883	2.870	2.832	2.749	2.587	2.309	1.903	1.422	1.003	0.809
Jun	2.158	2.147	2.117	2.052	1.928	1.718	1.415	1.060	0.752	0.610
Jul	1.923	1.910	1.878	1.814	1.694	1.497	1.218	0.897	0.622	0.495
Aug	1.784	1.775	1.749	1.696	1.593	1.419	1.167	0.872	0.617	0.498
Sep	1.861	1.853	1.828	1.774	1.669	1.488	1.224	0.912	0.640	0.513

Reserve flows without High Flows

Oct	2.011	2.005	1.981	1.927	1.819	1.628	1.341	0.994	0.688	0.547
Nov	2.164	2.161	2.144	2.108	2.034	1.894	1.654	1.297	0.878	0.610
Dec	2.974	2.971	2.949	2.901	2.800	2.608	2.275	1.774	1.180	0.799
Jan	4.022	4.022	3.995	3.934	3.806	3.552	3.099	2.404	1.565	1.024
Feb	4.264	4.261	4.228	4.158	4.011	3.731	3.243	2.511	1.642	1.086
Mar	4.809	4.803	4.764	4.681	4.511	4.190	3.639	2.819	1.856	1.240
Apr	3.811	3.799	3.753	3.650	3.443	3.076	2.527	1.862	1.276	1.005
May	2.883	2.870	2.832	2.749	2.587	2.309	1.903	1.422	1.003	0.809
Jun	2.158	2.147	2.117	2.052	1.928	1.718	1.415	1.060	0.752	0.610
Jul	1.923	1.910	1.878	1.814	1.694	1.497	1.218	0.897	0.622	0.495
Aug	1.784	1.775	1.749	1.696	1.593	1.419	1.167	0.872	0.617	0.498
Sep	1.742	1.734	1.711	1.662	1.565	1.399	1.156	0.868	0.618	0.501

13.5.4 IFR rule table for alternative scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.026	1.024	1.016	0.998	0.962	0.899	0.804	0.689	0.587	0.540
Nov	1.345	1.344	1.336	1.319	1.284	1.219	1.106	0.939	0.742	0.616
Dec	4.217	3.905	3.631	3.384	3.133	2.696	2.369	1.878	1.295	0.921
Jan	4.702	4.382	4.099	3.845	3.586	3.130	2.775	2.230	1.571	1.147
Feb	13.147	11.711	10.482	9.422	8.436	6.750	5.814	4.408	2.740	1.671
Mar	6.410	5.910	5.474	5.082	4.690	4.013	3.531	2.814	1.972	1.433
Apr	1.921	1.917	1.902	1.868	1.799	1.678	1.496	1.276	1.083	0.993
May	1.420	1.417	1.405	1.380	1.332	1.249	1.127	0.983	0.858	0.800
Jun	1.116	1.113	1.103	1.081	1.040	0.971	0.870	0.752	0.651	0.603
Jul	0.907	0.903	0.894	0.875	0.840	0.782	0.700	0.606	0.526	0.488
Aug	0.923	0.920	0.911	0.893	0.859	0.801	0.717	0.618	0.532	0.493
Sep	0.915	0.913	0.905	0.888	0.856	0.799	0.717	0.620	0.535	0.496
Reserve flows without High Flows										
Oct	1.026	1.024	1.016	0.998	0.962	0.899	0.804	0.689	0.587	0.540
Nov	1.178	1.177	1.171	1.158	1.130	1.079	0.990	0.858	0.703	0.604
Dec	1.835	1.834	1.823	1.800	1.752	1.660	1.500	1.259	0.974	0.792
Jan	2.237	2.237	2.226	2.201	2.149	2.045	1.860	1.576	1.233	1.013
Feb	2.139	2.138	2.127	2.103	2.054	1.960	1.797	1.551	1.259	1.073
Mar	2.609	2.606	2.591	2.559	2.493	2.369	2.155	1.838	1.465	1.227
Apr	1.921	1.917	1.902	1.868	1.799	1.678	1.496	1.276	1.083	0.993
May	1.420	1.417	1.405	1.380	1.332	1.249	1.127	0.983	0.858	0.800
Jun	1.116	1.113	1.103	1.081	1.040	0.971	0.870	0.752	0.651	0.603
Jul	0.907	0.903	0.894	0.875	0.840	0.782	0.700	0.606	0.526	0.488
Aug	0.923	0.920	0.911	0.893	0.859	0.801	0.717	0.618	0.532	0.493
Sep	0.915	0.913	0.905	0.888	0.856	0.799	0.717	0.620	0.535	0.496

13.6 GEOMORPHOLOGICAL CONSEQUENCES FOR C, B AND D SCENARIOS

Bed maintenance

The B category requirement is four events. This allows the regular movement and maintenance of bed material at this site. Because the site is an alluvial system and there is a natural tendency for sediment accumulation, one wants to avoid this within the hydraulic controls (rapids and riffles).

The C category requirement is three events. This will lead to limited sediment accumulation within the hydraulic controls for longer periods of time (between large flood events).

The D category requirement is two events. This will lead to greater sediment accumulation, particularly on the channel margins and behind obstructions. The length of time for accumulation is likely to be greater and in certain areas may be permanent.

Bench maintenance

The B category requirement is two events. This allows for the maintenance of the benches on the channel sides. This includes regular scour and deposition. The C and D category requirements are one event. This will allow some vegetation encroachment into the channel. The stability of the bars and vegetation is determined by the frequency of the larger events.

Channel maintenance

The B and C category requirements are one event. This very important flood event acts to scour the active channel and overturn and mobilise the bed. This event is important to ensure the regular movement of accumulated sediment and therefore needs to be considered together with other flood requirements. The D category requirement is for an event once in two years. This means that there is likely to be a slow accumulation of sediments in the channel. If these sediments become vegetated they will not be easily mobilised and may become permanent features.

Macro-channel and bed mobilisation

The B category requirement is for an event every year. This allows for the regular maintenance of the larger macro-channel, and for the mobilisation of very coarse bed material on an annual basis. The C category requirement is for a one in three year event. There is likely to be limited overbank topping and deposition of flood sediments, together with possible vegetation encroachment (terrestrial and riparian) within the macro-channel. The extensive alien vegetation present at the site already evidences this.

The D category requirement is for a one in four year event. Consequences are the same for the C category, but with a longer retention time for coarse sediments. This also needs to be considered, together with the channel maintenance requirements. The longer time period between events means a greater chance of permanent change, particularly along the channel margins.

Conclusion

As with all sites, any removal of flow events will lead to some geomorphological change. The degree of change and rate of change will be determined by the difference between natural and recommended flows (and their frequencies). Although this site is alluvial, it is relatively stable and the catchment condition is fairly good. The flood requirement for a C category river should maintain it as this category for at least 20 years.

13.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 13.5 IFR confidence for a C ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
10	Low flows	2	4	2	-
	High flows	3	3	2	4

The confidence ranges from low-to-medium to medium-to-high.

Invertebrates: The medium evaluation is a result of uncertainty regarding marginal vegetation linkages, and poor data availability.

Fish: The medium evaluation for fish, at high flows, is due to the scarcity of cobble/gravel beds, which impacts on breeding success. The medium-to-high evaluation for fish at low flows is due to the presence of good refugia in pools.

Riparian Vegetation: The low-to-medium evaluation for vegetation is attributable to poor cues, and the disturbed and developed nature of the sites.

Geomorphology: The evaluation of medium-to-high is based on the availability of daily data, good cues, and the fact that the site is alluvial.

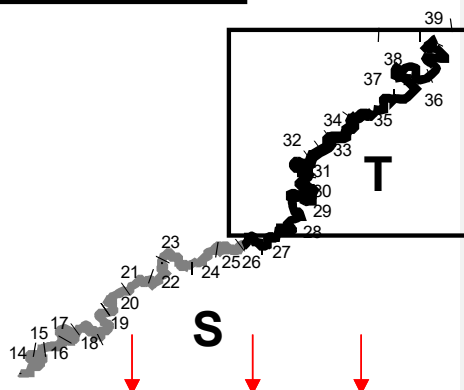
14 RU T. IFR 11. MOOI RIVER FALLS (Mooi River)

14.1 ECOLOGICAL CATEGORIES

4.1.1. Summary of Reserve scenarios

Three Ecological Reserve Scenarios were addressed for IFR 11. The recommended scenario is a B/C ERC. The alternative scenarios of a B and a C/D ERC were also considered.

Fig 14.1 Summary of the ERC scenarios



COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP	DOWN
WATER QUALITY	A/B	-	A/B	EIS	A/B		
GEOMORPH	C	-	C	H	C	B	D
RIPARIAN VEGETATION	C	-	C	I	C	B	D
FISH	B	0	B	S	B	B	C
AQUATIC INVERTS	B	0	B	H	B	B	C
ECOSTATUS	B/C	-	B/C	I	B/C	B	C/D

4.1.2. Criteria for Ecological Reserve Categories

Recommended Scenario: B/C ERC

Aquatic invertebrates (B)

- Marginal vegetation species:
Maintain mayflies as the dominant group of invertebrates.
- Flow dependent species:
Maintain a high diversity of mayflies including Oligoneuridae and Prosopistomatidae.
This is dependent on high (>0.7m/s) velocities in deep-water cracks between rocks (depth >0.5m), even if only in small portions of riffles.

Fish (B)

- Maintain existing species diversity and abundances.
- Ensure adequate refuge areas (winter) and breeding habitat (summer) to maintain a good population of *Amphilius natalensis*.

Riparian Vegetation (C)

- Maintain and improve distributions and abundances of grasses and sedges, especially *Setaria*, in the marginal areas on both banks and on islands.

Geomorphology (C)

- To maintain the river in its present state we need to keep the fine material moving through the bedrock rapids/riffles. Channel banks and floodplains must be maintained with regular overbank topping.

Alternative scenario: B ERC**Aquatic invertebrates (B)**

- As for the B/C ERC

Fish (B)

- As for the B/C ERC

Riparian Vegetation (B)

- Ensure wider riparian zone with improved abundances and distributions of *Salix* and *Juncus* on both banks and islands in the marginal areas.
- Improved abundances and species richness of other riparian taxa in the lower, main and upper riparian zone.
- Maintain and improve distributions and abundances of grasses and sedges especially *Setaria* in the marginal area on both banks and on islands.
- True improvement will also require the removal of alien species at the site.

Geomorphology

- As for the B/C ERC.

Alternative scenario: C/D ERC**Aquatic invertebrates (C)**

- Marginal vegetation species:
Maintain mayflies as the dominant group, with a lower abundance of organisms.
Less depth needed, with inundation of the vegetation.
- Flow-dependent species:
Oligoneuridae or one other family of mayfly may disappear due to reduced flow.
Sufficient velocity is still required to maintain the flow dependent species that are left.

Fish (C)

- All species present with a reduced abundance of *Amphilius natalensis*.
- Provide adequate *Amphilius* breeding and refuge habitat in riffles.
- Maintain fast-shallow habitat over at least 20% of cobble beds as *Amphilius* breeding and refuge habitat.

Riparian Vegetation (D)

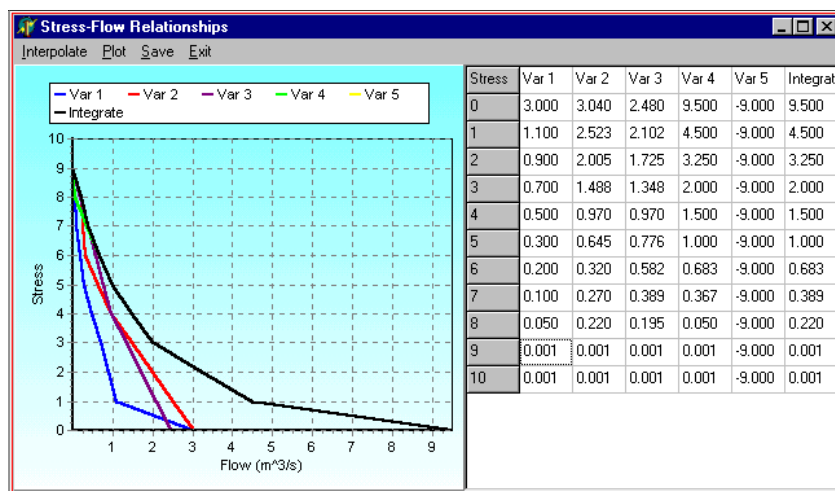
- Good abundances and healthy distributions of grasses (particularly *Setaria* and *Miscanthus*) and sedges in the marginal areas of both banks, and on islands.

- Other riparian species in limited abundances in lower riparian areas, and in healthy abundances in the middle and upper riparian zone.
- Maintain existing abundances and distribution of grasses and sedges in the marginal areas of both banks and islands.
- Maintain existing abundances of the other riparian species in the lower, middle and upper riparian zones.

Geomorphology (D)

- As for the B/C ERC.

Fig. 14.2 Critical curve for IFR 11



Var 1: Fish

Var 2: Flow Dependent Invertebrates

Var 3: Marginal Vegetation Invertebrates

Var 4: Riparian Vegetation 1

Var 5: Riparian Vegetation 2

14.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining Flow-Stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The Flow-Stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR11, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 14.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 14.2.

14.2.1 Invertebrates

Mayflies were previously noted (de Moor 1995) to be exceptionally diverse and worthy of protection in the Mooi River. For this reason, this investigation has concentrated on mayflies and not other taxa. Several mayfly species are also highly dependent on good flows, so they can be seen as critical indicators for this river. Another group of organisms that requires consideration, as they are particularly different to the mayfly communities, is that found in the marginal vegetation. This has been investigated, as small reductions in water depth rapidly expose this habitat and threaten its inhabitants. Many of these inhabitants will nevertheless survive in alternative substrates, but will be under threat.

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit (1,55 m³/s) as a fixed point. The stress index of 1 was set at 0.1m higher than observed, as this would result in significant inundation of extra vegetation habitat (using the hydraulic profile and tables to derive the characteristics). The indices of greater stress were derived similarly, but measuring the reduction in water level that would firstly leave just the bases of the *Juncus* reed inundated, and at higher stress levels, all habitat exposed.

The mayfly community investigation was dominated by the need to maintain high velocities in decreasing portions of the river. The habitat model and hydraulic data were used to determine the depths and velocities that would result in minimal stress to mayflies, going down to minimal depths and low velocities that would provide only remnants of their required habitat. Much of this investigation was based on the known presence of families such as Oligoneuridae, some Heptageniidae and some Baetidae, all of which require abundant clean, strong-flowing water over clean rocks.

14.2.2 Riparian Vegetation

Only *Juncus* was selected, using elevations and discharges associated with the ecological transect (i.e. 1.29 m below the habitat modelling elevation). The habitat modelling was used to locate *Juncus* distribution relative to various water levels.

Juncus spp. occurs in mats which cover a reasonably large area of the marginal zone. These mats are linked by rhizomes. Only the edges of these mats, which are located adjacent to the river's edge, are crucial, because the maximum stress levels of these mats would only occur once the water levels had dropped below the roots in these areas, i.e. at the 0.05m level.

The *Juncus* was found to be quite insensitive to reductions in water quantity, since its roots extended well into the level of the main channel, and it would therefore still remain relatively unstressed until the river had almost stopped flowing.

14.3 STRESS DURATION CURVES (PROFILES)

14.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 14.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 11, stress indices as determined were accepted and no changes were required.

14.3.2 Recommended stress profiles for each Reserve scenario

The recommended B/C scenario and the alternative C/D and B scenarios were estimated using the Desktop model and are shown in Figures 14.3 – 14.8 as the green, purple and yellow lines respectively. The observed (historical) hydrology as converted into stress, is reflected by the red line in Figures 14.3 – 14.8 (described as Present Day). Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 14.3 - 14.8. According to the specialists' evaluation, the Desktop-generated scenarios were adjusted (see Figures 14.9 - 14.10). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

14.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated B/C scenario consisted of Maintenance Low Flows of 22.1% MAR which remained unchanged, and Drought Low Flows of 8.6% MAR, which were adjusted to 5.4% MAR. The generated B scenario consisted of Maintenance Low Flows of 27.7% MAR which

remained unchanged, and Drought Low Flows of 8.6% MAR, which were adjusted to 5.4% MAR. The generated C/D scenario consisted of Maintenance Low Flows of 12.4% MAR, which remained unchanged, and Drought Low Flows of 8.6% MAR, which were adjusted to 5.4%. The Maintenance and Drought Low Flows were manually changed mainly in the wet season to better fit the specialists' requirements for stress patterns.

Fig. 14.3 IFR 11 – Stress duration curve for recommended scenario of a B/C ERC: Dry Season

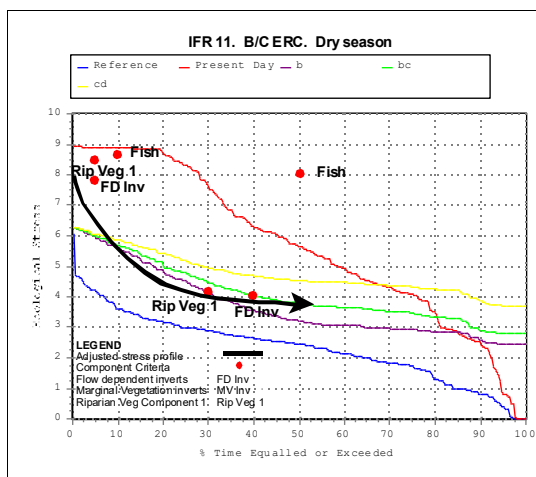


Fig. 14.4 IFR 11 - Stress duration curve for recommended scenario of a B/C ERC: Wet Season

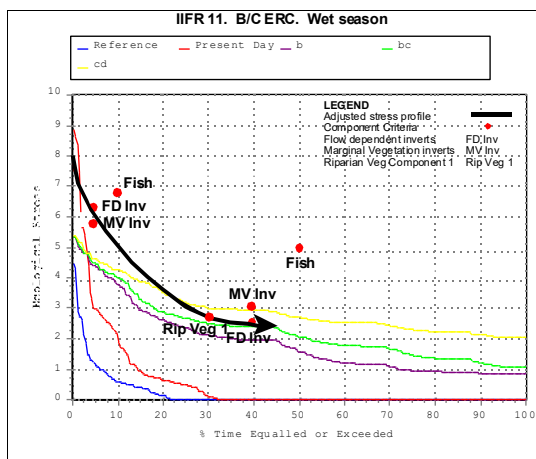


Fig. 14.5 IFR 11 – Stress duration curve for alternative scenario of a B ERC: Dry Season

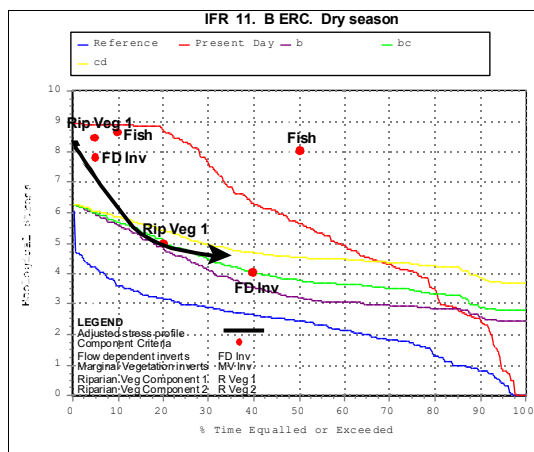


Fig. 14.6 IFR11 – Stress duration curve for alternative scenario of a B ERC: Wet Season

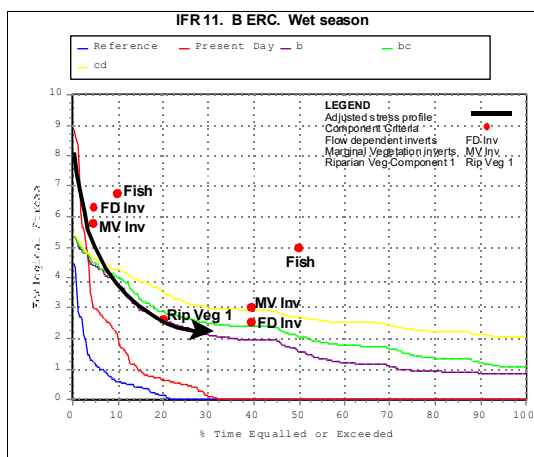


Fig. 14.7 IFR11 – Stress duration curve for alternative scenario of a C/D ERC: Dry Season

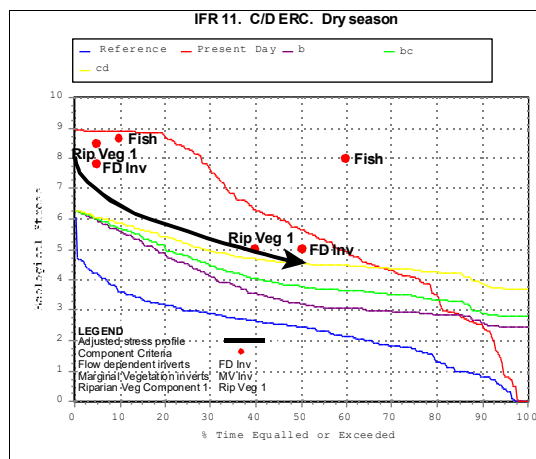
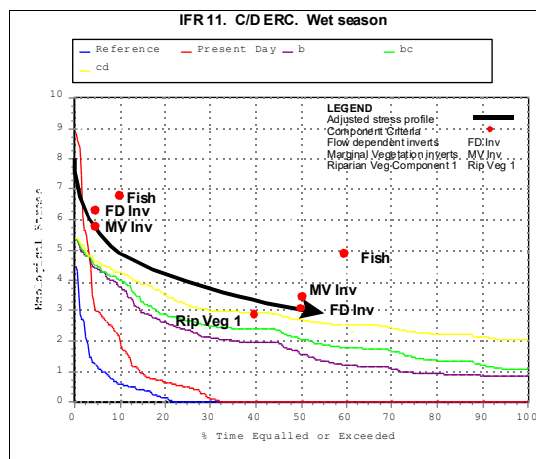


Fig. 14.8 IFR11 – Stress duration curve for alternative scenario of a C/D ERC: Wet Season



14.3.4 Final stress profiles for IFR 11

Fig. 14.9 IFR 11 - Final stress profiles: Dry Season

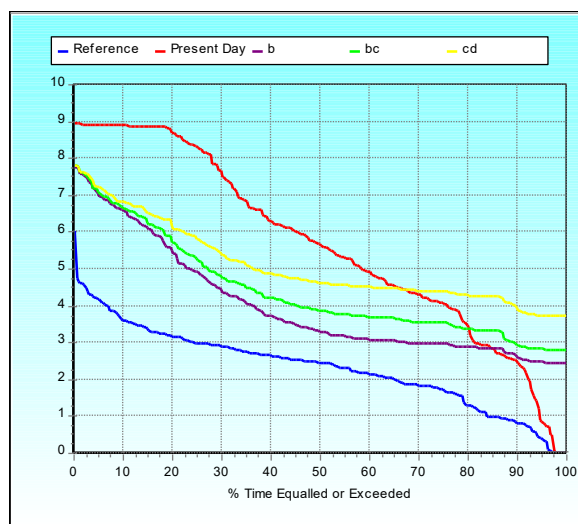
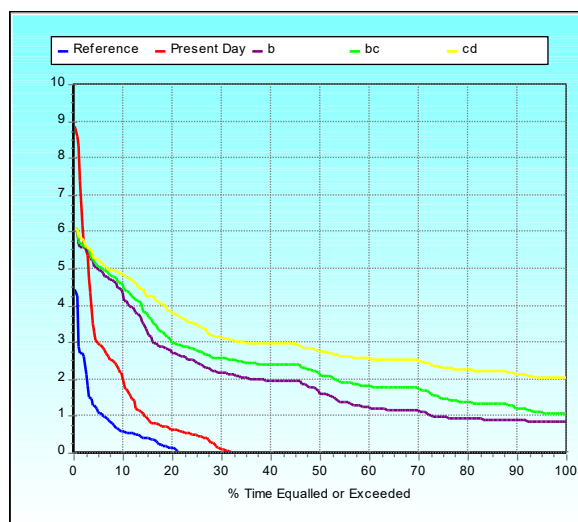


Fig. 14.10 IFR 11 - Final stress profiles: Wet Season



14.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 14.1. The number of events for each Flood Class required for B/C, B and C/D ERCs are also summarised in Table 14.1.

Table 14.1 A summary of the Flood Class ranges for IFR 11, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s				
	I	II	III	IV	V
Fish		9-12 12-20	20-35		
Invertebrates	2-5	10-15		30-60	
Vegetation	3-9	9-38		38-90	90-180
Geomorphology			23-35	35-78	78-208
Integrated	3-9	10-19	20-34	35-89	90-208
Geometric mean*		13	26	56	137
Recommended high flow events					
No of events for B/C ERC (Recommended scenario)	3 spring 1 autumn	4	3	1 in 3 years	1 in 4 years
No of events for B ERC (Alternative scenario)	5 (1 in spring, 1 in autumn)	4	3	1 in 2 years	1 in 3 years
No of events for C/D ERC (Alternative scenario)	3 (1 in spring)	3	2	1 in 4 years	1 in 5 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 90 - 208) specified by the geomorphologist were reduced to the lower discharge values (e.g. 90) for the Desktop model to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 14.2 and 14.3.

B - High flow maintenance was 9.3%, increased to 14.1%

B/C - High flow maintenance was 8.4%, increased to 14.1%

C/D - High flow maintenance was 7.1%, increased to 11.1%

Table 14.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a B/C ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	28	III	28	V incl. 1-IV	90	III	28		
Duration (days)	3		3		6		3			
Freshet size (m³/s)	II	15	I & II	6 + 15	II	15	II	15	I	6
Duration (days)	3		3		3		3		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)			I	6	I	6				
Duration (days)			2		2					

Table 14.3 Adjusted flood sizes as used in the Desktop model for the alternative scenario of a B ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	28	III	28	V incl. 1- IV	90	III	28		
Duration (days)	3		3		6		3			
Freshet size (m³/s)	I & II	6 + 15	I & II	6 + 15	I & II	6 + 15	II	15	I	6
Duration (days)	3		3		3		3		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)			I	6	I	6				
Duration (days)			2		2					

Table 14.4 Adjusted flood sizes as used in the Desktop (monthly) model for the alternative scenario of a C/D ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	28	III	28	V incl. 1- IV	80	III	28		
Duration (days)	3		3		6		3			
Freshet size (m³/s)	I	6	II	15	I	6	II	15	I	6
Duration (days)	2		3		2		3		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)					I	6				
Duration (days)					2					

14.5 FINAL RESULTS

14.5.1 IFR table for recommended scenario: B/C ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	326.524
S.Dev.	=	149.736
CV	=	0.459
Q75	=	7.620
Q75/MMF	=	0.280
BFI Index	=	0.451
CV(JJA+JFM) Index	=	1.345
Total IFR	=	118.376 (36.25 %MAR)
Maint. Lowflow	=	72.264 (22.13 %MAR)
Drought Lowflow	=	17.667 (5.41 %MAR)
Maint. Highflow	=	46.112 (14.12 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	Total Flows
				Maint.	Drought	Maint.	Maint.
Oct	14.524	19.049	1.312	4.122	0.937	0.726	4.848
Nov	22.258	18.754	0.843	4.756	1.140	0.726	5.482
Dec	38.108	29.187	0.766	6.053	1.741	6.687	12.741
Jan	54.597	36.226	0.664	7.655	2.143	7.620	15.275
Feb	59.563	40.254	0.676	8.755	2.322	22.939	31.694

Mar	51.770	32.093	0.620	9.050	2.411	6.687	15.738
Apr	30.905	20.006	0.647	8.206	1.866	0.726	8.932
May	16.651	14.230	0.855	6.517	1.607	0.000	6.517
Jun	10.505	5.876	0.559	5.047	1.166	0.000	5.047
Jul	8.447	4.780	0.566	4.358	0.937	0.000	4.358
Aug	7.906	7.505	0.949	3.873	0.670	0.000	3.873
Sep	11.289	23.235	2.058	3.872	0.726	0.000	3.872

14.5.2 IFR table for alternative scenario: B ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	326.524
S.Dev.	=	149.736
CV	=	0.459
Q75	=	7.620
Q75/MMF	=	0.280
BFI Index	=	0.451
CV(JJA+JFM) Index	=	1.345
Total IFR	=	137.401 (42.08 %MAR)
Maint. Lowflow	=	90.356 (27.67 %MAR)
Drought Lowflow	=	17.533 (5.37 %MAR)
Maint. Highflow	=	47.045 (14.41 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows Total Flows	
				Maint.	Drought	Maint.	Maint.
Oct	14.524	19.049	1.312	5.073	0.804	0.726	5.799
Nov	22.258	18.754	0.843	5.892	1.140	0.726	6.617
Dec	38.108	29.187	0.766	7.569	1.741	6.687	14.257
Jan	54.597	36.226	0.664	9.640	2.143	7.620	17.260
Feb	59.563	40.254	0.676	11.065	2.322	23.872	34.938
Mar	51.770	32.093	0.620	11.447	2.411	6.687	18.135
Apr	30.905	20.006	0.647	10.355	1.866	0.726	11.081
May	16.651	14.230	0.855	8.172	1.607	0.000	8.172
Jun	10.505	5.876	0.559	6.267	1.166	0.000	6.267
Jul	8.447	4.780	0.566	5.378	0.937	0.000	5.378
Aug	7.906	7.505	0.949	4.749	0.670	0.000	4.749
Sep	11.289	23.235	2.058	4.749	0.726	0.000	4.749

14.5.3 IFR table for alternative scenario: C/D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	326.524
S.Dev.	=	149.736
CV	=	0.459
Q75	=	7.620
Q75/MMF	=	0.280
BFI Index	=	0.451
CV(JJA+JFM) Index	=	1.345
Total IFR	=	76.824 (23.53 %MAR)
Maint. Lowflow	=	40.623 (12.44 %MAR)
Drought Lowflow	=	17.667 (5.41 %MAR)
Maint. Highflow	=	36.202 (11.09 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows Total Flows	
				Maint.	Drought	Maint.	Maint.
Oct	14.524	19.049	1.312	2.405	0.937	0.000	2.405

Nov	22.258	18.754	0.843	2.732	1.140	0.726	3.458
Dec	38.108	29.187	0.766	3.402	1.741	3.059	6.460
Jan	54.597	36.226	0.664	4.227	2.143	6.687	10.914
Feb	59.563	40.254	0.676	4.795	2.322	19.043	23.837
Mar	51.770	32.093	0.620	4.947	2.411	6.687	11.634
Apr	30.905	20.006	0.647	4.513	1.866	0.000	4.513
May	16.651	14.230	0.855	3.640	1.607	0.000	3.640
Jun	10.505	5.876	0.559	2.882	1.166	0.000	2.882
Jul	8.447	4.780	0.566	2.528	0.937	0.000	2.528
Aug	7.906	7.505	0.949	2.277	0.670	0.000	2.277
Sep	11.289	23.235	2.058	2.276	0.726	0.000	2.276

14.5.4 IFR rule table for recommended scenario: B/C ERC

Data are given in m³/s mean monthly flow

Month	% Points								
	10%	20%	30%	40%	50%	60%	70%	80%	99%
Oct	2.188	2.180	2.151	2.086	1.953	1.720	1.370	0.947	0.401
Nov	2.455	2.451	2.430	2.383	2.289	2.110	1.802	1.346	0.465
Dec	7.870	7.214	6.637	6.117	5.591	4.674	3.990	2.960	0.958
Jan	9.707	8.940	8.264	7.654	7.034	5.942	5.093	3.787	1.195
Feb	20.635	18.462	16.588	14.946	13.369	10.648	8.934	6.376	1.791
Mar	9.910	9.202	8.569	7.979	7.351	6.253	5.330	3.956	1.311
Apr	3.923	3.910	3.858	3.741	3.506	3.091	2.468	1.715	0.744
May	2.927	2.913	2.871	2.779	2.600	2.293	1.844	1.312	0.634
Jun	2.175	2.162	2.128	2.056	1.918	1.684	1.346	0.949	0.446
Jul	1.907	1.892	1.859	1.790	1.661	1.448	1.149	0.804	0.371
Aug	1.668	1.658	1.631	1.572	1.459	1.268	0.992	0.669	0.259
Sep	1.683	1.674	1.648	1.592	1.483	1.295	1.020	0.694	0.280

Reserve flows without High Flows

Oct	1.883	1.877	1.852	1.796	1.685	1.487	1.191	0.833	0.517	0.371
Nov	2.156	2.152	2.134	2.094	2.012	1.857	1.592	1.197	0.733	0.437
Dec	2.859	2.856	2.834	2.786	2.686	2.494	2.161	1.660	1.066	0.685
Jan	3.800	3.800	3.774	3.715	3.589	3.341	2.900	2.221	1.402	0.874
Feb	4.001	3.997	3.965	3.893	3.745	3.458	2.961	2.218	1.359	0.887
Mar	4.542	4.535	4.497	4.415	4.248	3.931	3.386	2.577	1.626	1.019
Apr	3.628	3.616	3.568	3.461	3.246	2.865	2.295	1.605	0.997	0.715
May	2.927	2.913	2.871	2.779	2.600	2.293	1.844	1.312	0.849	0.634
Jun	2.175	2.162	2.128	2.056	1.918	1.684	1.346	0.949	0.606	0.446
Jul	1.907	1.892	1.859	1.790	1.661	1.448	1.149	0.804	0.509	0.371
Aug	1.668	1.658	1.631	1.572	1.459	1.268	0.992	0.669	0.389	0.259
Sep	1.683	1.674	1.648	1.592	1.483	1.295	1.020	0.694	0.411	0.280

Natural Duration curves

Oct	10.926	7.126	5.278	4.279	3.492	2.793	1.983	1.825	1.474	1.154
Nov	16.734	12.922	9.913	7.844	5.828	5.335	4.484	3.334	2.292	1.165
Dec	35.143	21.092	16.377	14.063	11.578	10.849	7.967	5.860	3.611	1.424
Jan	41.295	32.751	27.415	21.863	18.355	16.387	12.408	9.219	7.403	4.733
Feb	48.227	33.072	24.272	21.629	19.052	14.262	11.932	11.033	8.255	6.149
Mar	36.876	28.555	25.169	21.123	17.283	16.100	13.893	12.963	9.846	7.097
Apr	18.940	14.449	12.929	11.682	9.610	8.285	7.620	7.183	5.253	2.976
May	9.772	7.265	6.667	5.702	5.081	4.834	4.356	3.735	3.437	1.998
Jun	6.351	4.439	4.040	3.610	3.386	3.293	2.972	2.602	2.360	1.665
Jul	5.162	3.731	3.407	3.156	2.782	2.677	2.465	2.234	1.937	1.458
Aug	4.813	3.495	2.894	2.554	2.360	2.154	1.964	1.871	1.695	1.381
Sep	7.292	4.215	3.017	2.587	2.053	1.908	1.803	1.688	1.352	1.157

14.5.5 IFR rule table for alternative scenario: B ERC

Data are given in m³/s mean monthly flow

	% Points									
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.538	2.529	2.493	2.413	2.251	1.966	1.537	1.020	0.563	0.352
Nov	2.853	2.848	2.822	2.767	2.654	2.439	2.071	1.523	0.879	0.468
Dec	8.439	7.783	7.201	6.668	6.116	5.149	4.377	3.218	1.842	0.961
Jan	10.500	9.733	9.050	8.424	7.770	6.611	5.643	4.155	2.358	1.200
Feb	22.160	19.899	17.941	16.215	14.540	11.643	9.744	6.911	3.633	1.833
Mar	10.877	10.167	9.523	8.911	8.237	7.053	5.981	4.387	2.514	1.317
Apr	4.712	4.696	4.631	4.486	4.193	3.675	2.899	1.960	1.132	0.749
May	3.544	3.526	3.473	3.356	3.130	2.740	2.171	1.497	0.910	0.638
Jun	2.607	2.592	2.549	2.459	2.287	1.994	1.572	1.076	0.648	0.449

Jul	2.270	2.252	2.211	2.125	1.966	1.704	1.334	0.907	0.543	0.374
Aug	1.975	1.963	1.929	1.858	1.720	1.488	1.153	0.759	0.419	0.261
Sep	1.993	1.982	1.951	1.882	1.748	1.519	1.184	0.787	0.442	0.282

Reserve flows without High Flows

Oct	2.239	2.231	2.199	2.129	1.987	1.737	1.362	0.908	0.508	0.322
Nov	2.560	2.556	2.533	2.484	2.383	2.192	1.865	1.378	0.805	0.439
Dec	3.428	3.425	3.397	3.336	3.210	2.968	2.548	1.917	1.168	0.689
Jan	4.593	4.593	4.560	4.485	4.325	4.011	3.450	2.589	1.549	0.879
Feb	4.850	4.845	4.804	4.713	4.525	4.160	3.528	2.584	1.492	0.892
Mar	5.508	5.500	5.451	5.347	5.134	4.730	4.038	3.008	1.798	1.025
Apr	4.423	4.408	4.347	4.211	3.937	3.454	2.728	1.851	1.078	0.720
May	3.544	3.526	3.473	3.356	3.130	2.740	2.171	1.497	0.910	0.638
Jun	2.607	2.592	2.549	2.459	2.287	1.994	1.572	1.076	0.648	0.449
Jul	2.270	2.252	2.211	2.125	1.966	1.704	1.334	0.907	0.543	0.374
Aug	1.975	1.963	1.929	1.858	1.720	1.488	1.153	0.759	0.419	0.261
Sep	1.993	1.982	1.951	1.882	1.748	1.519	1.184	0.787	0.442	0.282

14.5.6 IFR rule table for alternative scenario: C/D ERC

Data are given in m³/s mean monthly flow

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.404	1.400	1.383	1.345	1.268	1.133	0.930	0.685	0.468	0.368
Nov	1.998	1.995	1.978	1.943	1.870	1.731	1.494	1.142	0.727	0.463
Dec	4.422	4.121	3.853	3.605	3.343	2.884	2.501	1.925	1.243	0.805
Jan	7.955	7.282	6.694	6.173	5.657	4.755	4.110	3.118	1.921	1.149
Feb	16.713	14.911	13.361	12.010	10.728	8.521	7.188	5.197	2.895	1.631
Mar	8.667	7.961	7.341	6.780	6.211	5.224	4.491	3.402	2.121	1.303
Apr	2.549	2.542	2.512	2.444	2.308	2.068	1.707	1.271	0.887	0.708
May	2.097	2.088	2.061	2.002	1.888	1.691	1.404	1.063	0.767	0.629
Jun	1.596	1.588	1.565	1.517	1.425	1.269	1.043	0.778	0.549	0.443
Jul	1.427	1.417	1.394	1.346	1.257	1.111	0.904	0.666	0.463	0.368
Aug	1.260	1.253	1.233	1.191	1.111	0.975	0.779	0.548	0.349	0.256
Sep	1.268	1.262	1.244	1.204	1.127	0.994	0.800	0.570	0.370	0.277

Reserve flows without High Flows

Oct	1.404	1.400	1.383	1.345	1.268	1.133	0.930	0.685	0.468	0.368
Nov	1.645	1.643	1.629	1.601	1.544	1.435	1.248	0.969	0.642	0.433
Dec	2.130	2.128	2.114	2.081	2.015	1.887	1.664	1.330	0.934	0.681
Jan	2.771	2.771	2.754	2.716	2.634	2.473	2.185	1.744	1.211	0.867
Feb	2.905	2.903	2.882	2.835	2.739	2.552	2.229	1.746	1.187	0.880
Mar	3.298	3.294	3.269	3.216	3.107	2.901	2.548	2.023	1.405	1.011
Apr	2.549	2.542	2.512	2.444	2.308	2.068	1.707	1.271	0.887	0.708
May	2.097	2.088	2.061	2.002	1.888	1.691	1.404	1.063	0.767	0.629
Jun	1.596	1.588	1.565	1.517	1.425	1.269	1.043	0.778	0.549	0.443
Jul	1.427	1.417	1.394	1.346	1.257	1.111	0.904	0.666	0.463	0.368
Aug	1.260	1.253	1.233	1.191	1.111	0.975	0.779	0.548	0.349	0.256
Sep	1.268	1.262	1.244	1.204	1.127	0.994	0.800	0.570	0.370	0.277

14.6 GEOMORPHOLOGICAL CONSEQUENCES OF B/C, B AND C/D SCENARIO

Bed maintenance

B category requirement is four events. This should improve the present condition by ensuring regular mobilisation of smaller bed material.

C category requirement is three events. This will keep the channel bed in its present condition, with a temporary accumulation of material.

D category requirement is two events. This would cause a long-term accumulation of finer bed material. Interstitial fining and some temporary loss of habitat would be expected.

Bench maintenance

B category requirement is two events. This should ensure the continued maintenance of channel margins and benches.

C and D category requirement is one event. This will ensure that there is no long-term loss of benches and lateral morphology.

Channel maintenance

B category requirement is one event every two years. A very important component for keeping the channel clean and open and for maintaining habitat diversity.

C category requirement is one event every three years. This will allow temporary aggradation, sediment accumulation, and vegetation encroachment as is witnessed at present.

D category requirement is one event every four years. As with category C this will have the same effect, but over a longer period of time.

Macro Channel and bed mobilisation

B category requirement is one event every three years. This ensures the broad channel is maintained. Sediments are deposited over the bank and coarse material on the bed is moved. Every three years is quite a frequent event and similar to a natural condition.

C category requirement is one event every four years. Broad channel maintenance does not occur as regularly and as a result there may be some changes within the macro channel. Encroaching vegetation may stabilise areas and change general morphology. This has already happened and is likely to remain as it is.

D category requirement is 1 event every 5 years. Broad channel maintenance does not occur as regularly as it does at present. This is likely to lead to changes in the macro channel morphology

Conclusion

As with all sites, any removal of flow will lead to some geomorphological change. This site is relatively stable and consists of very coarse material within an incised channel. Recommended flows for the C category will keep the channel in its present condition within the 20-year period.

14.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 14.5 IFR confidence table for recommended scenario of a B/C ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
11	Low flows	4	4	4	-
	High flows	4	4	4	4

The confidence is medium-to-high for both low and high flows. This confidence evaluation is based on the following:

Invertebrate evaluation: Good data availability.

Riparian vegetation: Good vegetation cues.

Fish: Presence of *Amphilius natalensis* and a good understanding of its flow requirements.

Geomorphology: Sediment transport model is available, but no daily data. Presence of reasonable geomorphological cues.

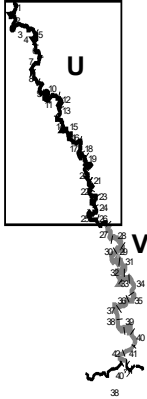
15 RU U. IFR 13. UPPER BUFFALO (Buffalo River)

15.1 ECOLOGICAL CATEGORIES

15.1.1 Summary of ERC scenarios

Two Ecological Reserve Scenarios were addressed for IFR 13. The recommended scenario is a D ERC. The alternative scenario of a C ERC was also evaluated.

Fig. 15.1 Summary of ERC scenarios



COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	UP
WATER QUALITY	C	0	C/D	EIS MODERATE SI	C	
GEOMORPH	D/E	-	D/E		D	D
RIPARIAN VEGETATION	D/E	-	E		D	D
FISH	C	0	C/D	MODERATE	C	B
AQUATIC INVERTS	C/D	0	D		C/D	B/C
ECOSTATUS	D	-	D/E		D	C

15.1.2 Criteria for the Ecological Reserve Categories

Recommended Scenario: D ERC

Aquatic invertebrates (C/D)

- Marginal vegetation species:
Abundant organisms in vegetation, especially in *Potamogeton*, including Baetidae and Elmidae should be present.
- Flow-dependent species:
Good diversity of mayflies and also Hydropsychidae and Perlidae should be present.

Fish (C)

- Maintain existing species diversity and facilitate recovery of populations of all species after a severe fish-kill.

Riparian Vegetation (D)

- Maintain extensive clumps of both *Setaria* and *Juncus* in the marginal areas of both banks and islands, by the provision of sufficient low flows and elevated flows throughout the year.
- Maintain existing populations of *Salix mucronata* and other riparian species in the main and upper riparian areas by the provision of adequate high/elevated flows during summer.
- Provide adequate flows to promote the maintenance of existing marginal and riparian species, provided that the existing non-flow related activities are addressed through appropriate means.

Geomorphology (D)

- Flow at this site is not an issue for geomorphology. If non-flow related issues (i.e. catchment problems) are addressed, a D would be achieved. The flow requirements are therefore set as if the catchment problems are addressed and within that context, to maintain the geomorphology features presently in the D/E state.

Alternative Scenario: C ERC

Aquatic invertebrates (B/C)

- Marginal vegetation species:
At least two mayfly families must be present.
- Flow-dependent species:
Heptageniidae should be present, together with abundant Perlidae.
- Flow velocities required for longer durations as recommended for the D ERC.

Fish (B)

- Existing species diversity with a higher abundance of all species.
- Maintain species diversity with a high density of all species.
- Avoid extinction of *L. natalensis*. Provide fast, shallow conditions over 80% of available gravel beds during summer.

Riparian Vegetation (D)

- Riparian and marginal vegetation is more abundant and with improved distributions, due to the improved recruitment and spread of *Salix* and *Juncus* in the marginal areas. This however, is likely to be achieved only through addressing non-flow related problems through appropriate activities.
- As for the D ERC.

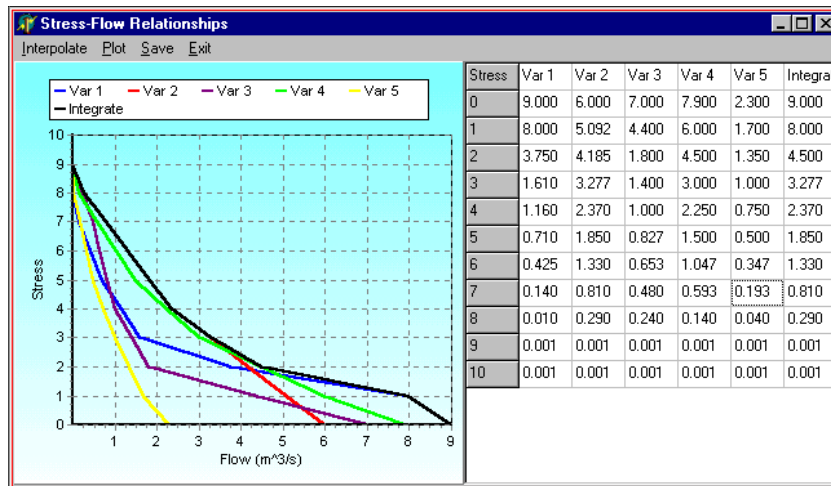
Geomorphology (D)

- As for the D ERC.

15.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining flow-stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The flow-stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 13 which is presented in Appendix G. The numerical flow-stress relationships are provided in Figure 15.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 15.2.

Fig. 15.2 Critical curve for IFR 13



Var 1: Fish
 Var 2: Flow Dependent Invertebrates
 Var 3: Marginal Vegetation Invertebrates
 Var 4: Riparian Vegetation 1
 Var 5: Riparian Vegetation 2

15.2.1 Invertebrates

The marginal vegetation community was investigated by using the observed habitat on the day of the field visit (1,8 m³/s) as a reference point. The stress index of 0 was set, by making use of the hydraulic data, so that there would be at least 0.1m inundation of the *Juncus*. The indices of greater stress were derived similarly, by measuring the reduction in water level that would leave just the bases of the *Juncus* inundated and lastly the bases of the *Phragmites*. Note that this assessment for marginal vegetation communities applies only for the wet season, as during dry seasons it can be expected that flows will recede from the vegetation.

The flow-dependent community investigation was dominated by the need to maintain high water velocities over quantities of stone, which was impacted and of poor quality. The hydraulic data were used to determine the depths and velocities that would produce minimal stress to rheophilic species. Higher stresses were determined by anticipating minimal depths and velocities that would provide only remnants of their required habitat. Much of this investigation was based on the known presence of families such as Perlidae and Hydropsychidae which require abundant clean, strong flowing water over clean rocks.

15.2.2 Riparian Vegetation

Two components were selected, using elevations and discharges associated with the ecological transect for the hydraulic modelling.

- *Salix* (adults) - applicable mainly to summer
Salix adults were identified at the 0.65m water level. Root lengths of 0.6m used, corresponding to water levels of 0.05m at the root bases.
- *Juncus* (adults) – Applicable all year round
Juncus adults were found on the banks as well as on islands. The elevation for the island individuals was averaged at the 0.45m level. The rooting depth of 0.3m was used which corresponded with a maximum rooting depth of 0.15m. It is felt that

since *Juncus* is in contact with the water throughout the year and is not necessarily dormant during winter, that this curve could be incorporated in the critical (composite) curve.

15.3 STRESS DURATION CURVES (PROFILES)

15.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 15.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions.

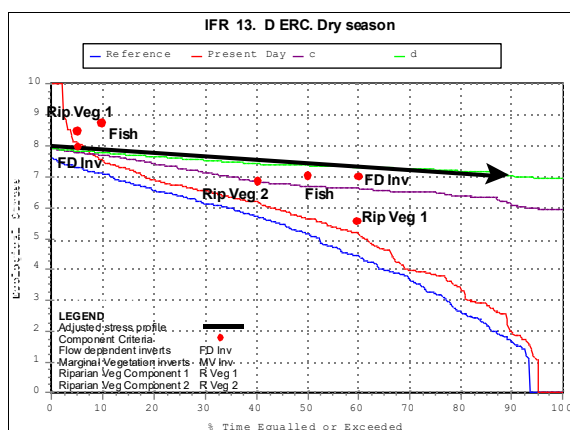
15.3.2 Recommended stress profiles for each Reserve scenario

The recommended scenario of a D and the alternative scenario of a C were estimated using the Desktop model and are shown in Figures 15.3 – 15.6 as the purple and green lines respectively. The present day hydrology as converted into stress, is reflected by the red line in Figures 15.3 – 15.6. Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 15.3 - 15.6. According to the specialists' evaluations, the Desktop generated scenarios were adjusted (see Figures 15.7 – 15.8). These adjusted scenarios were then checked with specialists to ensure that they were representative of their component requirements.

15.3.3 Process to adjust the Desktop output to fit specialist requirements

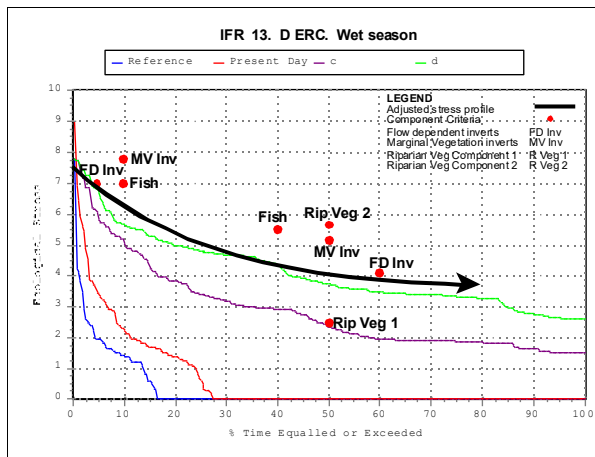
The generated C scenario consisted of Maintenance Low Flows of 9.19% which remained unchanged; and of Drought Low Flows of 3.56%, which remained unchanged. The generated D scenario consisted of Maintenance Low Flows of 3.93% which remained unchanged, and of Drought Low Flows of 3.56% which remained unchanged. The objective was to reduce wet season low flows at 40% (see Figure 15.3).

Fig. 15.3 IFR 13 – Stress duration curve for recommended scenario of a D ERC: Dry Season



Note that the vegetation points were not used in setting the requirements (represented by the hand drawn line). This is due to the low confidence in the evaluation as marginal vegetation responds quickly to flow changes. The point was therefore seen as an outlier and ignored.

Fig. 15.4 IFR 13 – Stress duration curve for recommended scenario of a D ERC: Wet Season



The fish point at a duration of 10% lay on the natural line and it is likely that the fish requirements for a C ERC are similar to natural (Figure 15.5). It was agreed that this point should not be considered. The adjusted line was not drawn in to coincide with Rip Veg 2. The confidence in the vegetation evaluation is low, as marginal vegetation responds quickly to flow changes. Taking this into account, the point was seen as an outlier and ignored.

Fig. 15.5 IFR 13 - Stress-duration curve for alternative scenario of a C ERC: Dry Season

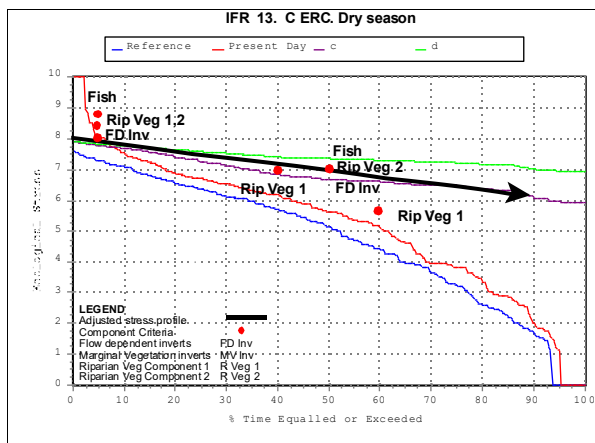
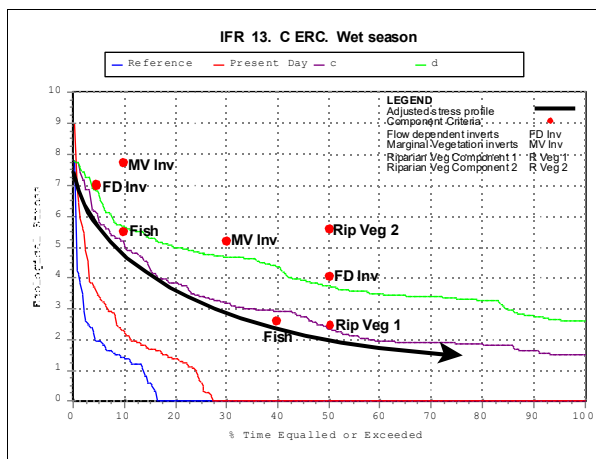


Fig. 15.6 IFR 13 - Stress-duration curve for alternative scenario of a C ERC: Wet Season



15.3.4 Final stress profiles for IFR 13

Fig. 15.7 IFR 13 – Final stress profiles: Dry Season

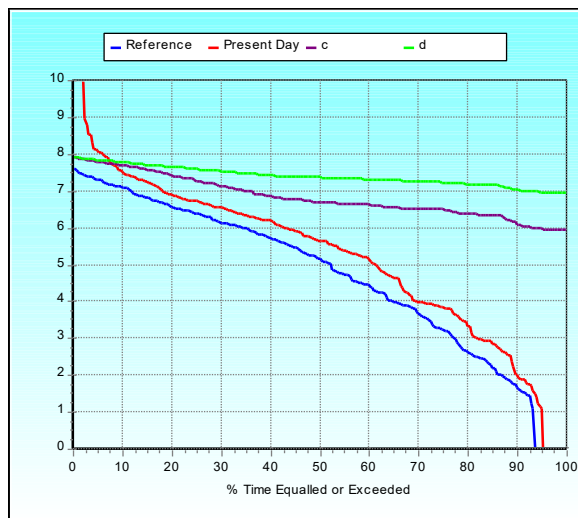
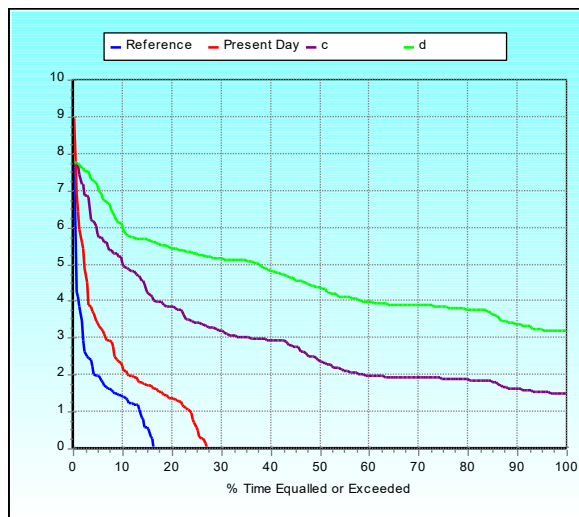


Fig. 15.8 IFR 13 - Final stress profiles: Wet Season



15.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 15.1. The number of events for each Flood Class required for an ERC of and are also summarised in Table 15.1.

Table 15.1 A summary of the Flood Class ranges for IFR 13, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s						
	I	II	III	IV	V	VI	VII
Fish		5-10	10-15 10-20				
Invertebrates	2-3	5-10	20-30				
Vegetation		4-12	12-40	40-90	90-160		
Geomorphology					80-115	115-200	201-381
Integrated	2-3	4-11	12-39	40-89	90-114	115-200	201-381
Geometric mean*				60	100	150	275
Recommended high flows							
No of events for D ERC (Recommended scenario)	2	3	4	2	1	1 in 3 years	1 in 4 years
No of events for C ERC (Alternative scenario)	2	4	5	2	1	1 in 3 years	1 in 4 years

NOTE: The number of events represent those required during the wet season (summer) unless otherwise stated.

NOTE: For geomorphology Flood Class VI: It is important that the large, infrequent floods (1:20 year events) are allowed to pass through the system unimpeded.

* A range of flows for each flood class could not be incorporated within the results. Thus, one value, the geometric mean, was used. The geometric mean is the square root of the multiplier of the upper and lower flows in each range.

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher discharge values (e.g. 58 to 100) specified by the geomorphologist were reduced to the lower values (e.g. 50) for the Desktop model, to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated for low assurances, and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 15.2 and 15.3.

Table 15.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a D ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	25	IV	60	VII incl. V, VI	190	IV	60		
Duration (days)	3		4		6		4			
Freshet size (m³/s)	I	2.5	II + III	8 + 25	III	25	II + III	8 + 25	III	25
Duration	2		3		3		3		3	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	2.5	II	8	II	8				
Duration (days)	2		2		2					

Table 15.3 Adjusted flood sizes as used in the Desktop Model for the recommended scenario of a C ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	III	25	IV	60	VII incl. V, VI	190	IV	60		
Duration (days)	3		4		6		4			
Freshet size (m³/s)	II	8	I + III	2.5 + 25	III	25	III	25	I	2.5
Duration (days)	2		3		3		3		2	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)			II	8	II	8				
Duration (days)			2		2					

15.5 FINAL RESULTS

15.5.1 IFR table for recommended scenario: D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	695.054
S.Dev.	=	407.128
CV	=	0.586
Q75	=	5.940
Q75/MMF	=	0.103
BFI Index	=	0.297
CV(JJA+JFM) Index	=	3.230
Total IFR	=	111.762 (16.08 %MAR)
Maint. Lowflow	=	27.340 (3.93 %MAR)
Drought Lowflow	=	24.766 (3.56 %MAR)
Maint. Highflow	=	84.421 (12.15 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : N.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High Flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	36.582	69.021	1.887	1.358	1.120	0.968	2.326
Nov	66.153	71.439	1.080	1.970	1.249	0.968	2.938
Dec	98.893	106.932	1.081	2.735	1.120	4.856	7.590
Jan	147.372	137.700	0.934	3.900	3.900	15.163	19.063
Feb	151.123	131.459	0.870	4.548	4.548	47.390	51.938
Mar	90.577	73.666	0.813	4.047	4.047	14.774	18.821
Apr	39.599	47.456	1.198	2.885	2.885	0.302	3.187
May	18.170	28.922	1.592	1.851	1.851	0.000	1.851
Jun	8.839	12.665	1.433	1.164	1.164	0.000	1.164
Jul	9.740	28.272	2.903	0.970	0.970	0.000	0.970
Aug	10.459	28.620	2.736	0.908	0.908	0.000	0.908
Sep	17.546	51.319	2.925	1.006	1.006	0.000	1.006

15.5.2 IFR table for alternative scenario: C ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	695.054
S.Dev.	=	407.128
CV	=	0.586
Q75	=	5.940
Q75/MMF	=	0.103
BFI Index	=	0.297
CV(JJA+JFM) Index	=	3.230
Total IFR	=	154.145 (22.18 %MAR)
Maint. Lowflow	=	63.848 (9.19 %MAR)
Drought Lowflow	=	24.766 (3.56 %MAR)
Maint. Highflow	=	90.297 (12.99 %MAR)

Monthly Distributions (Mill. cu. m.)

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows Maint.	High Flows Drought	Total Flows Maint.	Total Flows Maint.
Oct	36.582	69.021	1.887	3.075	1.120	1.244	4.319
Nov	66.153	71.439	1.080	4.570	1.249	1.244	5.814
Dec	98.893	106.932	1.081	6.434	1.120	4.190	10.624
Jan	147.372	137.700	0.934	9.278	3.900	16.019	25.297
Feb	151.123	131.459	0.870	10.862	4.548	47.390	58.253
Mar	90.577	73.666	0.813	9.642	4.047	16.019	25.661
Apr	39.599	47.456	1.198	6.799	2.885	3.888	10.687
May	18.170	28.922	1.592	4.277	1.851	0.000	4.277
Jun	8.839	12.665	1.433	2.602	1.164	0.000	2.602
Jul	9.740	28.272	2.903	2.124	0.970	0.000	2.124
Aug	10.459	28.620	2.736	1.974	0.908	0.000	1.974
Sep	17.546	51.319	2.925	2.211	1.006	0.302	2.513

15.5.3 IFR13 rule table for recommended scenario: D ERC

Data are given in m³/s mean monthly flow

Month	% Points								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Oct	1.502	1.492	1.470	1.423	1.337	1.195	0.995	0.765	0.567
Nov	1.830	1.818	1.789	1.730	1.619	1.436	1.179	0.882	0.629
Dec	5.774	5.143	4.602	4.105	3.218	2.793	2.194	1.503	0.913
Jan	15.339	13.331	11.661	10.210	7.635	6.740	5.477	4.023	2.780
Feb	39.896	34.046	29.210	25.060	17.706	15.379	12.093	8.311	5.077
Mar	11.080	10.996	10.806	10.412	9.678	8.470	6.763	4.799	3.120
Apr	2.045	2.036	2.016	1.973	1.893	1.761	1.576	1.362	1.179
May	1.289	1.283	1.271	1.245	1.197	1.118	1.007	0.878	0.769
Jun	0.806	0.802	0.794	0.778	0.747	0.696	0.624	0.541	0.470

Jul	0.694	0.691	0.684	0.669	0.643	0.599	0.537	0.465	0.404	0.376
Aug	0.629	0.626	0.620	0.607	0.583	0.543	0.487	0.422	0.367	0.341
Sep	0.696	0.693	0.686	0.672	0.645	0.601	0.539	0.467	0.406	0.377

Reserve flows without High Flows

Oct	0.971	0.966	0.954	0.930	0.885	0.811	0.706	0.586	0.483	0.435
Nov	1.326	1.318	1.299	1.261	1.189	1.071	0.904	0.712	0.548	0.472
Dec	1.848	1.834	1.804	1.740	1.622	1.428	1.153	0.837	0.567	0.441
Jan	2.655	2.644	2.620	2.571	2.480	2.329	2.116	1.870	1.661	1.563
Feb	2.812	2.801	2.777	2.727	2.634	2.481	2.265	2.017	1.804	1.705
Mar	2.853	2.842	2.816	2.764	2.665	2.503	2.274	2.010	1.785	1.680
Apr	1.891	1.883	1.865	1.829	1.761	1.649	1.491	1.310	1.154	1.082
May	1.289	1.283	1.271	1.245	1.197	1.118	1.007	0.878	0.769	0.718
Jun	0.806	0.802	0.794	0.778	0.747	0.696	0.624	0.541	0.470	0.437
Jul	0.694	0.691	0.684	0.669	0.643	0.599	0.537	0.465	0.404	0.376
Aug	0.629	0.626	0.620	0.607	0.583	0.543	0.487	0.422	0.367	0.341
Sep	0.696	0.693	0.686	0.672	0.645	0.601	0.539	0.467	0.406	0.377

Natural Duration Curves

Oct	28.704	15.702	9.977	7.442	4.765	4.128	3.048	1.879	1.358	0.806
Nov	68.138	50.071	26.490	17.570	14.094	10.891	8.337	5.290	2.968	1.057
Dec	95.143	64.707	46.543	35.224	18.846	15.760	11.150	7.512	4.734	2.396
Jan	29.406	92.648	83.489	60.213	43.730	34.327	26.688	13.123	7.779	4.286
Feb	40.644	97.065	67.402	47.480	42.488	31.231	26.333	16.226	0.637	4.215
Mar	87.467	68.333	52.509	35.280	28.352	20.953	14.703	10.524	7.713	5.688
Apr	30.899	22.435	15.539	11.839	8.401	7.669	6.832	4.667	3.659	2.509
May	14.529	7.519	5.563	4.579	3.931	3.260	2.955	2.523	1.674	1.154
Jun	5.585	3.849	3.386	2.684	2.050	1.859	1.538	1.292	1.045	0.631
Jul	4.622	3.229	2.531	2.176	1.563	1.335	1.165	1.015	0.764	0.579
Aug	4.865	3.103	2.244	1.822	1.553	1.363	1.124	0.967	0.721	0.530
Sep	9.771	4.540	2.587	2.281	1.762	1.549	1.251	0.941	0.840	0.582

15.5.4 IFR13 rule table for alternative scenario: C ERC

Data are given in m³/s mean monthly flow

% Points										
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.169	2.153	2.116	2.041	1.900	1.668	1.340	0.963	0.640	0.491
Nov	2.931	2.913	2.875	2.801	2.663	2.420	2.035	1.500	0.903	0.528
Dec	6.596	6.155	5.753	5.352	4.895	4.120	3.408	2.418	1.315	0.622
Jan	7.578	15.896	14.436	13.108	11.778	9.550	8.065	6.002	3.701	2.254
Feb	40.017	35.408	31.460	27.969	24.634	19.071	15.920	11.542	6.662	3.591
Mar	13.456	13.373	13.201	12.860	12.222	11.108	9.337	6.875	4.131	2.405
Apr	5.140	5.103	5.018	4.843	4.516	3.978	3.218	2.343	1.595	1.247
May	2.235	2.220	2.187	2.119	1.992	1.783	1.488	1.149	0.859	0.724
Jun	1.316	1.307	1.288	1.249	1.175	1.054	0.883	0.687	0.518	0.440
Jul	1.110	1.103	1.087	1.054	0.993	0.891	0.749	0.584	0.444	0.379
Aug	0.998	0.992	0.978	0.948	0.893	0.803	0.675	0.527	0.402	0.343
Sep	1.250	1.242	1.223	1.185	1.113	0.994	0.827	0.634	0.469	0.392

Reserve flows without High Flows

Oct	1.606	1.595	1.569	1.517	1.419	1.258	1.030	0.768	0.544	0.439
Nov	2.377	2.362	2.333	2.274	2.165	1.973	1.669	1.246	0.775	0.478
Dec	3.456	3.433	3.387	3.294	3.120	2.817	2.336	1.666	0.920	0.451
Jan	5.161	5.135	5.079	4.968	4.761	4.400	3.826	3.028	2.139	1.579
Feb	5.653	5.623	5.562	5.441	5.214	4.818	4.188	3.313	2.337	1.723
Mar	5.556	5.527	5.467	5.348	5.125	4.736	4.117	3.258	2.300	1.697
Apr	3.437	3.415	3.364	3.258	3.061	2.737	2.279	1.752	1.301	1.092
May	2.235	2.220	2.187	2.119	1.992	1.783	1.488	1.149	0.859	0.724
Jun	1.316	1.307	1.288	1.249	1.175	1.054	0.883	0.687	0.518	0.440
Jul	1.110	1.103	1.087	1.054	0.993	0.891	0.749	0.584	0.444	0.379
Aug	0.998	0.992	0.978	0.948	0.893	0.803	0.675	0.527	0.402	0.343
Sep	1.118	1.111	1.095	1.062	1.000	0.898	0.754	0.588	0.446	0.380

15.6 GEOMORPHOLOGICAL CONSEQUENCES OF A D AND C SCENARIO

D Scenario

Bed maintenance

A significantly smaller number of events than occurring under “natural” conditions will lead to periods of sediment accumulation, as evidenced at present.

Bench maintenance

The channel margins are unstable. Less frequent bench-maintenance flows (flood class V) will keep it in its present state.

Channel maintenance

A single event (of flood class VI) every three years will ensure that the channel remains open and clean, as observed at present.

Macro channel and bed mobilisation

An event (of flood class VII) once every four years should maintain the channel in its present condition.

Conclusion

As with all sites, any removal of flow events will lead to some geomorphological change. This site is largely alluvial and is therefore naturally unstable, worsened by poor catchment management. Floods are designed to keep the site in its present condition. This state could be improved with catchment management intervention.

15.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 15.4 IFR confidence table for recommended scenario of a D ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
13	Low flows	3	4	3	-
	High flows	3	4	3	3

The confidences are medium to medium-to-high.

Invertebrates: The medium evaluations are due to specialists' uncertainty, re the reaction of invertebrates to a mix of poor water quality and changed flow conditions as invertebrate cues are disturbed by poor water quality.

Fish: The medium-to-high evaluations for fish are due to the fact that the recommended flows are adequate to maintain pool (refuge) habitats.

Vegetation: The medium evaluations for vegetation are due to uncertainty regarding rooting characteristics of species, and confusing cues at elevated flows.

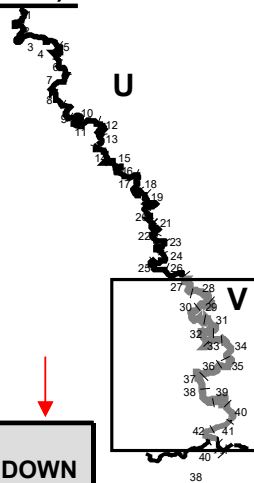
16 RU V. IFR 14. LOWER BUFFALO (Buffalo River)

16.1 ECOLOGICAL CATEGORIES

16.1.1 Summary of ERC scenarios

Two Ecological Reserve Scenarios were addressed for IFR14. The recommended scenario is a B ERC. The alternative scenario of a C/D ERC was also evaluated. **A B/C scenario was not evaluated, as the flow required for both a B and a B/C scenario would be the same. The requirement to improve from a B/C to a B ONLY applies to water quality.**

Fig. 16.1 Summary of ERC scenarios



COMPONENT	PES	TRAJ	LONG TERM (20 Y)		ERC	DOWN
WATER QUALITY	C	0	C	EIS	B	
GEOMORPH	B/C	-	B/C	M O D E R A T E	B/C	C/D
RIPARIAN VEGETATION	B/C	-	C	S I	B/C	C/D
FISH	C	0	C	M O D E R A T E	C	D
AQUATIC INVERTS	B	0	B		B	C
ECOSTATUS	B/C	-	B/C		B	C/D

16.1.2 Criteria for the Ecological Reserve categories

Recommended Scenario: B ERC

Aquatic invertebrates (B)

- Diverse mayflies families (5 families) with abundant organisms, are characteristic of this site. Hydropsychidae is also abundant.

Fish (C)

- Maintain existing species diversity and facilitate recovery of populations of all species after severe fish-kill.

Riparian Vegetation (B/C)

- Maintain existing abundances and distribution of *Juncus* in the marginal zones on the edges of the river and on islands, by the provision of adequate base flows and elevated flows.
- Maintain existing stands of *Nuxia oppositifolia* within the lower and main riparian zone of both banks.

Geomorphology (B/C)

- Maintain the present condition. In order to do this there is a need to keep the number of flood classes similar to the natural condition. Ensure the continued building up of the channel banks and maintenance of the instream habitat.

Alternative Scenario: C/D ERC

Aquatic invertebrates (C)

- Some loss of mayfly diversity with one family becoming scarce. Hydropsychidae should persist, but mayflies would remain the dominant group.
- Maintain velocities lower than those recommended for the B ERC, to ensure an invertebrate community with some Hydropsychidae and mayflies as the dominant groups.

Fish (D)

- Existing species diversity, with lower abundances of all species.
- Maintain existing species diversity.
- Maintain *L. natalensis* breeding habitat.
- Prevent extinction of *L. natalensis*. Provide fast-shallow conditions over 80% of available gravel beds during summer.

Riparian Vegetation (C/D)

- The marginal zone on the river edge and on the islands is occupied by *Juncus* in reduced abundance and restricted distribution.
- Allow for a reduction in the distribution and abundance of *Juncus* in marginal areas of both banks, while maintaining the existing stand of *Nuxia oppositifolia* within the lower and main riparian zones.

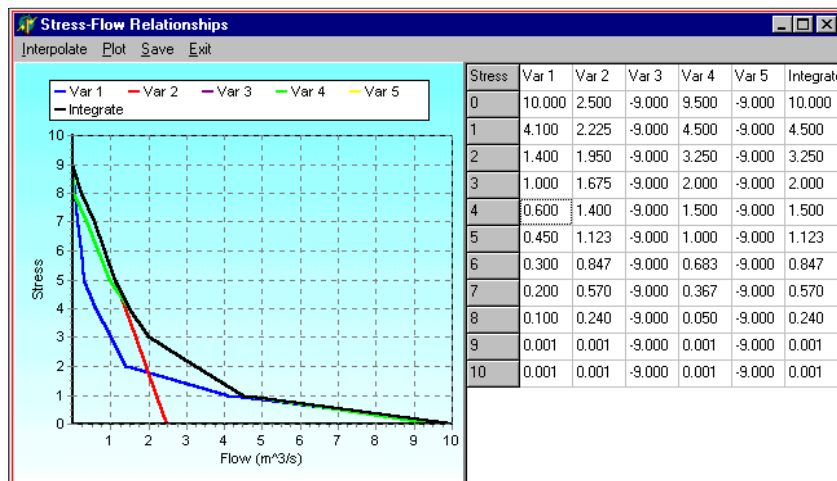
Geomorphology (C/D)

- A change in category from B to C/D will allow long periods of over-widened channel (after large floods). Residence time for instream substrate will also increase. Some loss of instream habitat due to aggradation.

16.2 FLOW-STRESS RELATIONSHIPS

The approaches to determining flow-stress relationships for each of the ecological components are described in Chapter 2, and site-specific information is presented here. The flow-stress relationships for fish, invertebrates and riparian vegetation components are documented in the spreadsheet for IFR 14, which is presented as Appendix G. The numerical flow-stress relationships are provided in Figure 16.2. The critical curve consists of the critical stress at any one time, no matter which component it relates to, and is represented by the black line in Figure 16.2.

Fig. 16.2 Critical curve for IFR 14



Var 1: Fish
 Var 2: Flow Dependent Invertebrates
 Var 3: Marginal Vegetation Invertebrates
 Var 4: Riparian Vegetation 1
 Var 5: Riparian Vegetation 2

16.2.1 Invertebrates

As marginal vegetation at this site would only be inundated at flows higher than base flow, the marginal vegetation dependent community would probably be non-existent and was thus not considered to be important. The flow-dependent community investigation was dominated by the need to maintain high water velocities over and under quantities of cobbles.

16.2.2 Riparian Vegetation

Only one component, i.e. *Juncus* spp., was selected, using elevations and discharges associated with the ecological transect (i.e. 1.29m below the habitat modelling elevation). The habitat modelling was used to locate *Juncus* distribution relative to various water levels.

Juncus spp. occurs in mats, which cover a reasonably large area of the marginal zone and are linked by rhizomes. Only the edges of these mats, which are located adjacent to the river's edge, are crucial because the maximum stress levels of these mats would only occur once the water levels drop below the roots in these areas, i.e. at the 0.05m level.

The *Juncus* was found to be fairly insensitive, since its roots extended well into the level of the main channel, and would therefore still remain relatively unstressed up to the time when the river had almost stopped flowing.

16.3 STRESS DURATION CURVES (PROFILES)

16.3.1 Natural stress duration profile

The natural flow regime was converted to a stress profile (see blue line, Figure 16.3), and evaluated to determine whether or not it was representative of the expected stress under natural flow conditions. For IFR 14, stress indices as determined were accepted, no changes were required.

16.3.2 Recommended stress profiles for each reserve scenario

The recommended scenario of a B ERC (referred to in the graphs as a B/C – see 16.1.1), and the alternative scenario of a C/D were estimated using the Desktop model and are shown in Figures 16.3 – 16.6 as the purple and green lines respectively. The present day hydrology, as converted into stress, is reflected by the red line in Figures 16.3 – 16.6. Specialists evaluated the generated scenarios for winter (dry) and summer (wet). The results of this evaluation are overlaid as points and bold black lines in Figures 16.3 - 16.6. According to the specialists' evaluations, the Desktop-generated scenarios were adjusted (see Figures 16.7 - 16.8). These scenarios were checked with specialists to ensure that they were representative of their component requirements.

16.3.3 Process to adjust the Desktop output to fit specialist requirements

The generated B scenario consisted of Maintenance Low Flows of 12.8% MAR, which were adjusted to 10.2% MAR, and of Drought Low Flows of 3.55% MAR, which were adjusted to 2.3% MAR. The generated C/D scenario consisted of Maintenance Low Flows of 6.7 % MAR, which were adjusted to 5% MAR, and of Drought Low Flows of 3.55% MAR, which were adjusted to 2.3% MAR. The Maintenance and Drought Low Flows were manually changed in the wet season only to achieve the above. Desktop-modelled dry season flows required no changes, as the points fell on the line. Figure 16.3 and 16.5 illustrate this and serves as the presentation of the final lines.

Fig. 16.3 IFR 14 - Stress-duration curve for recommended scenario of a B ERC: Dry Season

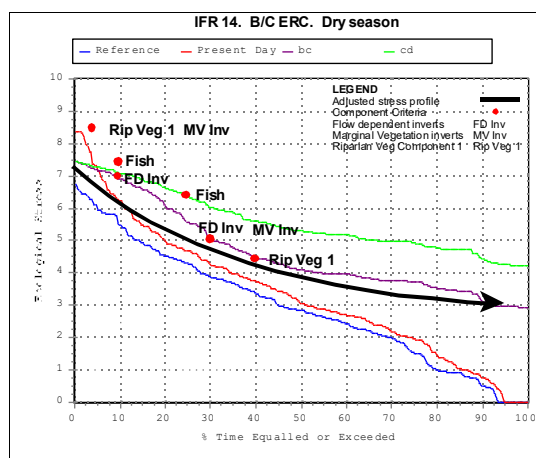


Fig. 16.4 IFR 14 - Stress-duration curve for recommended scenario of a B ERC: Wet Season

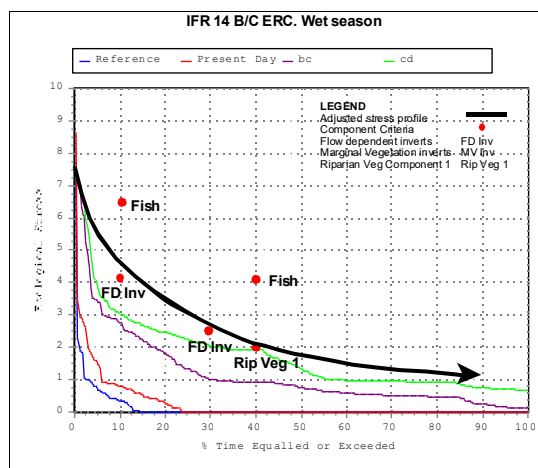


Fig. 16.5 IFR 14 - Stress-duration curve for alternative scenario of a C/D ERC: Dry Season

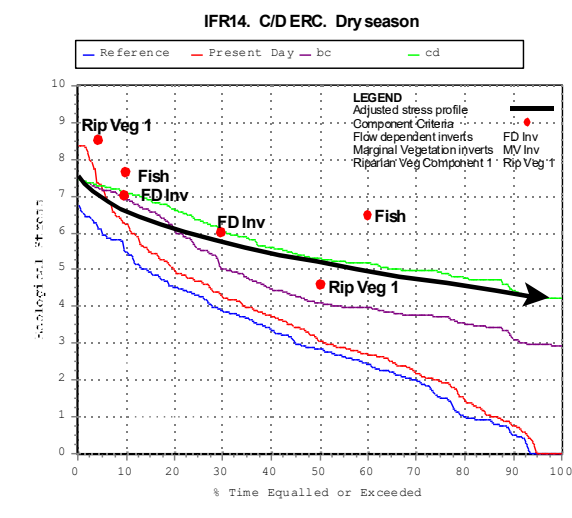
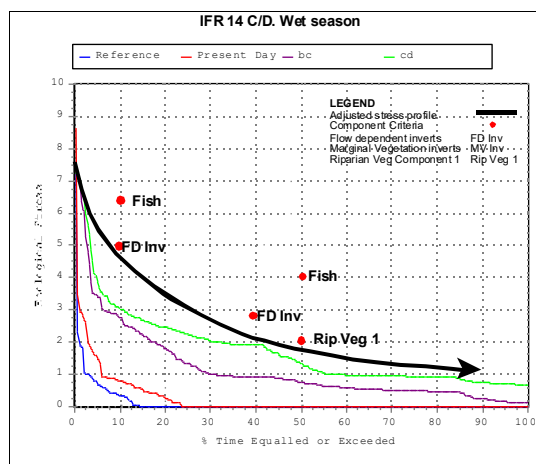


Fig. 16.6 IFR 14 – Stress duration curve for alternative scenario of a C/D ERC: Wet Season



16.3.4 Final stress profiles for IFR14

Fig. 16.7 IFR 14 – final stress profiles: Dry Season

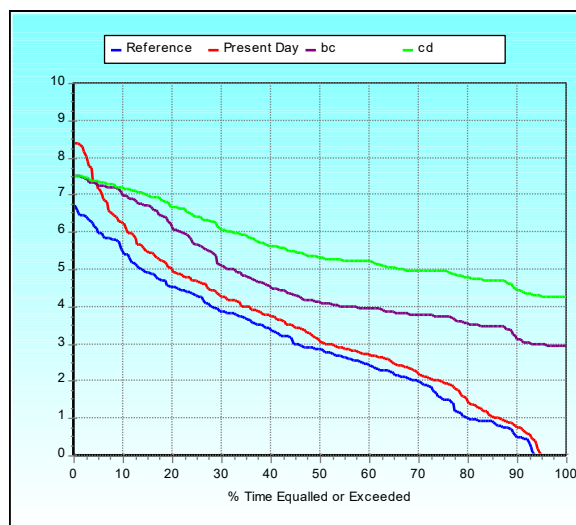
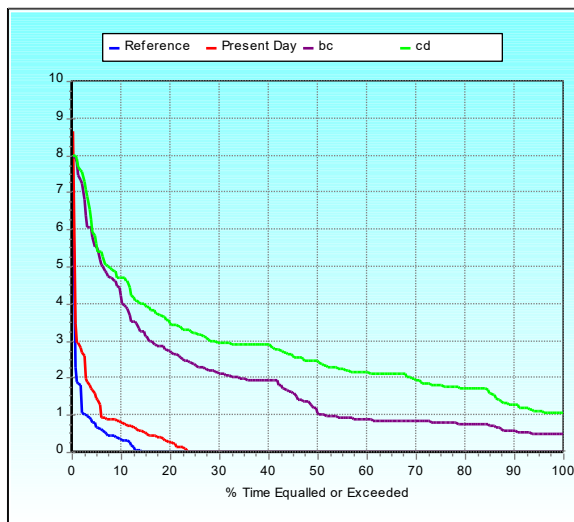


Fig. 16.8 IFR 14 – Final stress profiles: Wet Season



16.4 HIGH FLOWS

The functions for each Flood Class are described in spreadsheets in Appendix G. A summary of the Flood Class ranges is provided in Table 16.1. The number of events for each Flood Class required for an ERC of B and C/D are also summarised in Table 16.1.

Table 16.1 A summary of the Flood Class ranges for IFR14, and the recommended high flow events for each scenario

Component	Flood Classes m ³ /s						
	I	II	III	IV	V	VI	VII
Fish		5-10 10-15	20-35				
Invertebrates	2-3 3-5	5-10 10-20					
Vegetation		6-17	17-65		65-140	140-230	
Geomorphology					80-115	115-200	230-381
Integrated	2-4	5-19	20-34	35-64	65-139	140-229	230-381
Geometric Mean*				47	95	180	300
Recommended high flows							
No of events for B ERC (Recommended scenario)	2 spring 1 autumn	8	6	2	1	1	1 in 2 years
No of events for C/D ERC (Alternative scenario)	1 spring	6	4	2	1	1 in 2 years	1 in 3 years

These results were checked with the hydrology and were found to be acceptable.

To incorporate the high flows within the already established low flows, the following process was followed:

The higher values (e.g. 230 - 381) specified by the geomorphologist were reduced to the lower values (e.g. 190) for the Desktop model, to account for the way in which floods are treated in the Desktop model assurance rules. The maintenance flood values are elevated

for low assurances, and therefore will generate volume requirements that are consistent with the higher peak values used in the IFR model.

The adjustments as described above are illustrated in Tables 16.2 and 16.3.

Table 16.2 Adjusted flood sizes as used in the Desktop model for the recommended scenario of a B ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	IV	50	V	80	VII incl. 1- VI	190	IV	50		
Duration (days)	4		5		6		4			
Freshet size (m³/s)	II & III	14 + 28	II & III	14 + 28	II & III	14 + 28	II & III*2	14 + 28 + 28	I & II & III	3 + 14 +28
Duration (days)	3		3		3		3		3	
Spring										
	Sept		Oct		Nov					
Freshet size (m³/s)	I	3	I & II	3 + 14	II*2	14 + 14				
Duration (days)	2		3		3					

Table 16.3 Adjusted flood sizes as used in the Desktop model for the alternative scenario of a C/D ERC

Summer										
	Dec		Jan		Feb		Mar		Apr	
	Class	Flood	Class	Flood	Class	Flood	Class	Flood	Class	Flood
Flood size (m³/s)	IV	50	V	80	VII incl. 1- VI	190	IV	50		
Duration (days)	4		5		6		4			
Freshet size (m³/s)	III	28	II & III	14 + 28	II & III	14 + 28	II*2 & III	14 + 14+ 28	I & II & III	3 + 14 + 28
Duration	3		3		3		3		3	
Spring										
	Sept		Oct		Nov					
Freshet size	I	3	II	14	II	14				
Duration	2		3		3					

16.5 FINAL RESULTS

16.5.1 IFR table for recommended scenario: B ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	831.096
S.Dev.	=	501.645
CV	=	0.604
Q75	=	7.530
Q75/MMF	=	0.109
BFI Index	=	0.300
CV (JJA+JFM) Index	=	3.307
Total IFR	=	205.714 (24.75 %MAR)
Maint. Lowflow	=	84.400 (10.16 %MAR)
Drought Lowflow	=	19.413 (2.34 %MAR)
Maint. Highflow	=	121.314 (14.60 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : N.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	44.547	84.962	1.907	4.285	1.339	2.644	6.929
Nov	79.459	86.862	1.093	4.925	1.296	4.355	9.279
Dec	117.549	129.729	1.104	7.232	0.643	15.604	22.836
Jan	175.397	173.997	0.992	11.785	2.143	22.913	34.698
Feb	179.744	161.575	0.899	14.515	2.903	50.034	64.549
Mar	107.450	89.456	0.833	12.588	2.544	19.958	32.547
Apr	46.515	52.534	1.129	8.554	2.333	5.443	13.997
May	21.555	32.503	1.508	5.625	1.607	0.000	5.625
Jun	10.832	15.103	1.394	4.329	1.296	0.000	4.329
Jul	12.300	36.738	2.987	3.535	1.071	0.000	3.535
Aug	13.238	37.277	2.816	3.294	1.071	0.000	3.294
Sep	22.510	69.488	3.087	3.732	1.166	0.363	4.095

16.5.2 IFR table for alternative scenario: C/D ERC

Annual Flows (Mill. cu. m or index values):

MAR	=	831.096
S.Dev.	=	501.645
CV	=	0.604
Q75	=	7.530
Q75/MMF	=	0.109
BFI Index	=	0.300
CV(JJA+JFM) Index	=	3.307
Total IFR	=	150.648 (18.13 %MAR)
Maint. Lowflow	=	41.775 (5.03 %MAR)
Drought Lowflow	=	19.413 (2.34 %MAR)
Maint. Highflow	=	108.873 (13.10 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type : N.Natal

Month	Natural Flows			Modified Flows (IFR)			
	Mean	SD	CV	Low flows		High Flows	
				Maint.	Drought	Maint.	Maint.
Oct	44.547	84.962	1.907	2.678	1.339	2.177	4.856
Nov	79.459	86.862	1.093	3.110	1.296	2.177	5.288
Dec	117.549	129.729	1.104	3.482	0.643	13.427	16.908
Jan	175.397	173.997	0.992	5.089	2.143	22.913	28.002
Feb	179.744	161.575	0.899	6.532	2.903	50.034	56.566
Mar	107.450	89.456	0.833	5.892	2.544	15.604	21.496
Apr	46.515	52.534	1.129	3.888	2.333	2.177	6.065
May	21.555	32.503	1.508	2.946	1.607	0.000	2.946
Jun	10.832	15.103	1.394	2.333	1.296	0.000	2.333
Jul	12.300	36.738	2.987	1.955	1.071	0.000	1.955
Aug	13.238	37.277	2.816	1.821	1.071	0.000	1.821
Sep	22.510	69.488	3.087	2.048	1.166	0.363	2.411

16.5.3 IFR rule table for recommended scenario: B ERC

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	3.176	3.152	3.097	2.982	2.769	2.417	1.921	1.350	0.862	0.635
Nov	4.106	4.080	4.026	3.920	3.722	3.375	2.824	2.059	1.205	0.668
Dec	15.159	13.577	12.205	10.960	9.718	7.637	6.267	4.362	2.239	0.904
Jan	23.609	21.205	19.119	17.224	15.331	12.161	10.062	7.147	3.897	1.852
Feb	43.020	38.142	33.952	30.220	26.615	20.593	17.031	12.081	6.563	3.092
Mar	15.699	15.596	15.382	14.959	14.166	12.781	10.579	7.519	4.109	1.963
Apr	6.204	6.155	6.044	5.814	5.386	4.681	3.686	2.541	1.562	1.106
May	2.678	2.658	2.614	2.522	2.350	2.067	1.668	1.208	0.816	0.633
Jun	1.994	1.980	1.947	1.880	1.754	1.546	1.253	0.916	0.627	0.493
Jul	1.683	1.671	1.644	1.587	1.481	1.306	1.060	0.777	0.534	0.421
Aug	1.518	1.507	1.483	1.433	1.340	1.186	0.969	0.720	0.506	0.407
Sep	1.871	1.857	1.826	1.763	1.644	1.449	1.173	0.856	0.584	0.458

Reserve flows without High Flows

Oct	2.041	2.026	1.993	1.925	1.798	1.588	1.293	0.952	0.661	0.526
Nov	2.287	2.274	2.246	2.190	2.087	1.906	1.619	1.220	0.775	0.495
Dec	3.467	3.443	3.393	3.295	3.110	2.788	2.275	1.562	0.768	0.268
Jan	5.848	5.811	5.733	5.581	5.294	4.794	3.999	2.893	1.661	0.886
Feb	6.739	6.697	6.609	6.436	6.111	5.545	4.644	3.392	1.997	1.119
Mar	6.470	6.430	6.346	6.180	5.869	5.326	4.463	3.264	1.927	1.086
Apr	3.941	3.911	3.845	3.708	3.451	3.030	2.434	1.749	1.163	0.890
May	2.678	2.658	2.614	2.522	2.350	2.067	1.668	1.208	0.816	0.633
Jun	1.994	1.980	1.947	1.880	1.754	1.546	1.253	0.916	0.627	0.493
Jul	1.683	1.671	1.644	1.587	1.481	1.306	1.060	0.777	0.534	0.421
Aug	1.518	1.507	1.483	1.433	1.340	1.186	0.969	0.720	0.506	0.407
Sep	1.720	1.708	1.680	1.622	1.515	1.339	1.090	0.803	0.558	0.444

Natural Duration curves

Oct	34.109	17.913	14.282	8.094	6.292	5.181	3.839	2.593	1.640	1.123
Nov	89.542	66.346	28.991	19.930	16.129	13.486	10.129	6.396	3.618	1.520
Dec	124.151	80.428	56.863	43.117	21.547	18.800	12.353	8.468	6.485	2.986
Jan	147.326	113.534	88.673	69.951	50.411	38.079	29.857	16.367	9.116	4.841
Feb	173.204	113.015	76.310	56.481	46.666	37.683	27.599	17.899	12.369	5.317
Mar	99.934	82.664	61.847	39.761	31.461	22.801	17.212	12.471	9.226	7.883
Apr	35.185	26.478	17.432	14.027	10.797	9.577	8.572	5.776	4.704	3.110
May	17.018	9.290	7.438	5.475	4.799	4.035	3.561	3.160	2.203	1.478
Jun	7.213	4.701	4.122	3.278	2.796	2.330	1.829	1.549	1.292	0.795
Jul	6.223	3.993	3.245	2.616	2.091	1.686	1.451	1.258	0.934	0.752
Aug	5.970	3.883	2.923	2.251	1.915	1.669	1.363	1.198	0.904	0.683
Sep	11.216	5.649	3.185	2.823	2.244	1.829	1.561	1.195	1.042	0.743

16.5.4 IFR rule table for alternative scenario: C/D ERC

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.689	2.669	2.623	2.530	2.356	2.069	1.664	1.198	0.799	0.614
Nov	2.978	2.960	2.923	2.849	2.710	2.469	2.084	1.550	0.955	0.580
Dec	12.265	10.909	9.741	8.695	7.673	5.964	4.914	3.456	1.830	0.807
Jan	21.097	18.711	16.664	14.846	13.098	10.179	8.481	6.121	3.491	1.836
Feb	40.287	35.430	31.282	27.634	24.185	18.437	15.310	10.965	6.122	3.075
Mar	12.497	12.417	12.250	11.919	11.299	10.217	8.497	6.106	3.441	1.764
Apr	3.309	3.286	3.235	3.130	2.933	2.609	2.152	1.626	1.176	0.967
May	1.777	1.766	1.741	1.689	1.593	1.434	1.209	0.951	0.730	0.627
Jun	1.362	1.354	1.334	1.295	1.222	1.101	0.931	0.735	0.567	0.489
Jul	1.179	1.172	1.156	1.121	1.057	0.952	0.803	0.632	0.486	0.418
Aug	1.063	1.057	1.043	1.013	0.958	0.867	0.738	0.590	0.463	0.404
Sep	1.369	1.360	1.340	1.299	1.222	1.096	0.917	0.712	0.536	0.455

Reserve flows without High Flows

Oct	1.615	1.605	1.581	1.532	1.440	1.289	1.076	0.831	0.621	0.524
Nov	1.907	1.897	1.875	1.831	1.749	1.607	1.380	1.065	0.714	0.493
Dec	2.204	2.190	2.159	2.099	1.987	1.791	1.480	1.047	0.564	0.260
Jan	3.336	3.317	3.279	3.203	3.060	2.812	2.417	1.868	1.256	0.871
Feb	4.005	3.984	3.939	3.849	3.681	3.389	2.923	2.277	1.556	1.102
Mar	4.000	3.978	3.933	3.842	3.673	3.378	2.908	2.256	1.528	1.070
Apr	2.270	2.257	2.227	2.164	2.047	1.855	1.584	1.271	1.004	0.880
May	1.777	1.766	1.741	1.689	1.593	1.434	1.209	0.951	0.730	0.627
Jun	1.362	1.354	1.334	1.295	1.222	1.101	0.931	0.735	0.567	0.489
Jul	1.179	1.172	1.156	1.121	1.057	0.952	0.803	0.632	0.486	0.418
Aug	1.063	1.057	1.043	1.013	0.958	0.867	0.738	0.590	0.463	0.404
Sep	1.195	1.188	1.172	1.138	1.074	0.970	0.823	0.653	0.508	0.440

16.6 GEOMORPHOLOGICAL CONSEQUENCES FOR A B AND C/D SCENARIO**Bed maintenance**

B category requirement is two events. This should keep the river bed in its present condition.

C/D category is one event. This will cause a decrease in the mobilisation of smaller material on the bed and will allow a longer residence time of material.

Bench maintenance

B category requirement is one event. This should maintain the present channel benches in the present condition and allow the continued re-structuring.

C/D category requirement is one event. This is an important flow component for re-formation of channel margins and therefore will have the same consequences as for category B.

Channel maintenance

B category requirement is one event. This is a very important component for keeping the channel clean and open and for maintaining habitat diversity.

C/D category requirement is one event every two years. This will allow temporary aggradation, sediment accumulation and vegetation encroachment.

Macro - channel and bed mobilisation

B category requirement is one event every two years. This ensures the broad channel is maintained. Sediments are deposited over the bank and coarse material on the bed is moved.

C/D category requirement is one event every three years. Broad channel maintenance does not occur as regularly, and as a result there may be some changes within the macro-channel. Encroaching vegetation may stabilise areas and change general morphology.

Conclusion

As with all sites, any removal of flow will lead to some geomorphological change. This site is relatively stable and consists of very coarse material within an incised channel. Recommended flows for the B category will keep the channel in its present condition within the 20-year period.

16.7 IFR CONFIDENCE EVALUATION

The purpose is to attach a confidence value to the results of the IFR set based on the different specialist viewpoints. The scale of evaluation is as follows:

None = 1 Low to medium = 2 Medium = 3 Medium to high = 4 High = 5

Table 16.4 IFR result confidence table for recommended scenario of a B ERC

IFR Site		IFR Component			
		Aquatic Inverts	Fish	Riparian Vegetation	Geomorphology
14	Low flows	4	4	4	-
	High flows	4	4	4	4

The confidences are medium-to-high for low and high flows. The medium-to-high confidence evaluations are based on the following:

Invertebrate evaluation: The habitat is not very susceptible to alteration by flows.

Riparian vegetation: There are good vegetation cues which aid setting flow requirements at a high confidence.

Fish: The evaluation could not be higher, as there is some uncertainty regarding the impacts of low-flows on cobble habitats.

Geomorphology: A habitat model is available, but there is no daily data. The presence of reasonable geomorphological cues gives this site a medium-to-high confidence evaluation.

17 SUMMARY

17.1 RESULTS FOR RU WITHOUT IFR SITES

The results of RUs without IFR sites are provided in Appendix H. These results were generated by extrapolation from either upstream or downstream IFR sites. As these results were extrapolated, they are automatically low confidence.

17.2 EXPLANATION OF THE SUMMARY TABLE

The summary below (Table 17.1) summarises all the results as percentages of the natural MAR. The long term percentage (referred to as '% long') refers to the % of the natural MAR required to match the IFR time series generated by the IFR rules, i.e. including periods of drought, maintenance, between drought and maintenance and above maintenance flows. The '% tot' refers to the total maintenance IFR a percentage of natural MAR. The '% low' refers to the maintenance low flow IFR as a percentage of the natural MAR.

The colour code is as follows:

Category A		Category A/B	
Category B		Category B/C	
Category C		Category C/D	
Category D		Category D/E	
Category E		Category F	

Table 17.1 IFR results

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
THUKELA RIVER														
A		C/D	-	22	9.2	B/C	-	35.5	19.1	B	-	40.84	24.4	Low, extrapolated
B	1	-	-	-	-	D	22.3	17.3	7	C	31.7	29.9	14.9	IFR components: Med-high to high Hydraulics: Med-high MED-HIGH
C	2	D	22	18.2	4.2	C	29	27.4	11.1	B	37.5	38.5	19.2	IFR components: Med-low (low flow), med-high (high flow). Hydraulics: High. MED-LOW (low flow), MED-High (high flow)
D		D	-	19.1	6.1	C	-	24.8	10.5	B	-	35.1	18	Low, extrapolated
E		C	-	25.4	10.1	B	-	35.3	18	-	-	-	-	Low, extrapolated
F	4 *1	B/C	29	28.4	12.4	B	31.8	31.8	14.7	-	-	-	-	IFR components: Med-high Hydraulics: Med-high MED-HIGH
G		D	-	18.94	-	C/D	-	22.1	9	B/C	-	30.8	14	Low, extrapolated
H	9	-	-	-	-	D	24.3	20.3	6.1	C	28.2	27.8	12	IFR components: Med-low Hydraulics: Med-high MED-HIGH*2
I	15	D	22.7	18.2	6.2	C	27	25.5	12.6	-	-	-	-	IFR components: Med-high Hydraulics: Low (low flow), med-high (high flow) LOW (low flow), MED-HIGH (high flow)
J	16	D	29.6	23.7	8.4	C/D	32.6	28.4	11.4	B/C	36	36.1	18	IFR components: Med (low flow), med-high (high flow) Hydraulics: Med (drought), med-high (rest) MED (low flow) MED-HIGH (high flow)

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
LITTLE THUKELA RIVER														
L		D				C				B				Low, extrapolated
M	3	D		18.6	6.1	C/D		24.7	11.1	B/C		42.8	21.4	IFR components: Med (low flow), med-high (high flow) Hydraulics: High MED (low flow), MED-HIGH (high flow)
BUSHMENS RIVER														
N		C/D	-	31.3	13.1	B/C	-	44.3	22	B	-	49.8	27.5	Low, extrapolated
O	5	C/D	37.5	32.7	13.3	B/C	47.4	45.4	22.4	-	-	-	-	IFR components: Med (low flow), med-high (high flow) Hydraulics: High MED (low flow), MED-HIGH (high flow)
P	6	C/D	-	32.1	13.1	B/C	-	44.7	22.2	-	-	-	-	Low, extrapolated
SUNDAYS RIVER														
Q	7	C/D	29.3	25.8	10.9	B/C	35.8	36.7	28.6	-	-	-	-	IFR components: Med Hydraulics: Med MED
R	8	-	-	-	-	D	24.1	19.6	6.8	C	29.5	28.7	13.1	IFR components: Med Hydraulics: High MED-HIGH (low flow), MED (high flow)
MOOI RIVER														
S	10	D	24.9	18.6	9	C	32.4	29.9	17.2	B	41.9	43.6	28.04	IFR components: Low-med to Med-high Hydraulics: Low (droughts), Med-high (low flow) LOW (droughts), MED (high flow)
T	11	C/D	27.2	23.5	12.4	B/C	35.4	36.3	22.1	B	39.5	42	27.7	IFR components: Med-high Hydraulics: Med-high MED-HIGH

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
	BUFFALO RIVER													
U	13	-	-	-	-	D	18.1	16	3.9	C	23.1	22.2	9.2	IFR components: Med-high Hydraulics: Low-med (low), med-high (intermediate 0 LOW-MEDIUM (low flow), MEDIUM (>1.8)
V	14	C/D	20	18.1	5	B/C	24.1	24.8	10.2	-	-	-	-	IFR components: Med-high Hydraulics: High MED-HIGH

*1 Even though the IFR component evaluation is med-low, flows should be managed from Spioenkop to cater for IFR 4 which is a higher ERC than IFR 9. IFR 9 should therefore get more flows than recommended and the confidence in achieving the ERC is therefore linked to the hydraulics, i.e. med-high.

*2 IFR 4: 3 scenarios were supplied, B (recommended), B/C (alternative and PES), C/D (lower than PES). Only the B and B/C scenario fit into the table and C/D information need to be used within the design of additional scenarios if necessary.

C/D, LONG TERM % = 22.6
 MAINTENANCE TOTAL % = 21.8
 % LOW FLOWS = 8.8

17.3 EXPLANATION OF THE CONFIDENCE EVALUATION

The confidence column (last column in Table 16.1) combines three sets of confidence evaluation as well as the final evaluation. An explanation is provided below:

- Requirements of the IFR components: These refer to the confidence provided in the biophysical data which led to the biophysical recommendations of required hydraulic parameters. Specialists provided these evaluations which are documented at the end of each of the result chapters. These results are summarised in this column and where applicable it has been split for low and high flows. Confidence in the IFR sites to provide clues to set requirements are not included here, however IFR site confidence is inherently included within the confidence evaluation of the biophysical data.
- Hydraulics: Hydraulics confidence is provided and motivated within Appendix B. The confidence varies for different ranges of discharges, depending on the discharges obtained for calibration of the hydraulic rating relationship. This confidence evaluation has been summarised for drought, low and high flows.
- Final confidence evaluation: Provided in capitals in the confidence column. The confidence is a combination of the confidence in the IFR components and the conversion of ecological requirements to flow requirements by means of the hydraulics. A basic rule would be that even when one has reasonable confidence in the IFR components' requirements, the overall confidence would be low if the hydraulic information to translate these requirements is of low confidence. Or, when one has low confidence in the IFR components' requirements and the hydraulics' confidence is high; the overall confidence would be low as the conversion (of high confidence) to flow is irrelevant.

The information above should be converted into a rule-based system for future reserve studies which would formalise the confidence relationships. The confidence within IFR sites should also be included in such a system. Furthermore, the confidence of the IFR component which is the primary motivator for the IFR flows (i.e. has the highest requirements) should also be weighted. The reason for this is that if the IFR components which are secondary motivators have low confidence in their data and requirements, the confidence in the recommended flows for achieving their objectives should be high as more water than is required will be provided.

The major purpose for a consistent confidence evaluation is that the information provided can serve to unpack the overall confidence evaluation. If further work is therefore required to increase confidence, the thrust of such work can be identified through this evaluation. A site-by-site evaluation of the confidence and an identification of possible further work are provided in Table 16.2.

Note that apart from the confidence evaluation provided by the hydraulician (Dr Birkhead), the confidence evaluation as provided in both tables is an analysis undertaken by the IFR coordinator (Ms Louw) and not by the individual specialists. The information provided by the specialists at the end of each of the IFR result chapters does however form the basis of the analysis.

17.4 FURTHER WORK REQUIRED

The confidence evaluation is shortly discussed in column 2 of Table 16.2, the possible further work in column 3 and the opinion of the IFR coordinator regarding the necessity of the further work in column 4.

Table 17.2 Confidence evaluation approach

IFR site	Confidence Evaluation	Further work	Necessity
THUKELA RIVER			
1	Fish and invertebrates are primary motivators. Confidence for invertebrates is high and for fish medium to high. Hydraulics: Is low for the drought flow range. The lowest flow measured is 2.6m ³ /s - the lowest droughts flows are 0.2m ³ /s.	Fish: Information can be obtained through monitoring. Hydraulics: Flows below 1m ³ /s should be measured. Only necessary if the Reserve is challenged or if user requirements could impact the Reserve.	No immediate action required. Monitoring can address the issues.
2	Fish and invertebrates are primary motivators. Confidence at low flows is low to medium. This is related to lack of applicable habitat at the site. Hydraulics: Medium confidence for the drought flow range. The lowest flow measured is 1.5m ³ /s - the lowest droughts flows are 0.5 m ³ /s.	Fish and invertebrates: Information can be obtained through monitoring at more applicable sites. Requirements must then be translated for use at the IFR site. Hydraulics: Flows at 0.5m ³ /s should be measured. As the confidence is medium, it is doubtful whether this is necessary.	No immediate action is required. Monitoring can address the issues.
4	Invertebrates and riparian vegetation are primary motivators. The confidence is medium-high. The lowest flow measured is 1.2m ³ /s. The lowest droughts flows are 1.7m ³ /s. The relevant confidence evaluation is medium-high.	No additional work is required. Standard monitoring should improve the confidence from medium-high to high. Hydraulics: No work is required unless any revision in the IFRs result in flows being recommended below 1.2m ³ /s.	None.
9	Aquatic invertebrates are the primary motivator. The confidence is low-medium. Hydraulics: Low - High confidence.	This site is a poor IFR site providing few cues for IFR determination. The ERC of this site is a D compared to the B of the upstream site. If managing for the upstream B ERC, this site will receive more water than required.	Standard monitoring could improve the confidence if required in future and if the upstream site is not managed for the B ERC.
15	Invertebrates and fish are primary motivators. The confidence is medium-high to high. The lowest flow measured is 18m ³ /s - the lowest droughts flows are approximately 2m ³ /s. The relevant confidence evaluation is low.	The site provides good instream cues. Riparian vegetation: Has low confidence, but this is due to the lack of vegetation on site and monitoring will probably be focused on the increase of exotics. Hydraulics: This is a very difficult site for modelling of hydraulics and photopoint monitoring and additional calibrations at all flows below approximate 183m ³ /s are required.	As part of monitoring the hydraulics and IFR should be updated.
16	Marginal invertebrates are primary motivators. The confidence is low- medium in the low flow range. The lowest flow measured is 17.3m ³ /s. The lowest droughts flows are approximately 4m ³ /s. The relevant confidence evaluation is medium.	Further work is required to confirm the primary driver's requirements on the cross-section, i.e. the marginal dependant invertebrates. Hydraulic: Further hydraulic calibrations under 10m ³ /s are also required.	This work must be undertaken as part of the monitoring programme to confirm the invertebrate requirements. Hydraulics: Work to confirm the low flow conversions of the marginal invertebrate requirements is required as part of monitoring.

IFR site	Confidence Evaluation	Further work	Necessity
LITTLE THUKELA			
3	Fish, marginal invertebrates and riparian vegetation are primary motivators. The confidence is medium for low flows. Fish: The confidence is based on the use of <i>Amphilius</i> as indicator and the uncertainty whether it occurs at the site. However, requirements set for <i>Amphilius</i> would be conservative for the other species and it is therefore argued that the confidence in the IFRs from a fish perspective should be high. Invertebrates: The confidence is linked to a limited database. Hydraulics: The confidence is high.	Further work is required to refine the invertebrate requirements.	This work can be covered within the monitoring programme which should have specific emphasis on collating invertebrate baseline information.
BUSHMANS RIVER			
5	Marginal invertebrates (wet season) and riparian vegetation are the drivers. Some fish points drive the line, but some are off the line. The confidence is medium. Hydraulics: The confidence is high apart from flows below 0.9 m³/s and above 13m³/s.	Further work is required on the invertebrates and fish. This site formed part of the previous intermediate reserve assessment and no surveys on invertebrates have been undertaken. Hydraulics: Refinement at flows outside the range measured is required. Hydrology: The modelled hydrology was not representative of the hydrology at the site. The operation of the system in this river stretch is complex, especially the combination between abstractions and return flows. Further work is required to determine the applicability of the modelled hydrology (present day) to the IFR sites.	Invertebrates and fish: An extensive baseline study is required as part of monitoring. Hydraulics: Refinement at flows outside the range measured is required. Hydrology: A river reach specific hydrology study should be undertaken to determine the applicability of the RU hydrology to the site. All the above work must be included within the Reserve monitoring programme. This includes the refinement of the Reserve and the assumption on which the Reserve was based.
SUNDAYS RIVER			
7	Invertebrates, fish and riparian vegetation (drought) are drivers. Vegetation: The confidence is low to medium (due to a lack of cues and understanding of the vegetation) and invertebrates (due to a lack of information of the link between marginal invertebrates and the marginal vegetation on the cross-section). The hydraulics confidence is medium above 0.25m³/s.	The IFR site is complex but provides a variety of cues for IFR sites. Fish and invertebrates: Further work is required on fish in general, and marginal invertebrates and the link to marginal vegetation and flow. Hydraulics: An Improved rating table is required.	Fish and invertebrates baseline work is required as part of monitoring. This should also include the additional hydraulic refinement and the associated IFR refinement.
8	Riparian vegetation (and one point of flow dependant invertebrates) is the driver. The confidence is medium. Hydraulics: The confidence is high due to the flows of 6.1 m³/s. Higher flows are medium.	Further work is required for the riparian vegetation. However, as the vegetation is limited on site, further baseline collection surveys are not in the short-term going to supply any additional information. Monitoring on the vegetation and the status of alien vegetation would be more applicable. Hydraulics: Improved rating table is required.	Standard monitoring procedures are required as well as hydraulic refinement (and associated IFR refinement).

IFR site	Confidence Evaluation	Further work	Necessity
MOOI RIVER			
10	Fish and flow dependant invertebrates and riparian vegetation are drivers. Hydraulics: Confidence below 5.3m ³ /s is low.	This site was a checking site during a previous Mooi River IFR refinement study and limited studies were undertaken on the site. Further work on the fish, vegetation and invertebrates is therefore required as well as hydraulics refinement at flows below 5.3m ³ /s.	Intensive biological baseline required during monitoring. Hydraulics: Refinement is required - as well as the exact spacing of the cross-section.
11	The drivers are riparian vegetation and invertebrates. Confidence medium-high. Hydraulics: The confidence is medium below 1m ³ /s and above 47m ³ /s.	Limited additional information is required. Additional hydraulic refinement is only required if the Reserve flows fall outside the range.	Standard monitoring procedures.
12	This site was not evaluated as the benchmarks were removed. The results provided, were extrapolated and therefore of low confidence.	Once the benchmarks are re-established, a Reserve must be set after appropriate information has been collected.	As part of monitoring, the baseline information and hydraulic information must be collected. The Reserve must then be set.
BUFFALO RIVER			
13	The drivers are riparian vegetation, fish and flow dependant invertebrates. Confidence - Medium-high. Hydraulics: Medium below 1.8m ³ /s	Although the confidence in the IFR components are reasonable, the requirements set for the different categories were not of much use to set the requirements. Some revision of the Reserve is required after monitoring. Hydraulics: Refinements are required if the IFR range is below 1.8m ³ /s	Standard monitoring procedures as well as the refinement of hydraulics are required. A refinement of the IFR requirements for the different categories must be undertaken.
14	Drivers are flow invertebrates and riparian vegetation. Confidence: Medium-high. Hydraulics: Confidence is high to flows of 90 m ³ /s. Above 90 m ³ /s it is medium.	No further work is required.	Standard monitoring procedures is required.

17.5 CONCLUSIONS

The sites with the highest confidence are IFR 1, 4, 9, 8, 11, and 14. Of these sites IFR 4, 9 and 11 are old IFR sites, i.e. more than normal information is available. Furthermore, for IFR sites 4, 11 and 14 sediment transport modelling as well as habitat modelling has been undertaken. This should result in higher confidence results.

Further work to increase the confidence in the results can all be addressed as part of the monitoring programme and will be included as per the table above.

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