The Orange-Senqu River Commission (ORASECOM)

Sharing the Water Resources of the Orange-Senqu River Basin

Botswana | Lesotho | Namibia | South Africa

Contract No.: P-Z1-EAZ-048/CS/01

Preparation of Climate Resilient Water Resources Investment Strategy & Plan and Lesotho-Botswana Water Transfer Multipurpose Transboundary Project

PRE-FEASIBILITY PHASE

MAKHALENG RIVER ENVIRONMENTAL REQUIREMENTS

Component III

April 2024

FINAL REPORT

Report number: ORASECOM 015D/2019

FC/02979.cdr

The Preparation of a Climate Resilient Water Resources Investment Strategy & Plan and the Lesotho-Botswana Water Transfer Multipurpose Transboundary project was commissioned by the Secretariat of the Orange-Senqu River Basin Commission (ORASECOM) with technical and financial support from the African Development Bank, NEDPAD-IPPF (Infrastructure Project Preparation Facility), the Stockholm International Water Institute (SIWI), the Climate Resilient Infrastructure Development Facility – UK Aid, and the Global Water Partnership-Southern Africa.

PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT III

MAKHALENG RIVER ECOLOGICAL WATER REQUIREMENTS

Prepared for

Orange-Senqu River Commission (ORASECOM)

Von Willich LN, C nr Von Willich LN & Lenchen Avenue, Corporate 66 Office Park, Block A

Prepared by

WRP in association with Knight Piésold Consulting, INGEROP, GWC, WRC Water Resources Consultants, CORE

PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT III

MAKHALENG RIVER ECOLOGICAL WATER REQUIREMENTS

ORASECOM Document No.	**ORASECOM 015D/2019**
Date of Publication:	April 2024
Authors:	EWR Team
Status:	Final Report

APPROVALS

For the Consultants: ______________________

RS McKenzie: Study Team Leader

____

C Muir: Deputy Study Team Leader

For ORASECOM: ______________________

C Molosiwa

Executive Secretary: ORASECOM Secretariat

AUTHORS from the EWR Team

The following persons contributed to this report:

Authors	Company
Birkhead, A	Streamflow Solutions cc.
Huchzermeyer, N	Private
Koekemoer, S	Koekemoer Aquatic Services
Kotze, P	Clean Stream Biological Services
Louw, D	Rivers for Africa eFlows Consulting (Pty) Ltd.
Mackenzie, J	Bioriver Solutions
Mare, M	WRP Consulting Engineers
Scherman, P	Scherman Environmental

TABLE OF REPORTS

Reports submitted	ORASECOM Report No.[1]
Inception Report Components I and II	ORASECOM 010/2018
Inception Report Components III and IV	ORASECOM 011/2018
Preparation of climate resilient water resources investment strategy & plan Component I	
Core Scenario Update Report Component I	ORASECOM 003/2019
Core Scenario Supporting Report: Water Requirements and Return flows **Component I**	ORASECOM 004/2019
Core Scenario Supporting Report: Water Conservation, Water Demand management and Re-use Report **Component I**	ORASECOM 005/2019
Core Scenario Supporting Report: Ground Water Report **Component I**	ORASECOM 006/2019
Climate Change Report **Component I**	ORASECOM 007/2019
Review and assessment of existing policies, institutional arrangements and structures Component I	ORASECOM 008/2019
Optimized IWRMP Core Scenario economic approach Report Component **I**	ORASECOM 009/2019
Climate Resilient Water Resources Investment Plan Report **Component I**	ORASECOM 010/2019
System analysis Report Component I	ORASECOM 011/2019
Preparation of climate resilient water resources investment strategy & plan Component II	
Roadmap for IWRMP Operationalization Report Component II	ORASECOM 012/2019
Roadmap for IWRMP Operationalization Executive Summary	ORASECOM 012A/2019
Roadmap for IWRMP Operationalization: Appendix B Strategic Actions Concept Notes	ORASECOM 012B/2019
Roadmap for IWRMP Operationalization: Appendix C Core Scenario Concept Notes	ORASECOM 012C/2019
Climate Resilience Investment Plan (Brochure)	ORASECOM 012D/2019
Roadmap supporting Report: Strategic actions and TORs (Appendix A to Roadmap Report)	ORASECOM 013/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component III Pre-feasibility Phase	
Pre-feasibility report Phase 1 Report Component **III**	ORASECOM 014/2019
Pre-feasibility report Phase 2 Report Component **III**	ORASECOM 015/2019

Reports submitted	ORASECOM Report No.[1]
Report A Phase 2: Dam on the Makhaleng River	ORASECOM 015A/2019
Report B Phase2: Water Conveyance System	ORASECOM 015B/2019
Report C Phase 2: Environmental and Social Assessment	ORASECOM 015C/2019
Report D Makhaleng River Ecological Water Requirements	ORASECOM 015D/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component IV - Feasibility Phase	
Feasibility Study Interim Report Component IV	ORASECOM 016/2019
Feasibility Study Report Component IV : Volume **I** – Main Report	ORASECOM 017/2019
Feasibility Study Report Component IV : Volume **II** - Drawings	ORASECOM 017/2019
Geotechnical Investigation Report for the Dam on the Makhaleng River. Annexure A to Volume I – Main Report	ORASECOM 017A/2019
Survey Report Annexure B to Volume **I** – Main Report	ORASECOM 017B2019

EXECUTIVE SUMMARY

The Orange-Senqu River Basin

The Orange-Senqu River basin is one of the largest river basins south of the Zambezi with a catchment area of approximately 1 million km^2. It encompasses all of Lesotho, a significant portion of South Africa, Botswana and Namibia. The Orange-Senqu River originates in the Highlands of Lesotho and flows in a westerly direction for approximately 2,200 km to the west coast of South Africa and Namibia where it discharges into the Atlantic Ocean.

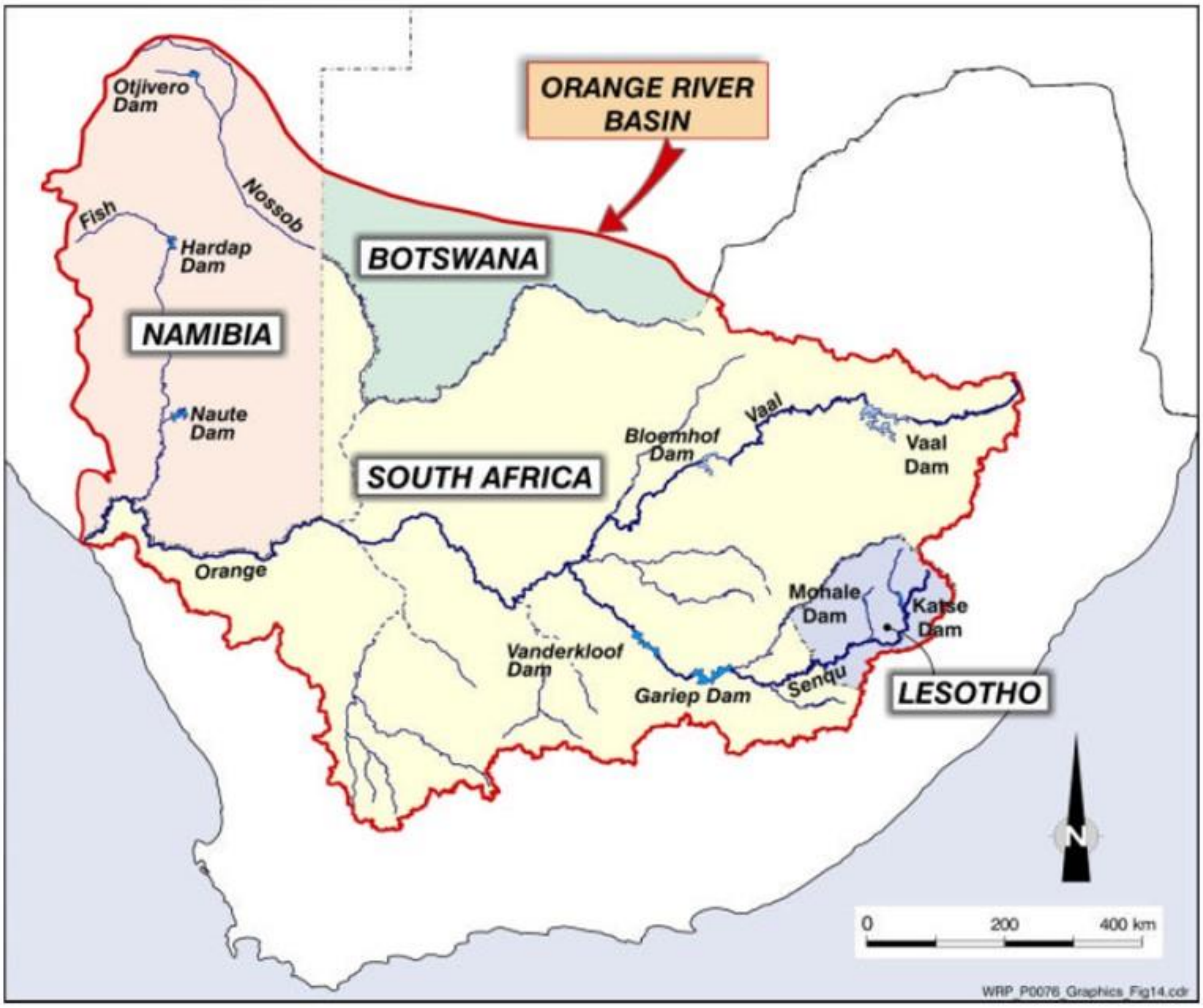

Figure A: Water Resources of the Orange-Senqu River Basin

It has been estimated that the natural runoff of the Orange-Senqu River basin is in the order of 11,300 million m^3/a, of which approximately 4,000 million m^3/a originates in the Senqu basin in the Lesotho Highlands, 6,500 million m^3/a from the Vaal and Upper Orange, with approximately 800 million m^3/a from the Lower Orange and Fish River (Namibia).

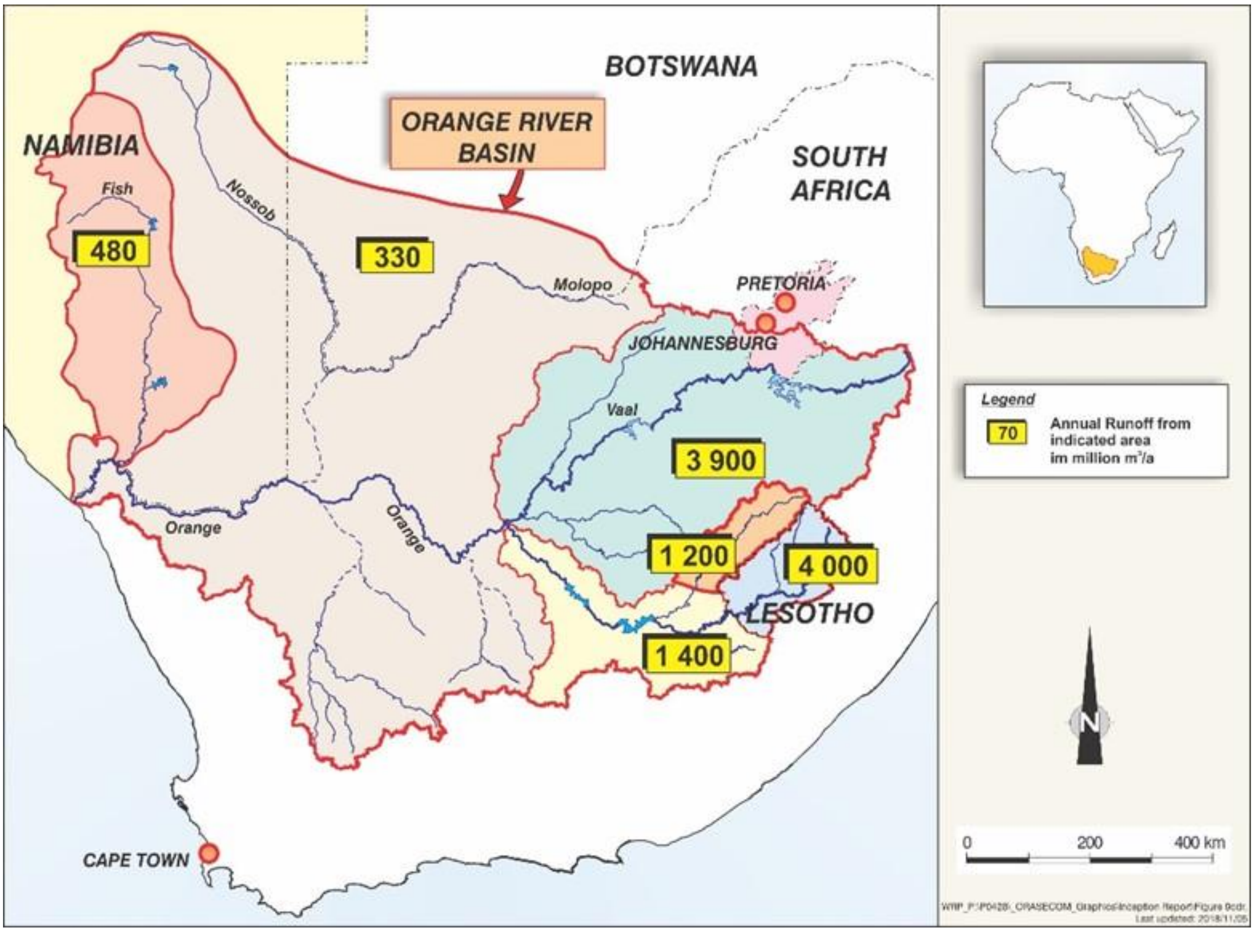

Figure B: Approximate Natural Run-off in the Basin

The runoff values provided highlight the highly variable and uneven distribution of runoff from east to west in the basin and the various water demands have already reduced the actual runoff reaching the river mouth to less than half the natural runoff. The Natural Runoff figures refer to the runoff which would have occurred had there been no developments or impoundments in the catchment.

It is important to note that the current demands for water within the basin are basically in balance with the available yields from the many different dams and transfer schemes. As such, it is important to analyse all possible new dam developments to assess their impacts on existing downstream users and to provide additional yield where necessary to rebalance any shortages caused by the new development.

Climate Change

It is generally accepted that southern Africa will be highly impacted by climate change and various studies have been completed which indicate that Climate Change is likely to affect the water resources of the basin to some degree. It is agreed that the temperature and thus also the evaporation will increase throughout the basin. The rainfall is expected to reduce especially in the lower areas to the west of the catchment although there is no clear indication of what will happen in the high laying wetter areas in Lesotho and to the East of the basin. This study therefore aims to enhance investment in transboundary water security and to develop resilience to climate change through strategic projects and actions, some of which are described in the Integrated Water Resource Development Plan.

The Republic of Botswana is an arid country with serious water constraints which will worsen with the expected effects of climate change. Botswana can expect to experience chronic water shortages in the near future unless a major new water source is developed. Gaborone has already experienced a serious drought which caused severe shortages in 2015 and 2016. Droughts are natural events which must be expected from time to time. It is clear, however, that they are becoming more frequent and more severe due to the impacts of Climate Change. The proposed Lesotho to Botswana Water Transfer Project is effectively a Water Resilience Project aimed at protecting the water supply to Southern Botswana by providing a reliable alternative water source to augment the existing local water resources as well as the supply from Northern Botswana through the North-South Carrier.

ORASECOM and the Integrated Water Resources Development Plan

Southern Africa has fifteen (15) transboundary watercourse systems of which thirteen exclusively stretch over the Southern African Development Community Member States. The Orange–Senqu is one of these thirteen transboundary watercourse systems. The Southern African Development Community member states embrace the ideals of utilizing the water resources of these transboundary watercourses for the regional economic integration and for the mutual benefit of riparian states. To enhance the objectives of integrated water resources development and management in the region, the Orange–Senqu River Basin Commission (ORASECOM) was established in November 2000.

ORASECOM was established by the Governments of the four States, namely, South Africa, Lesotho, Botswana and Namibia, for managing the transboundary water resources of the Orange-Senqu River basin and promoting its beneficial development for the socio-economic wellbeing and safeguarding the basin environment. This led to the development of a basin level Integrated Water Resources Management Plan adopted in February 2015 by the ORASECOM Member States. The Integrated Water Resources Development Plan provides a strategic transboundary water resources management framework and action areas and serves as a guiding and planning tool for achieving the long-term development goals in the basin. A key aspect of the transformative approach for strengthening cooperation has been identified as the need for joint project implementation that provides a mutually inclusive transboundary benefit.

The Integrated Water Resources Development Plan recommends strategies and measures for promoting sustainable management of the water resources of the basin and defines strategic actions that will ensure and enhance water security, considering the long term socio-economic and environmental demands on the water resources of the basin.

The Orange-Senqu River basin is a highly complex and integrated water resource system, characterised by a high degree of regulation and major inter-basin transfers to manage the resource availability between the location of relatively abundant precipitation and the location of greatest water requirements. The infrastructure involves storage and transmission of water to demand centres that are in some cases located outside of the basin through intra and inter basin transfers. The largest interbasin transfer is the Lesotho Highlands Water Project which transfers approximately 800 million m^3/annum water to South Africa through an 80km long transfer tunnel which runs through the Maluti Mountains.

Objective of this Study

The objective of this study is to assist ORASECOM and the riparian countries to implement various elements of the Integrated Water Resource Management Plan developed in 2015. The objective will be met through the following three processes:

- A Climate Resilient Investment Plan for the Orange-Senqu River Basin based on the updated Core Scenario. The Core Scenario is basically a detailed list of new water resource developments which have been planned by the 4 basin states to ensure that future water demands can be supplied into the future taking into account the possible impacts of Climate Change.
- A proposed Implementation Plan for a number (nine separate projects have been identified) of Key Strategic Actions selected from the updated Integrated Water Resource Management Plan. These proposed Strategic Actions are potential projects where ORASECOM will play a key role in the management and funding of the work.
- A Pre-feasibility level report for the Lesotho to Botswana Water Transfer Project, and a feasibility level report for a new dam on the Makhaleng River in Lesotho.

The study is divided into four components namely:

Component I

- Preparation of a Climate Resilient Investment Plan, based on the updated Water Resources Yield and Planning Model and the updated Core Scenario defined in the IWRM Plan of 2015.

Component II

- Operationalisation of the Integrated Water Resources Management Plan;

Component III

- A Pre-feasibility study of the Lesotho to Botswana Water Transfer Project;

Component IV

- A Feasibility Study of the Dam on Makhaleng River in Lesotho.

This report

This report falls under Component III the Pre-feasibility study of the Lesotho to Botswana Water Transfer Project. The initial desktop EWR assessment was carried out as part of the Phase 1 Pre-feasibility study and was documented in the Phase 1 Pre-feasibility Report. This was an extended desktop study and included some field work. The initial extended desktop EWR work was followed by the involvement of a full range of specialists, providing input in the determination of the EWR, including an additional site visit. This aspect is documented in this report. The follow up EWR study includes a comprehensive assessment of the EcoClassification as well specialist input in the determination of the EWR. The approach followed to determine the EWR was to review the desktop EWR, make recommendations regarding any proposed changes and then to remodel the flows according to specialist requirements - resulting in an EWR estimate.

After the EWR refinement, proposed water supply and operating scenarios from the proposed dam on the Makhaleng River were developed. The ecological consequences in terms of the impact on the ecological status were assessed for each scenario and the scenarios were then ranked in terms of the potential of meeting an Ecological Category (Recommended Ecological Category – REC). The purpose of this report is to describe the review of the EcoClassification and EWR by documenting the process followed and results obtained for the EWR site.

Summary of results

The flow requirements are summarised in the following tables. The Natural Mean Annual Runoff (nMAR) is 575.45 MCM. The low flow EWR in MCM is 101.779 and it equates to 17.7% of the nMAR and the total flow EWR in MCM is 144.84 which equates to 25.2% of the nMAR.

Table A: High flow requirements

Class	Frequency	Peak (m^3/s)	Duration (hours)	No. of Events	Volume (MCM)
1	Annual	25.637	68	3	2.649
2	Annual	40.475	72	2	4.427
3	Annual	80.642	76	1	9.311
4	1:2 year	281.024	96	1	40.987
5	1:5 year	372.406	104	1	58.841

Table B: Low flow: Flow Duration Table (EWR rule table)

m^3/s	10	20	30	40	50	60	70	80	90	99
Oct	4.434	3.223	2.485	2.150	1.815	1.387	0.884	0.542	0.219	0.118
Nov	5.551	4.306	3.979	3.549	2.895	2.334	1.564	1.046	0.613	0.082
Dec	5.978	5.953	5.656	5.162	4.487	3.350	2.139	1.326	0.643	0.470
Jan	7.332	7.032	6.455	4.965	4.343	3.286	2.195	1.395	0.758	0.342
Feb	9.097	7.653	7.208	5.924	5.374	4.540	3.312	1.993	0.966	0.511
Mar	9.202	8.898	8.402	7.645	6.689	**5.407**	3.841	2.098	**0.907**	0.422
Apr	8.498	7.887	7.693	6.827	5.914	4.673	3.276	2.156	1.110	0.539
May	6.265	5.370	5.048	4.059	3.548	3.019	2.152	1.471	0.856	0.397
Jun	3.102	3.006	2.703	2.523	2.219	1.767	1.213	0.988	0.621	0.224
Jul	2.120	2.082	1.851	1.685	1.593	1.313	0.902	0.664	0.384	0.302
Aug	2.461	2.165	1.770	1.569	1.310	**0.984**	0.775	0.544	**0.389**	0.221
Sep	3.563	2.611	1.988	1.400	1.093	0.765	0.542	0.346	0.200	0.090

Ranking of Scenarios for the Reach Downstream of the Proposed Weir.

A rank order method was used to determine the ranking order as well as illustrating the results on a traffic diagram (**Figure C**). The results show that all scenarios apart from Sc A1 achieve the REC of a D Ecological Category for the EcoStatus.

There were two main sets of scenarios:

- The A-set is based on the demands as applicable to the transfer option that excludes the support to Bloemfontein.
- The B-set is based on the demands as applicable to the transfer option that includes the support to Bloemfontein.

Two different typical operating rules can be followed to manage the releases from the large storage dam in support of the downstream requirements.

- Operating rule 1: Releases are made based on the downstream requirements. As there is a significant volume of flows generated from the catchments downstream of the dam, these flows can be utilized first and only the remainder of the requirement will then be supported by releases from the dam. This will have the disbenefit that during wet periods limited or even zero support might be required from the dam, resulting in no or very little hydro-power generation at times.

- Operating Rule 2: Releases are made based on a fixed demand pattern as determined from the downstream demands as if none of the generated downstream flow is utilized by the downstream users. This will be to the benefit of base hydropower generation but can lead to more severe restrictions during dry periods.

Detail description of the scenarios analysed are summarized in **Table C**.

Table C: Scenarios analysed in support of the EWR analysis

Scenario	Description
A1	The following assumptions apply to the base scenario” • Demands imposed on the dam are based on the 2050 development level. • Greater Bloemfontein is not supported by Makhaleng • Assume base hydro-power is supplied. • Local urb/rural requirement abstracted from the diversion weir • Irrigation located downstream of the weir represents 85% of the total irrigation requirement • Utilize downstream flows before releases are made from the dam.
A3	As the Scenario A1 with the following changes: • Releases are based on a fixed demand pattern as determined by the downstream demands as if none of the generated downstream flow is utilized by the downstream users.
A4	As the Scenario A3 with the following changes: • No irrigation requirements
A5	As the Scenario A3 with the following changes: • A different fixed demand pattern were used for irrigation based on current existing irrigation requirements in Lesotho.
B3	As Scenario A3 with the following changes: • Greater Bloemfontein is supported by the Makhaleng system. • Irrigation located downstream of the weir represents 75% of the total irrigation requirement

Sc A3 and A5 appears to be marginally better than ScA4 and B3; however, the difference is marginal and the resolution in the assessment is such that there is no strong motivation to recommend Sc A3 and A5 over Sc A4 and B3.

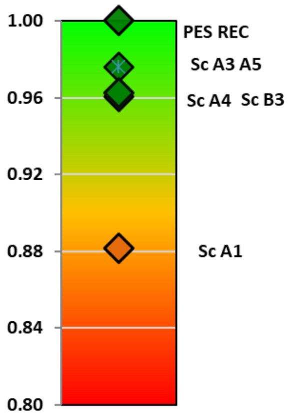

Figure C: EWR MA1: Ecological ranking of operational scenarios.

Consequences of Scenarios in the Reach Downstream of the Proposed dam on the Makhaleng River to the Proposed Weir

This reach (referred to as Reach 1) will be directly impacted by the proposed releases and especially from pulsed releases for hydropower. The impact will decrease further downstream from the dam as tributary inflows mitigate the impacts and provide natural floods to add to the infrequent spillage of the dam. A detailed evaluation could not be undertaken for this reach as there is no EWR site in the reach and no fieldwork undertaken for this reach. A desktop assessment of the PES has been undertaken as well as the EIS. Furthermore, broad statements on pulsed releases and the requirements for multi-level outlets have been made further in this section. The detailed EIA must give due consideration to these issues.

Based on the desktop assessment, it will be likely that the PES will be in a marginally better condition than for the EWR reach.

The EIS is MODERATE compared to the LOW of the EWR reach. This provides the motivation for the PES to be maintained as the REC.

Pulsed releases and recommendations

Pulsed hydropower releases, also commonly referred to as peaking releases, invariably have considerable impacts on the fluvial morphology, riverine habitat and biota along downstream river reaches. The relative magnitude of fluctuations reduces with distance downstream, however, due to *inter alia* hydrodynamic behaviour (e.g. peak attenuation) and potential tributary inflows. Nonetheless, fluctuations may promulgate over considerable distances, and are affected by not only the magnitude of peaks, but also the magnitude of off-peak flows as well as both their durations and relative timing.

Available information on operation of the Makhaleng hydro-power plant refers to three options, including base, mid-merit and peaking power. These operations allow for constant releases of 11.71, 14.64 and 46.85 m^3/s for 20, 16 and 5 hours/day, respectively. There is no indication of flows during off-peak times, and complete shut-down between constant peaks will likely have adverse effects (possibly substantial) along the downstream reach - even for the base power option. The so-called base power option (11.71 m^3/s for 20 hours/day) is not a truly baseload condition - at least from an environmental perspective, since the release is not over a 24-hour period. Typically, as off-peak discharges approach peak values, the impacts of peaking reduce since operation approaches a true baseload situation with constant intra-daily flows.

It would be unwise to recommend a peak to off-peak discharge ratio for the Makhaleng hydropower, since it depends on a number of factors, including morphological and hydraulic-habitat characteristics of the downstream reach, biota, spatial and temporal (seasonal) tributary inflows, etc. A more detailed study of the likely impacts of different peaking scenarios for the reach between the proposed dam on the Makhaleng River and downstream weir would be required. Having noted this, however, from experience gained with environmental flows assessments for reaches downstream of peaking hydropower plants, a point of departure for assessing at least partial mitigation of the impacts of intra-daily fluctuations, is a peak to off-peak discharge ratio of < ˜2.

Multi-level outlets and recommendations

Dams have a number of significant impacts on water quality of flowing water systems, particularly in terms of thermal regimes, chemistry (e.g. eutrophication due to influxes of organic materials and nutrients, often due to anthropogenic activity in the catchment) and sedimentation. The operation of the releases from a dam can therefore have a significant impact on the water quality downstream of the dam, particularly the reach directly downstream.

It is recommended that multi-level releases be part of the design of the dam, and that operation of the dam includes a multiple level outlet tower, particularly to mitigate thermal and oxygen impacts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ASPT	Average Score Per Taxon
DWAF	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Ecological Category
EI	Ecological Importance
EIS	Ecological Importance and Sensitivity
ES	Ecological Sensitivity
ESIA	Environmental and Social Impact Assessment
EWR	Ecological Water Requirements
FDT	Flow Duration Table
FRAI	Fish Response Assessment Index
GAI	Geomorphology Assessment Index
IHAS	Integrated Habitat Assessment System
IHI	Index of Habitat Integrity
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
MIRAI	Macroinvertebrate Response Assessment Index
nMAR	Natural Mean Annual Runoff
PD	Present Day
PES	Present Ecological State
RDRM	Revised Desktop Reserve Model
REC	Recommended Ecological Category
SASS5	South African Scoring System version 5
VEGRAI	Riparian Vegetation Response Assessment Index

1 INTRODUCTION

1.1 Study Area

In terms of the Ecological Water Requirement (EWR) determination, the study area is downstream of the proposed Dam on the Mkahaleng River with emphasis on the river. An existing Lesotho Flow Gauge MG23 is located between two of the proposed dam sites S2 and N1a. Before the confluence of the Makhaleng River with the Senqu (Orange) River, the Makhaleng River forms the border between Lesotho and the RSA. In the RSA the Makhaleng River is known as the Kornet Spruit. A South African flow gauge D1H006 is located on this river nor far downstream of the EWR site.

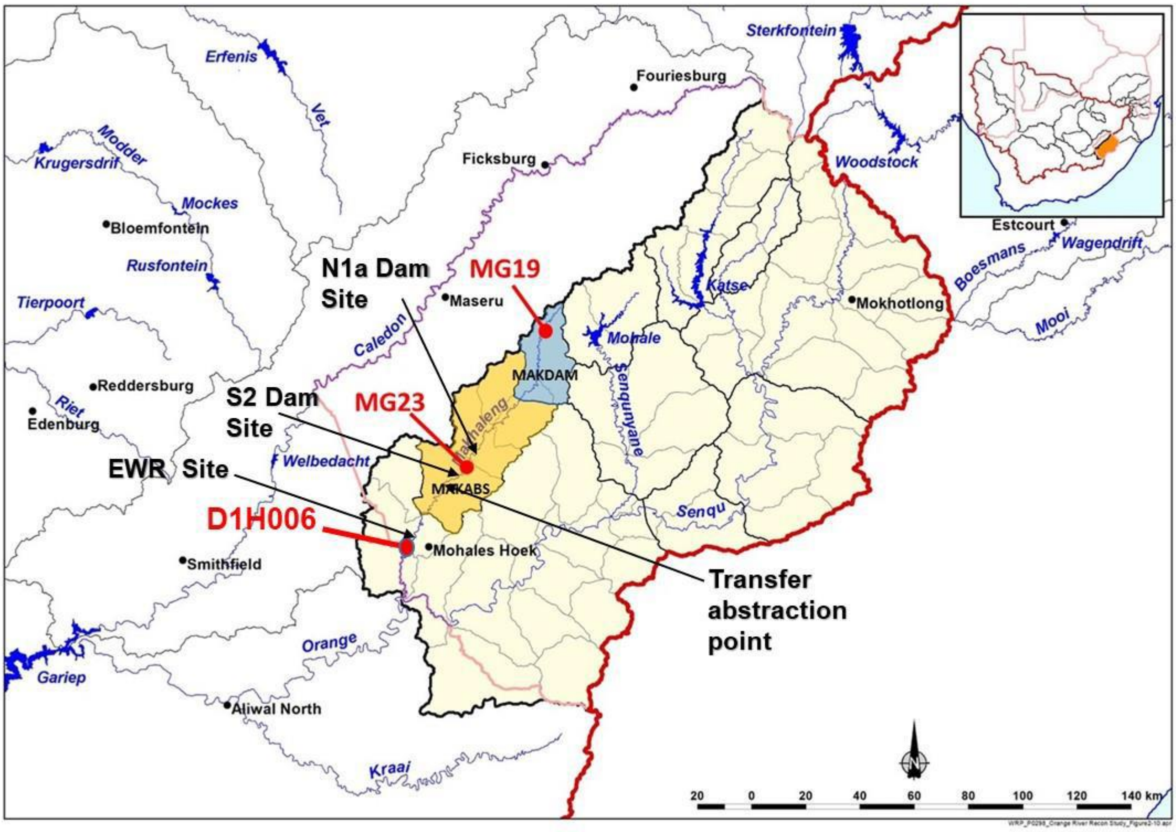

Figure 1-1:Loaction of the EWR site, existing flow gauges and possible dam sites

The EWRs in the Orange River are defined through the recent Preliminary Reserve determination and the agreed Preliminary Ecological Reserve Category (DWS, 2017).

1.2 EWR Site

The Makhaleng River downstream of the proposed dam is a uniform alluvial section and one EWR site sufficiently represented the variety (albeit limited) habitats in this section. The selected EWR site is situated 7 km downstream of the original (2018) proposed dam site on the Makhaleng River. Since the Desktop assessment of the EWR study, additional dam sites have been identified (**Figure 1-2** and **1-3**). Siltation and sedimentation, due to overgrazing and erosion, is evident at the EWR site which is also characterised by mostly alien vegetation growth.

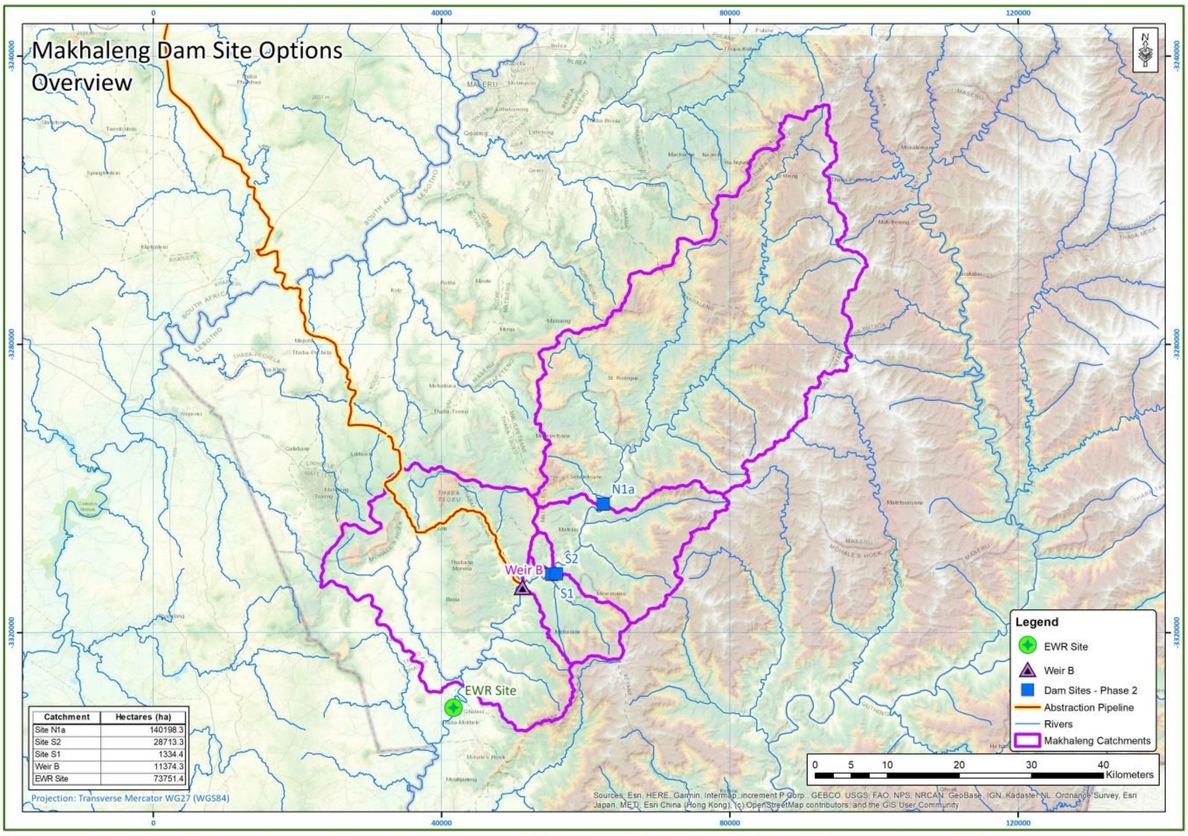

Figure 1-2 EWR_Makhaleng in relation to the proposed dam sites on the Makhaleng River

Figure 1-3 Location of the EWR site - EWR_Makhaleng

1.3 Desktop EWR assessment

The desktop analysis entails the determination of the Present Ecological State (PES), the estimation of environmental flows and flood releases for various different ecological states. To estimate the flooding regime, specialist input is required and forms part of the analysis to further increase the confidence in the desktop output.

In order to determine the types of releases that may be required for the environmental flow requirements of the riverine system downstream of the proposed dam on the Makhaleng River, an extended desktop study, which included fieldwork, was undertaken in October 2018. The fieldwork entailed a site visit to the study area where an EWR site was selected. This site, EWR_Makhaleng provided sufficient indicators to assess environmental flows, the condition of biophysical components (drivers such as hydrology, geomorphology and physico-chemical conditions), and biological responses (*viz*. fish, macroinvertebrates and riparian vegetation). For hydraulic modeling purposes, a cross-sectional survey was undertaken at the EWR site in order to convert requirements in terms of hydraulic parameters to flow. Using the measured hydraulics, the Revised Desktop Reserve Model (RDRM) (Hughes *et al*., 2012; 2014; 2018) was applied at the EWR site to quantify the environmental flows, ensuring that the desktop model output is of significantly higher confidence than a Desktop assessment where field data is excluded. These environmental flows were used for analysis carried out as part of the Pre-feasibility study, phases I & II.

1.4 EWR Refinement

The study was originally approached in a phased manner with the desktop EWR assessment part of the Pre-feasibility Phase of the project. This would have been followed up by the involvement of a full range of specialists, providing input in the determination of the EWR, including a site visit. This aspect is documented in this report. The EWR study includes a comprehensive assessment of the EcoClassification as well specialist input in the determination of the EWR. The approach followed to determine the EWR was to review the desktop EWR, make recommendations regarding any proposed changes and then to remodel the flows according to specialist requirements - resulting in an EWR estimate.

1.5 Scenario Evaluation

After EWR refinement, proposed supply and operating scenarios from the proposed dam on the Makhaleng River were developed. The ecological consequences in terms of the impact on ecological status were assessed for each scenario and the scenarios were then ranked in terms of the potential of meeting an Ecological Category (Recommended Ecological Category – REC)

1.6 Purpose and Outline of this Report

The purpose of the report is to review of the EcoClassification and EWR by documenting the process followed and results obtained for the EWR site.

Chapter 1 provides a general introduction to this Task while **Chapter 2** provides the Eco Classification results and **Chapter 3**, the EWR determination results. **Chapter 4** described the operational scenarios developed for assessment and **Chapter 5** provides the Ecological consequences. **Chapter 6** lists all references used in the compilation of the report, while **Chapter 7 – 9** are specialist appendices.

2 ECOCLASSIFICATION

The EcoClassification process was followed according to the methods of Kleynhans and Louw (2007a). Information provided in the following sections is a summary of the EcoClassification approach. For more detailed information on the approach and suite of EcoStatus methods and models, refer to:

- Physico-chemical Driver Assessment Index (PAI): Kleynhans et al. (2005); DWAF (2008).
- Geomorphology Assessment Index (GAI): Rowntree (2013).
- Fish Response Assessment Index (FRAI): Kleynhans (2007).
- Riparian Vegetation Response Assessment Index (VEGRAI): Kleynhans *et al*. (2007b).
- Index of Habitat Integrity (IHI): Kleynhans *et a*l. (2009).

EcoClassification refers to the determination and categorisation of the Present Ecological State (PES) (health or integrity) of various biophysical attributes of rivers compared to the natural (or close to natural) reference condition. The purpose of EcoClassification is to gain insight into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints has to be considered.

The state of the river is expressed in terms of biophysical components:

- Drivers (physico-chemical, geomorphology, hydrology), which provide a particular habitat template; and
- Biological responses (fish, riparian vegetation and macroinvertebrates).

Different processes are followed to assign a category (A→F; A = Natural, and F = critically modified) to each component. Ecological evaluation in terms of expected reference conditions, followed by integration of these components, represents the Ecological Status or EcoStatus of a river. The EcoStatus can therefore be 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 (modified from: Iversen *et al*., 2000). This ability relates directly to the capacity of the system to provide a variety of goods and services.

2.1 Present Ecological State

The steps followed in the EcoClassification process are as follows:

- Determine reference conditions for each component.

- Determine the PES for each component, as well as for the EcoStatus which represents an integrated PES for all components.
- Determine the reasons for the PES and whether these are flow or non-flow related.

The EcoClassification, as used in this study has been used in various other studies for Lesotho (LHDA, 2016; Louw *et al*., 2013) and is therefore an acceptable approach.

Table 2-1 Present Ecological State results and comments

Component	EC*	Comment
Instream IHI[1]	**C/D (57.1%)**	The instream IHI assessment is based on a site survey and Google Earth information of the catchment. Modelled hydrology was also used to populate the model. The diatom analysis results were used to derive water quality input. The C/D category result is largely due to impacts associated with overgrazing, erosion, sedimentation and alien vegetation. **Confidence: 3.6**
Riparian IHI[1]	**D (52.9%)**	The riparian IHI assessment was based on a site survey, Google Earth information of the catchment, photographs of terraces and general area, and a review by a riparian vegetation specialist. The riparian IHI was used as a surrogate for the VEGRAI[2] analysis which will only be undertaken during the Feasibility phase. The D category result is largely due to impacts associated with overgrazing, erosion, sedimentation and alien vegetation. **Confidence: 3.5**
Geo-morphology	**D (52.9%)**	The site is classified as a lowland river with a channel gradient of 0.0009 measured over a 10 km reach from Google Earth imagery. The anticipated reference condition would therefore be a mobile sand river with a braided low-flow channel pattern. Patches of coarse deposits near the channel edges could be the result of local delivery of coarse sediment from adjacent hillslopes. As a result of widespread catchment erosion, the present-day channel has a significant extent of silt deposition over the sand bars, impairing instream habitat. There may also have been a loss of heterogeneity in terms of sand and fine gravel patches, with fewer gravel patches. Any coarse sediments (cobble and coarse gravel), if present, have been buried by sand and silt. Bank disturbance, mainly by grazing livestock, has resulted in increased undercutting of banks, loss of marginal zone habitat and collapse of flood benches. In addition, catchment degradation is likely to have increased storm runoff, increasing flood peaks and the potential for bank erosion. **Confidence: 3**
Water quality	**B (83.6)**	The data record used for the assessment was from a monitoring point in the downstream SQR D15H-04889 in the same level II EcoRegion, i.e. the Komet Spruit at Maghaleen. Results were adjusted based on site-specific information. Driving variables of water quality state are sediment loads and slightly elevated nutrients. Evidence of algal instream growth was observed in October 2018 but not in July 2022. **Confidence: 3**

Component	EC*	Comment
Riparian vegetation	D (48.7)	The riparian zone at this site is heavily impacted by overgrazing and trampling pressure and this has facilitated extensive and severe erosion of banks with high sediment loads and extensive fine sand deposits forming in-channel, denuded bars and a braided channel. Banks in the marginal zone are being undercut and extensive slumping of the flood bench into the channel is prevalent. The marginal zone was mainly comprised of expanses of unconsolidated fine alluvial deposits within the broader braided channel and did not support vegetation. The only vegetation along the water's edge was where portions of the flood bench had slumped into the channel. Dominant habitats included unvegetated expanses of unconsolidated, mostly fine sand deposits, and a narrow portion of steep eroded bank along the active channel, but elevated due to undercutting. Dominant species included *Cyperus marginatus, C. longus, Berulla erecta* and *Isolepis stacea.* The flood bench is mostly consolidated medium and fine sand, mostly well vegetated with grasses and sedges but high levels of grazing and trampling pressure has caused pathways and resultant erosion. Erosion of the macro-channel banks has also deposited additional sediment to the zone and the bench is being undercut from the active channel and, in places, is slumping into the channel. Dominant species include *Cyperus marginatus, C. longus, Arundinella napalensis, Imperata cylindrica, Diospyros lyceoides* and a few *Salix mucronata* juveniles. Alien species *include Pinus halepensis, Nicotiana glauca* and *Acacia mearnsii.* The macro-channel bank is comprised of short but steep banks, highly eroded with loss of structural integrity and showing signs of extensive overgrazing and trampling pressure. Dominant species include *Eragrostis gummiflua, Felicia filifolia, Diospyros lyceoides, Artemisia affra* and alien species including *Nicotiana glauca* and *Acacia mearnsii*. **Confidence: 3.1**
Diatoms		Based on the 2018 and 2022 diatom results, the Makhaleng reach was determined to be in a **B category**. At times high organic loads prevail along with elevated nutrient levels and salinity concentrations with the potential of becoming problematic, leading to deteriorated biological water quality. The most pronounced impact on the site is cattle and goats, sedimentation and erosion. Sedimentation and fluctuating water levels impact the aquatic biota in terms of life-stage development and breeding and associated biotope availability. **Confidence: 2.5**

Component	EC*	Comment
Fish	**D (45.8%)**	Based on all available information it is estimated that five indigenous fish species may have occurred in the EWR reach under natural conditions (based on current distribution information for this catchment and estimated habitat availability under reference conditions). Refer to **Appendix B** for a detailed motivation of the reference and present status of the fish expected fish species. The presence of only one species (*Labeobarbus aeneus*) was confirmed during August 2022. It is estimated that two fish species *(Clarias gariepinus* and *Labeo capensis*) may still be present in this reach at reduced abundance and frequency of occurrence, while two species (*Austroglanis sclateri* and *Enteromius anoplus/oraniensis*) may have been lost from this reach. A FRAI score of 45.8% was calculated for this EWR site falling in an ecological category D. The primary cause for the deteriorated fish assemblage is associated with habitat deterioration (non-flow related). Extensive catchment and localised bank erosion resulted in transformation of the river bed (extensive sedimentation). This resulted in loss of or reduced availability of rocky/gravel substrates, clogging of interstitial spaces between rocks and gravel, and loss of water column / pool depth. The loss of rocky substrates especially impacted feeding and breeding habitats of *A. sclateri, L. aeneus* and *L. capensis*, while the loss of deep pools (water column as cover) impacted on the above mentioned species as well as *C. gariepinus*. Overgrazing and trampling of banks resulted in loss of natural marginal vegetation that created overhang as cover for fish (especially impacting *E. anoplus/oraniensis*). The loss of depth and cover (due to sedimentation) also impact the longitudinal and lateral migration of all fish species negatively. The presence of alien fish in this reach is uncertain with a very low probability of *Common Carp* and/or *Oncorhynchus mykiss* (Rainbow trout) being present. **Confidence: 3**
Macro-invertebrates[4]	**n/a**	The South African Scoring System (SASS5) protocol was applied during the August 2022 site visit to provide supporting information to the fish study regarding the water quality and habitat condition of instream biota in general (no MIRAI applied). A SASS5 score of only 52 was calculated for the site, indicating overall poor biotic conditions. Although the Average Score Per Taxon (ASPT) is of low confidence as a result of the low number of families sampled (9), the ASPT value of 5.8 indicated that the water quality of the site was relatively good at the time of the survey. This was also confirmed by the presence of Heptageniidae (Flat-headed mayflies), a family with a high requirement for unmodified water quality. The poor biotic condition (based on macroinvertebrates) was primarily the result of poor physical habitat conditions. No stones biotope was available for sampling, as a result of bed modification due to extensive siltation. Very limited vegetation was available due to extensive bank erosion (loss of marginal vegetation) and altered bed and water column (loss of instream vegetation). Vegetation can also be expected to be naturally low during the winter season. A total Integrated Habitat Assessment System (IHAS) score of only 52% was calculated, with a low habitat suitability and availability score of 12, confirming that habitat availability and condition/suitability was poor and the primary cause for the poor macroinvertebrate assemblage observed at the site. Heptageniidae (Flat-headed mayflies) was the most intolerant family present and is also the most important indicator taxon regarding water quality and flow. This taxon has a high requirement/preference for fast flows (0.3 - 0.6 m/s preferably over rocky (cobble) substrate, and can also occur in some vegetative habitats).
Instream	**D (45.8%)**	

Component	EC*	Comment
EcoStatus	D (47.3%)	The EcoStatus EC was derived using the EcoStatus4 model.

* Ecological Category
1 IHI Index of Habitat Integrity (Kleynhans *et al*., 2009).
2 Vegetation Response Assessment Index (Kleynhans, 2007).
3 Fish Response Assessment Index (Kleynhans *et al*., 2007).

In summary, the D EcoStatus represents the response of the biota to the lack of habitat diversity due to sedimentation from overgrazing, erosion and removal of riparian vegetation as well as the presence of alien vegetation in the riparian zone. All impacts are non-flow related (**Table 2-2**) as the present-day hydrology is very close to natural. Water quality is also in a relatively good condition. The key and dominant impacts are therefore related to sedimentation, scour, deposition and alien vegetation.

Table 2-2 Present Ecological State results and comments

Component	Cause leading to biophysical response	Source (origin) of the cause	Flow or non-flow related
Water quality & diatoms	Elevated turbidities.	Sedimentation from overgrazing, erosion and rural settlements.	Non-flow
	Elevated nutrient levels (algal growth).	Rural settlements in upper catchment.	
Geomorphology	Silt deposition. Bank erosion.	Catchment erosion.	Non-flow related
		Grazing by livestock.	
		Possibility of increased flood flows due to catchment degradation.	Flow related
Riparian vegetation	Loss of vegetation.	Severe overgrazing and trampling pressure	Non-flow
	Absence of recruitment	Grazing of seedlings and saplings, flowers and fruits.	
	Altered species composition.	Alien species presence.	
	Loss of marginal zone habitat.	Undercutting of eroded banks.	Non-flow (erosion)
Instream biota	Bed modification - loss of rocky substrates and diversity of cover. Bank modification - loss of marginal vegetation as cover, unstable undercut banks. Loss of habitat diversity - reduced FD and cover. Loss of depth – sedimentation.	Sedimentation - catchment and localized bank erosion. Over-grazing and trampling - bank erosion.	Non-flow

2.2 Ecological Importance and Sensitivity

2.2.1 EIS Approach

The Ecological Importance and Sensitivity (EIS) was calculated using a refined EIS model (from Kleynhans and Louw, 2007b and Louw *et al*., 2010), which was developed during 2010 by Dr Kleynhans. This approach estimates and classifies the EIS of the streams in a catchment by considering a number of components surmised to be indicative of these characteristics.

The following ecological aspects are considered as the basis for the estimation of EIS:

- The presence of rare and endangered species, unique species (i.e., endemic or isolated populations) and communities, intolerant species and species diversity were taken into account for both the instream and riparian components of the river.
- Habitat diversity was also considered. This included specific habitat types such as reaches with a high diversity of habitat types, i.e., pools, riffles, runs, rapids, waterfalls, riparian forests, etc.

With reference to the bullets above, biodiversity in its general form (i.e. Noss, 1990) is taken into account as far as the available information allowed:

- The importance of a particular river or stretch of river in providing connectivity between different sections of the river, i.e., whether it provided a migration route or corridor for species, was considered.
- The presence of conservation or relatively natural areas along the river section also served as an indication of ecological importance and sensitivity.
- The sensitivity (or fragility) of the system and its resilience (i.e., the ability to recover following disturbance) of the system to environmental changes was also considered. Consideration of both the biotic and abiotic components was included here.

The EIS categories are provided in **Table 2-3.**

Table 2-3 EIS categories (Modified from DWAF, 1999)

EIS Categories	General Description
Very high	Quaternaries/delineations that are considered to be unique on a national or even international level based on unique biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually very sensitive to flow modifications and have no or only a small capacity for use.
High	Quaternaries/delineations that are considered to be unique on a national scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) may be sensitive to flow modifications but in some cases, may have a substantial capacity for use.

EIS Categories	General Description
Moderate	Quaternaries/delineations that are considered to be unique on a provincial or local scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually not very sensitive to flow modifications and often have a substantial capacity for use.
Low/Marginal	Quaternaries/delineations that are not unique at any scale. These rivers (in terms of biota and habitat) are generally not very sensitive to flow modifications and usually have a substantial capacity for use.

2.2.2 EIS results

The EIS evaluation resulted in a **LOW** importance. The highest scoring metrics were:

- Intolerant macro-invertebrate species with reference to flows and physico chemical changes.
- Instream species/taxon richness.
- Rare, endangered and unique riparian biota.
- Riparian habitat sensitive to flow changes.

2.3 Recommended Ecological Category

As the Ecological Importance (EI) and Ecological Sensitivity (ES) is MODERATE, the Recommended Ecological Category (REC) is set to maintain the PES of a D category.

Flow is not the driving factor of the deteriorated ecological condition, and the biological response is not based on flow related issues. A D EWR would diminish the current buffering effect of good flows resulting in a further deterioration in the PES. EWR results for a D EWR would therefore be too stringent, as decreasing the flow significantly from the present flow conditions will not maintain the REC due to the other impacts on the system.

The EWRs that will be determined may include some improvement in the low flows to accommodate the catchment impacts.

3 EWR DETERMINATION

3.1 Desktop Approach

The Revised Desktop Reserve Model (RDRM, v2) was used to estimate the EWR requirements for the site (refer to Hughes *et al.*, 2012; 2014 and 2018). The time series of natural monthly flows was supplied by WRP Consulting Engineers (Pty) Ltd for the 85-year period 1920 to 2004 and provided a Mean Annual Runoff (MAR) of 575.45 10^6m^3. For the EWR site, the natural and Present Day (PD) MARs are deemed to be equivalent.

A field trip to the EWR site on the Makhaleng River took place on 18 October 2018. Topographical and hydraulic information was collected to improve the confidence of the default 'desktop' hydraulics of the RDRM, through the survey of a cross-sectional profile the modelling of the rating (or stage-discharge) relationship. The discharge at the time of the survey was 2.9 m^3/s (calculated using the velocity-area method). Site detail and the cross-sectional profile of EWR_Makhaleng is provided in **Figure 3-1**.

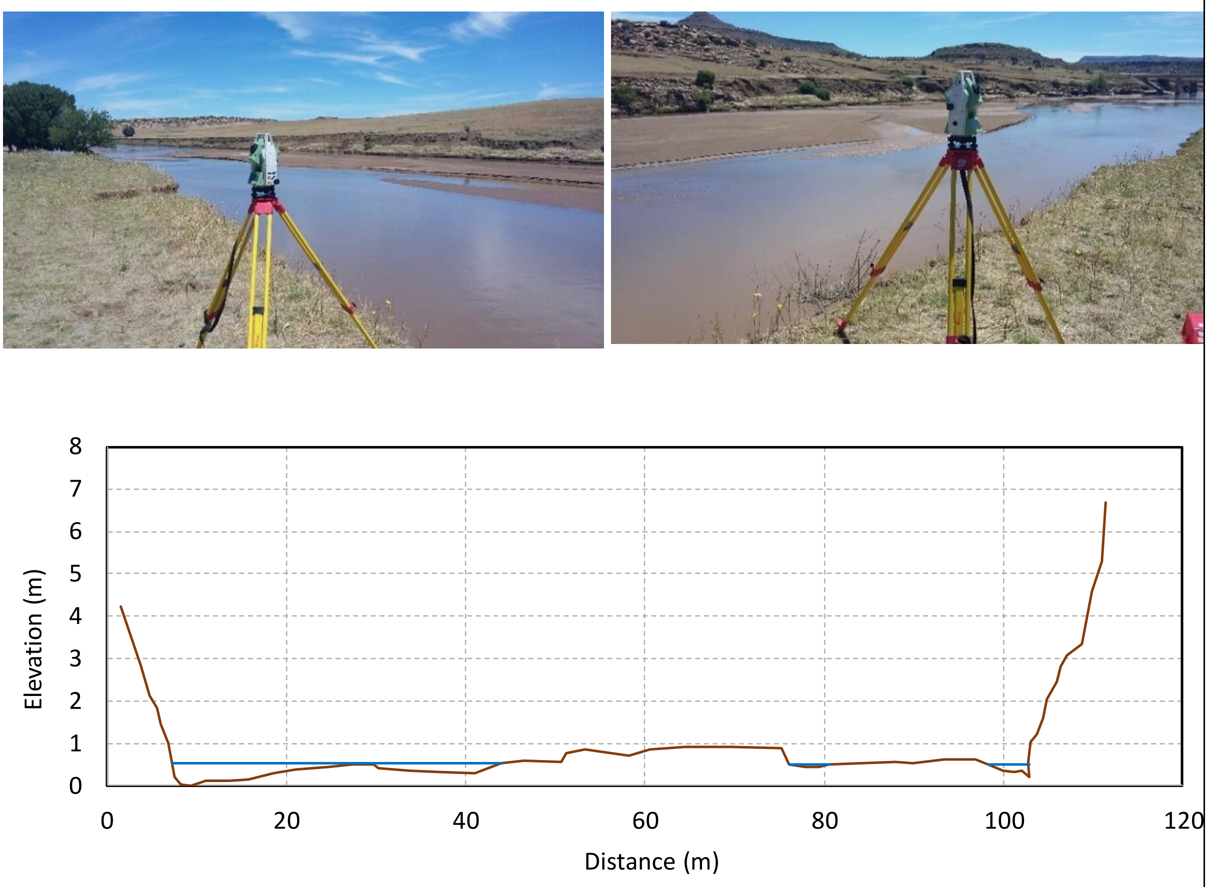

Figure 3-1 Top: Photographs of EWR_Makhaleng; bottom: Surveyed cross-sectional profile

Velocity-depth class weighting factors and stress index values at zero fast flow were derived from predicted fish species for the river reach, as described by Hughes *et al*. (2018). Default (i.e. 'desktop') shifts were applied to compute stress-duration and hence discharge-duration relationships (for the various ECs) relative to natural. The default high-flow component was used and checked using riparian indicators.

3.2 Low flow EWR

The low flow EWR used the following approach to review the 2018 Desktop EWR result.

- The Flow Duration Table (FDT) desktop low flow EWR for the 2022 PES Ecological Category for the EcoStatus (D) was extracted from the model output.
- The low flows for the 60th and 90th percentiles for the wettest (March) and driest (July) month was converted to m^3/s and was assessed by the Instream specialists to determine whether the flows are sufficient.
- If the discharges were not adequate, then a motivated adjusted discharge was recommended.
- Adjustments to the Desktop model were made to achieve the revised low flow regime. Firstly, the stress-flow profile curve was assessed, and changes recommended. If no changes are recommended, the prescribed discharges (60% and 90% on the flow-durations) were achieved by adjusting the low and high shifts on the stress-duration relationships for the relevant Ecological Category.

Table 3-1 Low flow EWR review and recommendations: D PES

Month	Percentile	Discharge (m^3/s)	Review	Recommended discharge (m^3/s)	Final EWR (m^3/s)
Jul	90th	0.274	Stress of approximately 8. Max depth of approx. 20 cm, SvS, SS, FvS and FS present (no SD and FD). Due to the fact that this system is primarily impacted by non-flow related impacts, an increase in flow-rated stress will potentially decrease the EC. D flows may not provide adequate habitat to maintain the current fish population (too shallow: potential water quality deterioration due to temperature fluctuations, reduced oxygen). It is recommended that flow is increased to at least 0.4 m^3/s.	0.4	Aug: 0.4
Jul	60th	0.795	Stress of approx. 6. Max depth of approx. 30 cm, SvS, SS, FvS and	1.00	Aug: 1

Month	Percentile	Discharge (m^3/s)	Review	Recommended discharge (m^3/s)	Final EWR (m^3/s)
			FS, limited FD present (no SD). Very limited FD will be available under D flows potentially jeopardizing water quality and depth below adequate levels. Increased flow recommended.		
March	90th	0.574	Stress of approximately 8. Max depth of approx. 28 cm, SvS, SS, FvS and FS present (no SD and FD). Some FD required and hence increased flow is recommended to at least 1 m^3/s.	1	0.9
March	60th	4.863	Stress of approx. 5.5. Max depth of approx. 60 cm. All velocity-depth categories present. Due to the fact that this system is primarily impacted by non-flow related impacts, an increase in flow-rated stress will potentially decrease the EC. Increased flow is recommended to increase.	5.9	5.41

3.3 High flow EWR

The following approach was used to review the 2018 Desktop EWR result and determine the high flow EWR. The desktop model provides a peak, frequency, number of floods and durations. The high flow specialists evaluated the floods and recommended changes in the peak, and number of floods.

Table 3-2 2018 Desktop EWR high flow recommendations

Class	Frequency	Peak (m^3/s)	Duration (hours)	Number of Events	Volume (MCM[1])
1	Annual	39.021	72	4	4.268
2	Annual	81.815	76	3	9.447
3	Annual	137.852	84	1	17.592
4	1:2 year	204.765	92	1	28.62
5	1:5 year	443.036	108	1	72.693

1 Million Cubic Meters

Table 3-3 High flow EWR review and recommendations

Class	Frequency	Peak (m^3/s)	Number of Events	Motivation
1	Annual	25 - 30	3 - 4	Inundates marginal zone sedges and grasses. Provides fine sediment for marginal zone vegetation. Moderate mobility of bed material.
2	Annual	40 - 50	2	Activates and inundates a portion of the flood bench woody component (*Salix mucronta*).

Class	Frequency	Peak (m^3/s)	Number of Events	Motivation
3	Annual	80 - 120	1	Inundates a portion of the flood bench graminoids. Provides sediment (predominantly very fine sand) to maintain flood benches. Channel bed fully mobile. Surface silt deposits on bars mobilised.
4	1:2 year	280	1:2-3	Inundates flood bench grasses to upper portions of the population.
5	1:5 year	370+	1:5+	Activates terrestrial species lower limit to prevent encroachment into the riparian zone. Provides sediment (predominantly very fine sand) to maintain higher flood benches. Channel bed fully mobile.

3.4 EWR Results

The flow requirements are summarised in the following tables. The detailed report has been provided as support to this report. The Natural Mean Annual Runoff (nMAR) is 575.45 MCM. The low flow EWR in MCM is 101.779 and it equates to 17.7% of the nMAR and the total flow EWR in MCM is 144.84 which equates to 25.2% of the nMAR.

Table 3-4 High flow requirements

Class	Frequency	Peak (m^3/s)	Duration (hours)	No. of Events	Volume (MCM)
1	Annual	25.637	68	3	2.649
2	Annual	40.475	72	2	4.427
3	Annual	80.642	76	1	9.311
4	1:2 year	281.024	96	1	40.987
5	1:5 year	372.406	104	1	58.841

Table 3-5 Low flow: Flow Duration Table (EWR rule table)

m^3/s	10	20	30	40	50	60	70	80	90	99
Oct	4.434	3.223	2.485	2.150	1.815	1.387	0.884	0.542	0.219	0.118
Nov	5.551	4.306	3.979	3.549	2.895	2.334	1.564	1.046	0.613	0.082
Dec	5.978	5.953	5.656	5.162	4.487	3.350	2.139	1.326	0.643	0.470
Jan	7.332	7.032	6.455	4.965	4.343	3.286	2.195	1.395	0.758	0.342
Feb	9.097	7.653	7.208	5.924	5.374	4.540	3.312	1.993	0.966	0.511
Mar	9.202	8.898	8.402	7.645	6.689	**5.407**	3.841	2.098	**0.907**	0.422
Apr	8.498	7.887	7.693	6.827	5.914	4.673	3.276	2.156	1.110	0.539
May	6.265	5.370	5.048	4.059	3.548	3.019	2.152	1.471	0.856	0.397
Jun	3.102	3.006	2.703	2.523	2.219	1.767	1.213	0.988	0.621	0.224
Jul	2.120	2.082	1.851	1.685	1.593	1.313	0.902	0.664	0.384	0.302
Aug	2.461	2.165	1.770	1.569	1.310	**0.984**	0.775	0.544	**0.389**	0.221
Sep	3.563	2.611	1.988	1.400	1.093	0.765	0.542	0.346	0.200	0.090

4 SCENARIO DESCRIPTIONS

4.1 Background

Study Component III was completed and included Phase I and Phase II of the Pre-feasibility Study. The final dam site was selected from the Phase II Pre-feasibility study. This dam site will be taken forward to the Feasibility Study which recently started. For the purpose of the Pre-feasibility Phases I and II an extended EWR desktop study, which included some fieldwork was carried out to determine the required environmental water requirements at the selected EWR site, located downstream of all the possible dam sites investigated at the time. These environmental water requirements were adhered to in most of the system yield and planning analysis carried out as part of Phases I and II of the Pre-feasibility Study.

A higher confidence environmental water requirements is required for the Feasibility Study. The additional EWR related work thus included a comprehensive assessment of the EcoClassification as well as specialist input in the determination of the EWR.

The way the proposed future dam on the Makhaleng River is going to be operated can significantly impact on the effective supply of the environmental water requirements at the selected EWR site. Different reaches of the river downstream of the dam will also react differently as water will be released mostly via the hydro-power turbines at the dam into the river and abstracted at various points downstream along the river. The main abstraction will be at the downstream weir from where the water is taken in support of the Lesotho Botswana RSA transfer.

The operating rules that will be applied are not yet known and will most probably only be determined and agreed on by the different countries close to the completion of the dam and the conveyance system. For this reason, several options of typical operating rules were analysed by using the WRYM set up for the final selected dam site and size of the dam obtained from Pre-feasibility Phase II study.

4.2 Water Supply System of the Proposed dam on the Makhaleng River

The N1a site was the final selected dam site from the Pre-feasibility Phase II study. The dam is a large dam with a gross storage capacity of 1 216 million m^3/a (3 MAR Dam). A simplified schematic of this water supply scheme is given in **Figure 4-1**. Water is released from the dam via the hydro-power turbines to supply the downstream requirements. A diversion weir is located about 17 km downstream of the dam. The transfer to Botswana, RSA and parts of Lesotho is pumped from this weir which represents the largest abstraction from this system. Local domestic supply for some towns and rural areas within Lesotho will most probably also be abstracted from the weir. It is expected that some irrigation might be supplied from the weir.

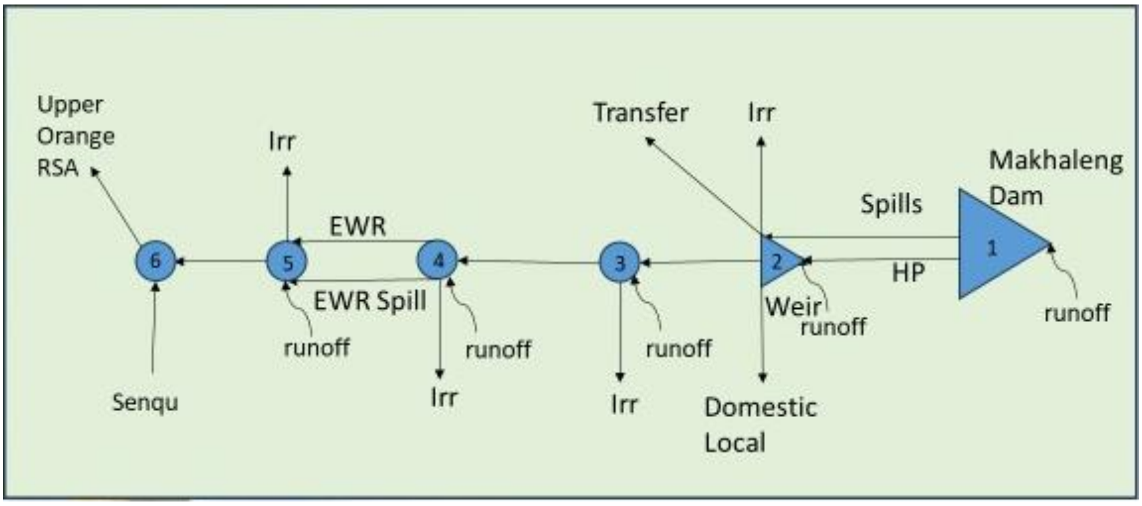

Figure 4-1 Makhaleng Water Supply System Schematic layout

The EWR site is located approximately 20 km (node 4) downstream of the diversion weir. Irrigation abstractions are expected to take place midway between the weir and the EWR site as well as just upstream of the EWR site. The bulk of the irrigation abstraction is expected to take place below the EWR site from close to the site to as far as about 25 km downstream of the site.

The historic firm yield of the dam was determined as 308.2 million m^3/a. There are two transfer options, one that includes support to Bloemfontein (set B demands) and one that excludes the support to Bloemfontein (set A demands). Details of the demands expected to be imposed on the dam on the Makhaleng River are given in **Table 4-1**.

Table 4-1 Possible demands expected to be imposed on the dam in the Makhaleng River

Demand description	Set A demands (million m^3/a)	Set B demands (million m^3/a)
Transfer	186.00	229.00
Local Lesotho domestic	13.00	13.00
Lesotho irrigation weir	5.45	5.45
Lesotho irrigation node 3	10.90	10.90
Lesotho irrigation node 4	10.90	10.90
Lesotho irrigation node 5	81.75	38.75
Total	**308.00**	**308.00**

The possible irrigation areas as distributed along the Makhaleng River are shown in **Figure 4.2**. Based on this distribution the estimated irrigation abstractions were sub-dived between nodes 3, 4 and 5 as shown in **Figure 4-1**. The estimated irrigation requirements were then split between these nodes as indicated in **Table 4-1**.

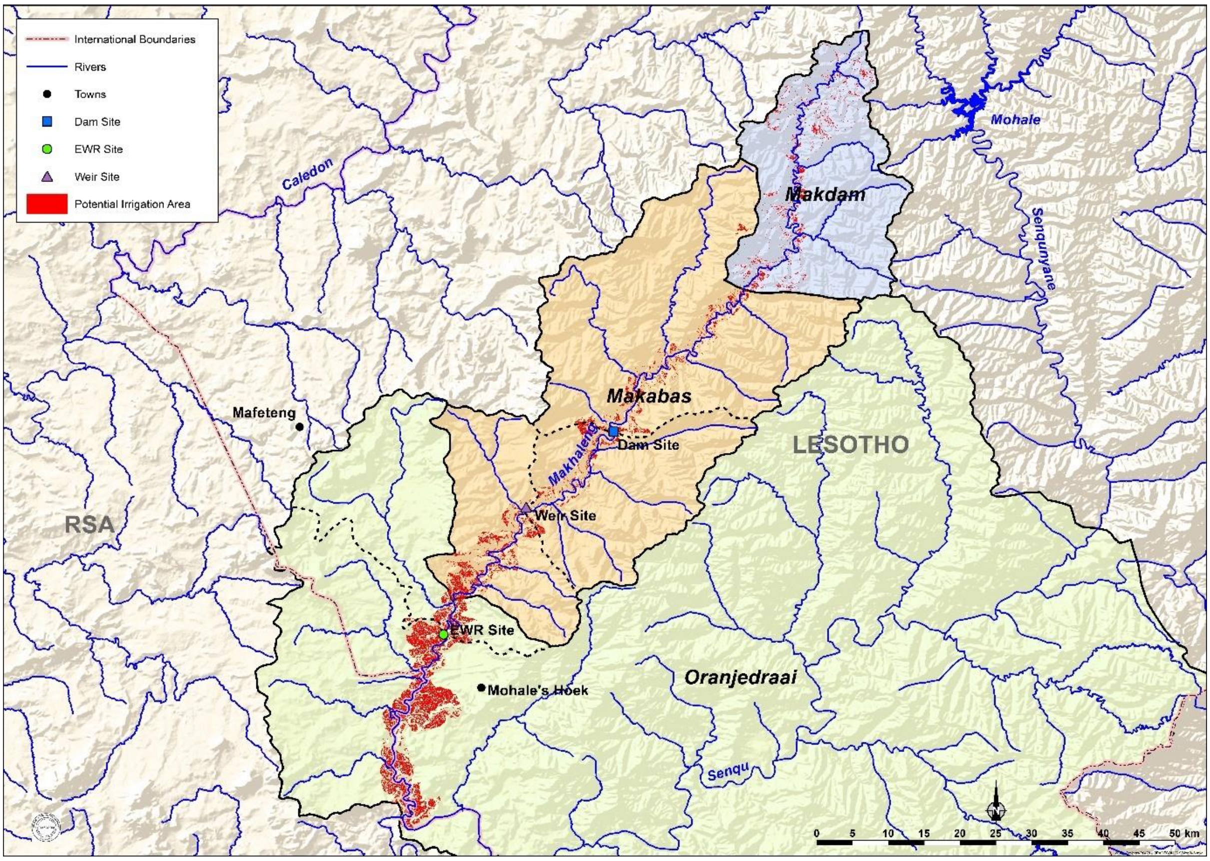

Figure 4-2 Potential irrigation areas located along the Makhaleng River

The hydro-power plant can be used to generate base power, mid-merit power or peaking power. These different options will significantly impact the flows in the Makhaleng River downstream of the dam, at least down to the diversion weir.

When the system yield is fully utilized the expected flows from the hydro-power turbines for the three different options will typically be as follow:

- Base power, assuming 20 hours per day – a constant flow of 11.71 m^3/s for 20 hours each day.
- Mid merit power, assuming 16 hours per day – a constant flow of 14.64 m^3/s for 16 hours each day.
- Peaking power, assuming 5 hours per day – a constant flow of 46.85 m^3/s for 5 hours each day.

The WRYM is a monthly model, and the three different hydro-power generation options will not result in differences in the monthly flows. It will be important to make provision for sufficient storage in the diversion weir downstream to cater for the fluctuation in flows. It will however be important to take this variation in flows into account when evaluating the different EWR scenarios.

For the monthly distribution of the releases in support of the transfer and the local Lesotho urban/rural requirements, an equal monthly distribution was assumed.

Table 4-2 Required monthly releases from the dam for different hydro-power release options with supply to Greater Bloemfontein excluded.

Month	Irrigation million m^3	Urb/Ind/Rural million m^3	Combined million m^3	24h/day m^3/s	20h/day m^3/s	16h/day m^3/s	5h/day m^3/s
Oct	12.11	16.58	28.69	10.713	12.856	16.070	51.423
Nov	11.52	16.58	28.10	10.842	13.010	16.263	52.040
Dec	14.60	16.58	31.18	11.641	13.970	17.462	55.878
Jan	15.56	16.58	32.14	12.000	14.400	18.000	57.599
Feb	11.25	16.58	27.83	11.403	13.684	17.105	54.734
Mar	10.39	16.58	26.97	10.069	12.083	15.104	48.331
Apr	6.88	16.58	23.47	9.054	10.864	13.580	43.457
May	4.38	16.58	20.97	7.828	9.394	11.742	37.575
Jun	3.48	16.58	20.07	7.742	9.290	11.612	37.160
Jul	4.35	16.58	20.93	7.814	9.377	11.721	37.507
Aug	6.10	16.58	22.68	8.469	10.163	12.704	40.651
Sep	8.39	16.58	24.97	9.633	11.560	14.450	46.241
Annual	**109.00**	**199.00**	**308.00**	**9.760**	**11.712**	**14.640**	**46.848**

Irrigation requirements, however, vary significantly from month to month and are in general high in the summer and low in the winter months. For the purpose of this analysis the typical monthly distribution as applicable to the Orange System was initially used.

Table 4-3 Required monthly releases from the dam for different hydro-power release options with supply to Greater Bloemfontein included.

Month	Irrigation million m^3	Urb/Ind/Rural million m^3	Combined million m^3	24h/day m^3/s	20h/day m^3/s	16h/day m^3/s	5h/day m^3/s
Oct	7.33	20.17	27.50	10.267	12.321	15.401	49.282
Nov	6.97	20.17	27.14	10.471	12.565	15.707	50.261
Dec	8.84	20.17	29.01	10.829	12.995	16.244	51.980
Jan	9.42	20.17	29.59	11.046	13.256	16.570	53.023
Feb	6.81	20.17	26.98	11.053	13.264	16.579	53.054
Mar	6.29	20.17	26.46	9.877	11.853	14.816	47.411
Apr	4.17	20.17	24.33	9.388	11.266	14.083	45.064
May	2.65	20.17	22.82	8.520	10.224	12.781	40.898
Jun	2.11	20.17	22.28	8.594	10.313	12.891	41.251
Jul	2.63	20.17	22.80	8.512	10.214	12.768	40.856
Aug	3.69	20.17	23.86	8.908	10.690	13.363	42.760
Sep	5.08	20.17	25.24	9.740	11.687	14.609	46.750
Annual	**66.00**	**242.00**	**308.00**	**9.760**	**11.712**	**14.640**	**46.848**

Table 4-4 Required monthly releases from the dam for different hydro-power release options with supply to Greater Bloemfontein excluded and using a different irrigation monthly distribution.

Month	Irrigation million m^3	Urb/Ind/Rural million m^3	Combined million m^3	24h/day m^3/s	20h/day m^3/s	16h/day m^3/s	5h/day m^3/s
Oct	13.85	16.58	30.44	11.364	13.637	17.046	54.547
Nov	15.44	16.58	32.02	12.355	14.826	18.533	59.305
Dec	18.64	16.58	35.22	13.151	15.782	19.727	63.127
Jan	16.68	16.58	33.27	12.420	14.904	18.630	59.617
Feb	11.07	16.58	27.65	11.328	13.594	16.992	54.375
Mar	8.83	16.58	25.41	9.488	11.385	14.232	45.542
Apr	3.29	16.58	19.87	7.667	9.200	11.500	36.801
May	3.41	16.58	19.99	7.465	8.958	11.197	35.830
Jun	2.97	16.58	19.55	7.544	9.052	11.315	36.209
Jul	3.29	16.58	19.87	7.419	8.903	11.129	35.612
Aug	5.02	16.58	21.61	8.068	9.681	12.101	38.724
Sep	6.50	16.58	23.09	8.907	10.688	13.360	42.753
Annual	**109.00**	**199.00**	**308.00**	**9.760**	**11.712**	**14.640**	**46.848**

The monthly distribution of the total requirement imposed on the dam in the Makhaleng River is given in Table 4-2 for the option when the Greater Bloemfontein is not supported from the dam and in Table 4-3 when Greater Bloemfontein is supplied from the Makhaleng. In Table 4- 4 a different monthly irrigation distribution pattern was used as based on typical irrigation distribution of existing Lesotho irrigation.

4.3 Scenarios analysed.

Based on the current understanding of the system the following scenarios were considered in support of the EWR analysis.

There will be two main sets of scenarios:

- The A-set is based on the demands as applicable to the transfer option that excludes the support to Bloemfontein.
- The B-set is based on the demands as applicable to the transfer option that includes the support to Bloemfontein.

Two different typical operating rules can be followed to manage the releases from the large storage dam in support of the downstream requirements.

- Operating rule 1: Releases are made based on the downstream requirements. As there is a significant volume of flows generated from the catchments downstream of the dam, these flows can be utilized first and only the remainder of the requirement will then be supported by releases from the dam. This will have the disbenefit that during wet periods limited or even zero support might be required from the dam, resulting in no or very little hydro-power generation at times.
- Operating Rule 2: Releases are made based on a fixed demand pattern as determined from the downstream demands as if none of the generated downstream flow is utilized by the downstream users. This will be to the benefit of base hydropower generation but can lead to more severe restrictions during dry periods.

Each of the sub-systems upstream of Gariep and Vanderkloof dams need to provide its own contribution to the environmental requirements. These contributions will be captured by Gariep and Vanderkloof dams which will in turn release the EWR for the River downstream of the two dams including that of the Orange River mouth.

Based on the above and the current understanding of the system the following scenarios were considered in support of the EWR analysis. More scenarios were initially defined but only those used in the final analysis were included in **Table 4-5**.

Table 4-5 Scenarios analysed in support of the EWR analysis.

Scenario	Description
A1	The following assumptions apply to the base scenario” • Demands imposed on the dam are based on the 2050 development level. • Greater Bloemfontein is not supported by Makhaleng • Assume base hydro-power is supplied. • Local urb/rural requirement abstracted from the diversion weir • Irrigation located downstream of the weir represents 85% of the total irrigation requirement • Utilize downstream flows before releases are made from the dam.

A3	As the Scenario A1 with the following changes: • Releases are based on a fixed demand pattern as determined by the downstream demands as if none of the generated downstream flow is utilized by the downstream users.
A4	As the Scenario A3 with the following changes: • No irrigation requirements
A5	As the Scenario A3 with the following changes: • A different fixed demand pattern were used for irrigation based on current existing irrigation requirements in Lesotho.
B3	As Scenario A3 with the following changes: • Greater Bloemfontein is supported by the Makhaleng system. • Irrigation located downstream of the weir represents 75% of the total irrigation requirement

These Scenarios were then analysed by using the WRYM and monthly flow records of 85 years each were obtained from the analysis at the following sites downstream of the dam:

- Flow between the dam and the weir (directly below dam)
- Flow between the weir and the EWR Site. (directly downstream of weir)
- Flow at the EWR site.

These monthly flow records were given to the environmental specialist for assessment and evaluation to determine the consequences of these scenarios compared to the Present Ecological State and the Recommended Ecological Class.

A summary of the average monthly flows at each of those sites as applicable to the different scenarios is given in **Table 4-6**.

The flows as expected under natural conditions at the EWR site is the first row of monthly average and annual average flows given in **Table 4-6**. From these results it is eviedent that the flows at the EWR site will reduce significantly from the natural flow of 575.45 million m^3/a to as low as 253.5 million m^3/a for Scenario B3.

A detailed scenario evaluation was undertaken at the EWR site which represents the river reach downstream from the proposed weir. These are described in **Sections 5.1 to 5.5**. This includes the explanation of the consequences of the scenarios compared to the PES and the REC.

The consequences of these scenarios in the river reach just downstream of the proposed Dam on the Makhaleng River to the proposed downstream weir are covered in **Section 5.7**.

Table 4-6 Summary of results from the different scenarios and given sites downstream of the dam on the Makhaleng River.

Description	Average monthly and annual flow volumes in million m^3

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
	Natural Conditions												
EWR Site	35.88	48.97	62.40	61.04	83.83	92.69	70.08	39.33	20.56	14.36	18.22	28.07	575.446
	Scenario A1												
Downstream of Dam	30.90	27.71	28.44	30.22	30.90	35.73	34.15	25.46	20.60	19.77	23.37	26.26	333.52
Downstream of Weir	15.05	14.47	16.20	17.58	22.90	26.97	23.29	10.99	4.74	2.58	6.24	10.57	171.57
EWR Site	21.40	24.15	28.55	29.40	41.16	47.57	39.05	19.74	9.07	5.23	9.48	15.76	290.56
	Scenario A3												
Downstream of Dam	30.34	29.51	34.09	33.33	33.05	31.96	29.90	23.24	22.10	21.47	24.58	26.53	340.12
Downstream of Weir	14.54	16.09	21.29	20.38	24.85	23.58	19.46	8.99	6.08	4.11	7.33	10.82	177.51
EWR Site	20.89	25.77	33.64	32.20	43.10	44.18	35.23	17.74	10.42	6.75	10.57	16.01	296.50
	Scenario A4												
Downstream of Dam	25.42	26.09	27.53	28.86	36.60	40.64	37.39	27.45	20.38	18.39	20.38	22.64	331.77
Downstream of Weir	10.72	13.59	16.11	17.13	28.60	31.90	26.54	13.00	4.71	1.55	3.86	7.73	175.45
EWR Site	19.50	25.57	31.38	32.06	49.10	54.58	43.68	22.62	9.74	5.06	8.31	14.60	316.21
	Scenario A5												
Downstream of Dam	32.17	33.42	37.90	34.27	32.62	30.46	26.53	22.51	21.61	20.43	23.50	24.70	340.13
Downstream of Weir	16.10	19.42	24.52	21.16	24.47	22.30	16.61	8.38	5.66	3.23	6.41	9.26	177.52
EWR Site	22.11	28.31	36.06	32.76	42.76	43.21	33.09	17.32	10.10	6.08	9.86	14.83	296.51
	Scenario B3												
Downstream of Dam	29.08	28.51	31.94	30.87	32.40	31.58	30.77	24.95	24.25	23.34	25.80	26.68	340.16
Weir to EWR site	9.75	11.66	15.70	14.51	20.92	19.58	16.71	6.88	4.49	2.14	4.78	7.42	134.53
EWR Site	16.11	21.33	28.05	26.33	39.18	40.18	32.48	15.63	8.82	4.78	8.02	12.61	253.52

5 EWR CONSEQUENCES OF SCENARIOS

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) – Level IV
- Fish Response Assessment Index (FRAI): Kleynhans (2007).
- Riparian Vegetation Response Assessment Index (VEGRAI): Kleynhans *et al*. (2007b) – Level IV.

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

- The operational scenarios were modelled, and a time series produced for each scenario at the EWR site.
- The time series for the scenarios were converted to flow duration tables and exceedance graphs and provided to the specialists, using 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, or at a percentage exceedance for all the months in the flow record (e.g. the 95% drought exceedance flow).
- 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 the 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 macroinvertebrate specialists). This was done prior to the instream biota assessment as riparian vegetation is a driver in terms of habitat for the instream biota.
- The riparian vegetation specialist ran the VEGRAI model to predict the EC for the operational scenarios.

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 to determine the EC.

The VEGRAI and FRAI results (EC percentages and confidence evaluation) were used to determine the EcoStatus per scenario and compared to the PES and Recommended Ecological Category (REC) (Kleynhans *et al* 2007a).

The scenario evaluation described in **Section 5.1 to 5.5** was undertaken at the EWR site which represents the river reach downstream from the proposed weir. It must be noted that the scenario analysis is based on the flow changes and associated impacts of each scenario and not on secondary impacts linked to these (such as the dam and weir construction, migration barriers, altered socio-economics of the area). These impacts are typically evaluated as part of the Environmental and Social Impact Assessment (ESIA). Furthermore, the impact of pulsed releases that may be required for hydropower generation can also not be evaluated as the scenario evaluation is based on a monthly flow average. Statements regarding pulsed releases are provided in Section 5.8.

5.1 Consequences of Scenario A1

Scenario A1 was evaluated. A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 5-1**, with the rating of the scenarios shown in **Figure 5-1**.

Table 5-1 Consequences of the scenario A1 on the driver and response component ECs

Component	PES & REC	Sc A1	Comment
Physico-chemical (Water quality)	B (83.6%)	B/C (81.8%)	The base hydropower scenario ensures that a constant flow moves past the site (20 in 24 hrs), although significant irrigation (85%) takes place d/s of the weir. Some fluctuations in flow are expected, but it is unlikely to force a change in water quality. Suspended sediment transport is expected to remain high in summer (see Geomorphology assessment). Irrigation return flows may impact on the nutrient load, although this will be counter-balanced by flows higher than the PES/EWR for much of the dry season. A

Component	PES & REC	Sc A1	Comment
			small change in WQ category is anticipated, largely due to the impact of increased irrigation return flows.
Geomorphology	D (52.9%)	D (42.2%)	It is anticipated under scenario A1 that the site will not improve from PD and that the site will remain a mobile sand river with a braided low-flow channel pattern and incised banks. However, it is predicted that reduced high flows (below PD) in the summer months will result in increased siltation of the bed due to a lack of sufficient flows to flush out fine silt. This will impair the few existing instream habitats. A uniform bed with little to no habitat heterogeneity is expected with fine silt deposits over sand and fine gravels. The bank conditions and processes are predicted to remain unchanged from PD. Suspended sediment transport is expected to remain high during high summer flows due to the inputs from the upstream tributaries. **Confidence: 3**
Riparian vegetation	D (48.7%)	D/E (41.8%)	The flooding component is largely intact with flows at the lower percentiles (1-15%) between PD and the EWR. Wet season base flows (50-60th percentile) are mostly lower than the EWR while dry season base flows are mostly higher than EWR with some inundation of marginal zone vegetation in the dry season, albeit minimal due to the absence of vegetation. In the very low flow spectrum (80-90th percentile) flows are generally above the EWR in the wet season but are temporally skewed towards the dry season with a tendency to become a seasonal and are higher than the EWR and PD flows. The increased regulation of base flows with wet season base flows being less than the EWR are likely to cause some mortality in marginal zone vegetation and inundation during dormancy will further reduce resistance to already high trampling pressure. Confidence: 3
Fish	D 45.8%)	D/E (39.9%)	**Fast habitats**: Wet season baseflow fish stress is very similar than EWR flow, although slightly less fast-deep (FD) habitats will be available for fish. Wet season drought flows will have lower fish stress than EWR flows with slightly more fast habitats available. Dry season baseflow fish stress is similar to EWR flows with slightly less fast-shallow (FS) habitats, while drought flow fish stress will be notably lower than EWR (but same as PD) with slightly less FS but more FD than EWR requirement. **Seasonality**: In terms of seasonal changes, base flows broadly follow the same pattern as PD and EWR, but less variability in flows (and hence habitat) may occur in wet months. Under drought conditions the PD highest flows occur in Feb/March, while under this scenario it moves earlier towards Dec/Jan and then decreases and may therefore create earlier high flows that then decreases, impacting breeding habitat of some fish negatively during droughts. **Substrates as habitat**: Reduced high flows (below PD) in the summer months will result in increased siltation of the

Component	PES & REC	Sc A1	Comment
			bed due to a lack of sufficient flows to flush out fine silt. This will impair the few existing instream habitats. A uniform bed with little to no habitat heterogeneity is expected with fine silt deposits over sand and fine gravels (refer to geomorphology). Decreased substrate quality will impact many fish species negatively due to loss in interstitial spaces (thus decrease in invertebrates/food source), loss of breeding and feeding habitat quality (already very limited rocky substrates available). **Undercut banks as habitat**: The bank conditions and processes are predicted to remain unchanged from PD. **Vegetation as habitat**: Some inundation of marginal zone vegetation in the dry season, albeit minimal due to the absence of vegetation. The increased regulation of base flows with wet season base flows being less than the EWR are likely to cause some mortality in marginal zone vegetation and inundation during dormancy will further reduce resistance to already high trampling pressure (refer to riparian vegetation). **Water quality (WQ) / physico-chemical habitat:** Suspended sediment (turbidity) to remain high in summer. A small change in WQ category is anticipated, largely due to the impact of increased irrigation return flows (refer to water quality). Potential increase in algae due to nutrients in return flows. Small change in fish expected due to WQ alteration (most fish species moderately tolerant to WQ alteration). **Migration**: Impacted negatively due to wet season drought flows alteration. **Trophic structure/food sources**: Slight decrease in macroinvertebrate assemblage expected due to slight water quality deterioration (irrigation return flows), loss of substrate habitat quality and availability (increased sedimentation). Decreased availability of food for fish (esp. invertivores). **SUMMARY:** No notable loss (change) in fast flowing habitats for fish expected. A notable negative impact will be slight alteration in seasonal patterns and migratory activity due to the earlier onset of higher flows under drought conditions (Dec/Jan rather than Feb/Mar highest flows) that may create earlier high flow conditions (and habitats) that then decreases earlier in the season (loss of habitat for spawning and nursery habitats during late summer period), impacting breeding success of some fish negatively during droughts. Deterioration of substrate quality (due to siltation) may furthermore impact fish negatively (feeding and breeding) while a small change in fish may also occur as a result of water quality deterioration. Overall the PES (fish) is expected to deteriorated slightly under this scenario.
EcoStatus	D (47.3%)	D/E 40.85	

Scenario A1 results in the EcoStatus falling to a D/E which is not the preferred outcome. This is due to a significant decrease in the geomorphological status (a drop of approximately 10%) and a drop from the PES for all other components.

5.2 Consequences of Scenario A3

Scenario A3 was evaluated. A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 5-2**, with the rating of the scenarios shown in **Figure 5-1**.

Table 5-2 Consequences of the scenario A3 on the driver and response component ECs

Component	PES & REC	Sc A3	Comment
Physico-chemical (Water quality)	B (83.6%)	B (87.3%)	During this scenario downstream releases are on a fixed demand pattern. Higher flows most of the time will result in dilution of any water quality issues, e.g. nutrient loads, resulting in a small increase in water quality state.
Geomorphology	D (52.9%)	D (56.5%)	It is anticipated under scenario A3 that the site will remain a mobile sand river with a braided low-flow channel pattern. However, it is predicted that increased flows from the dam releases might aid in reducing siltation of the bed, particularly under drought conditions. This will allow more instream habitats with a larger heterogeneity in terms of sand and fine gravel patches. Localised inputs of coarse gravels will also likely be exposed to flows more frequently. Suspended sediment transport and sediment supply is expected to remain high during high summer flows due to the inputs from the upstream tributaries. **Confidence: 3**
Riparian vegetation	D (48.7%)	D (42%)	The flooding component is largely intact with flows at the lower percentiles (1-15%) between PD and the EWR. Wet and dry season base flows (50-60th percentile) are higher than the EWR and lower than PD, except for September when flows are slightly higher than EWR with some inundation of marginal zone vegetation in the dry season. In the very low flow spectrum (80-90th percentile) flows are generally above the EWR in the wet season but are temporally skewed towards the dry season with a tendency to become aseasonal and are higher than the EWR and PD flows. Since the high and low flow components generally meet the EWR there is unlikely to be a notable change to the riparian vegetation, but some inundation during winter months is likely to cause some die-off of lower-level grasses. Confidence: 3
Fish	D 45.8%)	D (45.8%)	**Fast habitats**: Wet season baseflow fish stress moderately lower than EWR with slightly more fast habitats (than EWR requirement). Drought flows also lower stress than EWR requirement with very slightly more fast habitats than EWR requirement. Dry season baseflow fish stress slightly less

Component	PES & REC	Sc A3	Comment
			than EWR requirement and very slightly less fast habitats (than EWR requirement), while drought flows will result in lower stress than EWR and similar than PD flows, resulting in slightly less FS but more FD than EWR requirement. **Seasonality**: Baseflows broadly follow the same pattern as PD and EWR with higher flows in wet months. Drought flows are notably higher than PD and EWR from Aug to Jan, then significantly decreasing towards May. Increase in flow from Aug (rather than Oct) may result in early stimulation for migration/spawning, while conditions may not be adequate (temperature, etc.) impacting reproduction in some fish species negatively during droughts. **Substrates as habitat**: It is predicted that increased flows from the dam releases might aid in reducing siltation of the bed, particularly under drought conditions. This will allow more instream habitats with a larger heterogeneity in terms of sand and fine gravel patches. Localised inputs of coarse gravels will also likely be exposed to flows more frequently (see geomorphology). Improvement in substrate habitat will result in improvement in feeding and spawning habitats for most species. **Undercut banks as habitat**: No change expected. **Vegetation as habitat**: Unlikely to be a notable change to the riparian vegetation, but some inundation during winter months is likely to cause some die-off of lower-level grasses (see riparian vegetation). This may result in very slight negative impact on fish assemblage. **Water quality (WQ) / physico-chemical habitat:** Higher flows most of the time will result in dilution of any water quality issues, e.g. nutrient loads, resulting in a small increase in water quality state (see water quality) that may result in slight improvement in fish assemblage (most species moderately tolerant to WQ alterations). **Migration**: Early increase in flows during drought conditions (from Aug) may trigger unnatural/early migration/spawning. **Trophic structure/food sources**: Improvement in water quality and benthic substrate condition and availability may result in improved macroinvertebrate assemblage (i.t.o. diversity and abundance), resulting in improved food source for fish. **SUMMARY:** No notable change expected in fast habitat availability to fish. Altered seasonal trends (earlier onset of high flows) during drought conditions may impact breeding and migratory behavior of some fish species negatively. Improvement in substrate and water quality and food source should allow improvement in fish assemblage while no notable change expected due to vegetative cover changes. Overall, the slight negative impact under drought flows should be negated by improved conditions under baseflows and the fish PES should remain stable under this scenario.
EcoStatus	D (47.3%)	D (43.9%)	

Scenario A3 results in the EcoStatus being maintained in the same category for all components. There is a marginal drop in the EcoStatus percentage.

5.3 Consequences of Scenario A4

Scenario A4 was evaluated. A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 5-3**, with the rating of the scenarios shown in **Figure 5-1**.

Table 5-3 Consequences of the scenario A4 on the driver and response component ECs

Component	PES & REC	Sc A4	Comment
Physico-chemical (Water quality)	B (83.6%)	B (85.5%)	No irrigation requirements under Sc A4. Flows drop below the EWR/REC for much of the time during low flows, while flows exceed the EWR/REC during the wet season. Silt is expected to settle on the bed due to reduced flushing flows under drought conditions. Water quality is expected to stay largely unchanged under this scenario.
Geomorphology	D (52.9%)	D (53.2 %)	It is anticipated under scenario A4 that the site will remain a mobile sand river with a braided low-flow channel pattern and incised banks. It is predicted that reduced high flows (below PD) particular under drought base flows will result in increased siltation of the bed due to a lack of sufficient flows to flush out fine silt. This will impair the few existing instream habitats. A uniform bed with little to no habitat heterogeneity is expected with fine silt deposits over sand and fine gravels. The bank conditions are predicted to remain unchanged from PD. Suspended sediment transport and sediment supply is expected to remain high during high summer flows due to the inputs from the upstream tributaries. **Confidence: 3**
Riparian vegetation	D (48.7%)	D (48.7%)	The flooding component is largely intact with flows at the lower percentiles (1-15%) between PD and the EWR. Wet season base flows (50-60th percentile) are higher than the EWR and lower than PD, but dry season base flows are mostly lower than the EWR. Drought flows (80-90th percentile) remain seasonal but are extreme and lower than the EWR. Even though droughts are more extreme, no change is expected in the riparian vegetation. Confidence: 3
Fish	D 45.8%)	D (42.2%)	**Fast habitats**: Wet season baseflow fish stress lower than EWR flows with slightly more fast habitats available while drought flows also overall slightly lower fish stress than EWR. Dry season baseflows fish stress notably higher than EWR (of possible concern) with notably lower availability of

Component	PES & REC	Sc A4	Comment
			fast-deep habitats. Dry season drought flow fish stress only slightly higher than EWR with less fast habitat available. **Seasonality**: Although flows are notably reduced from PD/NAT under both maintenance and drought flows, same seasonal trend evident and should not have notable negative impact on fish. **Substrates as habitat**: It is predicted that reduced high flows (below PD) particular under drought base flows will result in increased siltation of the bed due to a lack of sufficient flows to flush out fine silt. This will impair the few existing instream habitats. A uniform bed with little to no habitat heterogeneity is expected with fine silt deposits over sand and fine gravels (see geomorphology). Slight decrease in already limited rocky substrate habitat will result in slight deterioration in fish (loss of feeding and breeding habitats and food source). **Undercut banks as habitat**: The bank conditions are predicted to remain unchanged from PD. **Vegetation as habitat**: No change is expected (see riparian vegetation). **Water quality (WQ) / physico-chemical habitat:** Water quality is expected to stay largely unchanged (see water quality). scenario. **Migration**: Although seasonal trend and thus migratory cues remain similar, lower than EWR flows may result in less depth (lateral and longitudinal) for migration, spawning, etc. impacting migratory success negatively. **Trophic structure/food sources**: Water quality remains largely unchanged and slight increase in siltation may result in slight loss of bottom substrate quality and hence invertebrate assemblage, resulting in very slight decrease in food source for some fish species. **SUMMARY**: Notably less fast habitats will be available for fish during the dry season (maintenance and droughts) and it can be expected to impact fish assemblage negatively. Decreased substrate quality (due to siltation) will furthermore affect fish negatively. Although the other variable assessed remained largely unchanged, a slight deterioration in the PES of the fish can be expected due to decreased fats habitats and substrate quality
EcoStatus	D (47.3%)	D (45.45%)	

Scenario A4 results in the EcoStatus being maintained in the same category for all components. There is a marginal drop in the EcoStatus percentage.

5.4 Consequences of Scenario A5

Scenario A5 was evaluated. A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 5-4**, with the rating of the scenarios shown in **Figure 5-1**.

Table 5-4 Consequences of the scenario A5 on the driver and response component ECs

Component	PES & REC	Sc A5	Comment
Physico-chemical (Water quality)	B (83.6%)	B (86.4%)	Irrigation demands in Lesotho result in a specific release pattern, resulting in higher flows than EWR/REC most of the time. This will result in a slight improvement of nutrients as they are flushed down the system.
Geomorphology	D (52.9%)	D (56.5%)	It is anticipated under scenario A5 that the site will remain a mobile sand river with a braided low-flow channel pattern. However, It is predicted that increased flows from the dam releases might aid in reducing siltation of the bed, particularly under drought conditions. This will allow more instream habitats with a larger heterogeneity in terms of sand and fine gravel patches. Localised input of coarse gravels will also likely be exposed to flows more frequently. Suspended sediment transport and sediment supply is expected to remain high during high summer flows due to the inputs from the upstream tributaries. **Confidence: 3**
Riparian vegetation	D (48.7%)	D (42%)	The flooding component is largely intact with flows at the lower percentiles (1-15%) between PD and the EWR. Wet and dry season base flows (50-60th percentile) are higher than the EWR and lower than PD, except for September when flows are slightly higher than EWR with some inundation of marginal zone vegetation in the dry season. In the very low flow spectrum (80-90th percentile) flows are generally above the EWR in the wet season but are temporally skewed towards the dry season with a tendency to become aseasonal and are higher than the EWR and PD flows. Since the high and low flow components generally meet the EWR there is unlikely to be a notable change to the riparian vegetation, but some inundation during winter months is likely to cause some die-off of lower-level grasses. Confidence: 3
Fish	D 45.8%)	D (45.8%)	**Fast habitats**: We season baseflow fish stress lower than EWR flows with slightly more fast habitats available. Drought flow fish stress also lower than EWR with slightly less FS but more FD habitat available. Dry season baseflow fish stress same as EWR with slightly less FS and very slightly more FD, while drought flows will also have notably less fish stress than EWR (same as PD), with slightly less FS but more FD than EWR requirement. **Seasonality**: Maintenance flows reflect similar seasonal trend as PD/Nat (and EWR) with no impact on seasonality under baseflow conditions. Drought flows reflect a notable increase from Aug to Dec, while PD/NAT increase occurs from October onwards. The onset of earlier increase in flows

Component	PES & REC	Sc A5	Comment
			may result in altered seasonality patterns in fish resulting in early migration/spawning during drought years when conditions may not be suitable/optimal. **Substrates as habitat**: It is predicted that increased flows from the dam releases might aid in reducing siltation of the bed, particularly under drought conditions. This will allow more instream habitats with a larger heterogeneity in terms of sand and fine gravel patches. Localised input of coarse gravels will also likely be exposed to flows more frequently (see geomorphology). Improved bottom substrate conditions should result in improved food source (invertebrates) and also breeding habitat for fish. **Undercut banks as habitat**: No change expected. **Vegetation as habitat**: September flows are slightly higher than EWR with some inundation of marginal zone vegetation in the dry season. Unlikely to be a notable change to the riparian vegetation, but some inundation during winter months is likely to cause some die-off of lower-level grasses that provide limited vegetative cover for fish (see riparian vegetation). **Water quality (WQ) / physico-chemical habitat:** Irrigation demands in Lesotho result in a specific release pattern, resulting in higher flows than EWR/REC most of the time. This will result in a slight improvement of nutrients as they are flushed down the system (see water quality). Very slight improvement in food source and WQ for fish expected. **Migration**: Early high flows in drought conditions may impact migration cues and spawning behavior negatively, resulting in negative impact on fish migration. **Trophic structure/food sources**: Slightly improved water quality and decreased siltation (improved instream habitats) should result in improved habitat condition and availability for macroinvertebrates, resulting in increased availability of food source for fish. **SUMMARY**: Although some deterioration in fish assemblage expected (especially during drought and loss of vegetation as cover), this should be negated by improvement in water quality, substrate as habitats and availability of fast habitats, resulting in over PES remaining unchanged.
EcoStatus	D (47.3%)	D (43.9%)	

Scenario A5 results in the EcoStatus being maintained in the same category for all components. There is a marginal drop in the EcoStatus percentage.

5.5 Consequences of Scenario B3

Scenario B3 was evaluated. A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in **Table 5-5**, with the rating of the scenarios shown in **Figure 5-1**.

Table 5-5 Consequences of the scenario B3 on the driver and response component ECs

Component	PES & REC	Sc B3	Comment
Physico-chemical (Water quality)	B (83.6%)	B (85.5%)	During this scenario downstream releases are on a fixed demand pattern, with Bloemfontein transfers supported from the system. Flows are similar to the EWR/REC, with a small drop below in May-June in the maintenance and drought periods. Suspended sediment transport is expected to remain high in summer (see Geomorphology assessment). Water quality conditions are expected to stay largely the same, with a small change in the clarity metric expected.
Geomorphology	D (52.9%)	D (53.51%)	It is anticipated under scenario B3 that the site will remain a mobile sand river with a braided low-flow channel pattern. However, It is predicted that increased flows from the dam releases, that reach the EWR site, might aid in reducing siltation of the bed, particularly under base flow conditions. This will allow more instream habitats with a larger heterogeneity in terms of sand and fine gravel patches but not exceeding the PD condition. Flows in the 70th-90th percentile drop to below the EWR requirements at the end of the wet season (May) which could result in an increase in sedimentation of the site by fine silt resulting in little to no habitat heterogeneity during winter months with a uniform shallow channel. Suspended sediment transport and sediment supply is expected to remain high during high summer flows due to the inputs from the upstream tributaries. **Confidence: 3**
Riparian vegetation	D (48.7%)	D (42.8%)	The flooding component is largely intact with flows at the lower percentiles (1-15%) between PD and the EWR. Wet season flows (50-60th percentile) are higher than the EWR and lower than PD, but dry season flows are mostly lower than the EWR. In the very low flow spectrum (80-90th percentile) flows are generally above the EWR in the wet season but are temporally skewed towards the dry season with a tendency to become aseasonal and are higher than the EWR and PD flows May to August), but not as severe as the other scenarios. The only anticipated change in vegetation is expected to relate to reduced dry season flows which will likely cause water stress with some mortality of higher-level sedges. Confidence: 3
Fish	D 45.8%)	D (44.3%)	**Fast habitats**: Wet season baseflow fish stress lower than EWR with slightly more fast habitats available. Under wet season drought conditions fish stress also slightly lower than EWR with less FS but more FD habitat available. Dry season baseflow fish stress slightly more than EWR (possible concern) with slightly more FS but less FD habitats available. Dry season droughts flows will result in notably less fish stress than EWR (same as PD) with less FS but more FD than EWR requirement (no concern). **Seasonality**: Maintenance flows have same seasonal trend as PD/Nat (and EWR) and no impact on seasonality expected. Drought flows increase earlier (from Aug rather than Nov) and may result in early cues for

Component	PES & REC	Sc B3	Comment
			migration/spawning, while conditions may not be adequate (temperature, etc.), impacting breeding of some fish species negatively during droughts (slight impact expected as the overall seasonal trend mostly similar than PD). **Substrates as habitat**: It is predicted that increased flows from the dam releases, that reach the EWR site, might aid in reducing siltation of the bed, particularly, resulting in more instream habitats with a larger heterogeneity in terms of sand and fine gravel patches. Lack of flows during drought flows will result in an increase in sedimentation of the site by fine silt resulting in little to no habitat heterogeneity during droughts. Overall it is expected that the impact on the substrate as cover for fish will remain the same or improve slightly from PES. **Undercut banks as habitat**: Remains largely unchanged. **Vegetation as habitat**: The only anticipated change in vegetation is expected to relate to reduced dry season base flows which will likely cause water stress with some mortality of higher-level sedges (see riparian vegetation). This may result in lower availability of overhanging vegetation as cover for some species during dry season. **Water quality (WQ) / physico-chemical habitat:** Water quality conditions are expected to stay largely the same (see water quality) **Migration**: Under drought flows, the earlier onset of increased flow from Aug (rather than Nov) may result in early cues for migration/spawning, while conditions may not be suitable (temperature, etc.), impacting breeding negatively during droughts (slight impact as overall trend mostly similar). **Trophic structure/food sources**: Only slight decrease in invertebrate assemblage expected and overall only very slight deterioration in food source for fish expected under this scenario. **SUMMARY**: Fast habitat availability for fish will be largely unchanged with the only notable slight impact occurring under dry season base flow conditions. Slightly altered drought flow seasonal trend (increase in flow from August rather than Nov) may impact fish negatively but only a slight impact expected since the overall seasonal trend mostly similar than PD. Overall it is expected that the impact on the substrate as cover for fish will remain the same or improve slightly from PES. A decrease in the already limited overhanging vegetation (sedges) as cover for fish also expected. Overall a very slight deterioration in the fish assemblage expected under this scenario.
EcoStatus	D (47.3%)	D (43.55%)	

Scenario B3 results in the EcoStatus being maintained in the same category for all components. There is a marginal drop in the EcoStatus percentage.

5.6 Ranking of Scenarios for the Reach Downstream of the Proposed Weir.

A rank order method was used to determine the ranking order as well as illustrating the results on a traffic diagram (**Figure 5-1**). The results show that all scenarios apart from Sc A1 achieve the REC of a D Ecological Category for the EcoStatus. Sc A3 and A5 appears to be marginally better than ScA4 and B3; however, the difference is marginal and the resolution in the assessment is such that there is no strong motivation to recommend Sc A3 and A5 over Sc A4 and B3.

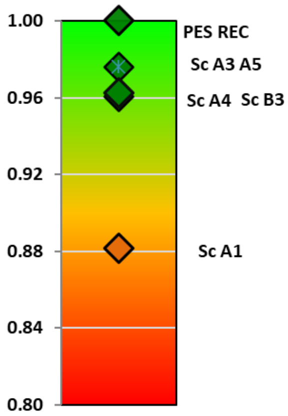

Figure 5-1 EWR MA1: Ecological ranking of operational scenarios

5.7 Consequences of Scenarios in the Reach Downstream of the Proposed dam on the Makhaleng River to the Proposed Weir

This reach (referred to as Reach 1) will be directly impacted by the proposed releases and especially from pulsed releases for hydropower. The impact will decrease further downstream from the dam as tributary inflows mitigate the impacts and provide natural floods to add to the infrequent spillage of the dam. A detailed evaluation could not be undertaken for this reach as there is no EWR site in the reach and no fieldwork undertaken for this reach. A desktop assessment of the PES has been undertaken as well as the EIS. Furthermore, broad statements on pulsed releases and the requirements for multi-level outlets have been made further in this section. The detailed EIA must give due consideration to these issues.

The IHI was undertaken based on Google Earth input and the results are provided in **Table 5-6** and **5-7**.

Table 5-6 Instream IHI for Reach 1

INSTREAM IHI	
Base Flows	-0.5
Zero Flows	0.0
Floods	1.0
HYDROLOGY RATING	**0.4**
pH	1.0
Salts	0.0
Nutrients	1.0
Water Temperature	1.0

Water clarity	-2.5
Oxygen	1.5
Toxics	0.0
PC RATING	**1.0**
Sediment	2.0
Benthic Growth	2.0
BED RATING	**2.0**
Marginal	1.5
Non-marginal	-2.0
BANK RATING	**1.7**
Longitudinal Connectivity	1.0
Lateral Connectivity	1.0
CONNECTIVITY RATING	**1.0**
INSTREAM IHI %	**77.2**
INSTREAM IHI EC	**C**
INSTREAM CONFIDENCE	**2.8**

The Instream IHI is a C EC compared to the D (55%) of the EWR reach. The improved category is based on a smaller impact regarding sedimentation due to the faster flowing river with bedrock and rapids and buffered by sections being in a gorge.

Table 5-7 Instream IHI for Reach 1

RIPARIAN IHI	
Base Flows	0.0
Zero Flows	0.0
Moderate Floods	0.0
Large Floods	0.0
HYDROLOGY RATING	**0.0**
Substrate Exposure (marginal)	4.0
Substrate Exposure (non-marginal)	3.0
Invasive Alien Vegetation (marginal)	3.0
Invasive Alien Vegetation (non-marginal)	3.0
Erosion (marginal)	3.0
Erosion (non-marginal)	3.0
Physico-Chemical (marginal)	3.0
Physico-Chemical (non-marginal)	0.0
Marginal	4.0
Non-marginal	3.0
BANK STRUCTURE RATING	**3.5**
Longitudinal Connectivity	3.0
Lateral Connectivity	3.5
CONNECTIVITY RATING	**3.2**
RIPARIAN IHI %	**54.7**
RIPARIAN IHI EC	**D**
RIPARIAN CONFIDENCE	**3.0**

The Riparian IHI is a D EC compared to the D/E (41.7%) of the EWR reach. There is an improvement in the riparian IHI due to similar reasons than for the instream. The presence of a significant number of alien vegetation (black wattle) in the gorge and agriculture in the riparian zone where the river is accessible result in the river still being in a low Ecological Category.

The IHI results, Google evaluation and other information available were used to populate a desktop PES model. The EcoStatus indicated a B/C. This may seem high compared to the IHI, but it must be noted that the desktop model is based on an average and the limited impact on instream habitat continuity (migration), potential flow and physico chemical modification activities have resulted in the B/C. In conclusion it can be said that it will be likely that the PES will be in a marginally better condition that for the EWR reach.

The EIS is MODERATE compared to the LOW of the EWR reach. This provides the motivation for the PES to be maintained as the REC.

5.8 Pulsed releases and recommendations

Pulsed hydropower releases, also commonly referred to as peaking releases, invariably have considerable impacts on the fluvial morphology, riverine habitat and biota along downstream river reaches. The relative magnitude of fluctuations reduces with distance downstream, however, due to *inter alia* hydrodynamic behaviour (e.g. peak attenuation) and potential tributary inflows. Nonetheless, fluctuations may promulgate over considerable distances, and are affected by not only the magnitude of peaks, but also the magnitude of off-peak flows as well as both their durations and relative timing.

Available information on operation of the Makhaleng hydro-power plant refers to three options, including base, mid-merit and peaking power. These operations allow for constant releases of 11.71, 14.64 and 46.85 m^3/s for 20, 16 and 5 hours/day, respectively. There is no indication of flows during off-peak times, and complete shut-down between constant peaks will likely have adverse effects (possibly substantial) along the downstream reach - even for the base power option. The so-called base power option (11.71 m^3/s for 20 hours/day) is not a truly baseload condition - at least from an environmental perspective, since the release is not over a 24-hour period. Typically, as off-peak discharges approach peak values, the impacts of peaking reduce, since operation approaches a true baseload situation with constant intra-daily flows.

It would be unwise to recommend a peak to off-peak discharge ratio for the Makhaleng hydropower, since it depends on a number of factors, including morphological and hydraulic-habitat characteristics of the downstream reach, biota, spatial and temporal (seasonal) tributary inflows, etc. A more detailed study of the likely impacts of different peaking scenarios for the reach between the proposed dam on the Makhaleng River and downstream weir would be required. Having noted this, however, from experience gained with environmental flows assessments for reaches downstream of peaking hydropower plants, a point of departure for assessing at least partial mitigation of the impacts of intra-daily fluctuations, is a peak to off-peak discharge ratio of < ˜2.

5.9 Multi-level outlets and recommendations

Dams have a number of significant impacts on water quality of flowing water systems, particularly in terms of thermal regimes, chemistry (e.g. eutrophication due to influxes of organic materials and nutrients, often due to anthropogenic activity in the catchment) and sedimentation. The operation of the releases from a dam can therefore have a significant impact on the water quality downstream of the dam, particularly the reach directly downstream. Depending on geographical location, water retained in deep reservoirs may become stratified. Releases of cold water from the hypolimnion (i.e. the deep cold layer) of a reservoir, is the most significant consequence of stratification. However, even without thermal stratification, water released from reservoirs is often thermally out of phase with the natural regime of the river.

The quality of water released from a reservoir is therefore determined by the elevation of the outflow structure(s). Water released from near the surface is generally well-oxygenated, warm, nutrient-depleted water. In contrast, water released from near the bottom is often cold, oxygen-depleted, nutrient-rich water that may be high in hydrogen sulphide, iron and manganese.

It is therefore recommended that multi-level releases be part of the design of the dam, and that operation of the dam includes a multiple level outlet tower, particularly to mitigate thermal and oxygen impacts.

6 CONCLUSIONS AND RECOMMENDATIONS

The outcome of the evaluation of the scenarios are documented in **sections 5.1 to 5.6** assessed at the EWR site and summarized in **Figure 6-1**.

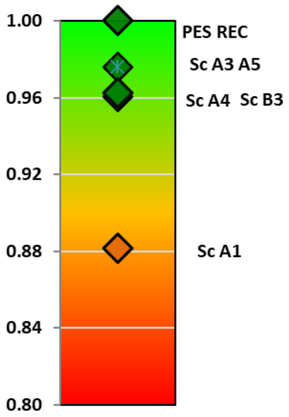

Figure 6-1 EWR MA1: Ecological ranking of operational scenarios

According to the evaluation, all scenarios except for Sc A1 will maintain the EcoStatus of a D Ecological Category (EC) which represents the Present and Recommended Ecological Category. It must be noted that this evaluation has not considered the impact on the Ecological Category downstream of the EWR site in South Africa based on any future possible abstractions.

The section downstream of the proposed dam on the Makhaleng River to the proposed abstraction weir (17 km) referred to as Reach 1, was broadly assessed with recommendations focusing on the operation of the dam in terms of pulsed releases (**Section 5.8).** A detailed evaluation of these different operational methods falls outside the scope of the EWR study and will have to be addressed as part of the Environmental and Social Impact Assessment (ESIA). It is acknowledged that impacts associated with pulsed releases will attenuate further downstream from the dam and also be mitigated by natural inflows from tributaries.

Similarly, the recommendation of multi-level outlets (**Section 5.9**) as well as the necessity and design of a fish ladder at the proposed abstraction weir, must also be considered part of the impact assessment.

7 REFERENCES

Department of Water Affairs and Forestry (DWAF). (1999) Resource Directed Measures for Protection of Water Resources. Volume 3: River Ecosystems Version 1.0, Pretoria.

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. (2017) Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Main Summary Report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0317. July 2017.

Hughes, D.A., Desai, Louw, D. and Birkhead, A.L. (2012) Development of a revised desktop model for the determination of the Ecological Reserve for rivers. Water Research Commission (WRC) Report no. 1856/1/12. WRC, Pretoria, South Africa. Available at http://www.wrc.org.za.

Hughes, D.A., Desai, A.Y., Birkhead, A.L. and Louw, D. (2014) A new approach to rapid, desktop-level, environmental flow assessments for rivers in southern Africa. Special Issue: Hydrological Science for Environmental Flows. *Hydrological Sciences Journal*. Volume 59, Issue 3-4. http://dx.doi.org/10.1080/02626667.2013.818220.

Hughes, D.A., Louw, D., Birkhead, A.L., Kotze, P. and Mackenzie, J. (2018) Refinement of the Revised Desktop Reserve Model. Project K5/2539/2. Water Research Commission (WRC), Pretoria, South Africa. Available at http://www.wrc.org.za.

Iversen, TM, Madsen, BL, and Bøgestrand, J. 2000. River conservation in the European Community, including Scandinavia.In: “Global Perspectives on River Conservation: Science Policy and Practice", Edited by P.J. Boon, B.R. Davies and G.E. Petts, John Wiley & Sons Ltd.

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 (2007a) Module A: EcoClassification and EcoStatus determination. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Kleynhans, C.J., Mackenzie, J. and Louw, M.D. (2007b) Module F: Riparian Vegetation Response Index. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Kleynhans, C.J., Louw, M.D., and Graham, M. (2009) Module G: EcoClassification and EcoStatus determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical manual) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.

Lesotho Highlands Development Authority, (LHDA). (2016) Specialist Consultants to Undertake Baseline Studies (Flow, Water Quality and Geomorphology) and Instream Flow Requirement (IFR) Assessment for Phase 2: Instream Flow Requirements for the Senqu River – Final report No 6001/2/e. Lesotho Highlands Development Authority, Maseru.

Louw, D, Kotze, P, and Mackenzie, J. (2010) Scoping study to identify priority areas for detailed EFR and other assessments. Produced for WRP as part of Support to Phase II ORASECOM Basin Wide Integrated Water Resources Management Plan.

Louw, M.D., Deacon, A., Koekemoer, S., Kotze, P., Mackenzie, J., Palmer, R., Rountree, M. and Scherman, P-A. (2013) Research project on environmental flow requirements of the Fish River and the Orange–Senqu River mouth: River EFR assessment, Volume 1: Determination of lower Orange River EFR. Prepared for the UNDP-GEF Orange-Senqu Strategic Action Programme (Atlas Project ID 71598). Technical Report 29.

Noss, RF. (1990) Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-364.

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

8 SPECIALIST APPENDIX: DIATOMS

8.1 Background

Diatoms have been shown to be reliable indicators of specific water quality problems such as organic pollution, eutrophication, acidification and metal pollution, as well as for general water quality. Diatoms are commonly employed in monitoring efforts as sensitive biological indicators to determine the anthropogenic impact on aquatic ecosystems, and have for a long time been used in bio-assessments (Kasperovičienė and Vaikutienė, 2007). As benthic diatom assemblages are sessile they are exposed to water quality at a site over a period antecedent to sampling. They therefore indicate recent as well as current water quality (Philibert *et al*., 2006). Diatoms (as a biological response variable) are included in biomonitoring as it provides additional information on the water quality assessment in terms of current pollution levels and possible trends in physical chemical variables. Diatoms also provide a general description of the water quality related habitat specifications linked to ecologically sensitive species requirements. Diatom-based water quality indices for riverine ecosystems have been implemented in South Africa since 2004 as there is a measurable relationship between water quality variables such as pH, electrical conductivity, phosphorus and nitrogen, and the structure of diatom communities as reflected by diatom index scores, allowing for inferences to be drawn about water quality (Taylor, 2004; De la Rey *et al*. (2004).

The specific water quality tolerances of diatoms have been resolved into different diatom-based water quality indices, used around the world. Most indices are based on a weighted average equation (Zelinka and Marvan, 1961). In general, each diatom species used in the calculation of the index is assigned two values; the first value (s value) reflects the tolerance or affinity of the particular diatom species to a certain water quality (good or bad) while the second value (v value) indicates how strong (or weak) the relationship is (Taylor, 2004). These values are then weighted by the abundance of the particular diatom species in the sample (Lavoie *et al*., 2006; Besse, 2007). The main difference between indices is in the indicator sets (number of indicators and list of taxa) used in calculations (Eloranta and Soininen, 2002). These indices form the foundation for developing computer software to estimate biological water quality. OMNIDIA (Lecointe *et al*., 1993) is one such software package; it has been approved by the European Union and is used with increasing frequency in Europe and will be used for this study.

8.2 Aims and Objectives

The aim of the diatom sampling and analysis is to provide biological water quality information for conditions on the day of biological component sampling regarding the aquatic health and functioning of the aquatic system, and providing additional input to the physico-chemical component of the study as a response variable. The overall objective of this report is to assess the impacts of anthropogenic activities on the Present Ecological State of the receiving aquatic ecosystem

8.3 Terminology

Terminology used in this specialist appendix is outlined in Taylor *et al*. (2007a) and summarised below.

Trophy	
Dystrophic	Rich in organic matter, usually in the form of suspended plant colloids, but of a low nutrient content.
Oligotrophic	Low levels or primary productivity, containing low levels of mineral nutrients required by plants.
Mesotrophic	Intermediate levels of primary productivity, with intermediate levels of mineral nutrients required by plants.
Eutrophic	High primary productivity, rich in mineral nutrients required by plants.
Hypereutrophic	Very high primary productivity, constantly elevated supply of mineral nutrients required by plants.
Mineral content	
Very electrolyte poor	< 50 µS/cm
Electrolyte-poor (low electrolyte content)	50 - 100 µS/cm
Moderate electrolyte content	100 - 500 µS/cm
Electrolyte-rich (high electrolyte content)	> 500 µS/cm
Brackish (very high electrolyte content)	> 1000 µS/cm
Saline	6000 µS/cm
Pollution (Saprobity)	
Unpolluted to slightly polluted	BOD <2, O_2 deficit <15% (oligosaprobic)
Moderately polluted	BOD <4, O_2 deficit <30% (β-mesosaprobic)
Critical level of pollution	BOD <7 (10), O_2 deficit <50% (β-ά-mesosaprobic)
Strongly polluted	BOD <13, O_2 deficit <75% (ά-mesosaprobic)
Very heavily polluted	BOD <22, O_2 deficit <90% (ά-meso-polysaprobic)
Extremely polluted	BOD >22, O_2 deficit >90% (polysaprobic)

8.4 Methods

8.4.1 Sampling and Analysis

Epilithic[2] and/or Epiphytic[3] substrate was sampled as outlined in Taylor *et al*. (2007a). Diatom samples were taken at the site by scrubbing the substrate with a small brush and rinsing both the brush and the substrate with distilled water.

Preparation of diatom slides followed the Hot HCl and $KMnO_4$ method as outlined in Taylor *et al.* (2007a). A Nikon Eclipse E100 microscope with phase contrast optics (1000x) was used to identify diatom valves on slides. The aim of the data analysis was to count 400 diatom valves to produce semi-quantitative data from which ecological conclusions can be drawn (Taylor *et al*., 2007a). This range is supported by Prygiel *et al.* (2002), Schoeman (1973) and Battarbee (1986) as satisfactory for the calculation of relative abundance of diatom species. Nomenclature followed Krammer and Lange-Bertalot (1986-91). Diatom index values were calculated in the database programme OMNIDIA (Lecointe *et al.*, 1993) for epilithon data in order to generate index scores to general water quality variables.

8.4.2 Diatom Based Water Quality Score

The European numerical diatom index, the Specific Pollution sensitivity Index (SPI) was used to assign biological water quality Ecological Categories (ECs) and associated water quality classes. Classes based on the class limits provided in **Table 5-1**. Other indices housed within the OMNIDIA programme used to characterise biological water quality included:

- Biological Diatom Index (BDI): Primarily a practical index, as it treats morphologically related taxa as one group and composes so-called associated taxa eliminating species that are difficult to identify.
- The ecological characterisation of diatom species based on Van Dam *et al.* (1994): Includes the preferences of 948 freshwater and brackish water diatom species in terms of pH, nitrogen, oxygen, salinity, humidity, saprobity and trophic state.
- Trophic Diatom Index (TDI) (Kelly and Whitton, 1995): This index provides the percentage pollution tolerant diatom valves (PTVs) in a sample and was developed for monitoring sewage outfall (orthophosphate-phosphorus concentrations), and not general stream quality. The presence of more than 20% PTVs shows significant organic impact.

[2] Diatoms growing on rock or stone surfaces.
[3] Diatoms growing on macrophytic surfaces.

- Valve deformities were also noted as it is an indication of possible metal toxicity that may be present within the system. According to Luís *et al*. (2008) several studies on metal polluted rivers have shown that diatoms respond to perturbations not only at the community but also at the individual level with alteration in cell wall morphology. In particular, size reduction and frustule deformations have been sometimes associated with high metal concentrations. The general threshold for the occurrence of valve deformities in a sample is usually considered between 1 - 2% and is regarded as potentially hazardous (Taylor, *pers. comm*.).

Table 8-1 Class limit boundaries for the SPI index applied in this study

Interpretation of index scores		
Ecological Category (EC)	**Class**	**Index Score (SPI Score)**
A	High quality	18 - 20
A/B		17 - 18
B	Good quality	15 - 17
B/C		14 - 15
C	Moderate quality	12 - 14
C/D		10 - 12
D	Poor quality	8 - 10
D/E		6 - 8
E	Bad quality	5 - 6
E/F		4 - 5
F		<4

8.5 Results and Discussion

A summary of the diatom results for October 2018 and August 2022 are provided in **Table 5-2** and a species list is provided at the end of this Appendix. Species contributing 5% or more to the total count were classified as dominant.

Table 8-2 Summary of diatom results

Site	No species	SPI score	Water Quality Class	Category	PTV (%)	Valve deformities (%)
October 2018						
MAK1	33	12.7	Moderate quality	C	66	0.5
August 2022						
MAK1	17	18	High quality	A/B	10.8	0

8.5.1 Diatom Results: 2018

The catchment is very degraded (overgrazed) with large sediment inputs. The observed impacts included cattle and goats, high levels of erosion and sedimentation while algae were present in the main stream at the time of sampling. Based on field observations flows were moderate, but seems to have been on the recession of a recent high flow (Dr Birkhead, *Pers. Comm*; 30 October 2018). Due to the recently elevated flows it was suspected that nutrient and organic pollution levels would be elevated due to runoff entering the system from the upper catchment areas which consist mainly of rural communities.

In October 2018 the SPI score was 12.7 (C Ecological Category) and the water quality was Moderate. PTVs made up 66% of the total count, suggesting that organic pollution levels were high. Further analysis of the various indices within OMNIDIA suggested that salinity and nutrient levels were elevated and moderate pollution levels were present at the time of sampling.

Achnanthidium minutissimum was dominant and while this species is associated with good water quality with high oxygenation rates, it is an indicator or recent disturbance and elevated flows. *Reimeria sinuata* was also dominant and is a cosmopolitan aerophilic species found montane biotopes (Taylor *et al.*, 2007b) with a preference for elevated nutrient levels.

The diatom community generally had a preference for moderate biological water quality with elevated organic pollution and nutrient levels as well as elevated salinity concentrations. Elevated nutrient were reflected by the dominance of *Cocconeis placentula* and *Cocconeis pediculus*; fast-growing, pioneer species that is able to colonise bare substrates quickly. The genus *Cocconeis* has a broad ecological range and is found in most running waters except where nutrients are low or acidic conditions prevail (Taylor *et al.*, 2007b). This genus is tolerant of moderate organic pollution and also extends into brackish waters.

Organic pollution levels were high and reflected by the dominance of *Navicula gregaria* which is very common in eutrophic to hypereutrophic fresh waters with moderate to high electrolyte content extending to brackish waters. It is tolerant of strongly polluted conditions and a good indicator species for these conditions (Taylor *et al.*, 2007b).

Salinity levels were elevated with the potential of becoming problematic. Within the diatom community species with a preference for high salinity concentrations were prolific at sub-dominant level and included *Eolimna subminuscula*, *Nitzschia frustulum*, *Craticula molestiformis* and *Navicula antonii*. These species also have a preference for elevated to high nutrient levels.

Surirella angusta, was sub-dominant and suggested that sedimentation was present and elevated. *Surirella* species are common in the benthos, especially epipelic habitats, across a wide range of water chemistry and have high motility compared to other diatom genera and are able to live within sand grains and fine sediment (Spaulding and Edlund, 2010). Valve deformities were noted at an abundance of 0.5% suggesting that metal toxicity was below detection limits.

8.5.2 Diatom results: 2022

In August 2022 the SPI score was 18 (A/B Ecological Category) and the water quality was High. PTVs made up 10.8% of the total count, suggesting that organic pollution levels were low, reflecting an improvement from 2018. Further analysis of the various indices within OMNIDIA suggested that salinity and nutrient levels were elevated and moderate pollution levels were present at the time of sampling.

Achnanthidium minutissimum was outright dominant in August 2022 and the reason for the high SPI score, as this species is associated with good water quality with high oxygenation rates. It is however also an indicator of recent disturbance and elevated flows. Aerophilic species were dominant and included *Adlafia bryophila* and *Encyonopsis microcephala*. While these species have a preference for well-oxygenated usually clean waters their dominance suggested that water level fluctuation was more prolific in 2022 in comparison to 2018 which would impact the life cycles of aquatic biota. The impact of livestock and resulting elevated nutrient levels were reflected by the dominance of *Eolimna subminuscula* and other species with a similar preference at sub-dominant level (Taylor *et al.*, 2007b). No valve deformities were noted suggesting that metal toxicity was below detection limits and not biologically available.

8.6 Conclusions

Based on the 2018 and 2022 diatom results, the Makhaleng reach was determined to be in a B Ecological Category. At times high organic loads prevail along with elevated nutrient levels and salinity concentrations with the potential of becoming problematic, leading to deteriorated biological water quality. The most pronounced impact on the site is cattle and goats, sedimentation and erosion. Sedimentation and fluctuating water levels impact the aquatic biota in terms of life-stage development and breeding and associated biotope availability.

8.7 Diatom Species list

List of diatom species collected during October 2018 and August 2022 is provided in **Table 5-3**.

Table 8-3 Diatom species list for 2018 and 2022

Species	2018	2022
Abnormal diatom valve (unidentified) or sum*	2	
Achnanthidium affine (Grunow) Czarnecki		30
Achnanthidium biasolettianum (Grunow) Lange-Bertalot		49
Achnanthidium minutissima Kützing (Czarnecki)	64	196
Adlafia bryophila (Petersen) Moser Lange-Bertalot & Metzeltin		28
Amphipleura pellucida (Kützing) Kützing	1	
Amphora coffeaeformis (Agardh) Kützing	4	
Amphora montana Krasske	5	
Amphora veneta Kützing	4	
Caloneis bacillum (Grunow) Cleve	1	
Cocconeis pediculus Ehrenberg	86	
Cocconeis placentula Ehrenberg	31	
Craticula halophila (Grunow) DG Mann	1	
Craticula molestiformis (Hustedt) Lange-Bertalot	7	7
Cymbella turgidula Grunow	2	
Encyonema silesiacum (Bleisch) DG Mann	1	
Encyonopsis microcephala (Grunow) Krammer	1	26
Eolimna subminuscula (Manguin) Lange-Bertalot	10	22
Gomphonema minutum (Agardh) Agardh	3	
Gomphonema parvulum (Kützing) Kützing	4	6
Gomphonema venusta Passy, Kociolek & Lowe		7
Hantzschia amphioxys (Ehrenberg) Grunow	1	
Mayamaea atomus var. *permitis* (Hustedt) Lange-Bertalot	3	10
Navicula antonii Lange-Bertalot	7	
Navicula gregaria Donkin	51	
Navicula kotschyi Grunow	1	
Navicula rostellata Kützing	4	
Navicula tripunctata (OF Müller) Bory		5
Navicula veneta Kützing	1	
Nitzschia archibaldii Lange-Bertalot		1
Nitzschia dissipata (Kützing) Grunow		3
Nitzschia frustulum (Kützing) Grunow	6	
Nitzschia heufleriana Grunow	1	
Nitzschia linearis (Agardh) W Smith	18	1
Nitzschia paleacea (Grunow) Grunow		2
Nitzschia perspicua Cholnoky	12	
Nitzschia sinuata var. *delognei* (Grunow) Lange-Bertalot		1
Nitzschia species	20	
Planothidium frequentissima (Lange-Bertalot) Round & Bukhityarova	5	
Planothidium rostrata (Oestrup) Round & Bukhityarova	1	

Species	2018	2022
Reimeria sinuata (Gregory) Kociolek & Stoermer	32	6
Surirella angusta Kützing	10	
Total count	**400**	**400**

8.8 References

Battarbee, R.W. (1986) Diatom Analysis. In Berglund BE (ed) *Handbook of Holocene Paleoecology and Paleohydrology*. John Wiley & Sons Ltd. Chichester. Great Briton. pp 527-570.

Besse, A. (2007) *Integrated Project to evaluate the Impacts of Global Change on European Freshwater Ecosystems:* Task 4 - Generation of an indicator value database for European freshwater species. Euro-limpacs. Project No. GOCE-CT-2003-505540. ALTERRA, Green World Research, Wageningen, Netherlands.

De la Rey, P.A., Taylor, J.C., Laas, A., Van Rensburg, L. & Vosloo, A. (2004) Determining the possible application value of diatoms as indicators of general water quality: A comparison with SASS 5. *Water SA* **30**: 325-332.

Eloranta, P. and Soininen, J. (2002) Ecological status of Finnish rivers evaluated using benthic diatom communities. *J. Appl. Phycol*. **14**: 1-7.

Kasperovičienė, J., and Vaikutienė, G. (2007) Long-term changes in diatom communities of phytoplankton and the surface sediments in the Curonian Lagoon (Lithuanian part) *Transit. Waters Bull*. **1**:27-37.

Kelly M.G., Whitton B.A. (1995) The Trophic Diatom Index: a new index for monitoring eutrophication in rivers, *Journal of Applied Phycology* 7, 433- 444.

Krammer, K. and Lange-Bertalot, H. (1986-1991) Bacillario-phyceae. Süßwasserflora von Mitteleuropa *2* (1-4). Spektrum Akademischer Verlag, Heidelberg. Berlin.

Lavoie I., Campeau S., Grenier M. and Dillon P.J. (2006) A diatom-based index for the biological assessment of eastern Canadian rivers: an application of correspondence analysis (CA). *Can. J. Fish. Aquat. Sci.* **63**(8): 1793–1811.

Lecointe, C., Coste, M. and Prygiel, J. (1993) “Omnidia”: Software for taxonomy, calculation of diatom indices and inventories management. Hydrobiologia 269/270: 509-513.

Luís, A.T., Teixeira, P., Almeida, S.F.P., Ector, L., Matos, J.X. and Ferreira da Silva, A. (2008) Impact of Acid Mine Drainage (AMD) on Water Quality, Stream Sediments and Periphytic Diatom Communities in the Surrounding Streams of

Aljustrel Mining Area (Portugal). Water Air Soil Pollution. DOI 10.1007/s11270-008-9900-z.

Philibert, A., Gell, P., Newall, P., Chessman, B. and Bate, N. (2006) Development of diatom-based tools for assessing stream water quality in south-eastern Australia: assessment of environmental transfer functions. *Hydrobiologia* **572**: 103–114.

Prygiel, J., Carpentier, P., Almeida, S., Coste, M., Druart, J.C., Ector, L., Guillard, D., Honoré, M.A., Iserentant, R., Ledeganck, P., Lalanne-Cassou, C., Lesniak, C., Mercier, I., Moncaut, P., Nazart, M., Nouchet, N., Peres, F., Peeters, V., Rimet, F., Rumeau, A., Sabater, S., Straub, F., Torrisi, M., Tudesque, L., Van der Vijver, B., Vidal, H., Vizinet, J. and Zydek, N. (2002) Determination of the biological diatom index (IBD NF T 90-354): results of an inter-comparison exercise. *Journal of Applied Phycology* **14**: 27-39.

Schoeman, F.R. (1973) A systematical and ecological study of the diatom flora of Lesotho with special reference to water quality. V&R Printers, Pretoria, South Africa.

Spaulding, S. and Edlund, M (2010) *Surirella*. In Diatoms of the United States. Retrieved September 26, 2013, from http://westerndiatoms.colorado.edu/taxa/genus/surirella.

Taylor, J.C. (2004) *The Application of Diatom-Based Pollution Indices in the Vaal Catchment*. Unpublished M.Sc. thesis, North-West University, Potchefstroom Campus, Potchefstroom.

Taylor, J.C., Harding, W.R. and Archibald, C.G.M. (2007a) A methods manual for the collection, preparation and analysis of diatom samples. Water Research Commission Report TT281/07. Water Research Commission. Pretoria.

Taylor, J.C., Harding, W.R. and Archibald, CGM. (2007b) An illustrated guide to some common diatom species from South Africa. Water Research Commission Report TT282/07. Water Research Commission. Pretoria.

Van Dam, H., Mertens, A. and Sinkeldam, J. (1994) A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology 28(1): 177-133.

Zelinka, M. and Marvan, P. (1961) Zur Prikisierung der biologischen Klassifikation der Reinheit fliessender Gewasser. Archiv. *Hydrobiol*. **57**: 389-407.

9 SPECIALIST APPENDIX: FISH

9.1 BACKGROUND

The Makhaleng EWR site situated in SQ reach D15G-4508 and falls within Ecoregion 15.01 (Eastern Escarpment Mountains). The site was visited and fish and aquatic macroinvertebrate sampling was performed during August 2022 by P. Kotze.

- The most visible impact at the site is **extensive sedimentation** of the river bed, resulting in serious modification of habitats for instream biota (also noted in IHI).
- **Instream IHI** = 55% (category D).
  - Hydrology = 0.7 (very slight modification).
  - Water quality rating = (moderately modified, nutrients and water clarity most notable impacts),
  - Bed modification = 4 (seriously modified) with sediment rated 4/5.
  - Bank modification = 3.6 (seriously modified) primarily due to erosion/over grazing, and alien trees.
- **Diatoms:** 2018: Category C (moderate quality). Organic pollution high, and nutrients and salinity elevated.
- **Macroinvertebrates:** The South African Scoring System (SASS5) protocol was applied by Dr. P. Kotze (DWS Accredited practitioner) during the August 2022 site visit to provide supporting information to the fish study regarding the water quality and habitat condition of instream biota in general (no MIRAI applied). A SASS5 score of only 52 was calculated for the site, indicating overall poor biotic conditions (Addendum A). Although the ASPT is of low confidence as a result of the low number of families sampled (9), the ASPT value of 5.8 indicated that the water quality of the site was relatively good at the time of the survey. This was also confirmed by the presence of Heptageniidae (Flat-headed mayflies), a family with a high requirement for unmodified water quality. The poor biotic conditions (based on macroinvertebrates) were primarily the result of poor physical habitat conditions. No stones biotope was available for sampling, the result of serious bed modification due to extensive siltation. Very limited vegetation was available due to extensive bank erosion (loss of marginal vegetation) and altered beds and water column (loss of instream vegetation). A total Integrated Habitat Assessment System (IHAS) score of only 52% was calculated, with a low habitat suitability and availability score of 12, confirming that habitat availability and condition/suitability was poor and the primary cause for the poor macroinvertebrate assemblage observed at the site. Heptageniidae (Flat-headed mayflies) was the most

intolerant family present and is also the most important indicator taxon regarding water quality and flow. This taxon has a high requirement/preference for fast flows (0.3 to 0.6 m/s preferably over rocky (cobble) substrate (can also occur in some vegetative habitats).

9.2 ECOCLASSIFICATION)

The 2018 fish assessment classified site in a category E (seriously modified). Notes: The fish information for the downstream reach D15J-04889 was used to apply a desktop Fish Response Assessment Index (FRAI) (without surveyed information). The result is an E Category which is mostly due to the habitat degradation linked to the lack of cover, sedimentation which amongst others affects migration.

2022 results:

A fish survey was undertaken at the EWR site on 24 August 2022. Sub-site 1 (right bank) consisted primarily of slow-shallow habitats with limited fast shallow areas (**Figure 6-1**, Plate 1). Cover for fish was very limited, primarily provided by dead tree stumps (snags) and undercut (eroded) banks with the bed consisting 100% of sand, mud and silt (no exposed rocks). The only fish species sampled in sub-site 1 was *Labeobarbus aeneus* (Smallmouth Yellowfish), present in low abundance (**Table 6-1**, Plate 3). Sub-site-2 (left bank) included more diverse habitat in terms of velocity-depth categories, with all four categories (fast-deep, fast-shallow, slow-deep and slow-shallow) being represented (**Figure 6-1**, Plate 2). Cover for fish was however again very limited and only present in the form of dead trees (Poplars) and undercut banks, with the substrate again consisting 100% of sand, mud and silt. *Labeobarbus aeneus* was again the only species sampled, being present in moderate abundance.

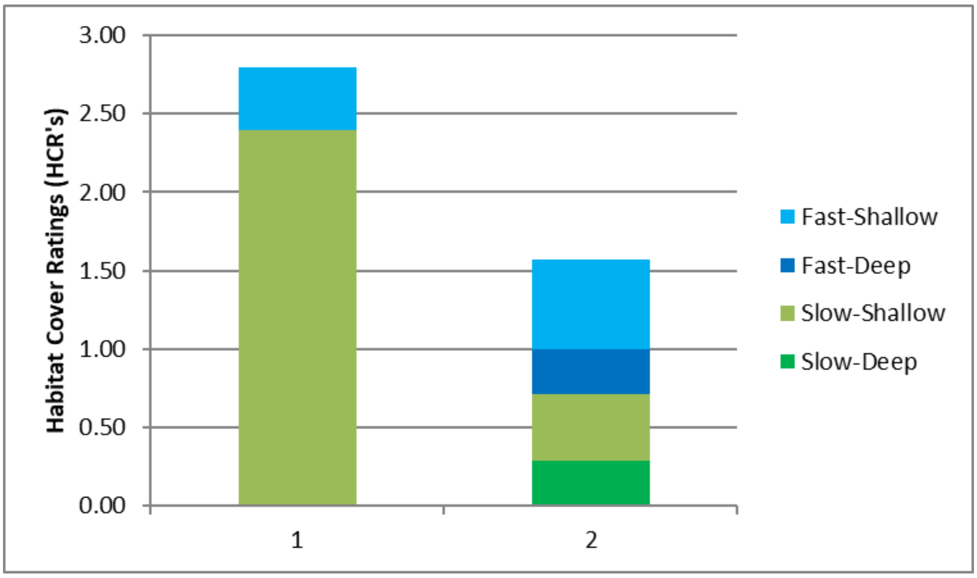

Figure 9-1 Habitat Cover Ratings (HCRs) for fish at the sub-sites sampled (August 2022)

Plate 1: Sub-site 1 (Right bank)

Plate 2: Sub-site 2 (Left-bank)

Plate 3: *Labeobarbus aeneus* (Smallmouth yellowfish) sampled at site EWR Makhalend (August 2022).

Table 9-1 Fish species expected in the EWR Makhaleng reach and fish sampling results for the August 2022 survey

Abbreviation	Scientific Name	English Common Name	Sub-site 1	Sub-site 2	Abundance: Overall for Si…	CPUE[1] (individuals/ minute)
ASCL	AUSTROGLANIS SCLATERI	ROCK-CATFISH			0	0
BAEN	LABEOBARBUS AENEUS	SMALLMOUTH YELLOWFISH	7	21	28	0.6
BANO	ENTEROMIUS ANOPLUS*	CHUBBYHEAD BARB			0	0
CGAR	CLARIAS GARIEPINUS	SHARPTOOTH CATFISH			0	0
LCAP	LABEO CAPENSIS	ORANGE RIVER LABEO			0	0

1 Catch Per Unit Effort
*Recent name change recommended: *Enteromius oraniensis* (Kambikambi *et al.*)

Based on all available information at the time of compiling this report it is estimated that five indigenous fish species may have occurred in the EWR reach under natural conditions (based on current distribution information for this catchment and estimated habitat availability under reference conditions). Refer to **Table 6-2** for a detailed motivation of the reference and present status of the fish expected fish species. The presence of only one species (*Labeobarbus aeneus*) was confirmed during August 2022. It is estimated that two fish species *(Clarias gariepinus* and *Labeo capensis*) may still be present in this reach at times at reduced abundance and frequency of occurrence, while two species (*Austroglanis sclateri* and *Enteromius anoplus/oraniensis*) may have been lost from this reach. A FRAI score of 45.8% was calculated for this EWR site falling in an Ecological Category D (**Table 6-3**). The primary cause for the deteriorated fish assemblage is associated with habitat deterioration (non-flow related). Extensive catchment and localised bank erosion resulted in transformation of the river bed (extensive sedimentation). This resulted in loss of or reduced availability of rocky/gravel substrates, clogging of interstitial spaces between rocks and gravel, and loss of water column / pool depth. The loss of rocky substrates especially impacted feeding and breeding habitats of *A. sclateri, L. aeneus* and *L. capensis*, while the loss of deep pools (water column as cover) impacted on the above mentioned species as well as *C. gariepinus*. Overgrazing and trampling of banks resulted in loss of natural marginal vegetation that created overhang as cover for fish (especially impacting *E. anoplus*). The loss of depth and cover (due to sedimentation) also impact the longitudinal and lateral migration of all fish species negatively. The presence of alien fish in this reach is uncertain with a very low probability of *Common Carp* and/or *Oncorhynchus mykiss* (Rainbow trout) being present.

Table 9-2 Motivation for fish species and ratings under reference and present (PES) conditions

Species Abbr.	Final Reference FROC[1]	Reference Rationale	Final PES FROC	PES Rationale
ASCL	1	Low probability of occurrence: Present in secondary catchment (D15), uncertainty about habitat availability under reference condition.	0	High probability that this species is lost from reach due to loss of habitat (sedimentation resulting in loss of rocky substrate habitat).
BAEN	4	High probability of occurrence: Present in secondary catchment (D15) and sampled during current survey.	3	Confirmed during EWR survey in low to moderate abundance. Present in reduced FROC due to habitat deterioration (loss of rocky/gravel substrates due to sedimentation, loss in food source, low probability of spawning requirements being met, migration limitations due to extensive sedimentation resulting in shallow habitat).
BANO	1	Moderate probability of occurrence: Present in secondary catchment (D15) and habitat should have been available under reference condition.	0	High probability that species is now absent from reach due to habitat deterioration. Loss of overhanging vegetation/undercut banks due to extensive bank erosion (over grazing/trampling) and loss of rocky substrates due to sedimentation (due to extensive catchment erosion).
CGAR	2	Moderate probability of occurrence: Present in secondary catchment (D15) and habitat should have been available under reference condition.	1	Estimated to still be present in a reduced FROC due to habitat deterioration (loss of pool depth (sedimentation), loss of food sources (sedimentation), and migration impact due to depth limitations (sedimentation).
LCAP	2	Moderate probability of occurrence: Present in secondary catchment (D15) and habitat should have been available under reference condition.	1	Estimated to still be present in a reduced FROC due to habitat deterioration (loss of rocky substrates due to sedimentation), loss of pool depth (sedimentation), loss of food sources (sedimentation), migration impact due to depth limitations (sedimentation).

1 Frequency of occurrence.

Table 9-3 Fish Response Assessment Index (FRAI) results for site EWR Makhaleng (August 2022)

METRIC GROUP	METRIC	*RATING (CHANGE)	METRIC GROUP WEIGHT (%)
VELOCITY-DEPTH CLASSES METRICS	Response of species w ith high to very high preference for FAST-DEEP conditions	-1.5	89
	Response of species w ith high to very high preference for FAST-SHALLOW conditions	-2	
	Response of species w ith high to very high preference for SLOW-DEEP conditions	-2.5	
	Response of species w ith high to very high preference for SLOW-SHALLOW conditions	-3.5	
COVER METRICS	Response of species w ith a very high to high preference for overhanging vegetation	-5	100
	Response of species w ith a very high to high preference for undercut banks and root w ads	-5	
	Response of species w ith a high to very high preference for a particular substrate type	-2	
	Response of species w ith a high to very high preference for instream vegetation	-5	
	Response of species w ith a very high to high preference for the w ater column	-1.5	
FLOW DEPENDANCE METRICS	Response of species intolerant of no-flow conditions	0	73
	Response of species moderately intolerant of no-flow conditions	-2	
	Response of species moderately tolerant of no-flow conditions	-5	
	Response of species tolerant of no-flow conditions	-2.5	
PHYSICO-CHEMICAL METRICS	Response of species intolerant of modified physico-chemical conditions	0	57
	Response of species moderately intolerant of modified physico-chemical conditions	0	
	Response of species moderately tolerant of modified physico-chemical conditions	-2.5	
	Response of species tolerant of modified physico-chemical conditions	-2.5	
MIGRATION METRICS	Response in terms of distribution/abundance of spp w ith catchment scale movements	0	62
	Response in terms of distribution/abundance of spp w ith requirement for movement betw een reaches or fish habitat segments	4	
	Response in terms of distribution/abundance of spp w ith requirement for movement w ithin reach or fish habitat segment	1	
INTRODUCED SPECIES METRICS	The impact/potential impact of introduced competing/predaceous spp?	0	35
	How w idespread (frequency of occurrence) are introduced competing/predaceous spp?	0	
	The impact/potential impact of introduced habitat modifying spp?	0	
	How w idespread (frequency of occurrence) are habitat modifying spp?	0	
FRAI SCORE (%)		**45.8**	
FRAI CATEGORY		**D**	
FRAI CATEGORY DESCRIPTION		**Largely Modified**	

Data and Information Availability, Confidence: 2
Fish ▪ Single site visit (August 2022). ▪ Very limited historic data for river system. ▪ 2013 desktop PES, EI-ES (DWA, 2013c) (including Fish.kml distribution maps). ▪ Atlas of Southern African Freshwater fishes (Scott et al., 2006). ▪ Reference Fish Frequency of Occurrence (FROC) Report (Kleynhans and Louw, 2007a).

Causes and sources

CAUSES	SOURCES	F[1]/NF[2]
Decreased overhanging vegetation as cover for fish result in decreased FROC of species with preference for these habitats. Loss of habitat also results in increased exposure to predators.	Increased bank erosion,	NF
Decrease in FROC and abundance of fish species with preference for rocky substrate (feeding and breeding habitats).	Increased catchment erosion.	NF
Slightly decreased water quality (increased turbidity) affect species with requirement for high water quality.	Increased turbidity (due to sedimentation, regular disturbance by livestock).	NF
Impact on longitudinal and lateral migration success of most species.	Catchment erosion and sedimentation resulting in loss of pool depths (too shallow for movement of especially larger fish species)	NF

1 Flow related 2 Non Flow related

9.3 REFERENCES

Dallas, H.F. (2007) River Health Programme: South African Scoring System (SASS) Data Interpretation Guidelines. Prepared for Institute of Natural Resources and Departments of Water Affairs and Forestry.

Dickens, C. and Graham, M. (2001) South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. River Health Programme Web Page.

Kambikambi, M.J., Kadye, W.T. and Chakona, A. () Allopatric differentiation in the *Enteromius anoplus* complex in South Africa, with the revalidation of *E. cernuus* and *E. oraniensis*, and description of a new species, *E. mandelai* (Teleostei: Cyprinidae).

Kleynhans, C.J. (2002) Fish Intolerance ratings. Personal electronic communication of proceedings resulting from the national fish workshop held at the WRC during 2001.

Kleynhans, C.J. (2003) National Aquatic Ecosystem Biomonitoring Programme: Report on a National Workshop on the use of Fish in Aquatic System Health Assessment. NAEBP Report Series No. 16. Institute for Water Quality Studies, DWAF, Pretoria. South Africa.

Kleynhans, C.J., Thirion, C. and Moolman, J. (2005) *A Level I River Ecoregion classification System for South Africa, Lesotho and Swaziland.* Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

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 Commision and Dpartment of Water Affairs and Forestry report. WRC Report No. TT 329/08.

Kleynhans, C.J. (2007) Module D: Fish Response Assessment Index in River Ecoclassification Manual for Ecostatus determination (Version 2). Joint Water Research Commision and Dpartment of Water Affairs and Forestry report. WRC Report No. TT 330/08.

Kotze, P.J. (2002) An investigation into the Ecological Integrity of the Klip River (Gauteng) and the development of a Sensitivity-weighted Index of Biotic Integrity (SIBI). Draft Ph. D. Thesis. Rand Afrikaans University, South Africa.

Niehaus, B.H. (1996) An Ecological Investigation of the Aquatic vertebrates below the proposed Mohale Dam wall in the Senqunyane River, Lesotho, with emphasis on the Rock Catfish (Austroglanis sclateri). Ms. Sc. Thesis, Rand Afrikaans University, JHB, RSA.

Addendum A: SASS5 and IHAS results for site EWR Makhaleng (24 August 2022)

Taxon	Common name	EWR Makhaleng		
		Veg	GSM	Total
Baetidae 1 sp.	Small minnow flies	-	B	B
Baetidae 2 spp.	Small minnow flies	B	-	B
Caenidae	Cainflies	1	A	A
Heptageniidae	Flat-headed mayflies	1	-	1
Gomphidae	Dragonflies	-	A	A
Veliidae*	Broad-shouldered water strid	A	-	A
Hydropsychidae 1sp.	Caseless caddisflies	A	-	A
Gyrinidae (adults*)	Whirligig beetles	A	-	A
Chironomidae	Midges	1	A	A
Simuliidae	Black flies	A	-	A
Total SASS5 score		46	18	52
No. of families		8	4	9
ASPT		5.75	4.50	5.78
Total IHAS				52
IHAS - Habs sampled				30
IHAS - Stream condition				22
Suitability score		3	9	12

High requirement for unmodified water quality

Moderate requirement for unmodified water quality

Low requirement for unmodified water quality

Very low requirement for unmodified water quality

Sampling Habitat	EWR Makhaleng	
	Desc	**Score**
Stones In Current (SIC)		
Total length of white water rapids (ie: bubbling water) (in meters)	none	0
Total length of submerged stones in current (run) (in meters)	none	0
Number of separate SIC area's kicked	0	0
Average stone sizes kicked (in cm's)	none	0
Amount of stone surface clear (in %)	n/a	0
Protocol: time spent actually kicking SIC's (in mins)	none	0
SIC score (max 20)		0
Vegetation (VEG)		
Length of fringing vegetation sampled (banks) (in meters)	>2	5
Amount of aquatic vegetation/algae sampled (in square meters)	0-0.5	1
Fringing vegetation sampled in	mix	5
Type of veg. (percent leafy as apposed to stems/shoots)	1-25	2
Veg score (max 15)		13
Other Habitat / General (O.H.)		
Stones Out Of Current (SOOC) sampled (in square meters)	none	0
Sand sampled (in minutes)	>1	5
Mud sampled (in minutes)	>0.5	4
Gravel sampled (in minutes)	0-0.5	1
Bedrock sampled (all = no SIC, sand, gravel)	none	0
Algal presence (m^2)	isolated	4
Tray identification	correct	3
O.H. score (max 20)		17
Sampling habitat totals (max 55)		30
Stream Condition		
Physical		
River make up	2 mix	4
Average width of stream (in meters)	>10	1
Average depth of stream (in meters)	0.5	4
Approximate velocity of stream	medium	3
Water colour	discoloured	3
Recent disturbances	none	5
Bank/Riparian vegetation	grass	2
Surrounding impacts	erosion	0
Left bank cover (rocks and vegetation) (in %)	0-50	0
Right bank cover (rocks and vegetation) (in %	0-50	0
Stream condition total (max 45)		22
Total IHAS score (%)		52

Addendum B: Preference ratings of expected fish species for various velocity-depth and cover categories

Abbreviation	Scientific Name	English Common Name	Slow-Deep (<0.3 m/s; >0.5 m)	Slow-Shallow (<0.3 m/s; <0.5 m)	Fast-Deep (>0.3 m/s; >0.3 m)	Fast-Shallow (>0.3 m/s; <0.3 m)	Overhanging Vegetation	Bank Undercut	Substrate	Aquatic Macrophytes	Water Column	Trophic Specialization	Habitat Specialization	flow Requirement	Requirement: Unmodified Water	Average Overall Intolerance Rating
ASCL	AUSTROGLANIS SCLATERI (BOULENGER, 1901)	ROCK-CATFISH	3.40	2.30	2.30	3.80	0.30	3.50	4.40	0.10	0.90	2.90	2.30	3.20	2.60	2.70
BAEN	LABEOBARBUS AENEUS (BURCHELL, 1822)	SMALLMOUTH YELLOWFISH	3.50	2.50	3.50	4.00	0.70	1.50	4.00	2.00	4.00	2.50	1.80	3.30	2.50	2.50
BANO	BARBUS ANOPLUS WEBER, 1897	CHUBBYHEAD BARB	4.10	4.30	0.90	2.50	4.00	2.70	2.30	3.20	1.10	2.80	2.80	2.30	2.60	2.60
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)	SHARPTOOTH CATFISH	4.30	3.40	1.20	0.80	2.80	2.90	2.80	3.00	2.60	1.00	1.20	1.70	1.00	1.20
LCAP	LABEO CAPENSIS (SMITH, 1841)	ORANGE RIVER LABEO	4.20	3.00	3.30	2.50	0.50	2.00	4.20	1.50	3.20	3.40	3.10	3.50	2.80	3.20

10 SPECIALIST APPENDIX: RIPARIAN VEGETATION

10.1 RIPARIAN VEGETATION PES

10.1.1 Introduction

The riparian zone is the interface between terrestrial and aquatic ecosystems. Plant communities along river margins are called riparian vegetation and are characterized by hydrophilic and phreatophytic plants to greater or lesser degrees. Riparian zones are significant in ecology, environmental management, and civil engineering because of their role in soil conservation, their biodiversity, and the influence they have on aquatic ecosystems. Riparian zones have frequently been referred to as interfaces, which possess specific physical and chemical attributes, biotic properties, and energy and material flow processes, and are unique in their interactions with adjacent ecological systems (Risser, 1995; Naiman & Décamps, 1997). They operate as both ecosystem drivers (flood attenuation, sediment dynamics, instream and riparian habitat provision) and biotic responses (**Table 7-1**). As such, the riparian zone is critical to any assessment of potential impacts on a stream, river, wetland or drainage channel.

Table 10-1 Uses and Importance of the riparian zone

Riparian zone Use	References
Control energy and material flux, longitudinally and between adjacent landscapes	Holland *et al.*, 1991; Hansen & di Castri 1992; Risser, 1995; Naiman & Décamps, 1997.
Are potentially sensitive sites for interactions between biological populations and their controlling variables	Holland *et al.*, 1991; Hansen & di Castri 1992; Risser, 1995; Naiman & Décamps, 1997.
Possess an unusually diverse array of species and environmental processes	Holland *et al.*, 1991; Hansen & di Castri 1992; Risser, 1995; Naiman Décamps, 1997; Naiman *et al.*, 1993; 1997.
Maintain critical habitat for rare and threatened species	Holland *et al.*, 1991; Hansen & di Castri 1992; Risser, 1995; Naiman & Décamps, 1997.
Are refuge and source areas for pests and predators, especially alien plant species	Holland *et al.*, 1991; Nilsson *et al.*, 1991; Hansen & di Castri 1992; Risser, 1995; DeFerrari & Naiman , 1994; Naiman & Décamps, 1997; Rountree, 1991.
Are corridors for longitudinal migration	Décamps *et al.*, 1987; Schneider & Sharitz, 1988; Holland *et al.*, 1991; Hansen & di Castri 1992; Risser, 1995; Machtans *et al.*, 1996; Pollock *et al.*, 1997; Naiman & Décamps, 1997.
Are vehicles for the mass movement of materials through the landscape	Griffiths, 1980; Hupp & Simon, 1986; Myers & Swanson, 1992; Beeson & Doyle, 1995; Naiman & Décamps, 1997.
Influence channel morphology and dynamics	Griffiths, 1980; Hupp & Simon, 1986; Myers & Swanson, 1992; Beeson & Doyle, 1995; Naiman & Décamps, 1997.

Riparian zone Use	References
Directly affect sediment dynamics via riparian vegetation	Lowrance *et al.*, 1986; Hubbard *et al.*, 1990; Abt *et al.*, 1994 .
Alter channel hydraulics	Nakamura & Swanson, 1993; Hupp *et al.*, 1995.
Influence river / stream microclimate	Naiman & Décamps, 1997; Brosofske *et al.*, 1997.
Are key landscape components in maintaining biological connections along extended and dynamic environmental gradients	Nilsson *et al.*, 1991; Naiman *et al.*, 1993; Pollock *et al.*, 1997.
Are sources of nourishment, for aquatic organisms and herbivorous fauna	Weigelhofer & Waringer, 1994.
Act as filters in the landscape	Triska *et al.*, 1993a, 1993b.
Are sources of specialized habitat	Malanson 1993; Naiman & Décamps, 1997.
Reduce / control flooding	Tabacchi *et al.*, 2000.
Improve water quality	Dosskey *et al.*, 2010.
Water storage	Naiman & Décamps, 1997.
Runoff control: The physical impact of living and dead plants (includes the role of pioneer vegetation, litter mats in small streams, coarse woody debris accumulations in the main channel, riparian corridor as a dissipative structure, riparian vegetation and hydraulic connectivity, effects of the rhizosphere, fluxes between the floodplain and the river, physical interactions between atmospheric water and plants)	Tabacchi *et al.*, 2000.

10.1.2 Available Information

The following sources of data / information were available and applicable to riparian zones and wetlands:

- National Biodiversity Assessment (new wetland map, 2018)
    - Diversity of wetland Hydrogeomorphic (HGMs) within quinary catchment - this is a count of different HGMs within the SQR excluding estuaries.
    - Overall extent of wetlands within quinary catchment (Ha per SQR).
- NFEPA (2011)
    - RAMSAR status – any wetland designated as a RAMSAR site would automatically be assigned a VERY HIGH EI.
    - Wetland FEPA status – any wetland denoted as a FEPA wetland was assigned a HIGH EI.
    - Wetland Cluster – does any of the wetlands within the SQ form part of a desigbated NFEPA wetland cluster.
- Habitats for rare and endangered species including:

- Cranes - wetlands (excluding dams) with the majority of its area within a sub-quaternary catchment that has sightings or breeding areas for threatened Wattled Cranes, Grey Crowned Cranes and Blue Cranes.
- Amphibians - wetlands within 500 m of an IUCN threatened frog / toad point locality.
- Water Birds - wetlands within 500 m of a threatened waterbird point locality.

- Known important peatland sites.
- Important Birding Areas (2015) - The Important Bird and Biodiversity Areas (IBA) Programme is a BirdLife International Programme to conserve habitats that are important for birds. These areas are defined according to a strict set of guidelines and criteria based on the species that occur in the area. The Important Bird Areas of Southern Africa directory was first published 1998 and identified within South Africa 122 IBAs. In September 2015 a revised IBA Directory was published by BirdLife South Africa. All these IBAs were objectively determined using established and globally accepted criteria. An IBA is defined by the presence of any of the following bird species in a geographic area: Bird species of global or regional conservation concern, assemblages of restricted-range bird species, assemblages of biome-restricted bird species, and concentrations of numbers of congregatory bird species. If any of the wetlands within the SQR overlap with a designated IBA then they are rated accordingly (see below).
- Regions / Centres of Plant Endemism (Van Wyk & Smith, 2001) – wetland that occur in regions or centres of plant endemism
- Region Conservation Plans including:
  - KwaZulu Natal - Terrestrial Critical Biodiversity Areas (CBAs) in KZN developed 2010. This is an update to the 2007 terrestrial C-Plan (EKZNW, 2010)
  - Mpumalanga - Mpumalanga Biodiversity Conservation Plan (2006, 2014) comprising the Terrestrial Biodiversity and Freshwater Assessment (Lötter & Ferrar, 2006; Lötter, 2014; MTPA, 2014)
- PES-EI-ES Assessment (DWS, 2014): Department of Water and Sanitation. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Primary Catchments in South Africa. Primary: catchments insert catchment No. here. Compiled by RQIS-RDM.
- National Spatial Biodiversity Assessment (2005)

- Updated vegetation map (Mucina & Rutherford, 2006, 2012, 2018 updates): spatial data and metadata with detailed vegetation type descriptions.
- Level 1 and 2 Ecoregions.
- Threatened wetland species distribution data e.g. cranes, plants.

10.2 METHODS

The riparian vegetation was assessed to determine a PES for both the riparian zone as a whole as well as for each of the sub-zones within the riparian zone. These sub-zones include the marginal, lower and upper zones (see **Table 7-2** for definitions). This is important since riparian vegetation distribution and species composition differs on different sub-zones, which has implications for flow requirements and flow-related impacts. **Figure 7-1** shows a schematic of the different sub-zones within the riparian zone. These sub-zones form the basis of the assessment, and all surveys are repeated on each of the following: Marginal zone, lower zone, upper zone (ephemeral features within the macro-channel floor), MCB (macro-channel bank) and floodplain (should this exist). Note, other zones or pertinent features that facilitate vegetation zonation may be prevalent at a site, and should be named and assessed as the others. The PES of the riparian zone is then assessed using the Riparian Vegetation Response Assessment Index (VEGRAI) level 4 (Kleynhans *et al.*, 2007; with modifications). A brief overview is given below for clarity.

Table 10-2 Description of riparian vegetation Sub-zones

	Marginal	Lower	Upper
Alternative descriptions	Active features Wet bank	Seasonal features Wet bank	Ephemeral features Dry bank
Extends from	Water level at low flow	Marginal zone	Lower zone
Extends to	Features that are hydrologically activated for the greater part of the year	Usually a marked increase in lateral elevation	Usually a marked decrease in lateral elevation
Characterized by	See above	Geomorphic features that are hydrological activated on a seasonal basis. May have different species than marginal zone	Geomorphic features that are hydrological activated on an ephemeral basis. Presence of riparian and terrestrial species Terrestrial species with increased stature

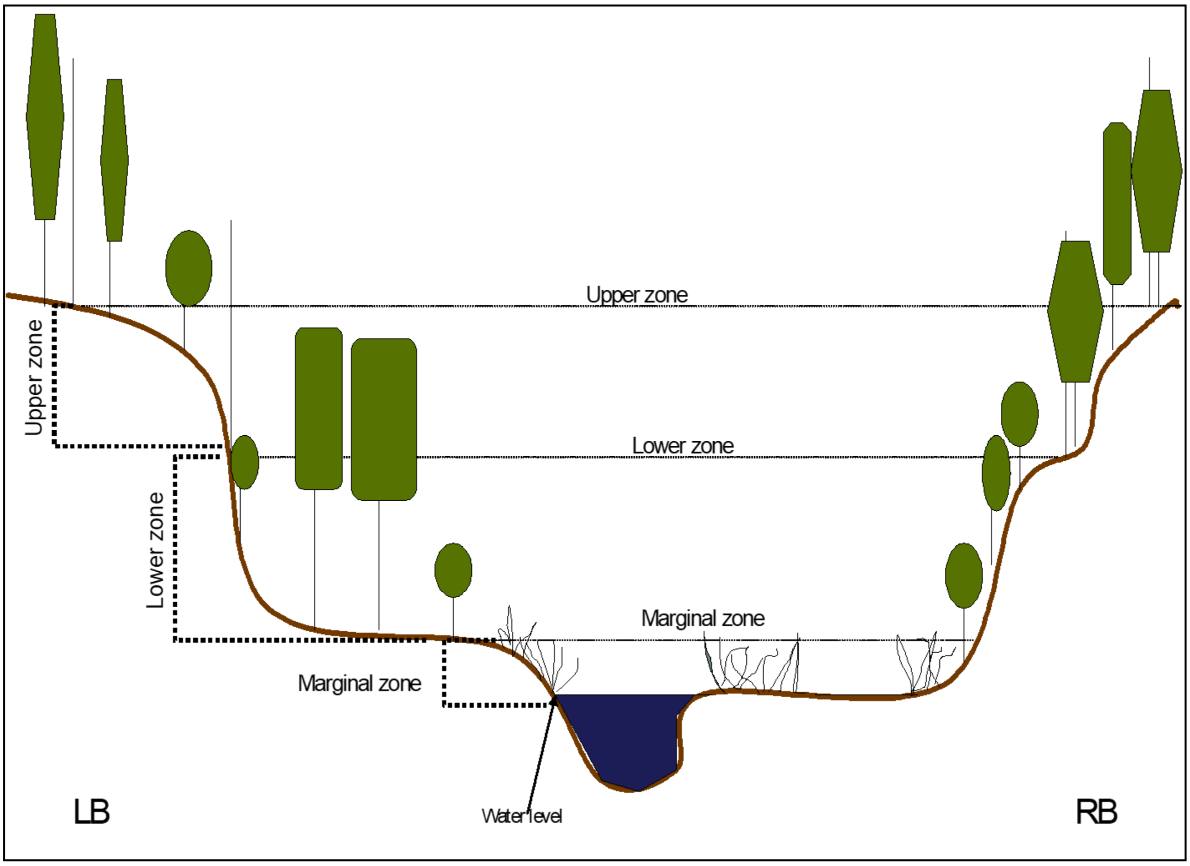

Figure 10-1 Schematic representation showing sub-zones within the riparian zone (LB = left bank, RB = right bank)

Since all VEGRAI assessments are relative to the natural unmodified conditions (reference state) it is necessary and important to define and describe the reference state for each site. This is done (in part) before going into the field using historic aerial imagery, present and historic species distributions, general vegetation descriptions of the area, any anecdotal data available, knowledge of the area and comparison of the site characteristics to other comparable sections of river that might be in a better state. Armed with this information the reference (and present state) is quantified on site whereby the assessor reconstructs and quantifies the reference state from the present state by understanding how visible impacts have caused the vegetation to change and respond.

Impacts to riparian vegetation at the site are then described and rated. It is important to distinguish between a visible/known impact (such as flow manipulation) and a response of riparian vegetation to said impact. If there is no response by riparian vegetation the impact is noted but not rated since it has no visible/known effect. This is often the case with water quality for example. Ratings of impacts are as follows: No Impact = 0; Small impact = 1; Moderate impact = 2; large Impact = 3; Serious impact = 4; Critical impact = 5.

Once the riparian zone and sub- zones have been delineated, the reference and present states have been described and quantified (aerial cover is used) and a species checklist for the site has been compiled, the VEGRAI metrics are rated and qualified. **Table 7-3** outlines metrics that are assessed.

Table 10-3 Metrics that are rated in VEGRAI 4 (with modification)

Vegetation Components	Level 3	Level 4	Modification
Woody	**Cover** **Abundance** **Species composition**	**Cover** **Abundance** **Species composition** **Recruitment** **Population structure**	**Cover** **Abundance** **Species composition** **Recruitment** **Population structure** **Vertical structure**
Non-woody (grasses, sedges, dicot herbs)	Cover Species composition	Cover Species composition	Cover Abundance Species composition
Specialized category (e.g. reeds, Palmiet)			Cover Abundance

10.3 RESULTS: MAKHALENG PES

10.3.1 Site Information

General information regarding the VEGRAI assessment site is shown in **Table 7-4**.

Table 10-4 General site information

Date of Assessment:	August 24, 2022
River (Site):	Makhaleng
Longitude (decimal degrees)	27.4316795
Latitude (decimal degrees)	-30.0930315
PES:	D

Site Layout: 	The Makhaleng River site assessment was done on both banks from the A2 bridge downstream to the first set of large Grey Poplars as the river takes the bend (indicated by red bars, see left).
Looking US: 	Looking DS: 
Quaternary Catchment:	D15F
Site Slope:	0.001
Geo Class:	F
River Type:	Lowland River
Ecoregion:	Drakensberg- Maluti Highlands (15.01)
Threatened Ecosystems:	None
Regions / Centres of Plant Endemism:	Site falls within the Drakensberg Alpine Centre of plant endemism

10.3.2 Sub-zones

The riparian zone was divided into 3 sub-zones for the VEGRAI assessment: The marginal zone, the flood bench (FB) and the macro-channel bank (MCB). **Figure 7-2** shows the field sketch of the sub-zones and general plant species distribution within sub-zones.

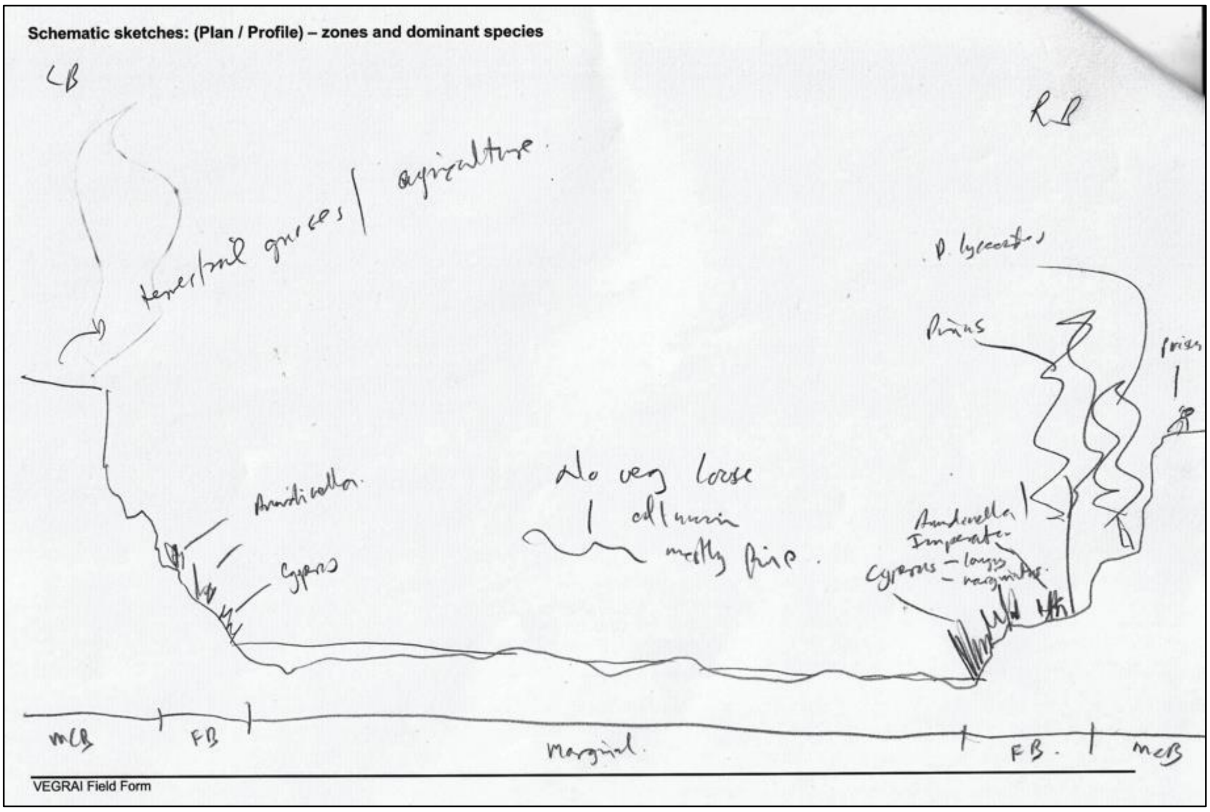

Figure 10-2 Schematic sketch of the riparian profile showing layout of the sub-zones and plant species distribution

10.3.3 Species

A total of 26 plant species were recorded within the riparian zone, of which 16 were indigenous and 10 alien (refer to **Appendix 1 (Chapter 10)** for a full species list).

10.3.4 Impacts at the Site

Table 7-5 outlines a summary of the impacts within sub-zones observed at the site.

Table 10-5 Observed impacts affecting the riparian vegetation at the Makhaleng site as at the date of assessment

IMPACTS	INTENSITY	EXTENT	NOTES
Marginal zone			
Vegetation Removal	3	5	Erosion of the zone with loss of integrity, fine alluvial deposits and high grazing and trampling pressure.

IMPACTS	INTENSITY	EXTENT	NOTES
Alien Species Invasion	0	5	Alien cover up to 2%. Negligible impact in the zone.
Water Quantity	0	5	No response by vegetation discerned.
Water Quality	3	5	Increased sediment loads due to erosion of overgrazed areas.
Erosion	3	5	Extensive undercutting of banks causing bank slumping.
Flood bench			
Vegetation Removal	3	5	Extensive overgrazing, trampling pressure and selected woody removal.
Alien Species Invasion	2	2	Alien cover up to 10%. Minimal, some Wattle and annual aliens weeds.
Water Quantity	0	5	No response discernable in vegetation.
Water Quality	1	5	Increased sediment loads likely due to extensive erosion.
Erosion	3.5	4	Extensive erosion due to overgrazing and high trampling pressure.
MCB			
Vegetation Removal	3	5	Extensive overgrazing, trampling pressure and selected woody removal.
Alien Species Invasion	2	2	Alien cover up to 15%. Poplar, Wattle and Wild tobacco.
Water Quantity	0	5	no response noted in riparian vegetation
Water Quality	0	5	no response noted in riparian vegetation
Erosion	2	4	Extensive erosion due to overgrazing and high trampling pressure.

10.3.5 Reference State

The site falls within the Zastron Moist Grassland Vegetation type within the Grasland Biome (Mucina & Rutherford, 2006, 2012, 2018). This unit comprises undulating plains, broken in places due to sandstone outcrops forming extensive terraces. These plains bear a mosaic of moist open sour grassland with affinity to Eastern Free State Sandy Grassland, on elevated areas above sandstone outcrops and Eastern Free State Clay Grassland in low-lying eroded areas as well as mudstone outcrops. Important taxa include: Graminoids: *Aristida congesta (d), Cymbopogon pospischilii (d), Digitaria argyrograpta (d), Eragrostis chloromelas (d), Microchloa caffra (d), Setaria sphacelata (d), Themeda triandra (d), Andropogon appendiculatus, Brachiaria serrata, Cynodon incompletus, Cyperus obtusiflorus var. obtusiflorus, Elionurus muticus, Eragrostis capensis, E. curvula, E. lehmanniana, E. plana, E. racemosa, Festuca scabra, Harpochloa falx, Heteropogon contortus, Panicum gilvum, Sporobolus africanus, Tetrachne dregei, Trichoneura grandiglumis, Triraphis andropogonoides.* Herbs*: Berkheya onopordifolia var. onopordifolia, Dianthus thunbergii, Gazania krebsiana subsp. krebsiana, Helichrysum rugulosum, Hermannia depressa, Limeum* *argute-carinatum, Nolletia ciliaris, Salvia stenophylla, Senecio erubescens var. crepidifolius, Trichogyne paronychioides, Wahlenbergia denticulata.* Geophytic Herb*: Moraea pallida*. Low Shrubs*: Helichrysum dregeanum (d), Anthospermum rigidum subsp. pumilum, Chrysocoma ciliata, Felicia muricata, Helichrysum asperum var. albidulum, H. niveum, Selago saxatilis, Senecio burchellii*. This vegetation unit is considered Vulnerable with none conserved in statutory conservation areas and only very small portion protected in a private Vulture Conservation Area. Almost a third is already transformed by cultivation or by urban sprawl. Historical satellite data show that besides the removal of few individual trees there has been little change in vegetation from 2004 to 2017 (**Table 7-6**).

In terms of the riparian sub-zones, the marginal zone would have been less eroded with less steep and more consolidated habitats that would support mostly non-woody riparian obligate grasses and sedges with scattered *Salix mucronata*. This scattered woody component would have been represented by adults and juveniles. The flood bench would have been more extensive and less eroded, dominated by dense non-woody vegetation and scattered riparian tree species (*Salix mucronata* mainly). Aerial cover would have been higher and alien species would be absent, especially *Pinus halepensis*, which prevents the development of understorey vegetation. The macro-channel bank would have been steep but with less erosion and more extensive grassed cover, with a scattered tree line, with a greater density and stature in the woody component, species as present except for the alien species.

Table 10-6 Satellite imagery from Google Earth © showing the Makhaleng site in 2004 and 2021

May 14, 2004	September 17, 2021
	
Besides the removal of few individual trees there has been little change in vegetation from 2004 to 2017.	

10.3.6 Present State

A description of the present state of sub-zones within the riparian zone is shown in **Table 7-7** and ratings of the applicable metrics are shown in **Table 7-8** for the marginal zone, **Table 7-9** for the flood bench, and **Table 7-10** for the macro-channel bank.

Table 10-7 Description of the present state of different riparian sub-zones

Marginal Zone: 	The marginal zone was mainly comprised of expanses of unconsolidated fine alluvial deposits within the broader braided channel and did not support vegetation. The only vegetation along the water's edge was where portions of the flood bench had slumped into the channel. Dominant habitats included unvegetated expanses of unconsolidated, mostly fine sand deposits, and a narrow portion of steep eroded bank along the active channel, but elevated due to undercutting. Dominant species included *Cyperus marginatus, C. longus, Berulla erecta* and *Isolepis stacea.*

Flood Bench: 	The flood bench is mostly consolidated medium and fine sand, mostly well vegetated with grasses and sedges but high levels of grazing and trampling pressure has caused pathways and resultants erosion. Erosion of the macro-channel banks has also deposited additional sediment to the zone and the bench is being undercut from the active channel and is slumping into the channel in places. Dominant species include *Cyperus marginatus, C. longus, Arundinella napalensis, Imperata cylindrica, Diospyros lyceoides* and a *few Salix mucronata* juveniles. Alien species include *Pinus halepensis, Nicotiana glauca* and *Acacia mearnsii.*
Macro-channel Bank: 	The macro-channel bank is comprised of short but steep banks, highly eroded and with loss of structural integrity and showing signs of extensive overgrazing and trampling pressure. Dominant species include *Eragrostis gummiflua, Felicia filifolia, Diospyros lyceoides, Artemisia affra* and alien species including *Nicotiana glauca* and *Acacia mearnsii.*

Table 10-8 Ratings of response metrics for the Marginal zone at the Makhaleng site

VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE	REASONING
WOODY	COVER	Y	3.5	3.0	Largely absent due to removal
	ABUNDANCE	N			Too low to assess
	POPULATION STRUCTURE	Y	3.5	3.0	Only juveniles present
	VERTICAL STRUCTURE	Y	3.5	3.0	Only juveniles present, therefore much shorter structure than expected
	RECRUITMENT	N			Only juveniles were present, rated in population structure
	SPECIES COMPOSITION	Y	1.0	3.0	As expected.
	MEAN		2.9	3.0	
SPECIAL CATEGORY (e.g. Reeds, Palmiet)	COVER	N			No reeds were present, and none are expected
	ABUNDANCE	N			
	MEAN				
NON-WOODY (Excl. Reeds)	COVER	Y	4.0	3.0	Largely denuded due to overgrazing and erosion
	ABUNDANCE	N			Mostly rhizomatous species so not rated
	SPECIES COMPOSITION	Y	1.0	3.0	Close to reference state
	MEAN		2.5	3.0	

Table 10-9 Ratings of response metrics for the Flood Bench at the Makhaleng site

VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE	REASONING
WOODY	COVER	Y	2.0	3.0	Two third decrease from expected
	ABUNDANCE	N			Too low to assess
	POPULATION STRUCTURE	Y	3.0	3.0	Only juveniles present
	VERTICAL STRUCTURE	Y	3.5	4.0	Since only juveniles represent the population so the stature is drastically reduced
	RECRUITMENT	N			Only juveniles were present, rated in population structure
	SPECIES COMPOSITION	Y	1.5	3.0	Largely intact, few alien species.
	MEAN		2.5	3.3	
SPECIAL CATEGORY (e.g. Reeds, Palmiet)	COVER	N			No reeds were present and none are expected
	ABUNDANCE	N			
	MEAN				
NON-WOODY (Excl. Reeds)	COVER	Y	3.0	3.0	Reduced by overgrazing and resultant erosion.
	ABUNDANCE	N			Mostly rhizomatous species so not rated
	SPECIES COMPOSITION	Y	2.0	3.0	Dicot forbs largely absent. Annual aliens.
	MEAN		2.5	3.0	

Table 10-10 Ratings of response metrics for the Flood Bench at the Makhaleng site

VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE	REASONING
WOODY	COVER	Y	3.0	4.0	100% decrease of riparian species. Due to targeted wood collection and browsing
	ABUNDANCE	N			
	POPULATION STRUCTURE	Y	1.5	3.0	Several cohorts present
	VERTICAL STRUCTURE	Y	1.5	3.0	Close to reference
	RECRUITMENT	N			
	SPECIES COMPOSITION	Y	2.0	3.0	Some aliens

	MEAN		2.0	3.3	
SPECIAL CATEGORY (e.g. Reeds, Palmiet)	COVER	N			No reeds were present and none are expected
	ABUNDANCE	N			
	MEAN				
NON-WOODY (Excl. Reeds)	COVER	Y	3.5	3.0	Reduced by overgrazing and erosion
	ABUNDANCE	N			Not an accurate assessment for grasses
	SPECIES COMPOSITION	Y	1.5	3.0	Close to reference, with some weeds
	MEAN		2.5	3.0	

10.3.7 PES Calculation and Riparian Vegetation Summary

The overall PES calculation for the riparian vegetation at Makhaleng is shown in **Table 7-11** and a summary of the woody and non-woody vegetation distribution in the riparian zone is show in **Figure 7-3** and **Figure 7-4** respectively. The overall PES score was 48 7% which equates to a D category for vegetation.

Table 10-11 PES calculation of the Makhaleng riparian zone

LEVEL 4 ASSESSMENT	**Makhaleng**				**24 August 2022**	
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**REASONING**
Marginal Zone	47.9	39.2	3.0	1.0	82.0	Weighted according to extent
Flood Bench	50.0	5.7	3.1	2.0	11.5	Weighted according to extent
Macro-channel Bank	56.3	3.7	3.1	3.0	6.6	Weighted according to extent
LEVEL 4 VEGRAI (%)						48.7
VEGRAI Ecological Category						**D**
AVERAGE CONFIDENCE						3.1
	Sub-zone					
	Marginal Zone	**Flood Bench**	**Macro-channel Bank**	**0.0**	**0.0**	**0.0**
VEGRAI % (Zone)	47.9	50.0	56.3	not assessed		

EC (Zone)	D	D	D			
Confidence (Zone)	3.0	3.1	3.1			
Main cause of PES:						
The riparian zone at this site is heavily impacted by overgrazing and trampling pressure and this has facilitated extensive and severe erosion of banks with high sediment loads and extensive fine sand deposits forming in-channel, denuded bars and a braided channel. Banks in the marginal zone are being undercut and extensive slumping of the flood bench into the channel is prevalent						

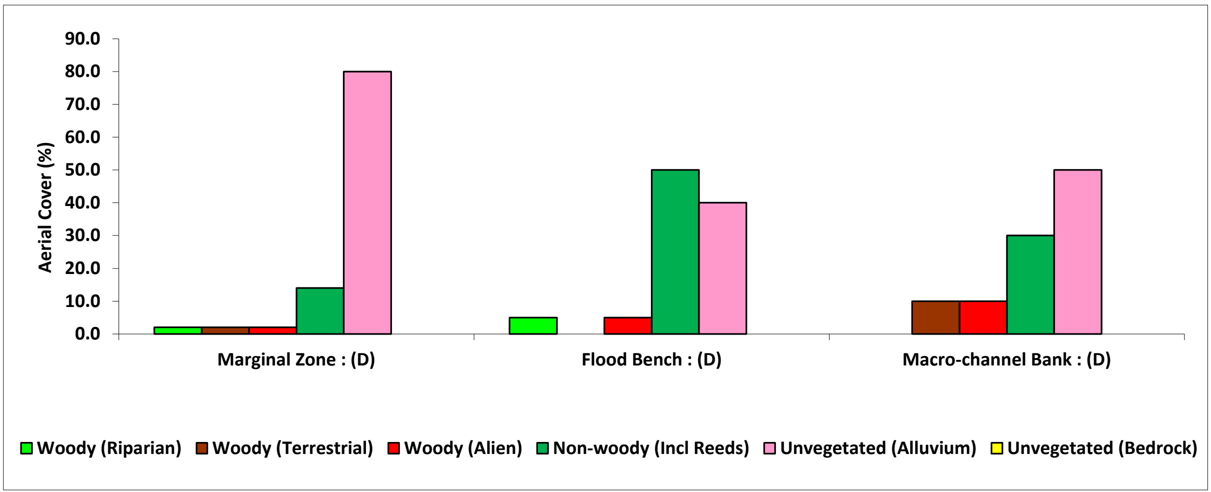

Figure 10-3 Summary of woody vegetation distribution in the riparian zone

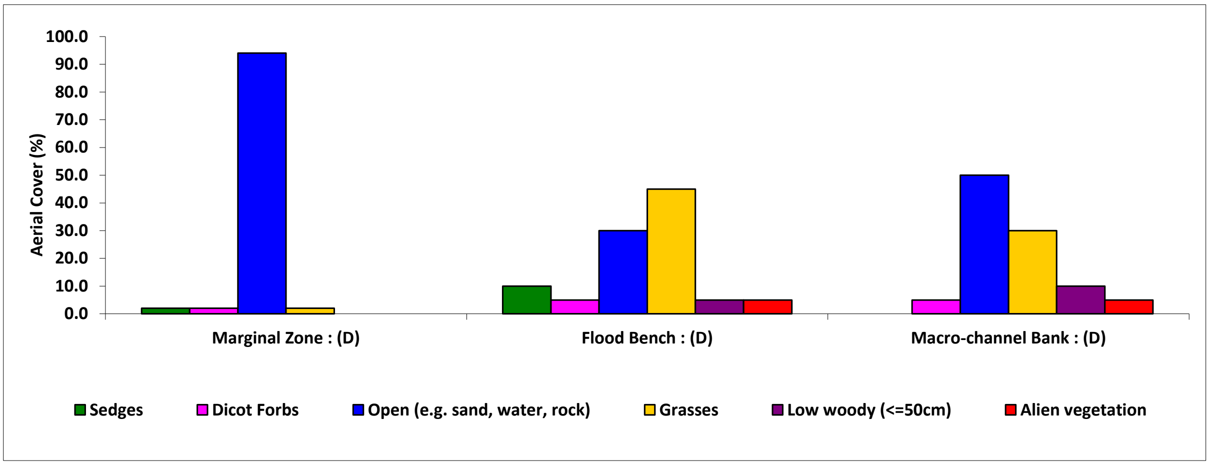

Figure 10-4 Summary of non-woody vegetation distribution in the riparian zone

10.4 DETERMINATION OF ENVIRONMENTAL FLOWS FOR RIPARIAN VEGETATION

10.4.1 Methods

The basis for determining the e-flows for riparian vegetation is to survey key riparian indicator sub-populations at the same time, and as close to as possible, as the hydraulic profile of the transect/s at the site. This enables accurate placement of the upper and lower limits of chosen sub-populations onto the profile. It is then a simple matter to use the rating curve or look-up tables for each transect to determine the flows at which sub-populations become activated (activation discharge - water level is at the lower limit of the sub-population, inundation at 0%) or inundated, or to calculate proportions of sub-population inundation. Similarly, this can be done for sub-zones or features within the riparian zone. This approach takes its roots from the Building Block Methodology (BBM, King and Louw, 1998), which is a holistic approach that requires identification of a single predetermined condition, usually the present state. A single flow regime is then determined to facilitate the maintenance of the present state. From there flows may be adjusted to facilitate the maintenance of a different state, the recommended ecological category for example. **Table 7-12** outlines generic indicators frequently used to determine environmental flow for riparian vegetation, and **Table 7-13** their general responses to flow.

Table 10-12 Generic riparian zone indicators that are frequently used to determine environmental flows

Indicator	Reasons for selection as indicator
Algae	Algae provide food for instream fauna (fish and invertebrates) and affect habitat quality.
Aquatic vegetation	Aquatic vegetation provide habitat, including protection and breeding sites, and food for fish and invertebrates.
Marginal zone graminoids	This guild includes grasses, sedges and reeds and is important for bank stabilisation, habitat creation for aquatic fauna (both inundated instream and overhanging vegetation) and for food (seeds, fruits, rotting leaf material).
Marginal zone woody vegetation	Marginal zone trees are important for bank stabilization, flood attenuation and provide overhanging shelter to instream fauna, particularly fish.
Lower zone / Seasonal feature graminoids	Like marginal zone graminoids this guild includes grasses, sedges and reeds growing in the lower zone. Non-woody vegetation in this zone is important for bank stabilization, grazing for animals and birds, and food and habitat for fish spawning during flooding.
Lower zone / Seasonal feature woody vegetation	Lower zone trees are important for bank stabilization, flood attenuation and the provision of food and habitat (including nesting sites) for riparian fauna.
Seasonal feature graminoids	This guild includes grasses, sedges and reeds and is important for bank stabilisation, habitat creation and for food (seeds, fruits, rotting leaf material).
Seasonal feature woody vegetation	Seasonal feature trees and shrubs are important for bank and sediment stabilization, flood attenuation and provide shelter and nesting sites for riparian fauna.
Flood feature graminoids	This guild includes grasses, sedges and post flood non-woody pioneers and is important for bank / sediment stabilisation and habitat creation.
Upper zone / Flood feature trees – riparian	Same function as lower zone trees but often more extensive in area and density and hence importance is elevated.

Upper zone trees – terrestrial	Terrestrialzation of the riparian zone occurs naturally to some extent but is kept at bay by the correct flooding regime, which affords the competitive edge to riparian trees. This indicator may be used as an integrity check for riparian zone structure and function.
Flood feature woody vegetation	Flood feature trees and shrubs are important for bank and sediment stabilization, flood attenuation and provide shelter and nesting sites for riparian fauna.
Terrestrial woody vegetation	These are woody species that are terrestrial and not considered riparian. Their presence in the riparian zone should be transient and may indicate potential; terrestrialisation

Table 10-13 General responses to flow by generic indicators

Indicator	Definition	Predicted change	References
Algae	Aquatic, filamentous or benthic, green or brown.	Algae is favoured by reduced water depth and velocity. Higher flows and floods tend to scour the indicator.	Dallas and Day (2004)
Marginal zone graminoids	Grasses, sedges or reeds growing in the marginal zone	Winter base flows are important for survival while summer base flows for growth and reproduction. Small floods and freshets produce growth response and maintain reproductive success. Moderate to large floods will scour the indicator. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996)
Marginal zone trees	Trees or shrubs growing in the marginal zone.	Winter base flows are important for survival while summer base flows for growth and reproduction. Small floods and freshets produce growth response and maintain reproductive success. Moderate to large floods will scour the indicator. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996)
Lower zone / Seasonal feature graminoids	Grasses, sedges or reeds growing in the lower zone	Winter base flows are important for survival while summer base flows for growth and reproduction. Small to moderate floods produce growth response and maintain reproductive success. Large floods will scour the indicator and zero flow will cause desiccation stress. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996)
Lower zone / Seasonal feature woody vegetation	Trees or shrubs growing in the lower zone.	Winter base flows are important for survival while summer base flows for growth and reproduction. Small to moderate floods produce growth response and maintain reproductive success. Large floods will scour the indicator and zero flow will cause desiccation stress. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996)
Upper zone trees – riparian	Trees or shrubs growing in the upper zone that are by definition riparian.	Depth to soil moisture should not exceed 4 - 4.5 m. Zero flows may result in desiccation stress. Large floods are important for the maintenance of species diversity and recruiting opportunities.	Friedman and Lee (2002) Lite and Stromberg (2005) Leenhouts *et al.* (2005)

Upper zone trees – terrestrial	Trees or shrubs growing in the upper zone that are by definition terrestrial.	Terrestrialisation of the upper zone occurs naturally, but the correct flooding regime is required to retard the process and maintain riparian species. Large floods provide riparian species with the competitive advantage.	Friedman and Lee (2002)

It is critical however, that the assessor understands the characteristics (such as phenology, reproductive strategies, survival techniques, growth requirements, rooting depths, etc.) and flow requirements (summer and winter, base flow and flooding) of the indicator species used. Incorrect interpretation of requirements of riparian species will render the method of little use. In addition it is imperative that a holistic view of the riparian zone be taken. For example, when setting flows for upper zone species, marginal zone species may (usually) be detrimentally affected, but these dynamics maintain the overall structure and functioning of the riparian zone in the long term.

The flow regime that is determined consists of different components i.e. base flows (discharge and seasonality) and floods (seasonality, frequency, timing, duration, magnitude). Indicator sub-populations (that are surveyed onto the profile), together with hydraulics are used to determine base flow requirements for the wet and dry season. As a general guide, the dry season base flow should facilitate survival of marginal and lower zone vegetation while the wet season base flow should facilitate growth, reproduction and recruitment. For high flows and floods there are multiple functions for different flows. Different class floods (usually class 1 to 5 but could be more or less) are determined and defined according to each of the sub-population requirements, and for the riparian zone as a whole. General flood functions are applied to each sub-population with specific considerations. **Table 7-14** provides a general guideline for flood function and determination.

The following aims apply to all flood classes:

- To maintain existing vegetation composition in the riparian zone by maintaining the important components of natural variability in flow fluctuations.
- To stimulate reproduction and recruitment and maintain a range of size classes of dominant riparian species in perennial channels.
- To discourage encroachment of additional alien and terrestrial species in the riparian zone by periodic flooding.
- To maintain overall species and habitat heterogeneity in the riparian zone and prevention of dominance to the point of biodiversity loss.
- To prevent encroachment of the marginal zone vegetation towards the channel.

Table 10-14 General guideline of criteria to consider for flood determination

Flood Class	Frequency	Seasonality	Rationale
I	Usually from 3 - 6 event per year but depends on type of river (perennial, seasonal, ephemeral)	growing season (spring to summer)	Required to inundate marginal zone vegetation. Prevents establishment of terrestrial or alien species in the marginal zone. Provides recruitment opportunities in the marginal and lower zones. Stimulates growth and reproduction. Prevents encroachment of marginal zone vegetation towards the channel. Required during growing season (spread over several months).
II	Usually from 2 event per year but depends on type of river (perennial, seasonal, ephemeral)	summer	Required to flood marginal zone and lower portion of lower zone. Prevents establishment of terrestrial or alien species in marginal and lower zones. Stimulates growth and reproduction. Prevents encroachment of marginal zone vegetation towards the channel. Required during mid to late summer.
III	An annual flood	late summer	Required to inundate lower zone vegetation and activate upper zone vegetation. Similar functions to above in these zones. Maintain heterogeneity in the marginal zone.
IV	A flood that occurs every second or third year	late summer	Required to inundate lower portion of the upper zone. Similar functions to above. Scour marginal and lower zones, maintain vegetation patchiness and heterogeneity.
V	An infrequent flood that occurs every 5 years or less.	late summer	Required to inundate upper zone macro channel and some portion of the MCB. Similar functions to above. Scour marginal, lower and upper zones, maintain vegetation patchiness and heterogeneity.

10.4.2 Results

The riparian zone at this site was heavily impacted by overgrazing and trampling pressure and this has facilitated extensive and severe erosion of banks with high sediment loads and extensive fine sand deposits forming in-channel, denuded bars and a braided channel. Banks in the marginal zone were being undercut and extensive slumping of the flood bench into the channel is prevalent. The activation discharge for indicators is shown in **Table 7-15** and these were used to derive flow requirements (base and flood) for the vegetation component of the site **Table 7-16**. These flows contribute to the overall determination of e-flows for the site when amalgamated with flow requirements of other components (such as fish, invertebrates, and geomorphology).

Table 10-15 Activation discharge measurements (m^3/s) for indicator species / guilds at their lowest limit along the Makhaleng profile

Indicator Species / Guild	Min Activation Discharge (m^3/s)
Berulla erecta	10.6
Cyperus marginatus	24.9
Cyperus longus	24.9
Marginal zone graminoids	24.9
Salix mucronata	43.9
Arundinella nepalensis	79.9
Equisetum ramosissimum	79.9
Diospyros lycioides subsp. lycioides	369.1
Pinus halepensis	369.1
Imperata cylindrica	622.2

Table 10-16 Flood and base flow requirements for the vegetation component at the Makhaleng site as per site indicators

Generic Indicators	Specific Indicators	Requirement		
		Wet season base flow	Dry season base flow	Floods
Marginal zone graminoids	*Berula erecta*		Q = 3 - 5 in dry season months for 50% of the time	
Marginal zone graminoids	*Cyperus marginatus*	Q = 10 - 15 in wet season months for 50% of the time		Q = 25 - 30 three times per year
Marginal zone graminoids	*Cyperus longus*	Q = 10 - 15 in wet season months for 50% of the time		Q = 25 - 30 three times per year
Flood feature graminoids	*Arundinella napalensis*			Q >= 80 - 120 every year; Q >= 280 every 2 - 3 years
Flood feature graminoids	*Equisetum ramosissimum*			Q >= 80 - 100 every year
Upper zone / Flood feature trees – riparian	*Salix mucronata*			Q = 44 - 50 twice per year
Upper zone trees – terrestrial	*Diospyros lycioides subsp. lycioides*			Q >= 370+ every 5 years
Terrestrial / Alien woody vegetation	*Pinus halepensis*			Q >= 370+ every 5 years

10.5 SPECIES LIST

Species	Family	Common Name/s	Alien	Threat status
Acacia mearnsii	FABACEAE	Black Wattle	*	Not Evaluated
Artemisia afra var. afra	ASTERACEAE	Wormwood		LC
Arundinella nepalensis	POACEAE	River Grass		LC
Asparagus suaveolens	ASPARAGACEAE	Wild Asparagus		LC
Berula thunbergii	APIACEAE	Toothache Root		LC
Bidens pilosa	ASTERACEAE	Blackjack	*	Not Evaluated
Buddleja salviifolia	BUDDLEJACEAE	Sagewood		LC
Conyza bonariensis	ASTERACEAE	Horseweed	*	Not Evaluated
Cyperus longus	CYPERACEAE	Sweet Cyperus		LC
Cyperus marginatus	CYPERACEAE	Water reed		LC
Diospyros lycioides subsp. lycioides	EBENACEAE	Bluebush		LC
Equisetum ramosissimum	EQUISETACEAE			LC
Eragrostis gummiflua	POACEAE	Gum grass		LC
Felicia filifolia	ASTERACEAE	Draaibos		LC
Imperata cylindrica	POACEAE	Cottonwool Grass		LC
Isolepis setacea	CYPERACEAE			LC
Nicotiana glaucea	SOLANACEAE		*	Not Evaluated
Olea europaea subsp. africana	OLEACEAE	Wild Olive		LC
Pinus halepensis	PINACEAE	Aleppo Pine	*	Not Evaluated
Populus alba var. alba	SALICACEAE	White Poplar, Silver-leafed Poplar	*	Not Evaluated
Populus X canescens	SALICACEAE	Grey Poplar	*	Not Evaluated
Salix babylonica var. babylonica	SALICACEAE	Weeping Willow	*	Not Evaluated
Salix mucronata subsp. mucronata	SALICACEAE	Cape willow		LC
Tagetes minuta	ASTERACEAE	Khaki Weed	*	Not Evaluated
Xanthium strumarium	ASTERACEAE	Large Cocklebur	*	Not Evaluated
Xyris capensis	XYRIDACEAE			LC

10.6 REFERENCES

Abt, S.R., Clary, W.P., Thornton, C.I. (1994) Sediment deposition and entrapment in vegetated streambeds. J. Irrig. Drain. Engin. 120:1098–113.

Beeson, C.E., Doyle P.F. (1995) Comparison of bank erosion and vegetated and nonvegetated channel bends. Water Res. Bull. 31:983–90.

Brosofske, K.D., Chen, J., Naiman, R.J., Franklin, J.F. (1997) Effects of harvesting on microclimate from small streams to uplands in western Washington. Ecol. Appl.

DeFerrari, C.M., Naiman, R.J. (1994) A multiscale assessment of the occurrence of exotic plants on the Olympic Peninsula, Washington. J. Veg. Sci. 5:247–58.

Dosskey, M.G., Philippe, V., Noel, P., Gurwick, C.J., Allan, T. Duval, P., and Lowrance, R. (2010) The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. Journal of the American Water Resources Association (JAWRA) 46(2):261-277. DOI: 10.1111/j.1752-1688.2010.00419.x

Griffiths, G.A. (1980) Stochastic estimation of bed load yield in pool-and-riffle mountain streams. Water Res. Bull. 16: 931–37.

Holland, M.M., Risser, P.G., Naiman, R.J., eds. (1991) Ecotones. New York: Chapman & Hall.

Hansen, A.J., di Castri, F., eds. (1992) Landscape Boundaries. New York: SpringerVerlag.

Hubbard, R.K., Sheridan, J.M., Marti, L.R. (1990) Dissolved and suspended solids transport from Coastal Plain watersheds. J. Environ. Qual. 19:413–20.

Hupp, C.R., Osterkamp, W.R., Howard, A.D., eds. (1995) Biogeomorphology, Terrestrial and Freshwater Systems. Amsterdam: Elsevier Sci.

Hupp, C.R., Simon, A. (1986) Vegetation and bank-slope development. Proc. 4th Fed. Interagency Sedimentation Conf., March 24–27, 1986, Las Vegas, Nevada. Vol. II:583–592.

Lowrance, R., Sharpe, J.K., Sheridan, J.M. (1986) Long-term sediment deposition in the riparian zone of a coastal plain watershed. J. Soil Water Conserv. 41:266– 71.

Malanson, G.P. (1993) Riparian Landscapes. Cambridge University Press.

Myers, T.J., Swanson, S. (1992) Variation in stream stability with stream type and livestock bank damage in northern Nevada. Water Res. Bull. 28:743–54.

Naiman, R.J., D´ecamps, H., Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecol. Appl. 3:209–12.

Naiman, R.J. and Décamps, H. (1997) The Ecology of Interfaces: Riparian Zones Annual Review of Ecology and Systematics. Vol. 28:621-658 (Volume publication date November 1997) https://doi.org/10.1146/annurev.ecolsys.28.1.621

Naiman, R.J., Fetherston, K.L., McKay, S., Chen, J. (1997) Riparian forests. In River Ecology and Management: Lessons from the Pacific Coastal Region, ed. RJ Naiman, RE Bilby. New York: SpringerVerlag.

Nakamura, F., Swanson, F.J. (1993) Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon. Earth Surf. Proc. Landforms 18:43–61.

Pollock, M.M., Naiman, R.J., Hanley, T.A. (1997) An empirically based model for predicting plant diversity in forested and emergent wetlands. Ecology.

Risser, P.G. (1995) The Status of the Science Examining Ecotones. *BioScience* Vol. 45, No. 5, pp. 318-325. Published By: Oxford University Press. https://doi.org/10.2307/1312492.

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A., Muller, E., Décamps, H. (2000) Impacts of riparian vegetation on hydrological processes. *Hydrol. Process*. 14, 2959-2976. John Wiley & Sons, Ltd.

Triska, F.J., Duff, J.H., Avanzino, R.J. (1993a) The role of water exchange between a stream channel and its hyporheic zone in nitrogen cycling at the terrestrial aquatic interface. Hydrobiologia 251:167–84.

Triska, F.J., Duff, J.H., Avanzino, R.J. (1993b) Patterns of hydrological exchange and nutrient transformation in the hyporheic zone of a gravel bottom stream: examining terrestrial-aquatic linkages. Freshwater Biol. 29:259–74.

Weigelhofer, G., Waringer, J.A. (1994) Allochthonous input of coarse particulate organic matter (CPOM) in a first to fourth order Austrian forest stream. Int. Rev. Ges. Hydrobiol. 79:461–71.