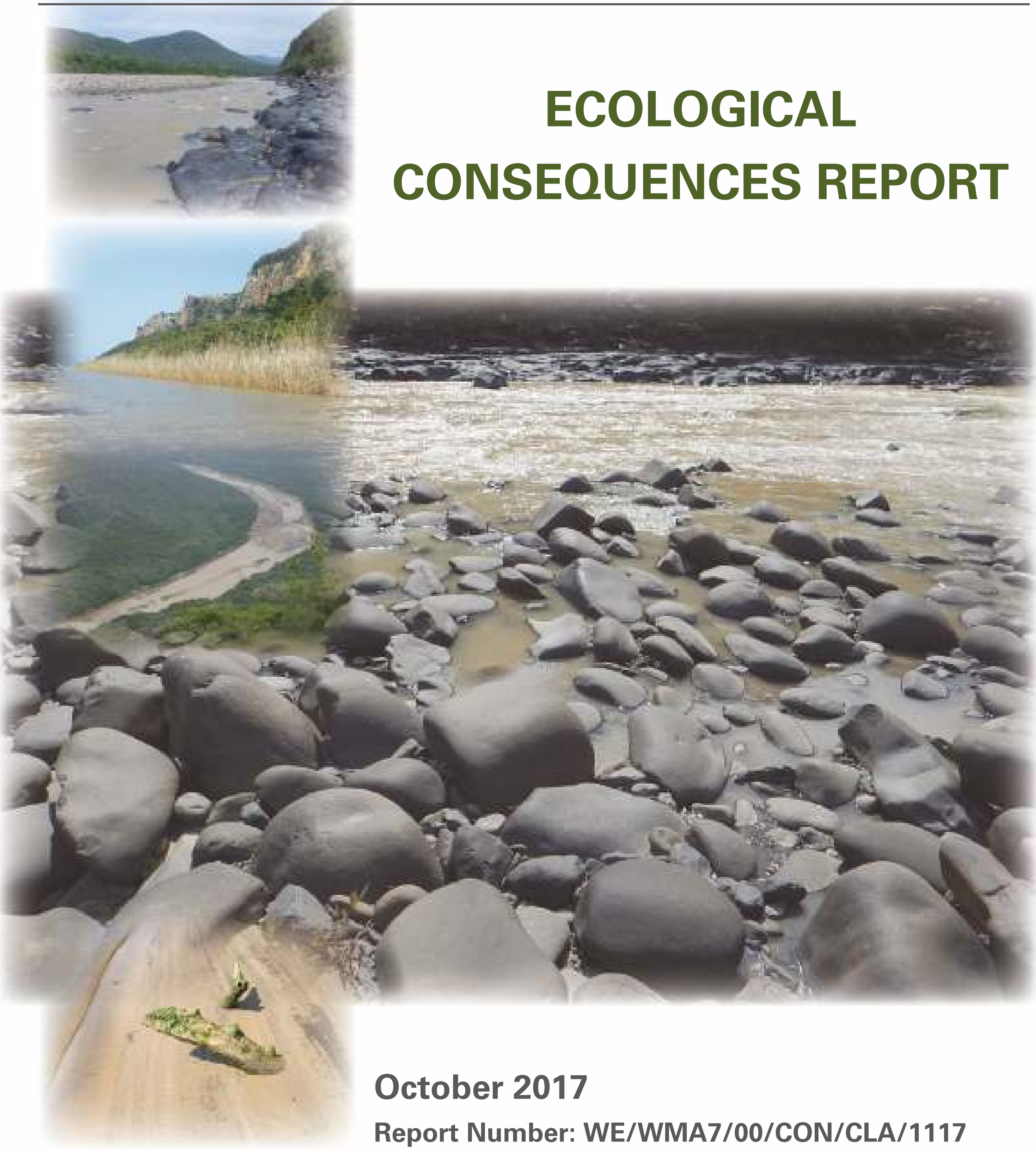
water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

WP 11004

DETERMINATION OF WATER RESOURCE CLASSES AND RESOURCE QUALITY OBJECTIVES FOR THE WATER RESOURCES IN THE MZIMVUBU CATCHMENT

ECOLOGICAL CONSEQUENCES REPORT



October 2017

Report Number: WE/WMA7/00/CON/CLA/1117

Published by

Department of Water and Sanitation
Private Bag X313
PRETORIA, 0001
Republic of South Africa

Tel: +27 (12) 336 7500
Fax: +27 (12) 323 0321

This report should be cited as:

Department of Water and Sanitation (DWS), South Africa. 2017. Determination of Water Resource Classes and Resource Quality Objectives for Water Resources in the Mzimvubu Catchment. Ecological Consequences Report. Prepared by Rivers for Africa eFlows Consulting (Pty) Ltd for Scherman Colloty and Associates cc. Report no. WE/WMA7/00/CON/CLA/1117.

Compiled by:
Scherman Colloty & Associates cc
22 Somerset Street
Grahamstown
6139

DOCUMENT INDEX

Report name	Report number
Inception Report	WE/WMA7/00/CON/CLA/0116
Survey Report	WE/WMA7/00/CON/CLA/0216
Status Quo and (RUs and IUA) Delineation Report	WE/WMA7/00/CON/CLA/0316
River Workshop Report	WE/WMA7/00/CON/CLA/WKSP/0117
River Desktop EWR and Modelling Report: Volume 1 – Systems Modelling Volume 2 – Desktop EWR Assessment	 WE/WMA7/00/CON/CLA/0217, Volume 1 WE/WMA7/00/CON/CLA/0217, Volume 2
BHNR Report (Surface and Groundwater)	WE/WMA7/00/CON/CLA/0317
Estuary Workshop Report	WE/WMA7/00/CON/CLA/WKSP/0417
Scenario Description Report	WE/WMA7/00/CON/CLA/0517
River EWR Report	WE/WMA7/00/CON/CLA/0617
Estuary EWR Report	WE/WMA7/00/CON/CLA/0717
Groundwater Report	WE/WMA7/00/CON/CLA/0817
Wetland EcoClassification Report	WE/WMA7/00/CON/CLA/0917
Scenario Non-ecological Consequences Report	WE/WMA7/00/CON/CLA/1017
Ecological Consequences Report	**WE/WMA7/00/CON/CLA/1117**
WRC and Catchment Configuration Report	WE/WMA7/00/CON/CLA/0118
River and Estuary RQO Report	WE/WMA7/00/CON/CLA/0218
Wetlands and Groundwater RQO Report	WE/WMA7/00/CON/CLA/0317
Monitoring and Implementation Report	WE/WMA7/00/CON/CLA/0418
Water Resource Classes and RQOs Gazette Template Input	WE/WMA7/00/CON/CLA/0518
Main Report	WE/WMA7/00/CON/CLA/0618a
Close Out Report	WE/WMA7/00/CON/CLA/0618b
Issues and Response Report	WE/WMA7/00/CON/CLA/0718

Bold indicates this report

APPROVAL

TITLE:	Ecological Consequences Report
DATE:	October 2017
AUTHORS:	Adams JB, Forbes N, Koekemoer S, Kotze P, Louw D, MacKenzie J, Rowntree K, Scherman P, Snow GC, Taljaard S, Turpie JK, Uys M, Weerts S, van Niekerk L.
EDITOR:	Gowans L
REVIEWERS:	Project Management Team
LEAD CONSULTANT:	Scherman Colloty & Associates cc
REPORT NO:	WE/WMA7/00/CON/CLA/1117
FORMAT:	MSWord and PDF
WEB ADDRESS:	http://www.dws.gov.za

Approved for Scherman Colloty & Associates cc:

____

Dr Patsy Scherman
Study Leader

Supported by:	Recommended by:
______________________________	______________________________
Lawrence Mulangaphuma Project Manager	Ms Lebogang Matlala Director: Water Resource Classification

Approved for the Department of Water and Sanitation by:

____

Ms Ndileka Mohapi
Chief Director: Water Ecosystems

ACKNOWLEDGEMENTS

The following persons contributed to this project.

Project Management Team

Matlala, L	DWS: Water Ecosystems; Classification
Mulangaphuma, L	DWS: Water Ecosystems; Classification
Scherman, P-A	Scherman Colloty & Associates cc
Sauer, J	Scherman Colloty & Associates cc
Weni, E	DWS: Eastern Cape Regional Office
Weston, B	DWS: Water Ecosystems; Surface Water Reserves
Neswiswi, T	DWS: Water Ecosystems; Surface Water Reserves
Kganetsi, M	DWS: Resource Protection and Waste
Molokomme, L	DWS: Water Ecosystems; Groundwater Reserves
Muthraparsad, N	DWS: Environment and Recreation
Thompson, I	DWS: Integrated Water Resource Planning
Matume, M	DWS: Stakeholder Engagement and Coordination
Cilliers, G	DWS: Resource Quality Information Services
Majola, S	DWS: Resource Quality Information Services

AUTHORS

The following persons contributed to this report:

River team

Author	Company
Koekemoer, S	Koekemoer Aquatic Services
Kotze, P	Clean Stream Biological Services
Louw, D	Rivers for Africa (Pty) Ltd
MacKenzie, J	MacKenzie Ecological & Development Services cc (MEDS)
Rowntree, K	EarthBound Africa
Scherman, P-A	Scherman Colloty & Associates cc (SC&A)
Uys, M	Laughing Waters

Estuary team

Author	Company
Adams, JB	Nelson Mandela University (NMU)
Forbes, N	Marine and Estuarine Research (MER)
Snow, G	University of the Witwatersrand
Taljaard, S	Council for Scientific and Industrial Research (CSIR), Stellenbosch
Turpie, J	Anchor Environmental Consultants
Van Niekerk, L	CSIR, Stellenbosch
Weerts, S	CSIR, Durban

The report was compiled by S Koekemoer and D Louw.

REPORT SCHEDULE

Version	Date
First draft	August 2017
Final	October 2017

EXECUTIVE SUMMARY

BACKGROUND

The Mzimvubu catchment has been prioritised for implementation of the Water Resource Classification System (WRCS) in order to determine appropriate Water Resource Classes and Resource Quality Objectives (RQOs) in order to facilitate the sustainable use of water resources without impacting negatively on their ecological integrity.

The main aims of the project, as defined by the Terms of Reference (ToR), are to undertake the following:

- Coordinate the implementation of the WRCS as required in Regulation 810 in Government Gazette 33541 dated 17 September 2010, by classifying all significant water resources in the Mzimvubu catchment, and
- determine RQOs using the DWS's procedures to determine and implement RQOs for the defined classes.

The purpose of this report is to document the consequences of the various operational scenarios in terms of its impact on the Tsitsa and Mzimvubu rivers and the Mzimvubu Estuary, i.e. the water resources impacted by scenarios.

STUDY AREA

The study area is represented by the Mzimvubu catchment which consists of the main Mzimvubu River, the Tsitsa, Thina, Kinira and Mzintlava main tributaries and the estuary at Port St Johns.

OPERATIONAL SCENARIOS

The operational scenarios are summarised below.

Scenarios 2a and 2b: Both these scenarios represent development scenarios at 2040 with no EWRs included, but with the Mzimvubu Water Project (proposed Ntabelanga and Lalini dams) included. The only difference between the scenarios is that Scenario (Sc) 2a caters for a realistic estimate of increased water use and return flows for the domestic sector, whereas Sc 2b includes an ultimate development where water requirements were increased to fully utilise the available yield of the proposed dams.

Scenarios 32 and 33: These scenarios are the same as Scenario 2b but include releases for EWRs at EWR1 Lalini and MzimEWR4. No EWRs are provided for MzimEWR1 and it is not a realistic scenario but was used for testing purposes only. The difference between the scenarios is that Sc 32 provides the total EWR (low flows and high (flood) flows), whereas Sc 33 provides only the low flows.

Scenarios 41 and 42: These scenarios are the same as Scenario 2b but include releases for MzimEWR1. The difference between the scenarios is that Sc 41 includes low flows only at MzimEWR1 and MzimEWR4, whereas Sc 42 includes a low flow EWR at EWR1 Lalini.

Scenarios 51 and 52: Initial analyses of Sc 41 and 42 showed that the REC is unlikely to be achieved at the estuary and MzimEWR4 due to the higher than natural low (base) flows, especially during the dry season which is released for power generation. Flows provided for hydropower were therefore decreased in the winter months to mitigate this impact. The aim was initially to bring the winter flows down to below natural and to ensure that it would be lower than the summer flows. Note that the implications of the decreased flows on power generation will be provided as part of the economic consequences analysis and were not considered for the ecological consequences analysis. Sc 51 is therefore the same as Sc 41 (and Sc 52 the same as Sc 51) but with less flow in the winter months available for hydropower generation.

Scenario 53: Initial analyses of Sc 51 and 52 showed that although these scenarios were an improvement on Sc 41 and 42, the impact of the high base flows were not sufficiently mitigated and the ecological objectives in terms of the Recommended Ecological Category (REC) were still not met. The flows available for hydropower during the dry season were therefore further reduced to a level indicated by the ecological specialists. Sc 53 is therefore the same as Sc 51 but with a further reduction in flows available for hydropower during the dry months.

EWR SITES AFFECTED BY OPERATIONAL SCENARIOS

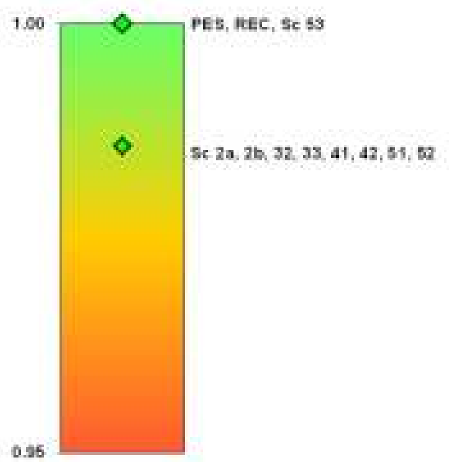
The impact of operational scenarios in a river system is assessed at EWR sites located within the river system. Two EWR sites in the Tsitsa and Mzimvubu rivers (MzimEWR1 and MzimEWR4) will be affected by the operational scenarios. An additional point, EWR1 Lalini, situated downstream of the proposed Lalini Dam in the Tsitsa River (T35L), was included to assess the impacts downstream of the proposed Lalini Dam. The detailed and high confidence results collected at MzimEWR1 were extrapolated to EWR 1 Lalini.

ECOLOGICAL CONSEQUENCES: RIVERS

The ecological consequences on the three EWR sites are provided in the table below. Note that the colouring of the traffic diagram denotes an improvement from red through orange to green. Shading is therefore according to the colours of a traffic light; implying that the items at the top (in the green section) are better than the ones below.

Ecological consequences as Ecological Categories (ECs)	**Ranked scenarios**
MzimEWR4 (Mzimvubu River)	

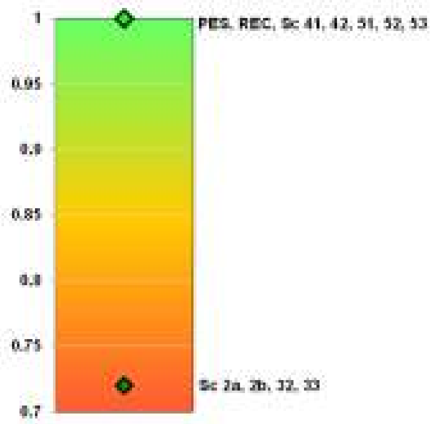
Component	PES and REC	Sc 2a	Sc 32	Sc 52	Sc 53
Physico-chemical	A/B	A	A	A	A/B
Geomorphology	C	C	C	C	C
Riparian vegetation	C/D	D	D	D	C/D
Fish	C	B/C	B/C	B/C	B
Macroinvertebrates	C	C	C	C	B
EcoStatus	C	C	C	C	C



Ranking rationale: The ranking of the scenarios indicate that only Sc 53 achieves the REC requirements. The rest of the scenarios maintain the Present Ecological State (PES) EcoStatus albeit at a marginally lower percentage. A deterioration in riparian vegetation and is evident in all scenarios except for Sc 53.

MzimEWR1 (Tsitsa River)

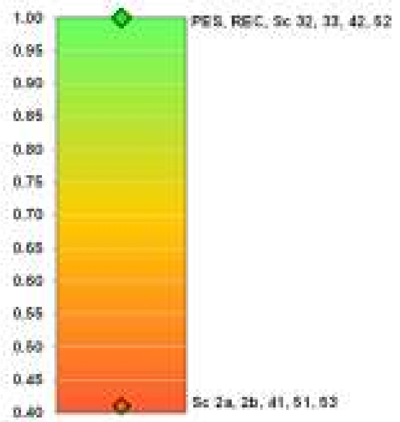
Component	PES and REC	Sc 2a	Sc 41
Physico-chemical	B	C/D	B
Geomorphology	C	C	C
Riparian vegetation	C/D	D/E	C/D
Fish	C	D	C
Macroinvertebrates	C	D/E	C
EcoStatus	C	D	C



Ranking rationale: The ranking of the scenarios indicates that Sc 2a, 2b, 32 and 33 do not achieve the PES and REC and all components deteriorate resulting in an EcoStatus of a D (bordering on a D/E). The rest of the scenarios achieve the REC requirements.

EWR1 Lalini (Tsitsa River)

Component	PES and REC	Sc 2a	Sc 33	Sc 32
Physico-chemical	B	E	B	B
Geomorphology	C	C	C	C
Riparian vegetation	C/D	F	C/D	C/D
Fish	C	D/E	C	C
Macroinvertebrates	C	F	C	B/C
EcoStatus	C	E/F	C	C



Ranking rationale: The ranking of the scenarios indicates that Sc 2a, 2b, 41, 51 and 53 do not achieve the PES and REC. Under these scenarios the EcoStatus falls within an E/F Category, which is ecologically unsustainable. The rest of the scenarios achieve the REC requirements.

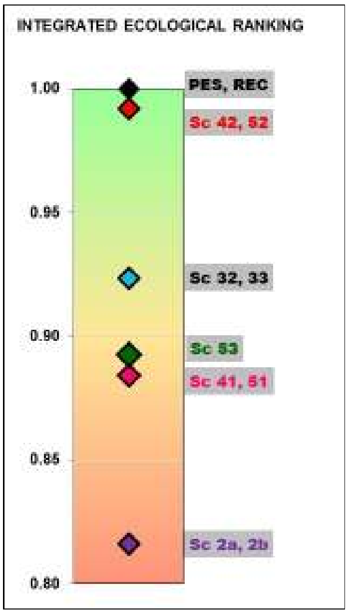
INTEGRATED RIVER ECOLOGICAL RANKING

The first step in the process to determine an integrated ranking is to determine the relative importance of the different EWR sites occurring in the study area. The site weighting process indicated that MzimEWR4 carries the highest weight due to the site being the most downstream site in the study area and represents the accumulated impact of all upstream activities. The evaluation at the EWR site represents 137 river km from the outfall of Lalini Dam to the estuary. The importance of MzimEWR1 is lower; due to less accumulated impacts of scenarios within the 76 km reach demarcated from Ntabelanga Dam to Lalini Dam. EWR1 Lalini has the lowest weight, as the Ecological Importance and Sensitivity (EIS) is Moderate and the site is situated in a relatively isolated reach in the Tsitsa River (18 km from Lalini Dam to the outfall of the dam).

The weighting was applied to the ranking value for each scenario at each EWR site and this provided an integrated score and ranking for the operational scenarios. The ranking of '1' refers to the REC and the rest of the ranking illustrates the degree to which the scenarios meet the REC. The results are provided below after the weights have been taken into account.

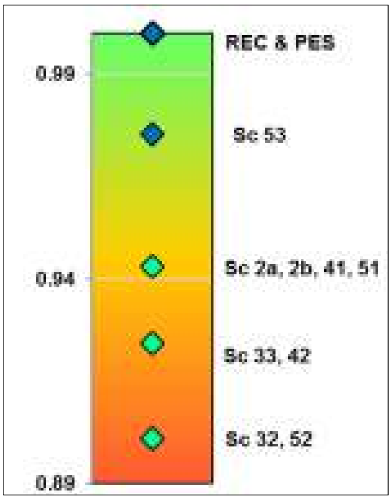
Site	PES and REC	Sc 2a, 2b	Sc 32, 33	Sc 41, 51	Sc 42, 52	Sc 53
MzimEWR1	0.24	0.17	0.17	0.24	0.24	0.24
EWR1 Lalini	0.18	0.08	0.18	0.08	0.18	0.08
MzimEWR4	0.57	0.57	0.57	0.57	0.57	0.57
	1.00	**0.82**	**0.92**	**0.88**	**0.99**	**0.89**

The above results were plotted on a traffic diagram to illustrate the integrated ecological ranking for the river sites.



ECOLOGICAL CONSEQUENCES: ESTUARY

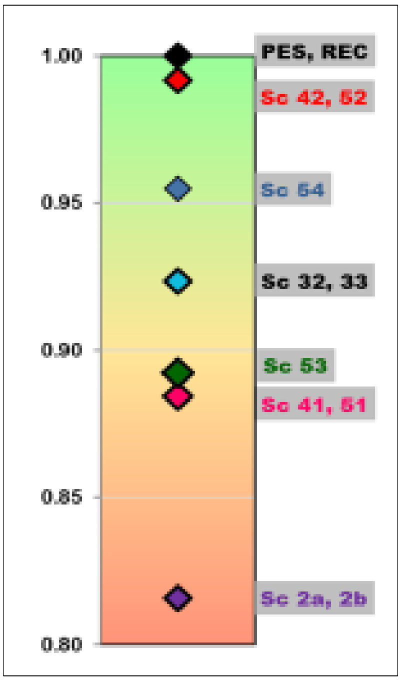
The ranking of scenarios indicate that only Sc 53 maintains the REC of a B Category, although the score is marginally lower than the REC (and PES) score. This scenario is better than all the other scenarios as water available for hydropower generation has been decreased sufficiently so that increased base flows are not a significant problem at the estuary.



OPTIMISATION OF SCENARIO 53

In the chronological process of developing scenarios, it was noted that Sc 53 was the only scenario that met the estuary REC as well as the REC at MzimEWR4, due to the process of minimising increased baseflows (linked to hydropower production) downstream of the dams. As these are the most important sites, it was of concern that the integrated river ranking scored lower than other scenarios. The investigation showed that the reason for the lower ranking was the significant impact of not providing EWR flows (Sc 53) from Lalini Dam and the severe impact it may have on at least 18 km of river downstream of the dam. An additional impact would be on the Lower Tsitsa Falls, with no water going over the falls.

Sc 53 was therefore further optimised to include some flows downstream of Lalini Dam, but lower than the REC low flows released in Sc 52. It was decided to use the flows that would result in a D category at MzimEWR1 and extrapolate these to EWR1 Lalini. The scenario was designed in such a way that the flows downstream of the outlet would be the same or similar to those of Sc 53. This scenario was called Sc 54. Although Sc 52 was still a 'better' scenario from the river viewpoint, Sc 54 was significantly better than the Sc 53 ranking.



If the estuary is also considered in the ranking above, with the estuary carrying a weight of either 30 or 50% of the integrated system, Sc 54 is still the highest ranking scenario.

CONCLUSIONS AND RECOMMENDATIONS

The recommendation from an ecological viewpoint is that Sc 54 should be implemented if the dams are approved. Based on the outcome of the economic analysis, further work may be required to adjust the flows downstream of Lalini Dam. Operating rules assumed for the modelling can be further adjusted to optimise water use and ecological conditions. This may be required once information is obtained on the current preliminary dam. These rules can be adjusted in the final design of the dam and hydropower system to meet downstream EWRs. It must be noted, however, that careful consideration is required regarding the section downstream of Lalini Dam as any additional flows above the D category may result in higher baseflows and impacts on seasonality at MzimEWR4 and the estuary. Decisions regarding this situation can only be made once the economic and other consequences are available.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AEC	Alternative Ecological Category
BHNR	Basic Human Needs Reserve
DWA	Department Water Affairs (Name change from DWAF applicable after April 2009)
DWAF	Department Water Affairs and Forestry
DWS	Department Water and Sanitation (Name change from DWA applicable after May 2014)
DO	Dissolved Oxygen
EC	Ecological Category
EIA	Environmental Impact Assessment
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirement
FRAI	Fish Response Assessment Index
FDI	Flow Dependent Macroinvertebrate
FROC	Frequency of Occurrence
EHI	Estuarine Health Index
GAI	Geomorphological Driver Assessment Index
IHI	Index of Habitat Integrity
MAR	Mean Annual Runoff
MIRAI	Macroinvertebrate Response Assessment Index
MCM	Million Cubic Metres
MPB	Microphytobenthos
MRU	Management Resource Unit
MVI	Marginal Vegetation Macroinvertebrates
NTU	Nephelometric Turbidity Units
MWP	Mzimvubu Water Project
%iles	Percentiles
PAI	Physico-chemical Driver Assessment Index
PD	Present Day
PES	Present Ecological State
REC	Recommended Ecological Category
REI	River Estuary Interface
RQO	Resource Quality Objective
RI	Recurrence Value (Number of years/frequency)
VEGRAI	Riparian Vegetation Response Assessment Index
Sc	Scenario
SQ	Sub Quaternary
ToR	Terms of Reference
WMA	Water Management Area
WRCS	Water Resource Classification System
WRYM	Water Resources Yield Model
WWTW	Waste Water Treatment Works

GLOSSARY

Alternative Ecological Category (AEC)	This terminology is not relevant within these processes but is provided here for completeness sake. The AEC represents any other category than the PES and REC for which flow requirements may be set. This terminology was used during Preliminary Reserve determination.
EcoClassification	EcoClassification (or the Ecological Classification process) refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various physical attributes of rivers relative to the natural reference condition. A range of models are used during EcoClassification, each of which relate to the indicators assessed.
Ecological Category (EC)	ECs are determined for all components of the ecosystem for driver (abiotic) and response (biotic) components. These are integrated into an overall or integrated state called the EcoStatus. This level of information with the entire component ECs is only available when detailed studies are undertaken. For more desktop type studies, only a single EC may be available which represent the EcoStatus. **Whenever an EC is referred to without specifying that it is applicable to a specific component, this will always refer to the EcoStatus.**
Ecological Importance and Sensitivity (EIS)	Key indicators in the ecological classification of water resources. Ecological importance relates to the presence, representativeness and diversity of species of biota and habitat. Ecological sensitivity relates to the vulnerability of the habitat and biota to modifications that may occur in flows, water levels and physico-chemical conditions.
Ecological Water Requirements (EWR)	The flow patterns (magnitude, timing and duration) and water quality needed to maintain a riverine ecosystem in a particular condition. This term is used to refer to both the quantity and quality components.
EcoStatus	EcoStatus is defined as the totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services.
EWR sites	Specific points on the river as determined through the ‘hotspot’ and site selection process. An EWR site consists of a length of river which may consist of various cross-sections assessed for both hydraulic and ecological purposes. These sites provide sufficient indicators to assess environmental flows and assess the condition of biophysical components (drivers such as hydrology, geomorphology and physico-chemical conditions) and biological responses (viz. fish, macroinvertebrates and riparian vegetation).
Water Resource Classification System (WRCS)	The Water Resource Classification System is a defined set of guidelines and procedures for determining the different classes of water resources (South African National Water Act (Act 36 of 1998) Chapter 3, Part 1, Section 2(a)). The outcome of the Classification Process will be the setting of the Class, Reserve and Resource Quality Objectives by the Minister or delegated authority for every significant water resource (river, estuary, wetland and aquifer) under consideration. This class, which will range from Minimally Used to Heavily Used, essentially describes the desired condition of the resource, and concomitantly, the degree to which it can be utilised.

Management Resource Units (Rivers)	The purpose of distinguishing MRUs from RUs is to identify a management unit within which the EWR can be implemented and managed based on one set of identified flow requirements. This means that an EWR site in the MRU, according to the EWR site selection criteria in context of the MRU, will provide for the whole MRU. MRUs are usually defined for river reaches only and differ from Resource Units in that the latter is a more detailed assessment.
Present Ecological State (PES)	The current state or condition of a water resource in terms of its biophysical components (drivers) such as hydrology, geomorphology, water quality and biological responses (viz. fish, invertebrates, riparian vegetation). The degree to which ecological conditions of an area have been modified from natural (reference) conditions.
Recommended Ecological Category (REC)	The Recommended Ecological Category is the future ecological state (Ecological Categories A to D) that can be recommended for a resource unit depending on the EIS and PES. The REC is determined based on ecological criteria and considers the EIS, the restoration potential of the system and attainability thereof.
Resource Quality Objectives (RQOs)	RQOs are numeric or descriptive goals that can be monitored for compliance to the Water Resource Class, for each part of each water resource.
Resource Units (RUs)	RUs are delineated during an Ecological Reserve determination study, as each will warrant its own specification of the Reserve, and the geographic boundaries of each must be clearly delineated. These sections of a river frequently have different natural flow patterns, react differently to stress according to their sensitivity, and require individual specifications of the Reserve appropriate for that reach. RUs are nested within IUAs and may contain an Ecological Water Requirement site.
Revised Desktop Reserve Model (RDRM)	The output from the RDRM is an estimated EWR for each Ecological Category, at a desktop level for biophysical nodes other than EWR sites. Due to the large study area, additional EWRs are estimated for every Resource Unit identified which is not addressed by the more detailed EWR assessment at EWR sites. These EWRs are therefore estimated using the RDRM.
Scenarios	Scenarios, in the context of water resource management and planning, are plausible definitions (settings) of factors (variables) that influence the water balance and water quality in a catchment and the system as a whole. Each scenario represents an alternative future condition, generally reflecting a change to the present condition.
Sub-quaternary catchments (SQ)	A finer subdivision of the quaternary catchments (the catchment areas of tributaries of main stem rivers in quaternary catchments), to a sub-quaternary or quinary level.
Water Resource Class	The Water Resource Class is representative of those attributes that the DWS (as the custodian) and society require of different water resources. The decision-making toward a Water Resource Class requires a wide range of trade-offs to be assessed and evaluated at a number of scales. The final outcome of the process is a set of desired characteristics for use and ecological condition for each of the water resources in a given catchment. Three classes are defined, i.e. Class I, II, and III, based on the extent of use and alteration of ecological condition from the predevelopment condition.

1 INTRODUCTION

1.1 BACKGROUND

The Mzimvubu catchment has been prioritised for implementation of the Water Resource Classification System (WRCS) in order to determine appropriate Water Resource Classes (and Resource Quality Objectives (RQOs) to facilitate the sustainable use of water resources without impacting negatively on their ecological integrity. These activities will guide the management of the Mzimvubu T3 primary catchment toward meeting the departmental objectives of maintaining, and if required, improving the present state of the Mzimvubu River and its four main tributaries, namely the Tsitsa, Thina, Kinira and Mzintlava rivers. This project is driven by threatened ecosystem services in the Mzimvubu catchment, due to the variety of inappropriate land uses and alien plant infestation that results in extensive erosion and degradation. Degradation can be observed in soil erosion, damage to infrastructure, water supply shortages and loss of grazing.

The Department of Water and Sanitation (DWS) has initiated a study to determine Classes and associated RQOs for the Mzimvubu T3 catchment in Water Management Area (WMA) 7.

The main aims of the project, as defined by the Terms of Reference (ToR), are to undertake the following:

- Coordinate the implementation of the WRCS as required in Regulation 810 in Government Gazette 33541 dated 17 September 2010, by classifying all significant water resources in the Mzimvubu catchment, and
- determine RQOs using the DWS's procedures to determine and implement RQOs for the defined classes.

An additional aim is to consolidate and undertake additional work as required to improve the work previously done on Ecological Water Requirements (EWR) and the Basic Human Needs Reserve (BHNR) for the purposes of Classification.

1.2 STUDY AREA OVERVIEW

The study area is represented by the Mzimvubu catchment which consists of the main Mzimvubu River, the Tsitsa, Thina, Kinira and Mzintlava main tributaries and the estuary at Port St Johns. The river reaches sizeable proportions after the confluence of these four tributaries in the Lower Mzimvubu area, approximately 120 km from its source, where the impressive Tsitsa Falls can be found near Shawbury Mission. The Mzimvubu catchment and river system lies along the northern boundary of the Eastern Cape and extends for over 200 km from its source in the Maloti-Drakensberg watershed on the Lesotho escarpment to the estuary at Port St Johns. The catchment is in Primary T, comprises of T31–36 and stretches from the Mzimkhulu River on the north-eastern side to the Mbashe and Mthatha river catchments in the south. The Mzimvubu catchment is found in WMA 7, i.e. the Mzimvubu to Tsitsikamma WMA.

1.3 STUDY PROJECT PLAN

The Mzimvubu study is being undertaken according to the Project Plan in **Figure 1.1** with each step broken down into sub-steps. This report pertains to Step 4, the evaluation of scenarios.

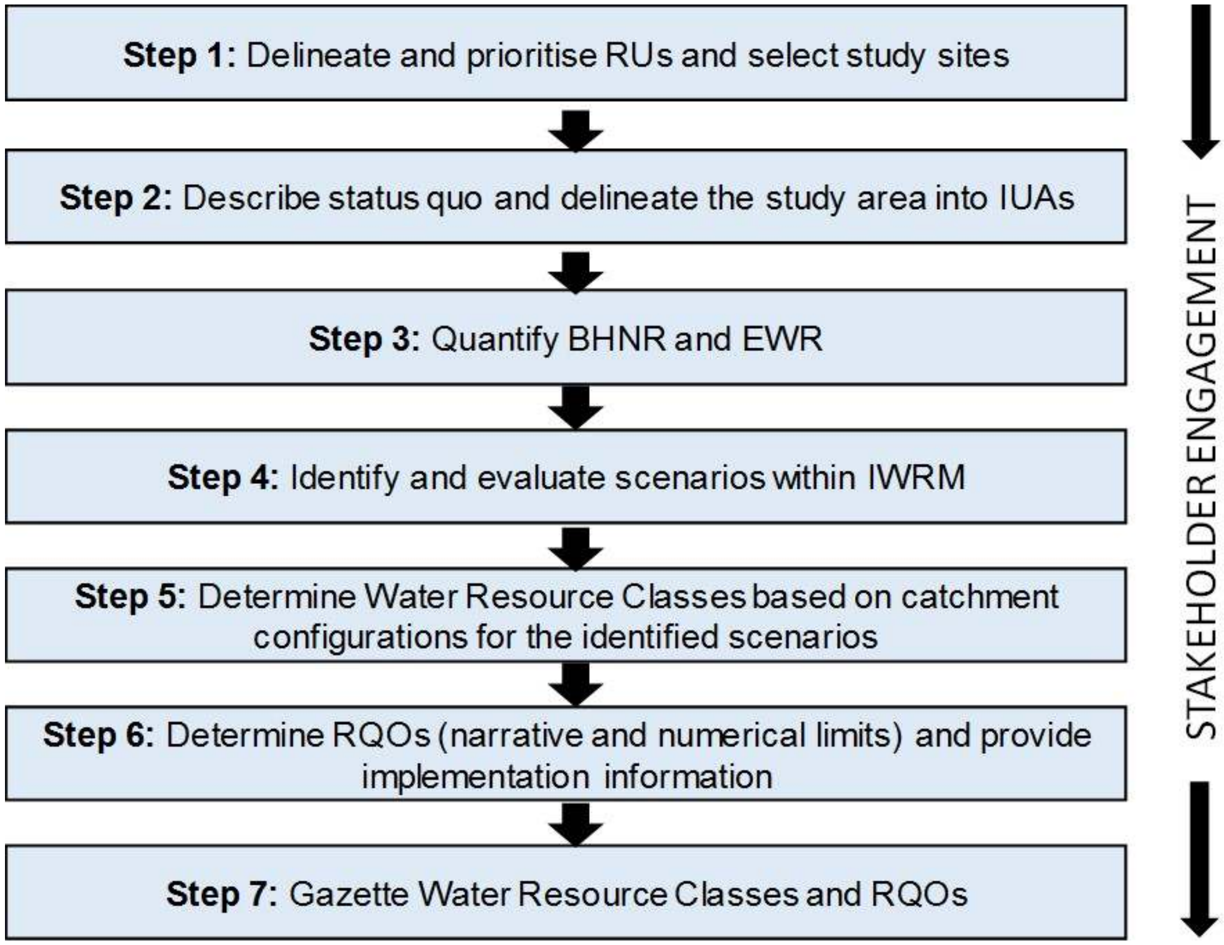


Figure 1.1 Project plan for the Mzimvubu Classification and RQO study

1.4 PURPOSE AND OUTLINE OF THIS REPORT

The purpose of this report is to document the consequences of the various operational scenarios in terms of their impact on the Tsitsa and Mzimvubu rivers and the Mzimvubu Estuary, i.e. the water resources impacted by scenarios. A summary of the estuary results can be found in Report no. WE/WMA7/00/CON/CLA/0717 (the Estuary EWR Report; DWS (2017a)), as well as **Chapter 7** of this report, i.e. the integration of the scenarios assessment results for both the rivers and the estuary. The report structure is outlined below.

Chapter 1: Introduction
This chapter provides general background to the project, study area and purpose of the report.

Chapter 2: Scenario descriptions
This chapter provides a summary of the different scenarios assessed.

Chapter 3: Approach and methodology
This chapter outlines the general approach and methodology to determining ecological consequences of operational scenarios on the riverine environment.

Chapter 4–6: Ecological consequences
Detailed consequences of the operational scenarios on the various ecological riverine components at MzimEWR1, MzimEWR4 and EWR1 Lalini (scaled from MzimEWR1) are provided.

Chapter 7: Ecological ranking of scenarios

The process to determine an integrated ranking of the different scenarios is described in detail.

Chapter 8: Conclusions

The ecological consequences (river and estuary) of the operational scenarios are summarised.

Chapter 9: References

2 SCENARIO DESCRIPTIONS

The Water Resources Yield Model (WRYM) was used for the study, and updated with the latest catchment development and land use information available in order to produce the best possible estimates of present day flow. Details regarding the modelling can be found in the following report: River Desktop EWR and Modelling Report: Volume 1 – Systems Modelling; Report no. WE/WMA7/00/CON/CLA/0217, Volume 1.

Table 2.1 presents the scenario (Sc) definition matrix indicating the identified variables as columns and the selected variable settings for the proposed scenarios in the respective rows. A qualitative description is provided below the table with further explanations on the scenarios. Details regarding the operational scenarios are provided in the Scenario Description Report, i.e. Report no. WE/WMA7/00/CON/CLA/0517. Note that the scenarios provided in the matrix only represent those scenarios that were initially analysed. This analysis may lead to further optimised scenarios, one of which is described later in the report. Any additional optimisation will be reported on in subsequent reports.

Table 2.1 Scenario definition matrix

Scenario	**Update water demands (2040)**		**EWRs**			**Development options**	
	Realistic projection (a)	**Ultimate development projection (b)**	**MzimEWR 4**	**MzimEWR 1**	**EWR1 Lalini (scaled from EWR1)**	**MWP[1] (Ntabelanga and Lalini dams with hydropower)**	**Port St Johns proposed WWTW**
Reference							
Present							
2a	Yes	No	No	No	No	Yes	No
2b	No	Yes	No	No	No	Yes	No
32	No	Yes	REC tot	No	REC tot	Yes	No
33	No	Yes	REC low	No	REC low	Yes	No
41	No	Yes	REC low	REC low	No	Yes	No
42	No	Yes	REC low	REC low	REC low	Yes	No
51	No	Yes	REC low	REC low	No	Yes – Reduced[2] hydro in dry months	No
52	No	Yes	REC low	REC low	REC low	Yes – Reduced hydro in dry months	No
53	Yes	No	REC low	REC low	No	Yes – Further reduced hydro in dry months	No
PresW1	Present river inflow, including 3.5 Mℓ per day WWTW inflow						Yes
PresW2	Present inflow, including 4.5 Mℓ per day WWTW inflow						Yes
Dam (1.5 MAR)	Large dam 1.5 MAR (Ntabelanga) (previous study's scenario 3 – DWS, 2014a)						No

1 MWP: Mzimvubu Water Project.
*The **ultimate development projection (b)** are the demands imposed to fully utilise the available yield of the new proposed dams.*
*The **realistic projection (a)** refers to an alternative projection which is felt to be more realistic in terms of the expected growth.*
[2] Reduced hydropower implies a reduction in the hydropower output initially envisaged. This reduction is undertaken to minimise the impact of increased baseflows in the downstream river. Sc 53 includes a further reduction as the reduction in Sc 52 did not mitigate the impact sufficiently. The economic implications of the reduction will be reported on in the non-ecological consequences report.

Scenarios 2a and 2b: Both these scenarios represent development scenarios at 2040 with no EWRs included, but with the Mzimvubu Water Project (proposed Ntabelanga and Lalini dams) included. The only difference between the scenarios is that Scenario (Sc) 2a caters for a realistic estimate of increased water use and return flows for the domestic sector, whereas Sc 2b includes an ultimate development where water requirements were increased to fully utilise the available yield of the proposed dams.

Scenarios 32 and 33: These scenarios are the same as Scenario 2b but include releases for EWRs at EWR1 Lalini and MzimEWR4. No EWRs are provided for MzimEWR1 and it is not a realistic scenario but was used for testing purposes only. The difference between the scenarios is that Sc 32 provides the total EWR (low flows and high (flood) flows), whereas Sc 33 provides only the low flows.

Scenarios 41 and 42: These scenarios are the same as Scenario 2b but include releases for MzimEWR1. The difference between the scenarios is that Sc 41 includes low flows only at MzimEWR1 and MzimEWR4, whereas Sc 42 includes a low flow EWR at EWR1 Lalini.

Scenarios 51 and 52: Initial analyses of Sc 41 and 42 showed that the REC is unlikely to be achieved at the estuary and MzimEWR4 due to the higher than natural low (base) flows, especially during the dry season which is released for power generation. Flows provided for hydropower were therefore decreased in the winter months to mitigate this impact. The aim was initially to bring the winter flows down to below natural and to ensure that it would be lower than the summer flows. Note that the implications of the decreased flows on power generation will be provided as part of the economic consequences analysis and were not considered for the ecological consequences analysis. Sc 51 is therefore the same as Sc 41 (and Sc 52 the same as Sc 51) but with less flow in the winter months available for hydropower generation.

Scenario 53: Initial analyses of Sc 51 and 52 showed that although these scenarios were an improvement on Sc 41 and 42, the impact of the high base flows were not sufficiently mitigated and the ecological objectives in terms of the Recommended Ecological Category (REC) were still not met. The flows available for hydropower during the dry season were therefore further reduced to a level indicated by the ecological specialists. Sc 53 is therefore the same as Sc 51 but with a further reduction in flows available for hydropower during the dry months.

Scenario naming: Scenario modelling and analysis is an iterative process, meaning that the naming of scenarios may not be consecutive, but represent those scenarios finally selected for the determination of consequences. Numbering (e.g. the number of letters or numbers used) is also bound by the models used (both for modelling and by the scenario comparison facility used by the ecologists). It is more important to retain consistency throughout the steps of the evaluation process than attempt to reorganize scenarios in consecutive numbering order.

3 APPROACH AND METHODOLOGY: RIVERS

3.1 DETERMINING RIVERINE ECOLOGICAL CONSEQUENCES

3.1.1 Available data

Data used during this task used the results of the EcoClassification process as outlined in DWS (2017b). The results of the individual EcoStatus models (presented as electronic data) were used to assess the changes in ecological state and present the results as Ecological Categories per component, as well as an integrated ecological state (the EcoStatus), for each scenario.

3.1.2 EWR sites affected by operational scenarios

Existing EWR sites selected during the feasibility study for the Mzimvubu Water Project (DWS, 2014b) were used during this study, as well as an additional site selected in the lower reach of the Mzimvubu River (MzimEWR4). An EWR site did not previously exist in this high priority reach. Details of the EWR sites are provided in **Table 3.1** and discussed in detail in DWS (2017b). A map showing the position of the sites is included as **Figure 3.1**.

The impact of operational scenarios in a river system is assessed at EWR sites located within the river system and those potentially impacted by those scenarios. Based on the previous studies outlined in **Section 3.1.1**, two EWR sites, located in the Tsitsa (MzimEWR1) and Mzimvubu (MzimEWR4) rivers, were identified which could possibly be impacted by the operational scenarios.

An additional site, EWR1 Lalini, situated downstream of the proposed Lalini Dam in the Tsitsa River (T35L), was included in this scenario assessment study. The site information from MzimEWR1 was used for this site as the study team did not survey the site, and on-site data for the Lalini EWR site surveyed during the DWS feasibility study of 2014 were not available to the team. The hydrology and EWR results from the upstream MzimEWR1 were therefore extrapolated to a point below Lalini Dam to include the inflows downstream of MzimEWR1. This node is referred to as EWR1 Lalini. Details are shown on **Table 3.1**.

Table 3.1 EWR sites where operational scenarios will be evaluated

EWR site	River	MRU[1]	Eco region	Geomorphic zone	SQ[2]	Latitude	Longitude
MzimEWR1	Tsitsa	MRU Tsitsa C	16.06	Lower foothills	T35E-05977	31.14800	28.67400
MzimEWR4	Mzimvubu	MRU Mzim	31.01	Lower foothills	T36A-06250	31.39636	29.29671
EWR1 Lalini	Tsitsa	MRU Tsitsa C	16.06	Lower foothills	T35L-05976	31.268552	28.928643[3]

[1] Management Resource Unit [2] Sub Quaternary reach

[3] This locality is represented by an arbitrary point close to the proposed Lalini Dam wall.

3.2 ECOLOGICAL CONSEQUENCES METHODS

The suite of EcoStatus models used during this task were:

- Physico-chemical Driver Assessment Index (PAI): Kleynhans et al. (2005); DWAF (2008).
- Geomorphology Driver Assessment Index (GAI): Rowntree (2013).
- Fish Response Assessment Index (FRAI): Kleynhans (2007).
- Macroinvertebrate Response Assessment Index (MIRAI): Thirion (2007).
- Riparian Vegetation Response Assessment Index (VEGRAI): Kleynhans et al. (2007a).

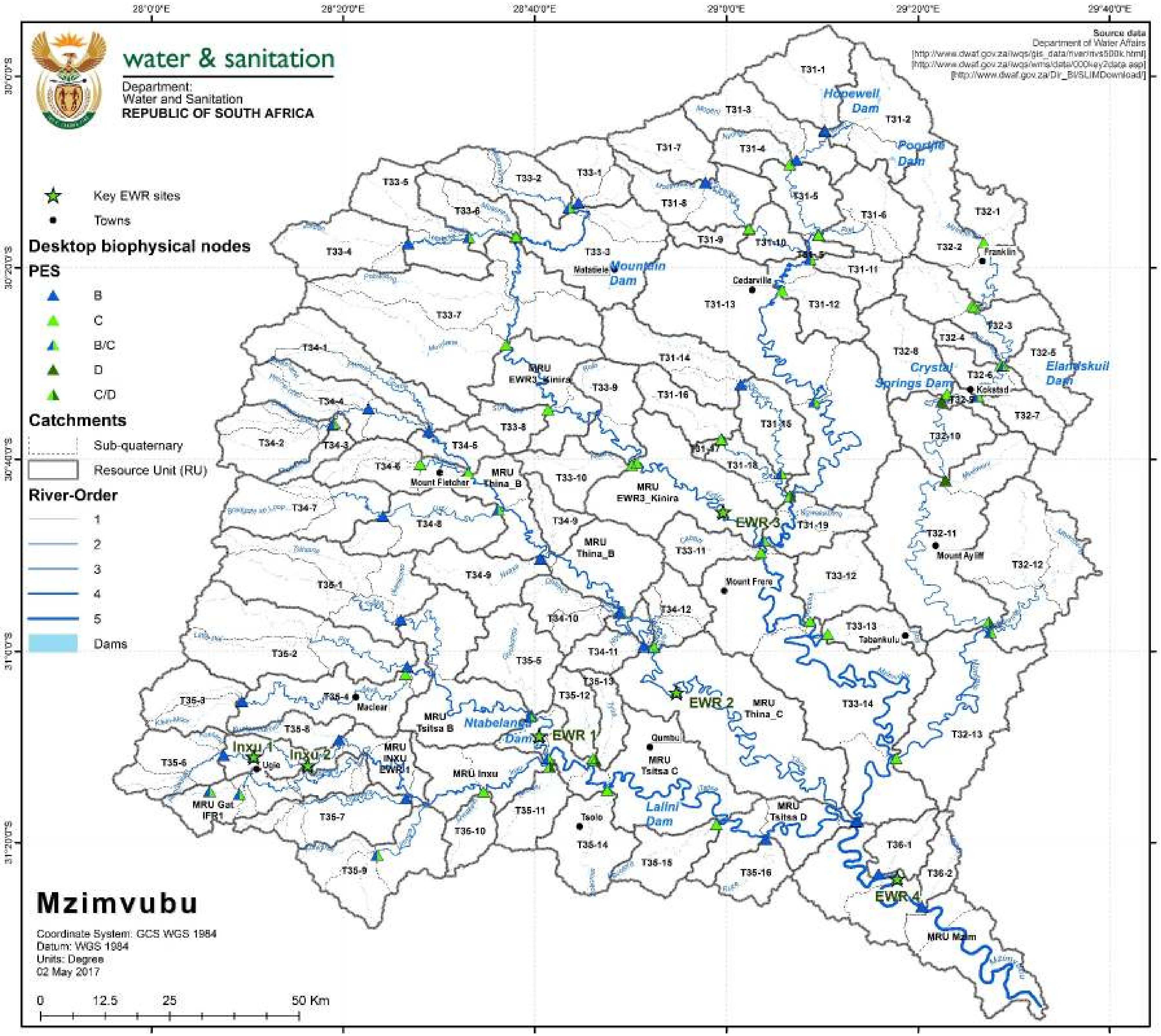


Figure 3.1 Catchment map showing the position of EWR sites

The process to determine ecological consequences of scenarios is shown in the following chronological steps:

- The operational scenarios were modelled and a time series was provided for each scenario at each EWR site.
- The time series for the scenarios were converted to flow duration tables and exceedance graphs and provided to the specialists, through the use of a Scenario Comparison Facility Tool. This tool was developed to evaluate a series of scenarios for the use of the ecological river team by Mr Pieter van Rooyen and Dr Andrew Birkhead. Time-series data can be evaluated at a particular EWR site for a particular month (e.g. the dry season month, August – **Figure 3.2**), or at a percentage exceedance for all the months in the flow record (e.g. the 95% drought exceedance flow – **Figure 3.3**).
- The driver components, i.e. physico-chemical (or water quality) and geomorphology, provided a first assessment of consequences, which were provided to the rest of the team. The geomorphologist worked closely with the riparian vegetation specialist in terms of impacts on floods.
- The consequences and resulting Ecological Category (EC) of each operational scenario for water quality were assessed at each EWR site and the PAI was populated to determine the resulting EC.
- The riparian vegetation specialist then assessed the response on the marginal and other riparian zones, and supplied this information to the instream biota specialists (i.e. fish and macroinvertebrates). This was done prior to the instream biota assessment as riparian vegetation is a driver in terms of important habitat for the instream biota.
- The riparian vegetation specialist ran the VEGRAI model to predict the EC for the operational scenarios.

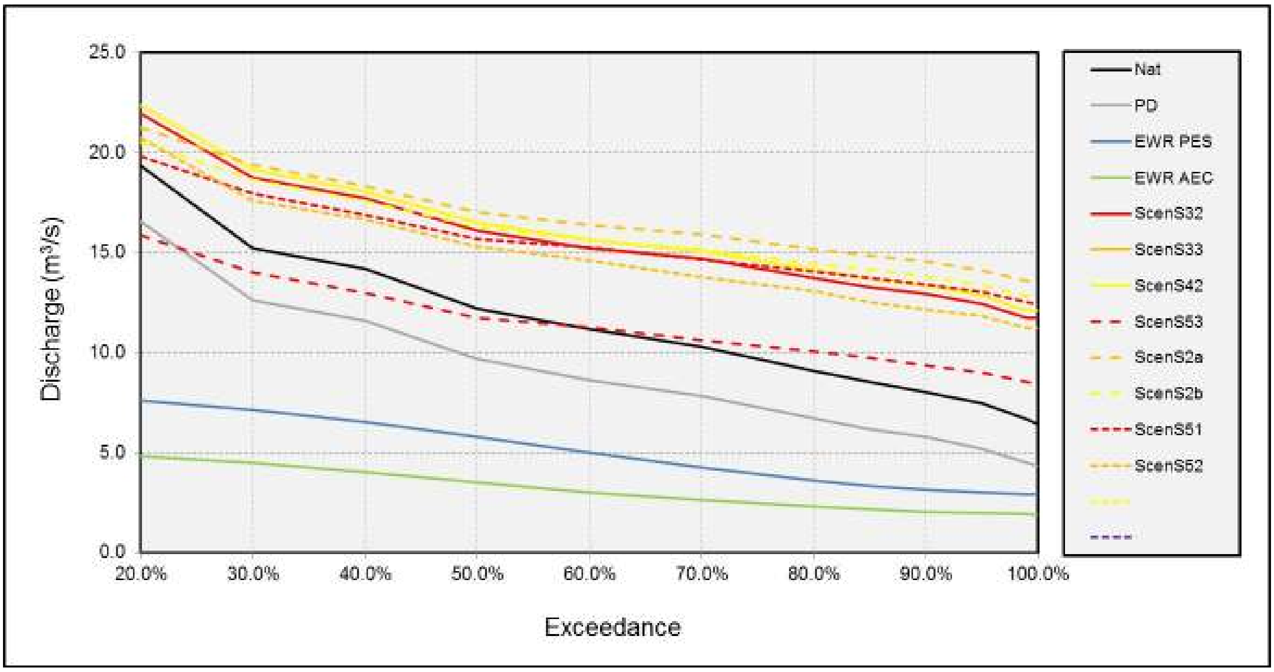


Figure 3.2 Use of the Scenario Comparison Facility Tool to assess changes under operational scenarios at MzimEWR4 for August

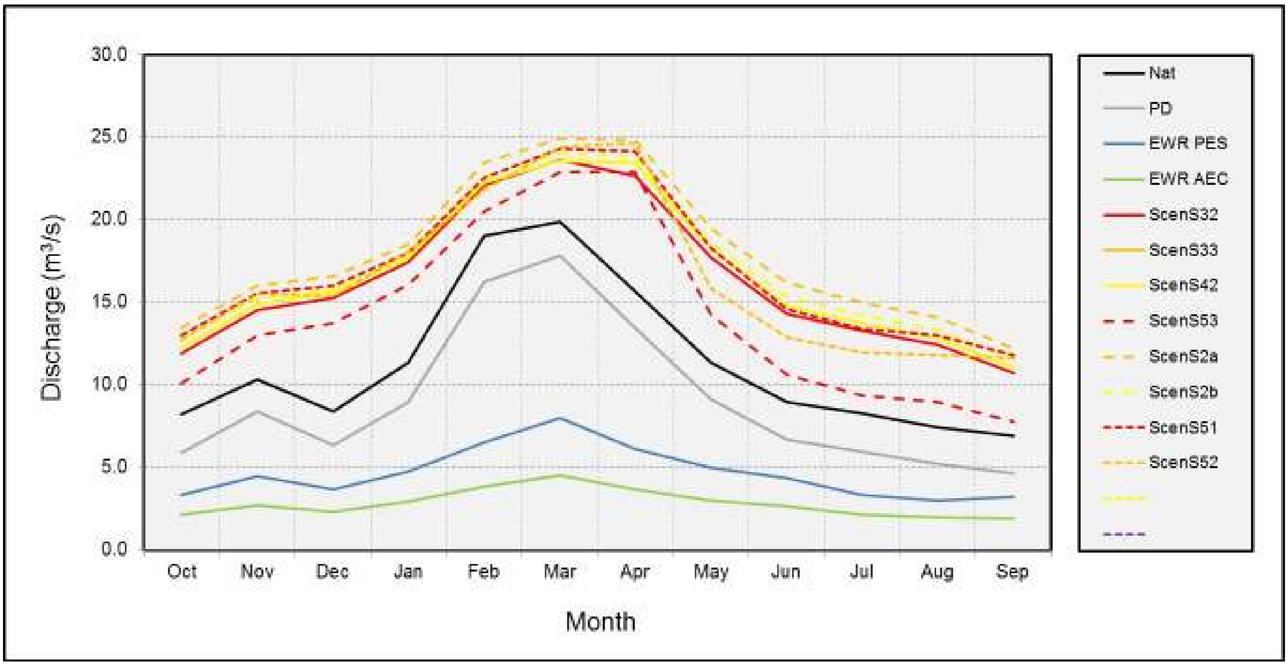


Figure 3.3 Use of the Scenario Comparison Facility Tool to assess changes under operational scenarios at MzimEWR4 during the drought period (95% exceedance)

This information formed the basis for the instream assessment to determine the responses to these driver changes for each scenario:

- The operational scenarios were compared to the EWRs set for various ECs. For example, if the operational scenario lies between the B EC and C EC for fish for a flow in the dry season, the operational scenario could either be a B, a B/C or a C.
- The information on the driver responses were also used to interpret the biotic response to the operational scenarios.
- The responses were modelled in the FRAI, MIRAI and VEGRAI to determine the EC.
- The VEGRAI, MIRAI and FRAI results (EC percentages and confidence evaluation) was used to determine the EcoStatus per scenario and compared to the PES and REC set during the EcoClassification process (DWS, 2017b).

The component-specific approaches to determine ecological consequences are provided below.

3.2.1 Water quality

The water quality approach to assessing ecological consequences is dependent on the results produced for the water quality component of EcoClassification for the affected EWR sites (DWS, 2017b). The PAI model, water quality tables and associated text describes the driving variables for the assigned water quality state. The PES flow exceedance curves therefore represent the flow conditions linked to the present state PAI table, and the values assigned to the metrics used in the PAI model. The metrics are salts, nutrients, pH, dissolved oxygen (DO), turbidity, temperature and toxics. Toxics and nutrients are therefore an integrated measure, with salts represented by electrical conductivity. The Scenario Comparison Facility Tool is used to evaluate changes to the flow regime under all months and exceedance percentages, and linked to expected changes in water quality driving variables. The PAI model is re-run for each set of scenarios to arrive at an integrated water quality category per scenario or set of scenarios.

3.2.2 Geomorphology

The assessment of the geomorphological response to different flow scenarios relies largely on a prediction of the extent to which flood magnitude and frequency will be impacted. Flow duration curves give an indication of how the larger flow events will be affected, but for sites downstream of dams a spill analysis provides more relevant data. The spill analysis is an estimate of how often, and by how much, the reservoir will overtop the outflow under the different scenarios. It depends on the rate of inflow to the reservoir and the level of water currently in the reservoir.

The data that informed the geomorphology analysis was the expected spill data provided for Ntabelanga and Lalini dams for selected scenarios, together with the flow duration curves of monthly data. It was assumed that flood flows would be contributed largely by the spills for reaches immediately below the two dams. MzimEWR1 on the Tsitsa River lies a short distance below the Ntabelanga Dam so the spills will indicate potential floods. MzimEWR4 is located on the Mzimvubu River, downstream of the Lalini Dam on the Tsitsa tributary. An adjustment was made at MzimEWR4, therefore, to account for the additional contribution from the rest of the Mzimvubu catchment. At this site, approximately 35% of the Mean Annual Runoff (MAR) comes from the Tsitsa catchment and 65% from the Mzimvubu River and other tributaries. [The last column in **Table 3.3** reflects this adjustment. These values are used in **Table 3.5** as the spills analysis refers to Lalini Dam].

Recommended EWR floods are given as instantaneous peaks whereas the spills data was given as monthly volumes for the 85 years from 1920 to 2004. It was therefore necessary to convert the peak to a volume for the flood hydrograph. The volume also depends on the flood duration. In the absence of duration data, the values given in **Table 3.2** and **Table 3.3** were assigned to the different flood classes for the two EWR sites. The duration of floods at MzimEWR1 was extended beyond those observed under natural conditions to take account of attenuation by the dam. Given the large size of the Mzimvubu catchment above MzimEWR4 relative to the catchment area of Lalini Dam, it was not thought necessary to adjust the duration of floods at MzimEWR4.

Due to the lack of information needed to disaggregate monthly values to daily values, it was assumed that the monthly spill value was comprised of one flood. In reality, it may have occurred as several smaller floods or simply as increased baseflow over a longer period. Flood peak magnitudes derived from the spill analysis are therefore overestimated by an unknown amount.

Table 3.2 Volume estimates for floods at the MzimEWR1

Flood class	Flood peak (m^3/s)	Duration (days)	Volume at site (MCM)
1	21	3	3
2	32	6	8
3	140	7	42
4	180	10	78
5	470	13	264

MCM: million cubic metres

Table 3.3 Volume estimates for floods at the MzimEWR4

Flood class	Flood peak (m^3/s)	Duration (days)	Volume at site (MCM)	Volume at Lalini (MCM)
1	156	3	20	7
2	305	5	66	22
3	526	6	136	45
4	1305	7	395	132
5	1600	10	691	230

To facilitate data sharing with the vegetation specialist, the spill data was analysed for the growing and reproductive season months of September to April. This captured the majority of floods that would have geomorphological significance and all potential Class 3 and 4 floods as they only occurred in these months. The monthly spill values for all years were ranked and assigned a recurrence value (RI) (exceedance frequency). The RI value (column 5 and 7 in **Table 3.4** and **Table 3.5**) indicates how often a value was exceeded, not how often that particular flood class was experienced (as recommended in Column 4). For example, the RI for Class 1 floods includes Class 2 floods and larger. The spill data from Ntabelanga Dam was used for MzimEWR1 and that from Lalini Dam for MzimEWR4.

Tables 3.4 and **3.5** provide derived flood frequency values for the two EWR sites for the different sets of scenarios. As noted above, the use of monthly rather than daily data introduces error in the estimation of flood magnitude and frequency and is likely to overestimate flood peaks. The data in **Tables 3.4** and **3.5** therefore present whether or not there is sufficient flow volume (Column 6) to meet the EWR requirement in any month (Column 3). Column 7 gives the frequency that the EWR volume estimated from the spills analysis will be exceeded. This can be compared to the recommended frequencies in Column 5. In reality the frequency of these flows could be less due to multiple events of lower magnitude in one month.

Table 3.4 Flood frequency estimates for floods at the MzimEWR4: Sc 52. The volume at Lalini, extrapolated from MzimEWR4, is used for the spills analysis.

EWR recommendation					Monthly spill analysis (at Lalini)	
Flood class	Flood peak (m^3/s)	Volume at Lalini (MCM)	Recommended frequency (per year)	Recommended frequency exceeded (RI) (per year)	Frequency EWR volume exceeded (RI) (per year)	Volume of monthly spill flow at EWR frequency (MCM)
1	156	7	4	8	6.1	3
2	305	22	2	4	2.9	12
3	526	45	1	2	1.8	37
4	1305	132	0.5	0.7	0.8	147
5	1600	230	0.2	0.2	0.3	274

Table 3.5 Flood frequency estimates for floods at the MzimEWR1: Sc 41, 42, 53

EWR recommendation					Monthly spill analysis (at Lalini)	
Flood class	Flood peak (m^3/s)	Volume at EWR (MCM)	Recommended frequency (per year)	Recommended frequency exceeded (RI) (per year)	Frequency EWR volume exceeded (RI) (per year)	Volume of monthly spill flow at EWR frequency (MCM)
1	21	3	4	8	6.6-6.7	1
2	32	8	2	4	5.2-5.4	17
3	140	42	1	2	2.5-2.8	52
4	180	78	0.5	0.7	1.4	110
5	470	264	0.2	0.2	0.01	179

Evaluating scenario outcomes

At sites some distance below a dam wall, which receive sediment from their effective catchment, a reduction in the frequency of flows in Class 1 and greater would result in increased deposition of sediment on the channel bed, whereas a reduction in larger floods would impact on the deposition of sediment in flood zones (marginal zones (Class 2), flood benches (Class 3) and terraces (Class 4 and 5)). This would be further aggravated by the reduced sediment concentrations in water released from, or spilling over the dam. Slow recovery from erosion by extreme flood events result in long-term channel widening.

At sites close to the dam wall (e.g. MzimEWR1), sediment free flows will induce armouring due to loss of fines from the bed. Increases in the frequency or volume of Class 1 and Class 2 flows will exacerbate this.

The low flow duration curves (flow exceedance > 20%) were examined to identify periods when flow either exceeded the natural flow by a significant amount which would increase flushing of fines from the channel bed, or when flow was significantly below natural or the EWR, in which case deposition of silts on the bed is a likely consequence.

The GAI (Rowntree, 2013) was used to assess the new ecological category under each scenario. Note that at both sites there is a reduction in the frequency of Class 1 floods for all scenarios and, conversely, the volume at the recommended frequency is significantly reduced. The frequency of Class 2 floods contributing to MzimEWR4 is also reduced and volumes are approximately halved for the recommended frequency. This is not the case at MzimEWR1 where both the frequency and volume of Class 2 floods is increased. The requirements for Class 3–5 floods are met at MzimEWR4 but at MzimEWR1, this is not the case for Class 5 floods.

3.2.3 Fish

The estimated change from PES in the fish assemblage under each scenario was assessed based on the expected change in various aspects of importance (drivers/stressors), i.e. flow, habitat and water quality:

- ***Flow***: The change in fast (fast-shallow (FS), fast-intermediate (FI) and fast-deep (FD)) and slow (slow-shallow (SS) and slow-deep (SD)) habitats were considered for the maintenance and drought flows during both wet and dry seasons (MS Excel based). This change was considered for each species using its specific preference rating for different velocity-depth categories.

- ***Substrate***: Geomorphological change (based particularly on changes in flood regimes) was used to determine the estimated percentage change in substrate quality and availability for fish. This change was considered for each species using its specific preference rating for substrate as cover.
- ***Vegetation***: The change in the marginal vegetation was estimated based on the marginal zone section of the VEGRAI and vegetation specialist input. The marginal zone change was applied to the relevant species based on their preference rating for overhanging vegetation as cover.
- ***Water quality***: The change in water quality under each scenario was based on input from the PAI and water quality specialist and the expected change in water quality was applied for each species based on their requirement for unmodified water quality intolerance rating.
- ***Seasonality/Seasonal variability***: The change in seasonality and seasonal variability was assessed using the Scenario Comparison Facility Tool.

The expected change of these aspects/metrics (or sub-components of these metrics) was rated as follows:

- 5: Extreme/critical increase/improvement (> 80%).
- 4: Serious increase/improvement (60–80%).
- 3: Large increase/improvement (40–60%).
- 2: Moderate increase/improvement (20–40%).
- 1: Slight increase/improvement (< 20%).
- 0: No change.
- -1: Slight decrease/deterioration (0–20%).
- -2: Moderate decrease/deterioration (20–40%).
- -3: Large decrease/deterioration (40–60%).
- -4: Serious decrease/deterioration (60–80%).
- -5: Extreme/critical decrease/deterioration (> 80%).

The overall change in these variables (metrics) were then used to change the present Frequency of Occurrence (FROC) (Kleynhans et al., 2007b) ratings of each fish species in the FRAI – but only considering the variable relevant to the specific species (e.g. eels would be more impacted by migratory impacts than potadromous species; a rheophilic species would be more intolerant to alterations in fast habitats than a limnophilic species, etc.).

The overall change, considering all these aspects, is then reflected by the change in FRAI score (%). This approach ensures that the change under each scenario will be relative to the actual change in the various drivers/stressors for the fish, also taking into consideration the specific requirements and intolerance of each fish species to different aspects in its environment.

The current scenario assessment for fish primarily focussed on the response of the fish assemblage to different flow scenarios and its associated secondary responses. The impacts directly associated with the construction and operation of the dams were not considered. Special reference must be made to the migration barrier effect of any dam in a system. It was established (from previous similar studies) that when the migration impact of a dam was also considered in the scenarios, it masked the actual potential improvement of certain flow scenarios. The migration barrier impact of the dams may certainly result in changes in the ecological status of the fish under the different scenarios. The impact of the migration barrier should be assessed in detail during the Environmental Impact Assessment phase of any dam development, as a number of factors that fall outside the current scope of work need to be considered, e.g. species specific migratory requirements and abilities, reason for migration, presence of viable habitats upstream of barrier, etc. Any studies evaluating the impacts of existing or future planned migration barriers (e.g. dams, weirs), should include a detailed fish migration specialist study. This is of special importance in the Mzimvubu river system due to the presence of catadromous eel species that require free movement between freshwater and the sea to complete their life cycle. Migration-barrier-specific specialist studies should ideally follow the proposed methodology as stated in Bok et al. (2007):

- Determine the need for providing a fishway at the said barrier (necessity protocol): Assess the ecological need for a fishway and the feasibility of providing a successful and cost-effective fishway.
- Determine the priority of fishway provision (priority protocol): Quantify the ecological impact of the barrier on migratory species present, i.e. importance of providing a fishway at the barrier.
- Provide biological consideration for the design of fishways at the barrier.
- Detailed investigation into the best design for the fishway based on all applicable considerations and the design of the fishway
- Overseeing and auditing during construction as well as a design and implementation of a fishway monitoring programme.

3.2.4 Macroinvertebrates

The hydrological details of each scenario were reviewed and assessed relative to natural, present day (PD) and EWR flows, using the flow duration graphs and tables in the Scenario Comparison Facility Tool. In assessing the effects of a scenario on the macroinvertebrate community, any alteration in the following parameters *relative to the PES* is taken into consideration: average and maximum velocity, hydraulic habitat availability, water quality, system connectivity and seasonality. Habitat changes are based on the geomorphological and riparian (marginal zone) vegetation input from the GAI and VEGRAI models and relevant specialist input. Water quality change is based on the PAI model and water quality specialist input.

The changes in each parameter (increase, improvement, decrease, deterioration) are assessed year-round and for dry and wet season. The MIRAI model with the PES data is then adjusted by revising the relevant ratings in the four MIRAI spreadsheets (flowmod, habitat, water quality, connectivity and seasonality). For example, if in the scenario assessed, flow at the site increases in the wet season and approximates natural flows rather than PD or EWR flows, then local velocities are likely to increase, habitat availability will be greater, and water quality may improve. Once decisions have been made in this regard, the relevant MIRAI ratings are adjusted to indicate deviation from the natural or reference state. The macroinvertebrate EC may or may not be altered for the scenario.

3.2.5 Riparian vegetation

The following steps comprise the process employed to assess the ecological consequences of various scenario flow regimes for riparian vegetation:

- An overall qualitative description of differences between the applicable scenario and natural, PD and EWR flows is provided utilising log charts of monthly flow at the following percentiles: 1%, 5%, 10%, 50%, 90% and 99%. Differences in quantity of water (overall, high flows and low flows) are noted as well as changes to the seasonal distribution of flows. General statements regarding the response of riparian vegetation are then made based on these qualitative overviews (see **Figure 3.4** as an example).

- Seasonality is critical for biological cues, even vegetation. A check of seasonality was conducted for the Mzimvubu study by expressing the monthly flow regime as a fraction of the natural annual flow (see Dettinger and Diaz, 2000). Should a significant change to seasonality apply to any of the scenarios, then a response by riparian vegetation is predicted and used to make changes to the scores within VEGRAI (Kleynhans et al., 2007a) for the applicable site (see **Figure 3.5** as an example).

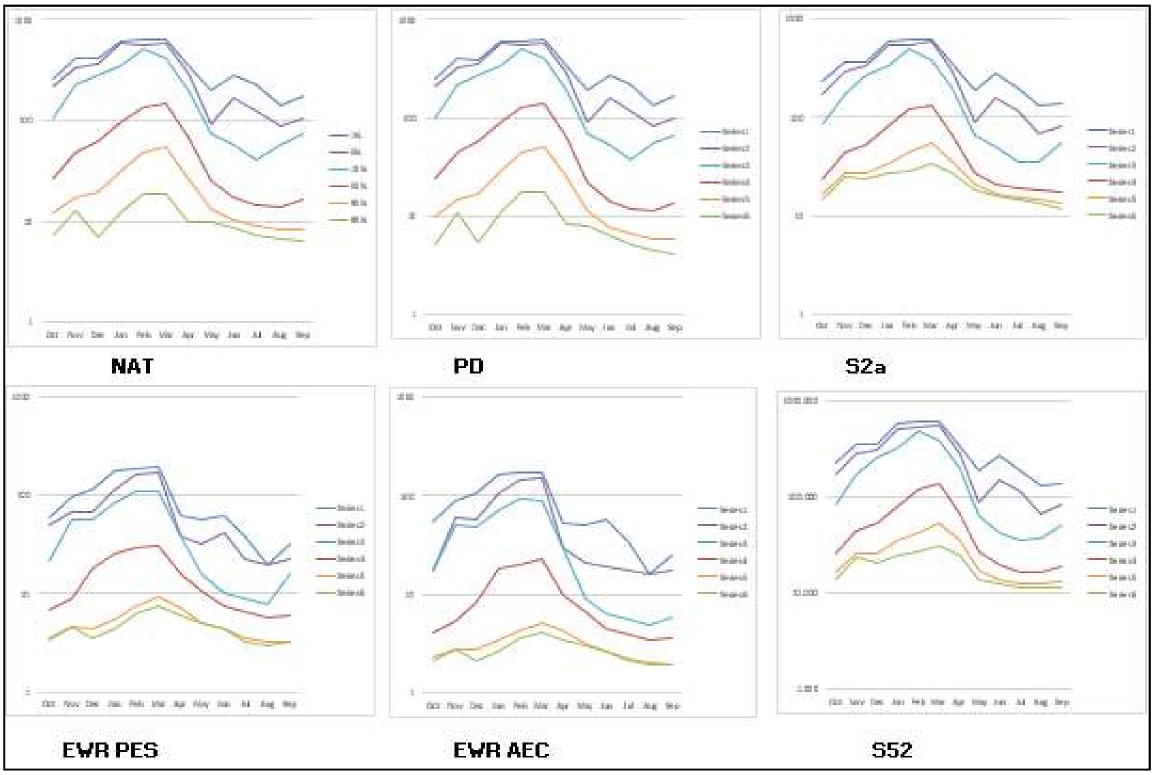


Figure 3.4 An example of the comparison of average monthly hydrological data (log plots)

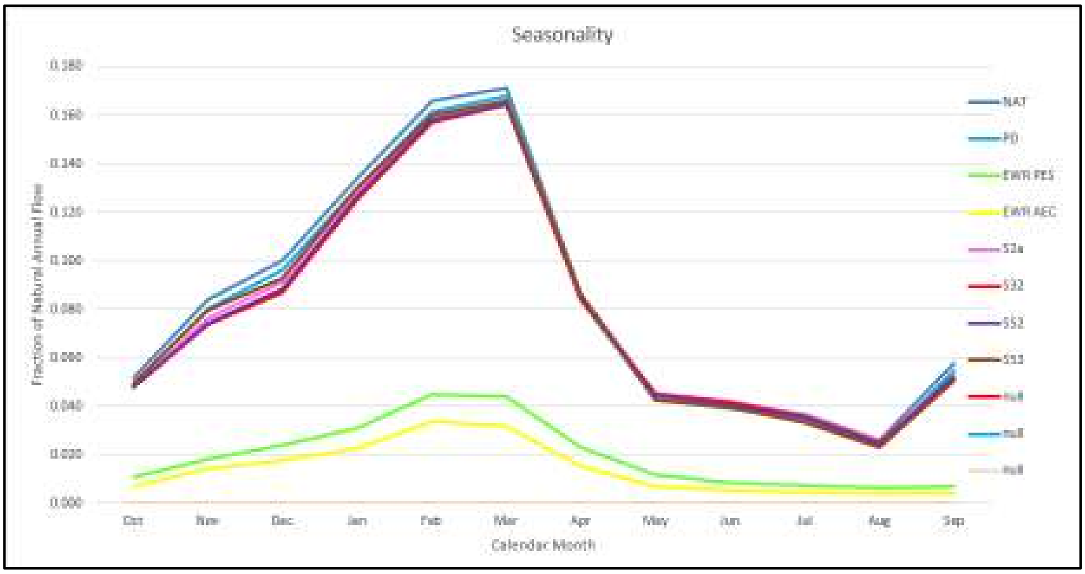


Figure 3.5 An example of a seasonality check for riparian vegetation

A month-by-month comparison of the exceedance curves of the applicable scenario to natural, PD and EWR flows was conducted. General statements are made concerning the probable response of riparian vegetation (usually indicator or guild-specific) taking specific cognisance of seasonal and phenological requirements of vegetation. The example below shows a comparison between the months of February and July (**Figure 3.6**). Response-appropriate changes are made to scores within the VEGRAI in order to score the scenario's effect on the EcoStatus.

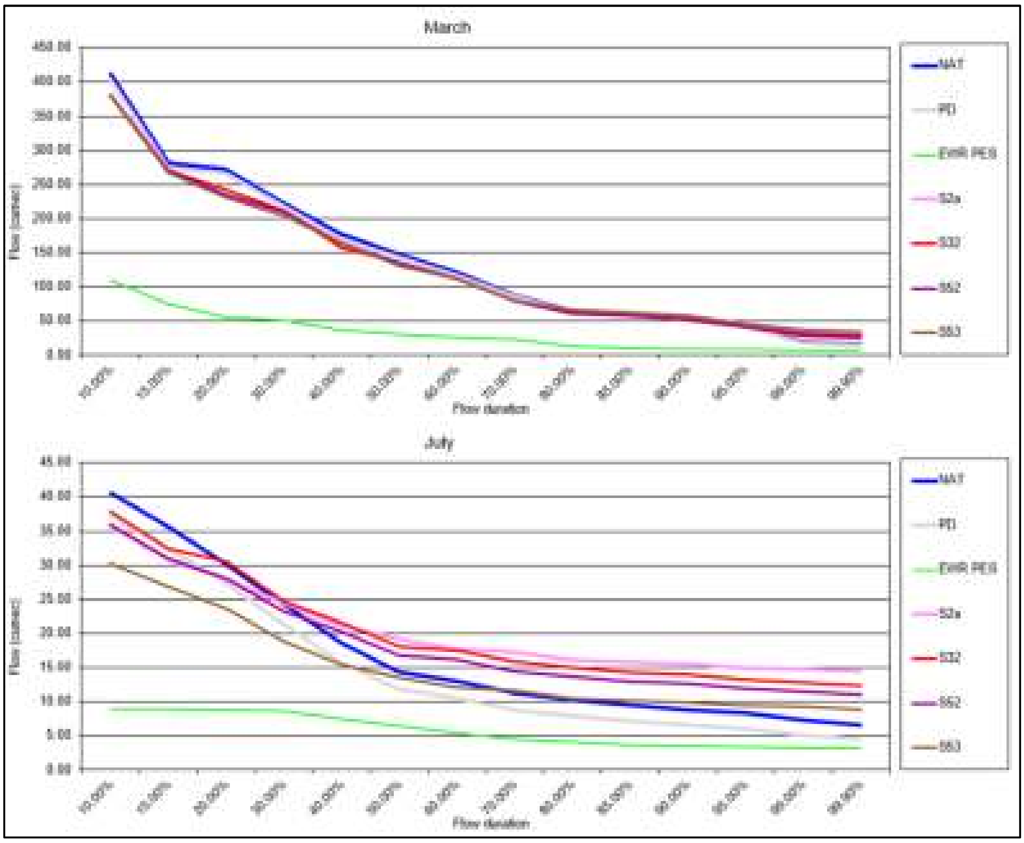


Figure 3.6 An example of the comparison of discharge exceedance patterns for wet (represented by March) and dry (represented by July) season

- A similar comparison was conducted at select percentiles (1%, 5%, 10%, 20%, 40%, 50%, 60%, 80%, 90% and 95%) to assess changes of seasonality i.e. compare temporal distribution over an average hydrological year (**Figure 3.7** as an example).

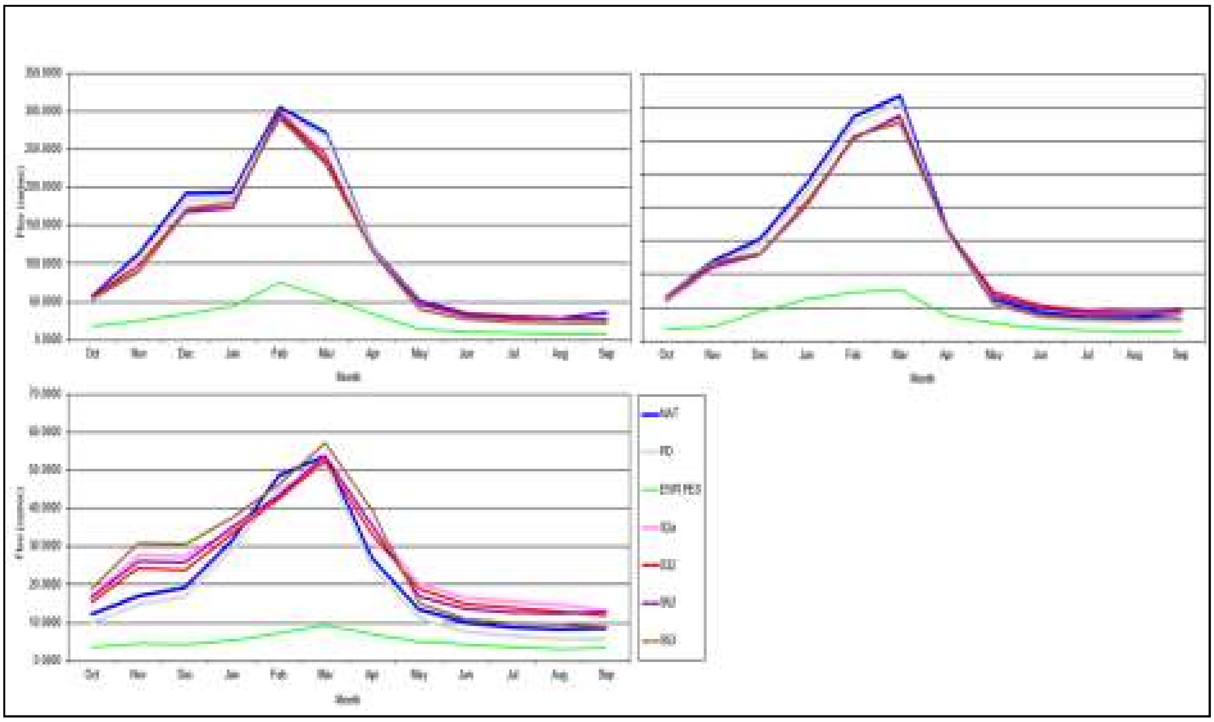


Figure 3.7 Average yearly temporal distribution of discharge at the 20th (top left), 50th (top right) and 90th (bottom) percentiles

- Stream permanency has been shown to be important for the persistence of riparian vegetation in perennial rivers (Lite and Stromberg, 2005; Leenhouts et al., 2006). Once stream permanency declines below 10%, population density declines and once stream permanency declines below 20% many species likely disappear or are replaced by other hardy drought-tolerant or terrestrial species. Each scenario was assessed for stream permanency (expressed as the % of an average year where flow does not cease) and compared to values for natural, PD and EWR flows. Conditions under scenarios were also checked against natural flows to ascertain whether flow ever exceeds natural. Such an increase in inundation may elicit a vegetation response such as zone shrinkage and changes to species composition.

- The flooding range for each riparian indicator (species or guild) was then used for a site-specific comparison of the scenario in order to determine to what extent the inundation or activation of each indicator changes and whether indicator drought tolerance is exceeded. This comparison is usually done for both the wet and dry season (using two or three representative months for each), and at percentiles representative of baseflows (i.e. 50% for the Tsitsa and Mzimvubu rivers). Knowledge of indicator-specific drought tolerance, maximum rooting depths and inundation requirements is used to assess whether changes will result in a response from the indicator. Likely responses of all indicators are then considered within respective sub-zones (such as marginal and lower zones) and (additional) changes made within the VEGRAI (Kleynhans et al., 2007a) to translate a vegetative response into a change in ecological state or category. The example below shows a comparison of the proportion of inundation of reeds at the 50th percentile for wet and dry seasons at MzimEWR4 (**Table 3.6**). The example data shown in **Table 3.6** were also provided to the fish specialist using all marginal zone vegetation indicators.

Table 3.6 Example of assessment showing the proportion (%) of the indicator population inundated in the wet and dry season for different flow regimes of operational scenarios (Green values indicate proportions higher than EWR required for the PES)

EWR site: MimEWR4		Proportion of each population (%) inundated at the 50th percentile for different scenarios							
Indicators	**Season**	**Natural**	**PD**	**PES**	**AEC[1]**	**Sc 2a**	**Sc 32**	**Sc 52**	**Sc 53**
Mud drape vegetation	Wet	100.0	100.0	50.5	31.3	100.0	100.0	100.0	100.0
	Dry	17.1	8.0	0.0	0.0	26.2	24.2	24.2	11.0
Marginal vegetation	Wet	100.0	100.0	35.6	20.7	100.0	100.0	100.0	100.0
	Dry	11.9	5.2	0.0	0.0	18.5	17.0	17.0	7.4
Pool vegetation	Wet	100.0	100.0	22.8	3.7	100.0	100.0	100.0	100.0
	Dry	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
Cyperus longus	Wet	100.0	100.0	0.0	0.0	100.0	100.0	100.0	100.0
	Dry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[1] Alternative Ecological Category

- The final check was to determine whether flood requirements that were specified for the EWR were met and if not, to what extent this is likely to affect riparian vegetation. Data from spill analyses were also used and assessed. The occurrence of flood events (as defined by the EWR) as well as timing and duration, were assessed over the given hydrological period. Any inferred responses by riparian vegetation are additionally captured in VEGRAI for a final assessment of ecological response, and a score produced for each scenario.

3.3 DETERMINING THE RANKING OF SCENARIOS PER EWR SITE

Deriving a single metric (one number), that reflects the ecological health relative to the REC for the river, requires several steps, sub-steps and the application of various tools. Broadly, the rationale to achieve this single rating is based on the following:

- Scenarios at each EWR site were ranked on the basis of the degree to which the scenarios meet the REC.
- The impact of the scenarios at the different EWR sites were compared to determine a ranking from a system context. This depends both on the degree to which the scenario meets the REC, as well as the relative ecological importance of the sites.

To further explain this, if a scenario is ranked highest at a site of low importance, but lower at a site of high importance, this scenario will not carry the same weight as the scenario that scored the highest at the sites of high importance.

The steps and sub-steps to derive a single number are discussed below, and are presented generically in a step-by-step way.

3.3.1 Step 1: Rank scenarios at each EWR site

- Apply the EcoClassification process (Kleynhans and Louw, 2007) at each EWR site where the scenario influences the flow or water quality to determine the EC for each component[1].
- Provide the associated percentage that represents the category.
- Calculate the degree to which the scenario meets the ecological objectives which are represented by the REC. That is, if the REC for a component is 62% and the scenario results in this component being at 62%, then the resulting score would be a 1 (or a 100% successful in meeting the REC). If a scenario's rating for the component is 48%, then the score would be 0.77 (or 77% successful in meeting the REC).
- A weighted average score is calculated to obtain a score for the scenario at the site.
- Each site's score is then normalised to obtain a rating that is 1 if the REC is achieved, above one if the REC is exceeded (i.e. 1.1) or between 1 and 0 if the score (EC) is below the REC.
- Rank the scenarios in terms of a numerical scale with values 0 and 1 (typically, where one (1) indicates the scenario that achieves the REC and a zero (0) representing the situation where the scenario results in a F category).

3.3.2 Step 2: Determine the relative importance of EWR sites to each other

The following aspects are considered when determining the relative importance of the EWR sites to each other:

- PES: The higher the PES, the more important the EWR site. The PES percentage is used in this calculation.
- Ecological Importance and Sensitivity (EIS): The higher the EIS rating, the more important the EWR site. The EIS score is used in this calculation.
- Conservation importance: The locality of the site within a declared conservation area is highlighted. A site within a Transfrontier Park or a Wilderness Area or representing these will be more important than a National Park which in turn will be more important than a provincial Nature Reserve.

The above metrics are averaged. The following is then also rated:

- Length of the river reach represented by the respective EWR sites, i.e. the longer the reach, the higher the importance of the scenario impacts.
- Relative position of the EWR sites in the system and how they affect the simulated operation. The ranking of the sites is dependent on the key sites in the modelling context which dictates the driver EWR site in terms of the 'releases' in the model. These key sites are sometimes the most downstream site (as is the case in this study), or could be site which has a higher REC (or PES) than other sites and therefore a higher flow requirement.

The above values are then averaged again, including the averaging of the initial metrics, and the score is normalised out of 1.

3.3.3 Step 3: Rank the scenarios in a system context

All the scores from the EWR sites are then combined into a single score by accounting for the site importance ranking shown in Step 2. This is achieved by assigning different weights (factors) to each site to reflect the importance relative to the others. The individual ranking and consequences at each

[1] Component: Habitat drivers (geomorphology and water quality (hydrology is a given)); Biological responses (fish, macroinvertebrates, riparian vegetation).

EWR site have therefore been integrated into one ranking and consequences applicable to the specific river system. Once all the scores for each scenario have been calculated, these can then be ranked and plotted on a traffic diagram illustrating the degree to which the REC is met.

3.3.4 Traffic diagrams

A traffic diagram is used to present results of the consequences. The description of a traffic diagram is as follows:

- A traffic diagram is a bar graph that is shaded according to the colours of a traffic light.
- This implies that the items at the top (in the green section) are better than the ones below.
- The scale of the bar graph should be noted. The importance is the ranking of scores relative to each other.
- The purpose is to rank scenarios for all the different components using different scales of measurements, but visually being able to compare the rankings using traffic diagrams.

4 ECOLOGICAL CONSEQUENCES: MZIMEWR4 (MZIMVUBU RIVER)

4.1 ECOCLASSIFICATION RESULTS

MZIMEWR4: MZIMVUBU RIVER		
EIS: MODERATE Rare and endangered riparian species, unique instream biota, diversity of instream and riparian types and features, and high taxon richness. Important migration route for eels. **PES: C** ▪ Sedimentation due to catchment erosion. ▪ Presence of alien, predatory and habitat modifying fish species and loss of vegetation. ▪ Alien vegetation removal, grazing pressure and wood removal. **REC: C** The EIS was moderate and the REC is set to maintain the PES as most impacts relate to non-flow related impacts.	**Component**	**PES and REC**
	IHI Hydrology	**A/B**
	Physico-chemical	**A/B**
	Geomorphology	**C**
	Fish	**C**
	Macroinvertebrates	**C**
	Instream	**C**
	Riparian vegetation	**C/D**
	EcoStatus	**C**
	Instream IHI	**B/C**
	Riparian IHI	**C**
	EIS	**MODERATE**

IHI: Index of Habitat Integrity

4.2 EVALUATED SCENARIOS

Scenarios 2a, 32, 52 and 53 were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecological responses could be differentiated:

- **Sc 2a** = Sc 2b
- **Sc 32** = Sc 33 = Sc 41 = Sc 42 = Sc 51

4.2.1 Consequences

A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 4.1**.

Table 4.1 MzimEWR4: Consequences of the scenarios on the driver and response component ECs

Physico-chemical variables				
PES and REC	**Sc 2a**	**Sc 32**	**Sc 52**	**Sc 53**
A/B: 88.3%	A: 93.5%	A: 93.5%	A: 93.5%	A/B: 91.85%
The water quality state is good, with a slight impact from nutrient load and increased turbidity. All scenarios other than Sc 53 result in an improvement to an A Category as there is substantially more water than the PES EWR requirements, resulting in a dilution of the small nutrient load. The impact of the upstream dams will result in the trapping of sediments, resulting in clearer water, which would be more similar to the natural state. Conditions under Sc 53 may stay in an A/B Category due to slightly lower flows in dry months as compared to other scenarios.				
Geomorphology				
PES and REC	**Sc 2a**	**Sc 32**	**Sc 52**	**Sc 53**
C: 76.5%	C: 76.5%	C: 76.5%	C: 76.5%	C: 76.5%
▪ Sc 2a: No spill data was available for analysis. However, given that no EWR is being released, the frequency of spills will increase as more water is retained in the dam. No change in the PES is expected.				

- Sc 32 and Sc 52: These two scenarios largely meet the flood requirements, with a small reduction indicated for the frequency of Class 1 to Class 3 floods. Confidence in the result is reduced due to extrapolation from Lalini to the EWR site. Increased dry season baseflows will reduce the potential for silt deposition over coarse gravels and in lateral pools on margins of rapids. The PES category remains unchanged but may be nearer to a B Category.
- Sc 53: No spill data for Lalini was available and therefore the scenario could not be evaluated. However it is not likely to be very different to the PES.

Riparian vegetation

PES and REC	Sc 2a	Sc 32	Sc 52	Sc 53
C/D: 59.4%	D: 55.7%	D: 55.7%	D: 55.7%	C/D: 59.4%

Seasonality and stream permanency remain intact, although dry season baseflows are generally more than natural. Floods are similar to the EWR requirements for Sc 32, 33, 42 and 52. Marginal zone vegetation (notably *Cyperus longus* and *Persicaria senegalensis*) had an elevational range from 0.8 to 1.7 m above the channel. This equates to a discharge range of 10.06 to 96.11 m^3/s that activates the lower and upper limits of the zone vegetation respectively. On average, the lower limit of marginal zone vegetation will be inundated for 70–80% of the time in the wet season and 5–15% of the time in the dry season. Wet season inundation remains similar for all scenarios, but not for dry season inundation. The expected proportion of marginal zone vegetation inundation in the dry season is 4.4% or 11.1% under natural flow conditions. These values are 20%, 17.8%, 15.6% and 8.9% for Sc 2a, 32, 52 and 53 respectively. Inundation in the dry season is therefore more than natural, except for Sc 53, which will result in marginal zone shrinkage as vegetation succumbs to inundation stress at periods of low growth.
More detailed data of comparisons are provided electronically.

Fish

PES and REC	Sc 2a	Sc 32	Sc 52	Sc 53
C: 76.1%	B/C: 81.8%	B/C: 81.8%	B/C: 81.8%	B: 82.8%

- Sc 2a, Sc 32, and Sc 52: All scenarios assessed are expected to improve the ecological state from a PES of C towards a Category B/C. The improvement is associated with improved water quality, as well as general improvement in fast habitat for fish (fast shallow to fast deep), availability and quality (higher dry season flows may flush sediment from rocky substrates). This improvement will especially benefit the four eel species (improvement in food source and general habitat conditions). The higher than natural (and present) dry season flows may have a slightly negative impact on vegetative cover (marginal zone and aquatic vegetation), as well as the availability of slow habitats for fish (slow shallow and slow deep). These changes are however expected to be minimal and would not negate the positive impact of the wet season flows as well as improved fast habitats in the dry season. Seasonality will remain unchanged and migratory cues and depth (for longitudinal migration) will be adequate under all scenarios.
- Sc 53: The improvement will be more significant under this scenario which is expected to improve the fish towards a Category B. This improvement is primarily attributed to improved marginal vegetation conditions (not exceeding natural dry season flows), and hence being more favourable for species such as *Barbus anoplus* and *Oreochromis mossambicus*.

Macroinvertebrates

PES and REC	Sc 2a	Sc 32	Sc 52	Sc 53
C: 74.1%	C: 73.1%	C: 73.1%	C: 73.1%	B: 85.2%

- Sc 2a, Sc 32: Elevated wet season flows will result in an increase in diversity and abundance of the macroinvertebrate taxa, which should result in the community more closely resembling the reference community. However during the dry season, elevated flows and the associated increase in habitat availability result in increased abundances of both Flow Dependent Invertebrates (FDIs) and taxa with a preference for Marginal Vegetation (MVIs). Seasonal cues are altered and this is likely to affect reproductive patterns. Under these scenarios, there is an increased opportunity for an imbalance to arise in the macroinvertebrate community, e.g. through dominance of a taxon that is particularly successful in the dry season as a result of elevated flows. The overall community deviation from natural (reference) increases (as shown in MIRAI), resulting in a lowering of the PES to a C Category. The macroinvertebrate response to these scenarios is likely to have the same effect on the PES.
- Sc 52: Flows are slightly closer to natural in the wet summer season than in the former scenarios, but baseflows are similarly high during the drier months. The macroinvertebrate responses should be similar to Sc 2a and Sc 32.

- Sc 53: As flows emulate a very similar pattern and timing to those of natural hydrology, and water and habitat quality are somewhat improved, additional high-scoring taxa (such as the 'expected' taxa) may occur, and abundances will increase during the wet season months. The baseflow reductions that occur naturally in the dry season are mirrored in this scenario. As a result, the community will more closely resemble the natural or reference community. Therefore, deviation from natural (reference) decreases and the MIRAI PES score increases to 85% (B Category).

The resulting ECs for each component and the EcoStatus are provided in **Table 4.2**. The ranking of the scenarios is provided as a traffic diagram (**Figure 4.1**).

Table 4.2 MzimEWR4: Ecological consequences

Component	PES and REC	Sc 2a	Sc 32	Sc 52	Sc 53
Physico-chemical	A/B	A	A	A	A/B
Geomorphology	C	C	C	C	C
Riparian vegetation	C/D	D	D	D	C/D
Fish	C	B/C	B/C	B/C	B
Macroinvertebrates	C	C	C	C	B
EcoStatus	C (68.2%)	C (66.3%)	C (66.3%)	C (66.3%)	C (71.3%)

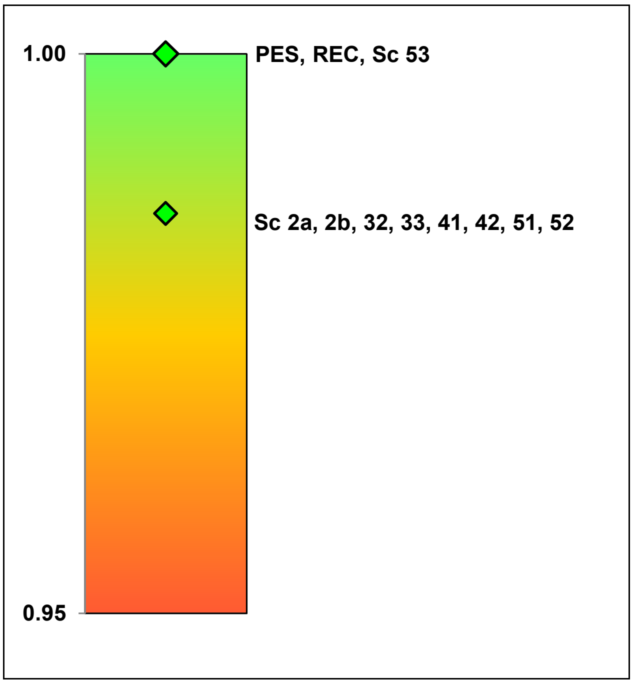


Figure 4.1 MzimEWR4: Ecological ranking of operational scenarios

4.2.2 Conclusions

The ranking of the scenarios indicate that only Sc 53 achieves the REC requirements. The rest of the scenarios maintain the PES EcoStatus albeit at a marginally lower percentage. A deterioration in riparian vegetation and macroinvertebrates is evident in all scenarios other than Scenario 53.

5 ECOLOGICAL CONSEQUENCES: MZIMEWR1 (TSITSA RIVER)

5.1 ECOCLASSIFICATION RESULTS

MZIMEWR1: TSITSA RIVER

EIS: MODERATE

Highest scoring metrics were rare and endangered taxa, unique instream biota, biota intolerant to physico-chemical changes and high taxon richness. Important migration route for eels.

PES: C

- Sedimentation due to catchment erosion.
- Presence of alien, predatory and habitat modifying fish species, erosion, and loss of vegetation.
- Alien vegetation removal, grazing pressure and wood removal.

REC: C

The EIS was moderate and the REC is set to maintain the PES as most impacts relate to non-flow related impacts.

Component	PES and REC
IHI Hydrology	A/B
Physico-chemical	B
Geomorphology	C
Fish	C
Macroinvertebrates	C
Instream	C
Riparian vegetation	C/D
EcoStatus	C
Instream IHI	B/C
Riparian IHI	C
EIS	MODERATE

5.2 EVALUATED SCENARIOS

Scenarios 2a and 41 were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecological responses could be differentiated:

- **Sc 2a** = Sc 2b = Sc 32 = Sc 33
- **Sc 41** = Sc 42 = Sc 51 = Sc 52 = Sc 53

5.2.1 Consequences

A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 5.1**.

Table 5.1 MzimEWR1: Consequences of the scenarios on the driver and response component ECs

Physico-chemical variables		
PES and REC	**Sc 2a**	**Sc 41**
B: 86.4%	C/D: 61.8%	B: 87.3%
▪ Flows are elevated well above the PES EWR requirements for all scenarios in the high flow season. Sc 2a: Conditions worsen under dry season flows and become very poor, with impacts on salts, nutrients, temperatures, oxygen levels, turbidity and toxics. ▪ Sc 41: Dry season flows are similar to the PES EWR requirements, with an overall improvement in water quality under this set of scenarios due to improved nutrient and turbidity levels during the high flow season. However, water quality remains in a B Category.		
Geomorphology		
PES and REC	**Sc 2a**	**Sc 41**
C: 67.8%	C: 67.8%	C: 67.8%
▪ Sc 2a: No spills data was available to evaluate this scenario. Given that no EWR is being released the frequency of spills will increase as more water is retained in the dam.		

- Sc 41: The dam is full most of the time during the wet season so spills should be of sufficient volume to meet EWR Class 1–4 flood requirements. Larger floods are less likely to be achieved. Attenuation of flows means that increased volume is required to achieve the same peak as under natural conditions.
- Although the EWR is likely to be achieved, the frequency of floods is likely to be reduced from natural. Sediment trapped in dam but local input continues. Reduced sediment in flood flows often result in channel widening as flood benches cannot recover after large floods. Dry season baseflow is below present day but matches the EWR requirement. There may be some increase of fines on the bed. Overall, positive and negative impacts balance out and result in a C Category.

Riparian vegetation

PES and REC	Sc 2a	Sc 41
C/D: 59%	D/E: 40.2%	C/D: 61.4%

- Sc 2a: This scenario has more flows than the EWR requirement and mostly close to present day and natural, but in the dry season zero flows occur frequently. Stream permanency is reduced from 100% to 66% and is bordering a seasonal stream. Seasonality is maintained but becomes extreme in the dry season. The prevalence of the wet season base and higher flows will maintain the upper zone and bank woody vegetation and prevent encroachment to within the channel, but the lack of flows in the dry season will have severe impacts on marginal and lower zone grasses and sedges. Mortality from water stress is likely to be high and the marginal and lower zones are likely to support less vegetation to the point of being mostly bare. This, together with existing grazing pressure, will likely increase the probability of erosion.
- Sc 41: This scenario is similar to the EWR requirement in the dry season and more than the EWR requirement in the wet season, but less than natural. Seasonality and stream permanency remain intact. Spill analyses show that floods are met and some additional flooding occurs, mostly Class 2 to 4 floods. This will benefit the *Arundinella napalensis* population in the upper zone on the flood benches and also prevent encroachment of alien woody species such as wattle into the channel floor or towards the marginal zone.

More detailed data of comparisons are provided electronically.

Fish

PES and REC	Sc 2a	Sc 41
C: 68.3%	D: 51.6%	C: 71.6%

- Sc 2a: A significant deterioration can be expected in the fish assemblage, decreasing from a Category C to a D. The most significant impact on the fish is expected to be the cessation of flow during the dry season, resulting in notable loss of habitat (fast and slow habitats) for both expected fish species. The wet season flows may be slightly better than the PES but the slight improvement in habitat will be totally negated due to the lack of flow in the dry season. A notable deterioration in water quality is expected that may influence especially *B. anoplus*. The loss of marginal and possibly instream vegetation will furthermore impact significantly on this species. Seasonality will also be impacted due to the extreme low flows or cessation of flows in the dry season, transforming the river towards a seasonal system. The impact of the Lalini and Ntabelanga dams on migration were not considered, and can be expected to further aggravate the impact if not addressed.
- Sc 41: A slight improvement in the fish assemblage can be expected but the fish will remain in the same Ecological Category (C). The improvement is primarily attributed to slight improvement in water quality and generally improved habitat for fish in the wet season. No notable changes are expected in the dry season, while vegetative cover and substrate quality is expected to remain unchanged in terms of its suitability for fish. The impact of the Lalini and Ntabelanga dams on migration were not considered, and it can be expected that they may result in a decreased ecological status of this reach if adequate mitigation measures are not considered.

Macroinvertebrates

PES and REC	Sc 2a	Sc 41
C: 72.9%	D/E: 41.2%	C: 72.9%

- Sc 2a: During the wet season total and baseflows match or exceed the flows set for the EWR, and approximate natural or PD at times. For the period of May to October (late summer, winter dry season and early summer), flows are either extremely low and there are long periods of no flow. The hydrology is thus transformed from perennial seasonal to temporary seasonal. The dry season macroinvertebrate taxa are adapted to a perennial seasonal flow regime and this transformation will initially result in the eradication of the more sensitive elements of the fauna, and ultimately the majority of the macroinvertebrate fauna (assuming sustained periods of zero flow and therefore dry-down). Only the most resilient taxa will survive in pools at the EWR site. It is uncertain to what extent the eggs laid in summer will become non-viable, but it is expected that a high percentage will be lost, so that recovery of the community during summer will be reliant on recolonisation. The MIRAI PES is based on the changes during the May to October period, as these will most likely govern the future character of the macroinvertebrate fauna.

- Sc 41: During the wet season, these flows approximate natural and PD flows. During the June to September period the proposed flows are similar to natural for a small percentage of the time, and for the balance of the time approximate the EWR flows. There may be a slight improvement in PES during the wet season; however, this is likely to be balanced by the effect of the reduced flows (relative to Present Day) during the dry season. It is expected that overall the macroinvertebrate PES will remain within a C Category, with slight variances in percentage between wet and dry season.

The resulting ECs for each component and EcoStatus is provided in **Table 5.2**. The ranking of the scenarios are provided as a traffic diagram (**Figure 5.1**).

Table 5.2 MzimEWR1: Ecological consequences

Component	PES and REC	Sc 2a	Sc 41
Physico-chemical	B	C/D	B
Geomorphology	C	C	C
Riparian vegetation	C/D	D/E	C/D
Fish	C	D	C
Macroinvertebrates	C	D/E	C
EcoStatus	C (65.05%)	D (42.7%)	C (66.9%)

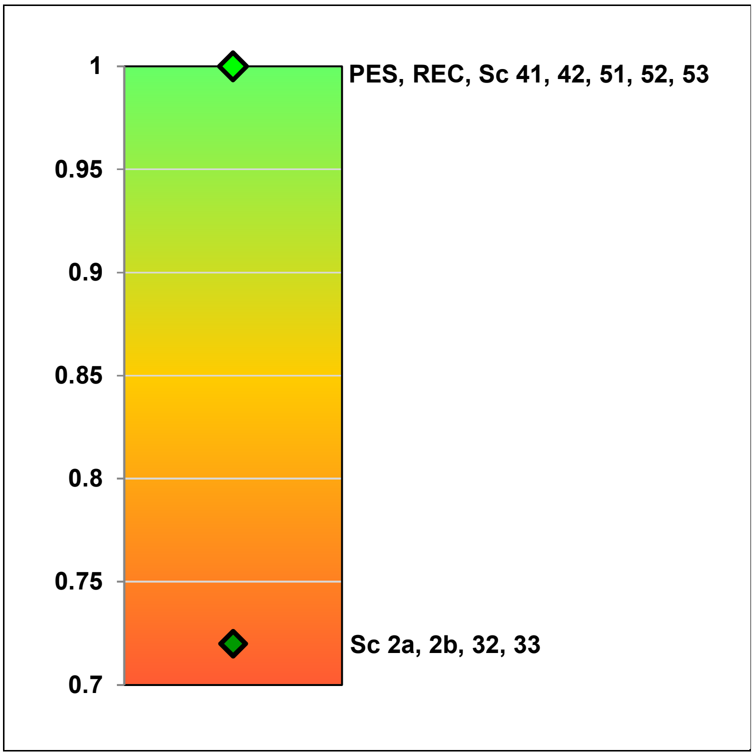


Figure 5.1 MzimEWR1: Ecological ranking of operational scenarios

5.2.2 Conclusions

The ranking of the scenarios indicates that Sc 2a, 2b, 32 and 33 do not achieve the PES and REC and all components deteriorate resulting in an EcoStatus of a D (bordering on a D/E). The rest of the scenarios achieve the REC requirements.

6 ECOLOGICAL CONSEQUENCES: EWR1 LALINI (TSITSA RIVER)

6.1 ECOCLASSIFICATION RESULTS

This site represents a point immediately downstream of the proposed Lalini Dam. All results were extrapolated to this site from MzimEWR1. This was felt to be more appropriate than using any downstream EWR results which may be of lower confidence and would also have to be extrapolated.

6.2 EVALUATED SCENARIOS

Scenarios 2a and 33 were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecological responses could be differentiated:

- **Sc 2a** = Sc 2b = Sc 41 = Sc 51 = Sc 53
- **Sc 33** = Sc 42 = Sc 52

The total flows to achieve the REC EWR are supplied under Sc 32 and it was therefore not evaluated.

6.2.1 Consequences

A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 6.1**.

Table 6.1 EWR1 Lalini: Consequences of the scenarios on the driver and response component ECs

<table>
<tr><th colspan="3">Physico-chemical variables</th></tr>
<tr><th>PES and REC</th><th>Sc 2a</th><th>Sc 33</th></tr>
<tr><td>B: 86.4%</td><td>D (53.5%) - E (26.5%)</td><td>B: 84.5%</td></tr>
<tr><td colspan="3">▪ Conditions under Sc 2 worsen under dry season flows and become very poor, with impacts on salts, nutrients, temperatures, oxygen levels, turbidity and toxics. It is expected that oxygen levels will be so low in the dry season that the PAI model threshold will be reached, pulling the water quality integrated state down to an E Category. Even if the threshold is not reached, water quality is still expected to deteriorate to a D Category (53.5%).
▪ The reduction in flows during some of the wet season months (November to February) under Sc 33 may result in a small impact in water quality, but it is expected to stay in a B EC.</td></tr>
<tr><th colspan="3">Geomorphology</th></tr>
<tr><th>PES and REC</th><th>Sc 2a</th><th>Sc 33</th></tr>
<tr><td>C: 67.8%</td><td>C: 67.8%</td><td>C: 67.8%</td></tr>
<tr><td colspan="3">The rapid assessment classified the PES for geomorphology as a C due to some deposition of sediment derived from upstream catchment erosion and possible loss of lateral benches as a result of erosion by flashier flood flows. Both of these impacts would be mitigated by the upstream dams but the frequency of floods would be reduced by storage in the dam. Sediment deposition is in any case limited by the steep and rocky nature of the reach. Intra-annual and annual floods should have sufficient velocity to transport fine sediments; the extent of bedrock in the channel will not be conducive to channel incision but there could be some bank erosion, especially if riparian vegetation is negatively impacted. Given the reduced sediment loads at this point (due to the dam) it is unlikely that any change to the low flow hydrology will have a significant impact on the geomorphology. Under unregulated conditions fine sediment would settle out in pools during low flows.</td></tr>
</table>

<table>
<tr><th colspan="3">Riparian vegetation</th></tr>
<tr><th>PES and REC</th><th>Sc 2a</th><th>Sc 33</th></tr>
</table>

C/D: 59%	F: 15.9%	C/D: 59%
▪ Sc 2a: In the wet season there is more flow than the EWR needs for small proportions of time, but mostly less and frequently zero. In the dry season zero flows occur perpetually. Mortality from water stress is likely to be total for any marginal and lower zone vegetation. Larger tree species such as figs may also die due to desiccation stress. ▪ Sc 33: No notable deterioration in vegetative cover will occur and no change from the PES is expected. More detailed data of comparisons are provided electronically.		
Fish		
PES and REC	**Sc 2a**	**Sc 33**
C: 68.3%	D/E: 38.3%	C: 68.3%
▪ Sc 2a: A significant deterioration in water quality and especially low oxygen levels (related to dry season low or no baseflow) will impact negatively on especially *B. anoplus*. Mortality from water stress is likely to be total for any marginal and lower zone vegetation, impacting significantly on the *B. anoplus* population (high requirement for marginal vegetation as cover). Habitat suitability and availability for fish will be drastically reduced in both the wet and dry season with a significant impact on the overall fish assemblage. An extreme impact on the macroinvertebrate assemblage is also expected which will result in loss of food availability for both expected fish species. Overall the fish assemblage is expected to deteriorate towards a Category D/E. ▪ Sc 33: A slight reduction in water quality is expected but it will not impact notably on the fish assemblage (no water quality intolerant species present). No notable deterioration in vegetative cover will occur while the habitat availability and condition (fast and slow habitats) for fish will also remain mostly unchanged from the PES and hence overall no notable impact on the fish assemblage is expected.		
Macroinvertebrates		
PES and REC	**Sc 2a**	**Sc 33**
C: 72.9%	F: 11.8%	C: 72.9%
▪ Sc 2: No flows are released from the dam, and only spills will provide any water for this site. This scenario represents an extreme impact on the macroinvertebrate community, as it is anticipated that the channel will be be dry for the majority of the time. The macroinvertebrate community can be considered exterminated, and the PES reduced to an F Category. Note that the biota of the waterfall will also be eliminated. These have, to our knowledge, not been sampled. Lesser-known trichopterans peculiar to waterfall habitats could potentially occur here. ▪ Sc 33: The macroinvertebrate PES will be maintained as the EWR requirement is supplied.		

The resulting ECs for each component and EcoStatus is provided in **Table 6.2**. The ranking of the scenarios are provided as a traffic diagram (**Figure 6.1**).

Table 6.2 EWR1 Lalini: Ecological consequences

Component	PES and REC	Sc 2a	Sc 33	Sc 32
Physico-chemical	**B**	**E**	**B**	**B**
Geomorphology	**C**	**C**	**C**	**C**
Riparian vegetation	**C/D**	**F**	**C/D**	**C/D**
Fish	**C**	**D/E**	**C**	**C**
Macroinvertebrates	**C**	**F**	**C**	**B/C**
EcoStatus	**C (65.05%)**	**E/F (19%)**	**C (65.05%)**	**C (65.05%)**

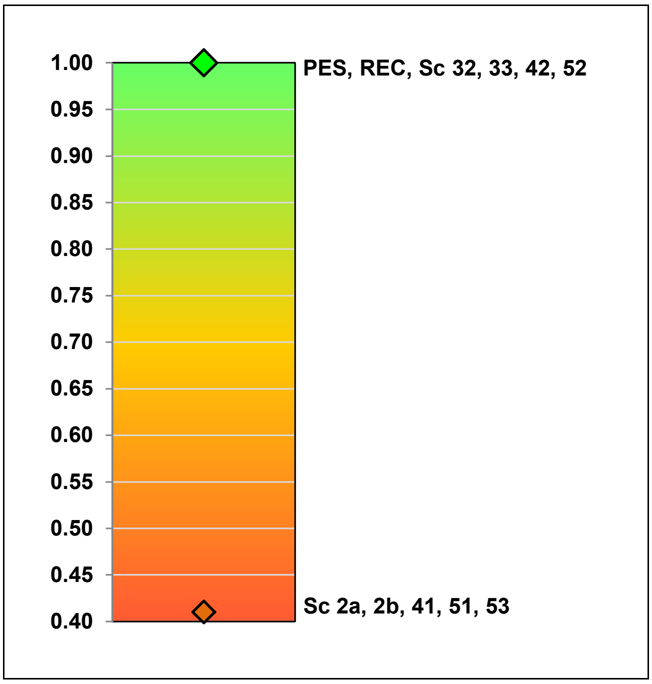


Figure 6.1 EWR1 Lalini: Ecological ranking of operational scenarios

6.2.2 Conclusions

The ranking of the scenarios indicates that Sc 2a, 2b, 41, 51 and 53 do not achieve the PES and REC. Under these scenarios the EcoStatus falls within an E/F Category, which is ecologically unsustainable. The rest of the scenarios achieve the REC requirements.

The situation and issues downstream of Lalini Dam are complex. **Figure 6.2** shows a reach of 4.8 km downstream of Lalini Dam to the Lower Tsitsa Falls. The rest of the reach to the outfall (where the water diverted from the dam will re-enter the river) is 13.5 km long. There are no major tributaries contributing to the flow in this reach. Under normal circumstances, the Tsitsa Falls act as a natural barrier and it is highly unlikely that fish migration can take place past this point. The barrier effect of Lalini Dam in this case is therefore not a major concern.

Sc 53 is the only scenario that achieves the REC at MzimEWR4 (as well as the estuary; see **Chapter 7**). However, the reason why Sc 53 does not meet the EWR at this point and Sc 52 does meet requirements, is because Sc 52 includes the REC release for EWR1 Lalini. This release results in higher flows in the lower Mzimvubu River.

As it is not considered acceptable to dry the Tsitsa Falls for large proportions of time, an optimised scenario (Sc 54) which allows for some flow over the Tsitsa Falls, is discussed in the report Conclusions (**Chapter 8**).

Figure 6.2 Google Earth image illustrating the layout of the river reach downstream of Lalini Dam and the hydropower outlet (or outfall)

7 SUMMARY OF ESTUARY CONSEQUENCES

The hydrological analysis and results showed that the following scenarios were considered similar. Only one scenario in each group (shown in bold text) is therefore presented in this summary.

- Sc 21 = 2b = 41 = **51** = 33 = 42
- Sc 32 = **52**
- Sc **53**

For more detail, refer to the Estuary EWR Report (DWS, 2017c), Report no. WE/WMA7/00/CON/CLA/0717.

The occurrences of the flow distributions (mean monthly flows in m^3/s) under the future scenarios derived from the 1920 to 2004 simulation period are provided in **Tables 7.1** to **7.3.**

Table 7.1 Summary of the monthly flow (in m^3/s) under Scenario 51

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	323	441	399	611	672	970	506	391	294	306	153	746
99	269	393	381	599	623	691	377	235	292	228	143	259
95	128	264	302	445	541	526	264	81	82	103	57	84
90	91	182	249	313	508	367	174	66	44	37	39	55
85	74	117	195	224	388	278	129	59	37	33	29	32
80	55	88	176	178	281	242	113	49	30	28	27	26
70	39	63	129	145	184	198	102	37	24	23	21	23
60	29	54	68	103	151	159	79	29	22	21	18	19
50	25	43	49	79	118	138	66	27	19	18	17	18
40	22	35	39	67	84	111	54	24	18	16	16	16
30	21	33	35	55	67	82	47	22	17	16	15	15
20	19	31	30	48	56	63	44	21	16	14	14	14
15	17	28	29	39	53	62	40	20	15	14	14	14
10	16	28	27	33	43	53	35	19	15	14	14	13
5	16	26	23	30	36	42	31	19	15	14	13	12
1	14	24	22	26	27	32	26	17	14	13	12	12

Table 7.2 Summary of the monthly flow (in m^3/s) Scenario 52

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	323	420	387	595	671	970	496	391	292	308	152	747
99	267	386	372	587	616	691	375	235	289	227	142	258
95	129	258	298	425	529	526	264	81	83	103	57	83
90	93	176	248	309	490	372	171	66	47	38	41	56
85	77	117	193	223	378	278	131	59	37	34	31	35
80	58	92	163	167	276	240	115	50	33	30	28	28
70	41	66	130	148	190	207	102	39	25	24	22	25
60	33	55	73	101	155	164	81	29	23	21	19	20
50	27	45	53	82	122	139	68	28	20	17	17	19
40	23	38	40	67	85	113	55	24	17	16	16	17
30	22	34	36	57	70	80	49	20	16	15	14	15
20	19	30	30	48	57	63	45	19	15	14	13	14
15	18	28	29	41	53	60	41	18	14	13	13	13
10	17	27	26	35	43	54	36	17	14	13	12	13
5	15	25	22	30	38	43	30	17	13	12	12	12
1	14	24	21	24	26	31	25	14	12	11	11	12

Table 7.3 Summary of the monthly flow (in m³/s) under Scenario 53

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	324	449	401	611	672	970	487	391	297	314	155	747
99	279	406	392	599	619	691	374	235	295	232	143	272
95	129	275	300	446	541	526	264	81	81	103	56	83
90	92	189	254	310	508	369	174	65	47	34	37	51
85	80	129	201	222	381	278	131	55	34	29	27	29
80	58	92	176	178	272	237	111	45	28	25	23	23
70	41	67	130	147	188	201	102	33	21	20	17	19
60	32	57	71	107	153	162	81	25	18	17	14	15
50	27	47	53	82	121	133	70	23	16	14	13	14
40	24	39	43	70	86	113	58	20	14	12	12	12
30	23	37	39	58	70	80	52	18	13	12	11	11
20	21	35	34	52	58	68	48	17	12	10	10	10
15	20	32	33	43	54	63	44	16	11	10	10	10
10	19	31	31	37	46	57	40	15	11	10	10	9
5	18	30	27	35	40	47	35	15	11	10	9	8
1	16	28	26	30	31	37	31	13	10	9	8	8

7.1 HYDROLOGY

Tables 7.4 provides a summary of the changes in low flows and flood regime under the various scenarios. The percentage of flow under each scenario at the estuary as compared to the 100% of the natural MAR of 2 737.0 MCM, is also shown.

Table 7.4 Summary of hydrological changes under present and future scenarios

Scenario	Summary of hydrological changes	%nMAR at estuary
Present	There is a 17% decrease in baseflows from reference. Floods are very similar to reference with only a 2% decline in magnitude.	95.5
2a	There is a 23% increase in baseflows from reference. Floods are similar to reference with a 4% decline in magnitude.	94.2
2b	There is a 20% increase in baseflows from reference. Floods are similar to reference with a 5% decline in magnitude.	92.7
32	There is a 20% increase in baseflows from reference. Floods decline by 7% in magnitude from reference conditions.	92.7
33	There is a 21% increase in baseflows from reference. Floods are similar to reference with a 6% decline in magnitude.	92.7
41	There is between a 20 and 21 % increase in baseflows from reference. Floods are similar to reference with a 5% decline in magnitude.	92.7
42	There is a 21% increase in baseflows from reference. Floods decline by 6% in magnitude from reference conditions.	92.7
51	There is a 19% increase in baseflows from reference. Floods are similar to reference with a 5% decline in magnitude.	92.7
52	There is a 19% increase in baseflows from reference. Floods decline by 7% in magnitude from reference conditions.	92.7
53	There is a 2% increase in baseflows from reference. Floods decline by 5% in magnitude from reference conditions.	92.7

7.2 HYDRODYNAMICS AND MOUTH CONDITION

A summary of the hydrodynamic changes under each of the scenarios and the hydrodynamic scores for various scenarios are provided in **Tables 7.5**.

Table 7.5 Summary of hydrodynamic changes under present and future scenarios

Scenario	Summary of hydrodynamic changes
Present	Mouth conditions will be similar to present, i.e. 100% open. Retention increase slightly as a result of a decrease in baseflows.
51, 52	Mouth conditions will be similar to present, i.e. 100% open. Retention decreases slightly as a result of elevated baseflows from reference conditions, i.e. 7% loss of State 2: Intermediate saline penetration.
53	Mouth conditions will be similar to present, i.e. 100% open. Retention decreases slightly as a result of elevated baseflows from reference conditions, i.e. 3% loss of State 2: Intermediate saline penetration.

7.3 WATER QUALITY

A summary of water quality changes under each of the scenarios and the water quality scores for various scenarios are provided in **Tables 7.6**.

Table 7.6 Summary of water quality changes under present and future scenarios

Water quality parameter	Scenarios	Summary of changes in water quality
Salinity	Present	Slight increase in salinity penetration.
	51, 52, 53	Decrease in salinity penetration.
Dissolved inorganic nitrogen, dissolved inorganic phosphate (µg/ℓ)	Present	Increased nutrient input from diffuse sources in the catchment, mainly settlements and cattle herds.
	51, 52, 53	
Dissolved oxygen (mg/ℓ)	Present, 51, 52, 53	No marked change from reference.
Turbidity (NTU)	Present, 51, 52, 53	Limited erosion as a result of catchment practices. However, this catchment naturally introduced turbid waters to the estuary. Slight increase in future scenarios relates to increase in high flow states.
Toxic substances	51, 52, 53	Some accumulation (e.g. trace metals) associated with urban development along banks of estuary.

7.4 MICROALGAE

A summary of the changes in microalgae under each of the scenarios and the microalgae health scores for various scenarios are provided in **Table 7.7**.

Table 7.7 Summary of changes in microalgae under present and future scenarios

Scenario	Summary of changes in microalgae
51	A change in flow (loss of State 2) results in a loss of residence time for phytoplankton; development of an River Estuary Interface (REI) requires > 2 weeks of residence time. As a result, phytoplankton biomass is likely to remain low (< 5 µg/L) throughout the estuary (the average biomass flowing in river water is elevated as a result of elevated nutrients but the estuary acts as a conduit). The phytoplankton community composition shifted from a diatom-dominated community (reference; high diatom:flagellate ratio) to a community where flagellate, chlorophyte and dinoflagellate abundances were higher (reduced diatom:flagellate ratio); this is lower than present due loss of State 2 (loss of dinoflagellates from upper zone). The dam is likely to trap coarser sediments and there should be a shift in sediment composition to fines (muddier). The benthic microalgal scores were determined based on changes to 'muddiness' of inter- and subtidal zones alone; assuming half of the present state change was related to nutrients (8% for richness and composition, and 10% for

Scenario	Summary of changes in microalgae
	abundance), then the average change in physical characteristics of the inter- and subtidal zones for Sc 2a (12%) was used to determine benthic microalgal scores.
52	A change in flow (loss of State 2) results in a loss of residence time for phytoplankton; development of an REI requires > 2 weeks of residence time. As a result, phytoplankton biomass is likely to remain low (< 5 µg/L) throughout the estuary (the average biomass flowing in river water is elevated as a result of elevated nutrients but the estuary acts as a conduit). The phytoplankton community composition shifted from a diatom-dominated community (reference; high diatom:flagellate ratio) to a community where flagellate, chlorophyte and dinoflagellate abundances were higher (reduced diatom:flagellate ratio); this is lower than present due loss of State 2 (loss of dinoflagellates from upper zone). The dam is likely to trap coarser sediments and there should be a shift in sediment composition to fines (muddier). The benthic microalgal scores were determined based on changes to 'muddiness' of inter- and subtidal zones alone; assuming half of the present state change was related to nutrients (8% for richness and composition, and 10% for abundance), then the average change in physical characteristics of the inter- and subtidal zones for Sc 2a (22%) was used to determine benthic microalgal scores.
53	The 4% State 3 flow (elevated residence time) is likely to increase microalgal abundance but not as severely as the 13% State 3 flows at present; 25% increase from reference. A 5% change in muddiness of intertidal and subtidal sediments is likely to support an increase in microphytobenthos (MPB) biomass. Changes in phytoplankton richness (27% change from natural) and community composition (32%) are related to the shift from a diatom-dominated reference state as described in the scenarios Sc 2a–Sc 52 above. Changes in the MPB community composition and richness (20% change from natural) are related to a shift to epipelic microalgal taxa.

7.5 MACROPHYTES

A summary of the changes in macrophytes under each of the scenarios and the macrophyte health scores for various scenarios are provided in **Table 7.8**.

Table 7.8 Summary of changes in macrophytes under present and future scenarios

Scenario	Summary of changes in macrophytes
51	Reduced hydropower in dry months to introduce low flow to the estuary (State 2). However, this does not influence abiotic characteristics and therefore has no effect on the macrophytes. In terms of floods this scenario is similar to Scenario 2b and 41 as there is a 5% decline in floods which causes an increase in reeds growing into the main channel.
52	Reduced hydropower in dry months to introduce low flow to the estuary (State 2). Similar to worst case Scenario 32, 7% decline in floods leading to sediment stability and an increase in macrophyte growth.
53	Salinity moves closer to reference conditions, as State 2 is reinstated. Floods are reduced which causes a change in habitat. Floods are similar to Scenarios 41 and 51, i.e. a 5% reduction which causes infilling and sediment stability. This results in an increase in the encroachment of reeds and sedges.

7.6 INVERTEBRATES

A summary of the changes in invertebrates under each of the scenarios and the invertebrate health scores for various scenarios are provided in **Table 7.9**.

Table 7.9 Summary of changes in invertebrates under present and future scenarios

Scenario	Summary of changes in invertebrates
Present	This a system with a natural low diversity and abundance. This is driven by the very dominant physical processes such as high volume of strong outflows, low retention and mobile sediments. All of these drive a zooplankton and benthic community comprised of the tougher, opportunistic species and development of a more diverse communities and higher biomass occurs during times of lower flow and greater marine penetration extending estuarine conditions beyond Zone 1 and into Zone 2. Studies on other large dynamic systems provide show that the response of the invertebrate community under low flow conditions can occur over short time periods (two weeks). Under present conditions, the similar flow volumes, mouth behaviour and physical habitats suggests that the invertebrate community is very similar to reference from a species richness, biomass and community composition point of view.
51	The increases in flow for these scenarios and the resultant loss of State 2 is considered to have no effect on species richness as the small number of freshwater tolerant and opportunistic species which are found within the estuary would still occur in the lower zone. However, the increase in baseflows over the critical low flow periods results in a loss of the productive middle zone as an estuary habitat means that overall abundance will be reduced and species composition is slightly altered by the fresher conditions.
52	Increase in baseflows further reduces species richness and productivity as a result of the change in salinity and to a small extent the increase in flood magnitude.
53	Small loss of estuarine species as the system gets more fresh than present with more of an effect on abundance as the middle zone of the estuary feels most of this effect.

7.7 FISH

A summary of the changes in fish under each of the scenarios and the invertebrate health scores for various scenarios are provided in **Table 7.10**.

Table 7.10 Summary of changes in fish under present and future scenarios

Scenario	Summary of changes in fish
Present	The hydrophysical and ecological processes that drive this system are still largely intact. There is some increase in the frequency of penetration of saline waters into the middle zones of the estuary, which favours use of this zone by a higher abundance of estuarine dependent marine spawning fishes. There may be some loss of freshwater fish abundance in these conditions, but this is likely to be minimal, because freshwater fishes in the lower river are strongly dominated by hardy *Oreochromis mossambicus* and *Clarias gariepinus*. The former especially is highly tolerant of salinity. As a consequence it is unlikely that any fish species will have been permanently lost from the estuary. Abundance and biomass of estuarine dependent marine spawning will have decreased, however, as a direct result of fishing pressure. Species targeted in recreational, commercial and subsistence fisheries will have declined in abundance (regionally and within the estuary). Species significantly impacted will include most notably *Pomadasys commersonnii* and *Argyrosomus japonicas*. There are also declines in the abundance of the Zambezi shark, *Carcharhinus leucas*. These reductions in abundance of fisheries species will result in a direct change in community composition due to changes in relative abundance of the constituent fishes. Indirect effects could also be expected due to changes in predation pressure on smaller species as a result of piscivores (such as *Argyrosomus japonicas*, *Lichia amia* and *Carcharhinus leucas*) being reduced in the estuary.
51, 52	The most important aspect of all of these scenarios is that they all involve baseflows higher than reference (and present) conditions. Under these scenarios, hydrodynamic and associated water quality State 2 will no longer occur in the system during the low

Scenario	Summary of changes in fish
	flow period, as it did under reference conditions or as it does in the present day. Significant impacts can be expected with changes in salinity regime. Fish in this estuary are sensitive to changes in salinity distribution (in time and space) in the range of freshwater to oligohaline, and much less so in the mesohaline and polyhaline ranges. The loss of salinity penetration into the middle zones of the system therefore affects the estuary's nursery function and fisheries value, especially for estuarine-dependent fishes (fish category IIa, Whitfield, 1998). Some estuarine migrant fishes (particularly some mullet species, most notably *Myxus capensis* and *Mugil cephalus*) and estuarine resident species (such as *Gilchristella aestuaria*) will remain in the middle zone of the estuary under fresh conditions but the abundance of many others will decline markedly. This is important when considering that only two of the three estuarine zones (under the estuarine delineation considered, i.e. the lower and middle zones) experience salinity intrusion under the hydrodynamic states considered (reference, present and scenarios). Therefore at least 50% of the present estuarine influence by salinity, and the entire middle reach, will be affected in the low flow months because of elevated baseflows under these scenarios. The estuarine nature of the system will be lost during these low flow periods. This is the critical nursery period that coincides with estuarine-dependant marine fishes breeding and recruitment cycles. Complete loss of estuarine-dependant marine species under these freshwater conditions is unlikely. Even species which generally show a preference for saline water will include a small percentage of individuals which will comfortably inhabit the middle zone under freshwater conditions. The full species complement will remain in the estuary as a whole, as the saline states generally persist in the lower reaches of the system over most of the low flow period. Indeed, while the system as a whole will see reduced abundance of fishes because of reduced habitat for estuarine-dependent marine species, the concentrations of these fishes in the lower reaches may increase under conditions of the middle reaches not being favourable (assuming that the lower reaches are not presently used to full capacity, which is unlikely given fishing pressure). This may make these populations susceptible to increased exploitation by fishing in the lower reaches. Under conditions of increased freshwater state in the middle reaches of the estuary it is unlikely that loss of abundance of estuarine-dependent marine fishes will be offset by an increase in freshwater fish abundance. The latter are largely restricted by daytime habitat availability (reed beds along the estuary banks). Impacts from turbidity (and other water quality changes) are probably negligible in the light of the changes in salinity. There is some decrease in floods which may affect the offshore estuary and result in changes in recruitment cueing signals. This might affect recruitment of Anguillid eels, Zambezi sharks, and (to a lesser degree) estuarine fish. These impacts are probably not significant over the short term, but in the long-term population changes in the estuary, and the river upstream may result. In this regard it is also important that the 'offshore estuary' be considered. This is the area offshore of the Mzimvubu that is seasonally affected by the summer outflows. This is a critical area that is used by the estuarine fish assemblage under high flow conditions. During these periods these fishes are dependent on the turbid, low salinity conditions that are created offshore. Floods are therefore important for the fish assemblage of the Mzimvubu Estuary. Sediment budgets might be an issue at the the Mzimvubu depocentre, which is likely to be a feeding ground for some estuarine species. Scenarios that involve relative reductions in high flow floods (Sc 32, 42 and 52) are therefore likely to result in some degree of loss of fish health score in the estuary, over the long term.
53	Flows under this scenario are very similar to those under the reference condition. Indeed, the distribution of abiotic states is closer to reference conditions than it is under resent conditions. An important difference however, is that baseflows are slightly higher than under reference conditions (rather than slightly lower as is presently the case). This results in a reduced frequency of State 2 compared to reference conditions with impacts similar to those described above, and losses in abundance of estuarine dependent marine species. These fishes are more susceptible to the complete loss of salinity than they are to slight gains in the mesohaline and polyhaline ranges. Impacts to the fish health score can be

Scenario	Summary of changes in fish
	anticipated, and although not as significant as those associated with flow scenarios involving a hydroelectric scheme, these changes are expected to result in a loss in fish health score to below those experienced under present day conditions.

7.8 BIRDS

A summary of the changes in birds under each of the scenarios and the invertebrate health scores for various scenarios are provided in **Table 7.11**.

Table 7.11 Summary of changes in birds under present and future scenarios

Scenario	Summary of changes in birds
Present	There has been an overall decrease in bird numbers. Waterfowl have decreased due to a variety of anthropogenic pressures as well as increased salinity, and have shifted in composition to increaser species. Terns have decreased due to disturbance and changes in the mouth area. Waders have decreased slightly due to general population declines and habitat loss.
51, 52	Waterfowl increase from present as a result of the system being fresher; waders decrease as a result of decreased habitat and benthic invertebrate abundance; piscivores decrease as a result of decreased fish abundance.
53	Effects are very similar to the above but less pronounced.

7.9 ECOLOGICAL CATEGORIES ASSOCIATED WITH FUTURE SCENARIOS

The individual health scores for the various abiotic and biotic components are used to determine the ecological status or ecological category for the Mzimvubu Estuary under various future scenarios (**Table 7.12**), using the Estuarine Health Index (EHI).

Table 7.12 EHI score and corresponding Ecological Categories under present and future scenarios

Component	Weight	Scenarios									
		Pres	2a	2b	32	33	41	42	51	52	53
Hydrology	25	89	85	86	85	85	86	85	87	86	97
Physical habitat	25	98	97	97	97	97	97	97	97	97	99
Hydrodynamics/ mouth condition	25	75	67	67	66	66	67	66	67	66	77
Water quality	25	94	92	89	79	84	89	84	89	79	89
Habitat health score	**50**	**89**	**85**	**85**	**82**	**83**	**85**	**83**	**85**	**82**	**90**
Microalgae	20	65	74	73	68	73	75	73	75	68	68
Macrophytes	20	63	63	62	58	59	62	59	62	58	62
Invertebrates	20	95	75	75	75	75	75	75	75	70	75
Fish	20	77	64	64	62	64	64	62	64	62	72
Birds	20	61	62	62	62	62	62	62	62	62	62
Biotic health score	**50**	**72**	**68**	**67**	**65**	**67**	**68**	**66**	**68**	**64**	**68**

Component	Weight	Scenarios									
		Pres	2a	2b	32	33	41	42	51	52	53
ESTUARY HEALTH SCORE		81	76	76	73	75	76	75	76	73	79
ECOLOGICAL CATEGORY		B	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B

The results are also displayed as a traffic diagram **(Figure 7.1)** to illustrate how successful the scenarios are in meeting the REC.

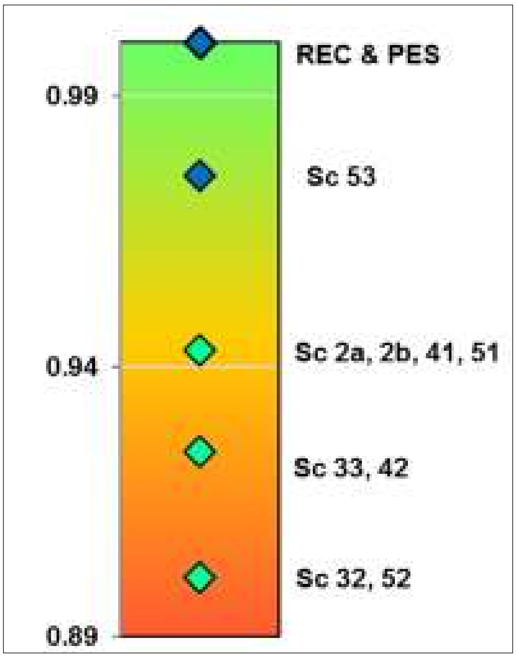


Figure 7.1 Ecological ranking of operational scenarios for the Mzimvubu Estuary

8 INTEGRATED ECOLOGICAL RANKING OF SCENARIOS, CONSEQUENCES AND RECOMMENDATIONS

8.1 SUMMARY OF CONSEQUENCES

- **MzimEWR4 (Mzimvubu):** Only Sc 53 achieves the REC as it was designed to minimise the increased baseflows associated with other scenarios. These increased baseflows are more than natural, resulting in a lack of seasonal variation.
- **MzimEWR1 (Tsitsa):** The ranking of the scenarios indicates that Sc 2a, 2b, 32 and 33 do not achieve the PES and REC, with all components deteriorating and resulting in an EcoStatus of a D. These scenarios do not include releases for MzimEWR1. The rest of the scenarios achieve the REC requirements as the proposed Ntabalenga Dam releases the low flow EWRs and the spills and inflows are sufficient to cater for the high flow requirements.
- **EWR1 Lalini (Tsitsa):** The ranking of the scenarios indicates that Sc 2a, 2b, 41, 51 and 53 do not achieve the PES and REC. Under these scenarios the EcoStatus falls to an E/F Category, which is ecologically unsustainable. The rest of the scenarios achieve the REC requirements.
- **Mzimvubu Estuary:** The ranking of scenarios indicate that only Sc 53 maintains the REC of a B Category. The score is marginally lower than the REC (and PES) score. The reason why this scenario is better than all the other scenarios is that the water available for hydropower generation has been decreased sufficiently, so that increased baseflows are not a major problem.

8.2 INTEGRATED RIVER ECOLOGICAL RANKING

The process followed to determine an integrated ranking of the different scenarios is described in detail in **Section 3.3**.

The first step in determining an integrated RIVER ranking (i.e. integrating MzimEWR1, EWR1 Lalini and MzimEWR4) was to determine the relative importance of these EWR sites occurring in the study area. The site weight (**Table 8.1**) indicated that MzimEWR4 carried the highest weight due to the site being the most downstream site in the study area and the accumulated impact of the scenarios will be the highest within this river reach (137 km in length from the outfall of Lalini Dam to the estuary). The importance of MzimEWR1 is lower; due to lower accumulated impacts of scenarios within the 76 km reach demarcated from Ntabelanga Dam to Lalini Dam. EWR1 Lalini has the lowest weight as the EIS is Moderate and the site is situated in a relatively isolated reach in the Tsitsa River (18 km from Lalini Dam to the outfall).

The weights are provided in **Table 8.1**. The weight is based on the conversion of the PES and EIS to numerical values to determine the normalised weight.

Table 8.1 Weights allocated to EWR sites relative to each other

EWR site	PES	EIS	Locality in protected areas	Distance	Position	Normalised weight
MzimEWR1	C	Moderate	1	0.33	0.10	0.24
EWR1 Lalini	C	Moderate	2	0.07	0.10	0.18
MzimEWR4	C	Moderate	1	0.6	1.00	0.57

The weight was applied to the ranking value for each scenario at each EWR site and this provided an integrated score and ranking for the operational scenarios. The ranking of '1' refers to the REC and the rest of the ranking illustrates the degree to which the scenarios meet the REC. The results are provided in **Table 8.2** once the weights have been taken into account.

Table 8.2 Ranking value for each scenario resulting in an integrated score and ranking

Site	PES and REC	Sc 2a, 2b	Sc 32, 33	Sc 41, 51	Sc 42, 52	Sc 53
MzimEWR1	0.24	0.17	0.17	0.24	0.24	0.24
EWR1 Lalini	0.18	0.08	0.18	0.08	0.18	0.08
MzimEWR4	0.57	0.57	0.57	0.57	0.57	0.57
	1.00	**0.82**	**0.92**	**0.88**	**0.99**	**0.89**

The above results are plotted on a traffic diagram (**Figure 8.1**) to illustrate the integrated ecological ranking.

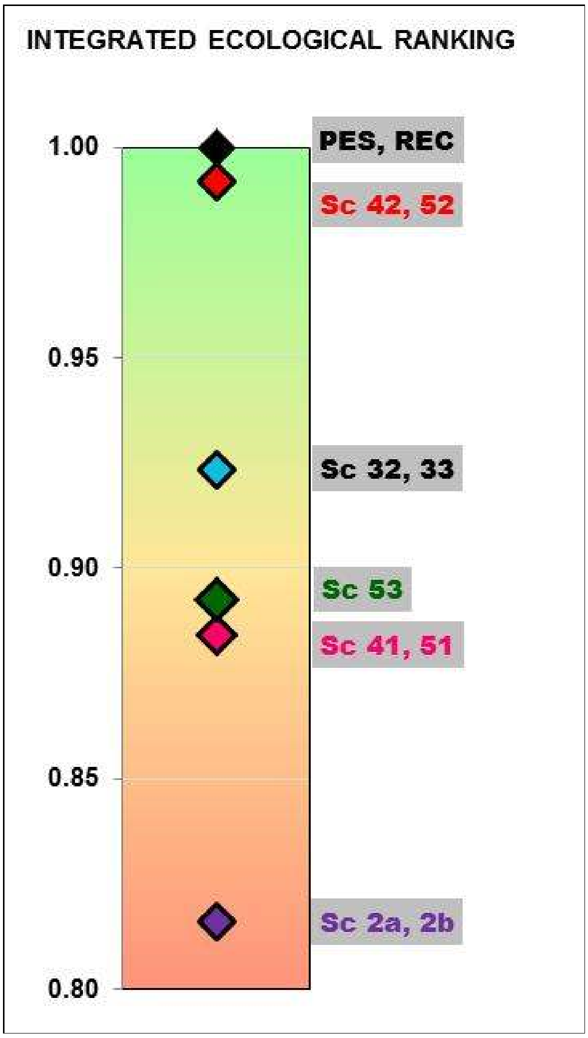


Figure 8.1 Integrated ecological ranking of the scenarios on the Tsitsa and Mzimvubu rivers

8.3 ESTUARY ECOLOGICAL RANKING

The estuary ranking is illustrated in **Figure 8.2** below.

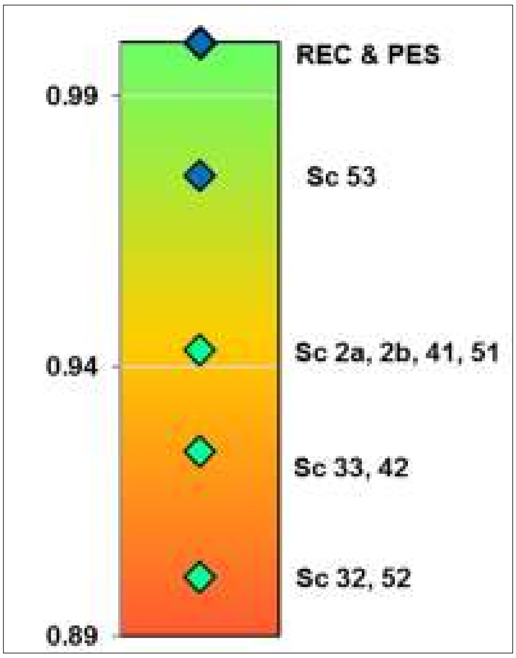


Figure 8.2 Mzimvubu Estuary: Ecological ranking of operational scenarios

As can be seen from **Figure 8.2**, Sc 53 maintains the estuary in a B category.

8.4 OPTIMISATION OF SCENARIO 53

In the chronological process of developing scenarios, it was noted that Sc 53 was the only scenario that met the estuary REC as well as the REC at MzimEWR4, due to the process of minimising increased baseflows downstream of the dams. As these are the most important sites, it was of concern that the integrated river ranking scored lower than other scenarios. The investigation showed that the reason for the lower ranking was the significant impact of not providing EWR flows (Sc 53) from Lalini Dam and the severe impact it may have on at least 18 km of river downstream of the dam. An additional impact would be on the Lower Tsitsa Falls, with no water going over the falls.

Sc 53 was therefore further optimised to include some flows downstream of Lalini Dam, but lower than the REC low flows released in Sc 52. It was decided to use the flows that would result in a D category at MzimEWR1 and extrapolate these to EWR1 Lalini. The scenario was designed in such a way that the flows downstream of the outlet would be the same or similar to those of Sc 53. This scenario was called Sc 54, which was then included in the river ranking (**Figure 8.3**). Although Sc 52 was still a 'better' scenario from the river viewpoint, Sc 54 was significantly better than the Sc 53 ranking.

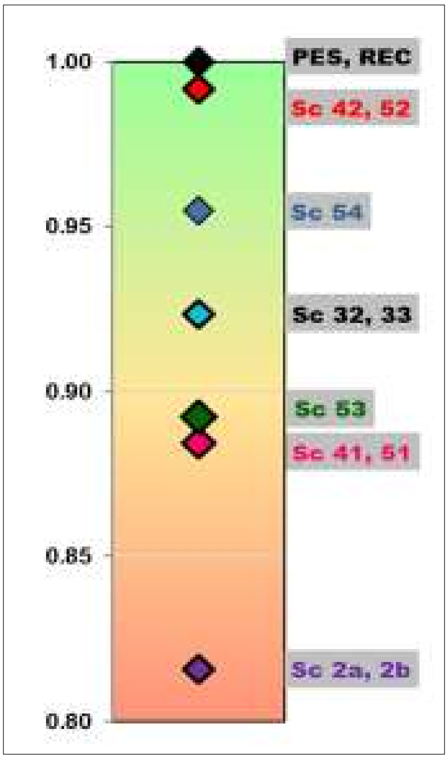


Figure 8.3 Integrated ecological ranking of the scenarios on the Tsitsa and Mzimvubu rivers, including Sc 54

8.5 ESTUARY AND RIVER INTEGRATED RANKING

The estuary is incorporated in the ranking using the scenario scores as illustrated in **Figure 8.2**. As the estuary is now evaluated together with the river EWR sites, a weighting for the estuary is required. Since the Mzimvubu Estuary is important from an ecological and socio-economic aspect, a high weight has to be provided to the estuary. For demonstration purpose, two traffic diagrams are provided with a 30 and 50% weight afforded to the estuary (**Figure 8.4**).

Figure 8.4 shows that for both weighting options, the optimised Sc 54 will be the preferred option as it is the only scenario that achieves the REC at the two most important sites, MzimEWR4 and the Mzimvubu Estuary. Sc 54 also maintains the REC at MzimEWR1. The only negative point is the trade-off at EWR1 Lalini where the REC and the PES of a C category (extrapolated from MzimEWR1) will not be reached.

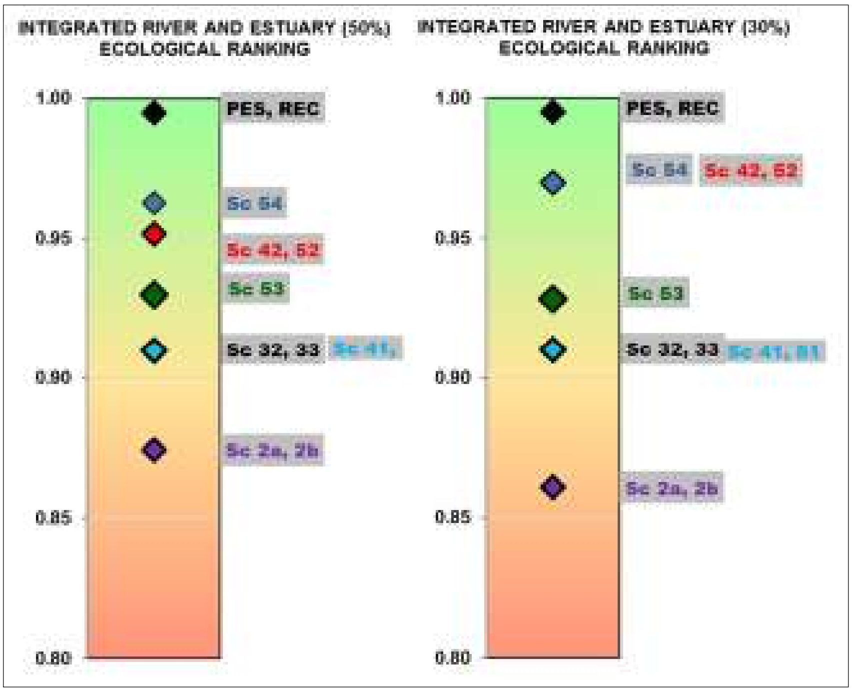


Figure 8.4 Integrated ranking with the estuary weighted at 50% (left) and 30% (right)

8.6 RECOMMENDATION

The recommendation from an ecological viewpoint is that Sc 54 should be implemented if the dams are approved. Based on the outcome of the economic analysis, further work may be required to adjust the flows downstream of Lalini Dam. Operating rules assumed for the modelling can be further adjusted to optimise water use and ecological condition. This may be required once information is obtained on the current preliminary dam. These rules can be adjusted in the final design of the dam and hydropower system to meet downstream EWRs. It must be noted however that careful consideration is required regarding the section downstream of Lalini Dam as any additional flows exceeding the D category may result in higher baseflows and impacts on seasonality at MzimEWR4 and the estuary. Decisions regarding this situation can only be made once the economic and other consequences are available.

9 REFERENCES

Bok A., Kotze, P., Heath, R., and Rossouw, J. 2007 Guidelines for the planning, design and operation of fishways in South Africa. WRC Report No TT 287/07. Water Research Commission, Pta, South Africa.

Department of Water Affairs and Forestry (DWAF). 2008. Methods for determining the water quality component of the Ecological Reserve. Report prepared for Department of Water Affairs and Forestry, Pretoria, South Africa by P-A Scherman of Scherman Consulting.

Department of Water and Sanitation (DWS), South Africa. 2014a. Environmental Impact Assessment for the Mzimvubu Water Project: Rapid Reserve Determination: Tsitsa River at Lalini. DWA Report No: P WMA 12/T30/00/5314/17. Prepared for: Directorate – Options Analysis. Prepared by: GroundTruth Water, Wetlands and Environmental Engineering, P O Box 2005, Hilton, 3245.

Department of Water and Sanitation (DWS), South Africa. 2014b. Feasibility Study for the Mzimvubu Water Project: Volume 1 – Rivers. Prepared by Jeffares and Green (Pty) Ltd. for: DWS Directorate: Options Analysis. Report No: P WMA 12/T30/00/5212/7, Volume 1.

Department of Water and Sanitation (DWS), South Africa. 2017a. Determination of Water Resource Classes and Resource Quality Objectives for Water Resources in the Mzimvubu Catchment. Estuary EWR Report. Prepared by Council for Scientific and Industrial Research for Scherman Colloty and Associates cc. Report no. WE/WMA7/00/CON/CLA/0717.

Department of Water and Sanitation (DWS), South Africa. 2017b. Determination of Water Resource Classes and Resource Quality Objectives for Water Resources in the Mzimvubu Catchment. River EWR report. Compiled by Rivers for Africa eFlows Consulting (Pty) Ltd for Scherman Colloty and Associates cc. Report no. WE/WMA7/00/CON/CLA/0617.

Department of Water and Sanitation (DWS), South Africa. 2017c. Determination of Water Resource Classes and Resource Quality Objectives for Water Resources in the Mzimvubu Catchment. Estuary EWR report. Compiled by Council for Scientific and Industrial Research (CSIR) for Scherman Colloty and Associates cc. Report no. WE/WMA7/00/CON/CLA/0717.

Dettinger, M.D. and Diaz, H.F. 2000 Global characteristics of stream flow seasonality and variability. J. Hydromet. 1 289-310.

Kleynhans, C.J., Louw, M.D., Thirion, C. Rossouw, N.J., and Rowntree, K. 2005. River EcoClassification: Manual for EcoStatus determination (Version 1). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

Kleynhans, C.J. 2007. Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 330/08.

Kleynhans, C.J. and Louw, M.D. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT329/08.

Kleynhans, C.J., Mackenzie, J. and Louw, M.D. 2007a. Module F: Riparian Vegetation Response Index. In River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT333/08.

Kleynhans, C.J., Louw, D. and Moolman, J. 2007b. Module D: Reference frequency of occurrence of fish species in South Africa in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT331/08.

Leenhouts, J.M., Stromberg, J.C. and Scott, R.L. 2006. Hydrologic requirements of and consumptive ground-water use by riparian vegetation along the San Pedro River, Arizona. USGS Scientific Investigations Report 2005. 5163.

Lite, S.J. and Stromberg, J.C. 2005. Surface water and ground-water thresholds for maintaining *Populus-Salix* forests, San Pedro River, Arizona. Biological Conservation 125: 153–167.

Rowntree, K.M. 2013. Module B: Geomorphology Driver Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 551/13.

Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT332/08.

Whitfield, A.K. 1998. Biology and ecology of fishes in southern African estuaries. Ichthyological Monographs of the JLB Smith Institute of Ichthyology 2: 223 pp.

APPENDIX A: COMMENTS REGISTER

Page / Section	Report statement	Comments	Changes made?	Author comment
DWS Project Management Committee, L Mulangaphuma – 6 October 2017				
Report		Editorial comments	Yes	Addressed throughout.
Executive summary; tables of consequences as categories		Colouring of the figure (traffic diagram) is not explained.	Yes	Text adjusted to explain the colouring of the traffic diagram.
Chapter 2		A brief description of method (for scenario description used) will be appreciated. For example, WRYM and/or water reconciliation strategy study that were used to define water requirements and return flows to PD levels.	Yes	A description of methods has not been included, other than a line on the model used and where information on the modelling can be found, i.e. the Systems Modelling Report for the study.
Chapter 2		Naming of scenarios. Where does the naming of scenarios come from? For example, we have scenario 2a, 2b instead of scenario 1, 2, 3, etc.	Yes	Text included to explain scenario naming.
Chapter 7: Estuary consequences		A graph to show summary of the monthly flow for each scenario to show trend will be appreciated.	No	Table 7.4 is provided to show a summary of hydrological changes under each scenario. This is provided in text rather than graphic form, which would be difficult to produce as monthly flow data is shown from 1 to the 99.9th percentile. A column has been added to Table 7.4 to show the % nMAR under each scenario at the estuary.
Chapter 8: Ranking of scenarios and recommendations		In conclusion, report shortcoming should have been highlighted as the report is limited to the ecological consequence for rivers and estuary. The report doesn't include other ecological component such as wetland.	No	The purpose of this report, i.e. ecological consequences on affected rivers and the estuary, is shown in the Executive Summary and Chapter 1.