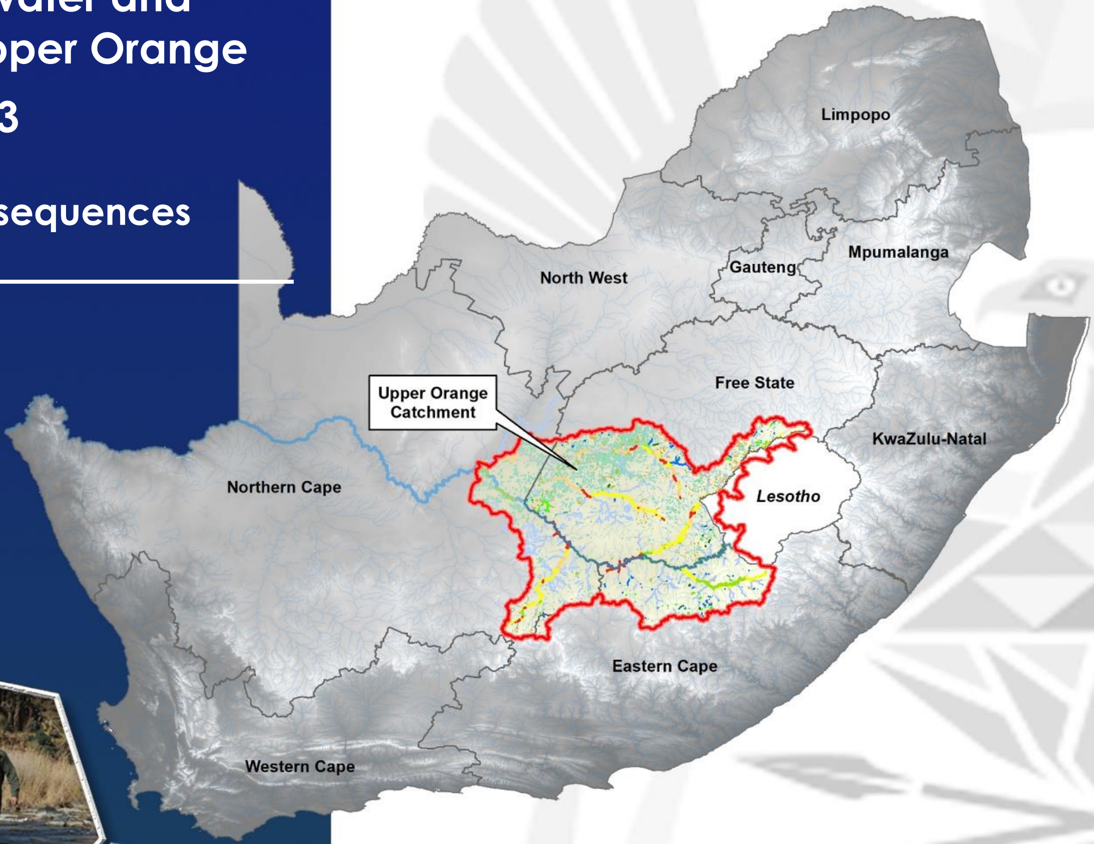
DEPARTMENT OF WATER AND SANITATION

A High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange

WP11343

Scenario and Consequences Report



REPORT NO.:
RDM/WMA13/00/CON/COMP/1423

December 2023

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Published by

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

Tel: (012) 336 7500/ +27 12 336 7500
Fax: (012) 336 6731/ +27 12 336 6731

This report is to be cited as:

Department of Water and Sanitation, South Africa. December 2023. A High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange Catchment: Scenario and Consequences Report. No: RDM/WMA13/00/CON/COMP/1423.

Prepared by:

GroundTruth

Title:	*Scenario and Consequences Report*
Authors:	*M. Graham, K. Farrell, R. Stassen, G. de Winnaar, B. Grant, B. van der Waal, B. Haasbroek*
External Reviewer	*Dr Neels Kleynhans and DWS*
Project Name:	*A High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange Catchment: WP11343*
DWS Report No.:	*RDM/WMA13/00/CON/COMP/1423*
Status of Report	*Final*
First Issue:	*7 November 2023*
Final Issue:	*12 December 2023*

Approved for the Professional Service Provided by:

……………………………………………………………………………………………………….

Dr Mark Graham *Date*

Director, GroundTruth

DEPARTMENT OF WATER AND SANITATION

Chief Directorate: Water Ecosystems Management

Approved for DWS by:

……………………………………………………………………………………………………….

Ndivhuwo Netshiendeulu (Project Manager) *Kwazikwakhe Majola (Scientific Manager)*

Date: ……………………………………… *Date:* ……………………………………

……………………………………………………………

Director: Yakeen Atwaru

Date: …………………………………………………..

DOCUMENT INDEX

Reports as part of this project:

Bold type indicates this report

INDEX	REPORT NUMBER	REPORT TITLE
1.0	RDM/WMA13/00/CON/COMP/0121	Inception Report
2.0	RDM/WMA13/00/CON/COMP/0221	Stakeholder Engagement Plan
3.0	RDM/WMA13/00/CON/COMP/0321	Gaps Analysis Report
4.0	RDM/WMA13/00/CON/COMP/0422	Resource Units Report
5.0	RDM/WMA13/00/CON/COMP/0522	Wetland Field Survey Report
6.0	RDM/WMA13/00/CON/COMP/0622	Groundwater Survey Report
7.0	RDM/WMA13/00/CON/COMP/0722	River Survey Report 1
8.0	RDM/WMA13/00/CON/COMP/0822	Basic Human Needs Assessment Report
9.0	RDM/WMA13/00/CON/COMP/0922	Wetland Report
10.0	RDM/WMA13/00/CON/COMP/1022	Groundwater Report
11.0	RDM/WMA13/00/CON/COMP/1123	Socio-Economics Outline Report
12.0	RDM/WMA13/00/CON/COMP/1223 (a)	Eco-Categorisation Report – Volume 1
12.0	RDM/WMA13/00/CON/COMP/1223 (b)	Eco-Categorisation Report – Volume 2
13.0	RDM/WMA13/00/CON/COMP/1323	Quantification of Ecological Water Requirements Report
14.0	**RDM/WMA13/00/CON/COMP/1423**	**Scenario and Consequences Report**

LIST OF ACRONYMS

ACC	Australian Community Climate and Earth System Simulator (ACCESS1-0), hereafter referred to as ACC
CC	Climate Change
CCS	Community Climate System Model (CCSM4), hereafter referred to as CCS
CD: WEM	Chief Directorate: Water Ecosystems Management
CNR	National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5), hereafter referred to as CNR
DRM	Desktop Reserve Model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EIS	Ecological Importance and Sensitivity
EI	Ecological Importance
ES	Ecological Sensitivity
EWR	Ecological Water Requirements
FCS	Fast course substrate
FD	Fast deep
FI	Fast Intermediate
FS	Fast shallow
FS	Fast shallow
GCM	General Circulation Model
GDP	Gross Domestic Product
GFD	Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3), hereafter referred to as GFD
HFSR	Habitat Flow Stressor Response
JBS	Joint Basin Survey
MAR	Mean Annual Runoff
MPI	Max Planck Institute Coupled Earth System Model (MPI-ESM-LR), hereafter referred to as MPI
NOR	Norwegian Earth System Model (NorESM1-M), hereafter referred to as NOR
NWA	National Water Act
PES	Present Ecological State
REC	Recommended Ecological Category
REMP	River Eco-Status Monitoring Programme
VFCS	Very fast, course substrate
WMA	Water Management Area
WRCS	Water Resources Classification System
WRYM	Water resources yield model

WRPM	Water resources planning model
WRC	Water Research Commission

EXECUTIVE SUMMARY

Introduction and Background

This phase forms part of the following study: A High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange. The purpose of this study is to determine the Reserve (quantity and quality of the EWR and BHN) for priority rivers, wetlands and groundwater areas at a high level of confidence in the Upper Orange Catchment. The results from the study will guide the Department of Water and Sanitation (DWS) to meet the objectives of maintaining, and if attainable, improving the ecological state of the water resources. The primary deliverable will be the preparation of the Reserve templates for the Upper Orange River Catchment, specifying the Ecological Water Requirements (EWR) for rivers and ecological specifications/conditions for the management of the priority rivers, wetlands and groundwater areas.

Purpose of this Report

The purpose of this report is to provide the processes, approaches and results of step 5 in accordance with the 8-step process as outlined in Regulation 810 (Government Gazette 33541) dated 17 September 2010, as well as The Reserve determination process as outlined in "Development of Procedure to operationalise Resource Directed Measures (DWS, 2017)".

i. A description of the process to define the operational scenarios;

ii. The approaches and results of the assessments to determine the ecological consequences of these scenarios for the rivers, and

iii. The approach and results of the high level/ qualitative socio-economic consequences of the defined scenarios.

Therefore, the report strives to assess the operational flow scenarios to evaluate the ecological consequences to finalise the Ecological Water Requirements (EWRs).

Study Area and final EWR sites

The study area consists of the water resources of the Upper Orange River from the Lesotho border to the confluence with the Vaal River, including the Modder/ Riet Rivers and includes secondary catchments D1, D2, D3 and C5 namely:

i. The Orange River from the Lesotho Border to the Gariep Dam, including the main tributaries: Kornetspruit, Sterkspruit, Stormbergspruit and Brandwaterspruit (catchments D12, D14 and the SA part of D15 and D18);
ii. The Caledon River from its headwaters and its tributaries to the Gariep Dam (catchments D21, D22, D23, D24);
iii. The Kraai River catchment (catchment D13); and
iv. The Orange River from the Gariep Dam to Marksdrift weir (catchments D31, D33, D34 and D35), just upstream from the confluence with the Vaal River. This includes the Seekoei River (catchment D32) in the south and the Modder-Riet River (catchments C51 and C52) in the north.

The EWR sites were selected on all the major/ mainstem rivers and assessed on an Intermediate level (10 sites), smaller tributaries on a Rapid 3 level (6 sites) and several field verifications (24 sites) where little or no information was available. For more details on the selection of the EWR sites, see DWS report RDM/WMA13/00/CON/COMP/0422.

Proposed project scenarios

The seven (7) proposed scenarios are listed in **Table 1** below.

Table 1-: Summary of the proposed management scenarios for the study

Number	Code	Description
Sc1	PRS1	Present day without EWR
Sc2	PRS2	Present day with EWR for REC
Sc3	FUT1	2040 Polihali, Makhaleng (pipeline to Botswana), Pipeline from Garrie to Bloemfontein, Caledon weirs without EWR
Sc4	FUT2	2040 Polihali, Makhaleng (pipeline to Botswana), Pipeline from Gariep to Bloemfontein, Caledon weirs with EWR=REC, estuarine requirements
Sc5	FUT3	2060 Polihali, Makhaleng, Pipeline from Gariep, Caledon weirs, Verbeeldingskraal on Upper Orange, Vioolsdrift on Lower Orange, without EWR
Sc6	FUT4	2060 Polihali, Makhaleng, Pipeline from Gariep, Caledon weirs, Verbeeldingskraal on Upper Orange, Vioolsdrift on Lower Orange, with EWR=REC, estuarine
Sc7	WQ	Present day with EWR for REC (Sc2) but with progressive water quality decline

Scenario and Consequences results

Refer to **Table 2** for a summary of which operational flow scenarios can be taken forward following the evaluation of the ecological consequences to finalise the EWRs that can be met.

Table 2: Summary of the EWR sites and operational scenarios (S1 – S6 are related to flow, while Sc7, is related to water quality)

Site	River	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
UO_EWR01_I	**Middle Caledon**	√	√	√	√	√	√	X
UO_EWR02_I	**Sterkspruit**	X	X					X
UO_EWR03_I	**Upper Orange**	√	√	√	√	√	√	X
UO_EWR04_I	**Lower Caledon**	√	√	√	√	√	√	X
UO_EWR05_I	**Seekoei**	√	√					X
UO_EWR06_I	**Upper Riet**	√	√	x	√			X
UO_EWR07_I	**Upper Modder**	√	√					X
UO_EWR08_I	**Lower Kraai**	√	√					√

Site	River	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
UO_EWR09_I	Lower Riet	√	√	√	X			X
UO_EWR10_I	Lower Orange	√	√	√	√	√	√	X

With regards to Sc7, it is reasonable to predict that the described observations will deteriorate further and reach a critical stage for all sites, except the lower Kraai River. The ultimate consequence will be a marked decrease in the overall health and functionality of this ecosystem, particularly in its capacity to provide essential ecosystem services, primarily clean water and the ability to dilute, process, and mitigate the impact of polluted water in collaboration with its indigenous biota. Furthermore, the frequency and persistence of waterborne diseases are likely to increase. This could result in a heightened seasonal risk for local communities that rely on the river, recreational users, and have a substantial impact on the biodiversity (fish and macroinvertebrates) associated with this river system.

In terms of the socio-economics consequences, these vary in the Upper Orange catchment area. Some regions have moderate vulnerability, focusing on commercial agriculture with sufficient water flow. Others face high vulnerability, low GDP, and limited agriculture, risking inadequate water resources. Few areas with low vulnerability and moderate water use face potential challenges. Urban and farming communities with agriculture and tourism thrive but face socio-economic risks due to water quality. Urban and smallholder farming regions concentrating on agriculture and agro-processing also have potential socio-economic risks related to water quality and dilution.

TABLE OF CONTENTS

LIST OF ACRONYMS v
EXECUTIVE SUMMARY vii
TABLE OF CONTENTS x
LIST OF FIGURES xii
LIST OF TABLES xii
1. INTRODUCTION 1
1.1 Background 1
1.2 Purpose of this study 1
1.3 Purpose of this report 2
2. OVERVIEW OF THE STUDY AREA 3
3. THE EVALUATION OF SCENARIOS WITHIN THE WATER RESOURCE MANAGEMENT PROCESS 5
3.1 Objectives of the scenario evaluation step 6
3.2 Resource Units delineated in the Upper Orange catchment area 6
4. WATER RESOURCE PLANNING ANALYSIS 9
4.1 Present Day Scenarios 10
4.2 Future Development Scenarios 12
4.3 Climate Change 15
5. ECOLOGICAL CONSEQUENCES 18
5.1 Approach 18
5.1.1 Water Quality 19
5.1.2 Geomorphology 19
5.1.3 Riparian vegetation 19
5.1.4 Biota (fish and macroinvertebrates) 20
5.1.5 Socio-economics 21
5.1.6 Determining the ranking of scenarios per EWR site 22
5.1.7 Selection of scenarios for evaluation 23
5.2 Ecological Consequences Results 24
5.2.1 UO_EWR01_I: Middle Caledon 24
5.2.2 UO_EWR02_I: Sterkspruit 32
5.2.3 UO_EWR03_I: Upper Orange 40
5.2.4 UO_EWR04_I: Lower Caledon 49
5.2.5 UO_EWR05_I: Seekoei 57
5.2.6 UO_EWR06_I: Upper Riet 64

5.2.7 UO_EWR07_I: Upper Modder (Sannaspos) ... 72
5.2.8 UO_EWR08_I: Lower Kraai ... 80
5.2.9 UO_EWR09_I: Lower Riet ... 87
5.2.10 UO_EWR10_I: Lower Orange ... 94
6. WATER QUALITY IN THE UPPER ORANGE CATCHMENT: THE ULTIMATE DRIVER OF CATCHMENT CONDITIONS ... 102
7. CONCEPTUAL FLOW MANAGEMENT PLAN (DOWNSTREAM GARIEP AND VANDERKLOOF DAMS) ... 110
7.1 Background and objective ... 110
7.2 Data from JBS2 and JBS3 ... 110
7.2.1 Site description: ... 110
7.2.2 Water quality ... 111
7.2.3 Macroinvertebrates ... 113
7.3 Summary of Proposed Action Plans ... 113
7.3.1 Immediate ... 113
7.3.2 Short-term ... 113
7.3.3 Medium-term ... 113
7.3.4 Long-term ... 114
7.4 Proposed flow management changes to improve PES ... 114
8. CONCLUSION ... 118
9. REFERENCES ... 121
10. APPENDICES ... 124

LIST OF FIGURES

Figure 1-1: Integrated steps for the determination of the Reserve (DWS, 2017) 2
Figure 2-1: Upper Orange Catchment 4
Figure 3-1: EWR sites for the Upper Orange Reserve study 8
Figure 5-1: Seasonal distribution of scenarios at site UO_EWR01_I: Middle Caledon 25
Figure 5-2: Seasonal distribution of scenarios at site UO_EWR02_I: Sterkspruit 33
Figure 5-3: Seasonal distribution of scenarios at site UO_EWR03_I: Upper Orange 41
Figure 5-4: Seasonal distribution of scenarios at site UO_EWR04_I: Lower Caledon 50
Figure 5-5: Seasonal distribution of scenarios at site UO_EWR05_I: Seekoei....................... 58
Figure 5-6: Seasonal distribution of scenarios at site UO_EWR06_I: Upper Riet 65
Figure 5-7: Seasonal distribution of scenarios at site UO_EWR07_I: Upper Modder............ 73
Figure 5-8: Seasonal distribution of scenarios at site UO_EWR08_I: Lower Kraai................ 81
Figure 5-9: Seasonal distribution of scenarios at site UO_EWR09_I: Lower Riet 88
Figure 5-10: Seasonal distribution of scenarios at site UO_EWR10_I: Lower Orange........ 95
Figure 7-1: "Examples of interrelated physical and ecological riverine processes at varying spatial and temporal scales. Key functional flows supporting specific processes are shown in boxes." – from Yarnell et al. (2015). 116

LIST OF TABLES

Table 3-1: Summary of the selected Intermediate EWR sites for the study area, along with their identified REC... 7
Table 4-1: Main dams in the catchment 10
Table 4-2: Anticipated and proposed major developments in the Upper Orange Catchment 13
Table 4-3: Summary description of the management Scenarios 15
Table 4-4: Global Climate Models for the different sub-catchments in the Upper Orange catchment area 16
Table 4-5: Effect on long term historical yield of the different GCMs and catchment areas on average compared to observed historical hydro-climatic conditions 16
Table 5-1: Ranking of ecological consequences of the scenarios 22
Table 5-2: Percentiles and flow (m3/s) for July per scenario at Middle Caledon (UO_EWR01_I).. 25
Table 5-3: Percentiles and flow (m3/s) for February per scenario at Middle Caledon (UO_EWR01_I).. 26
Table 5-4: Evaluated scenarios per component 26
Table 5-5: Physical-chemical ecological consequences of the scenarios........................... 27

Table 5-6: Geomorphological and riparian vegetation ecological consequences of the scenarios 28

Table 5-7: Biotic consequences of the scenarios 28

Table 5-8: UO_EWR01_Middle Caledon: Ecological consequences..... 30

Table 5-9: Percentiles and flow (m3/s) for July per scenario at Sterkspruit (UO_EWR02_I)..... 33

Table 5-10: Percentiles and flow (m3/s) for March per scenario at Sterkspruit (UO_EWR02_I)..... 34

Table 5-11: Evaluated scenarios per component 35

Table 5-12: Physical-chemical ecological consequences of the scenarios..... 35

Table 5-13: Geomorphological and riparian vegetation ecological consequences of the scenarios 36

Table 5-14: Biotic consequences of the scenarios 36

Table 5-15: UO_EWR02_I: Sterkspruit: Ecological consequences 38

Table 5-16: Percentiles and flow (m3/s) for July per scenario at Upper Orange (UO_EWR03_I)..... 41

Table 5-17: Percentiles and flow (m3/s) for February per scenario at Upper Orange (UO_EWR03_I)..... 42

Table 5-18: Evaluated scenarios per component 42

Table 5-19: Physical-chemical ecological consequences of the scenarios..... 43

Table 5-20: Geomorphological and riparian vegetation ecological consequences of the scenarios 44

Table 5-21: Biotic consequences of the scenarios 45

Table 5-22: UO_EWR03_I: Upper Orange: Ecological consequences..... 47

Table 5-23: Percentiles and flow (m3/s) for July per scenario at Lower Caledon (UO_EWR04_I)..... 50

Table 5-24: Percentiles and flow (m3/s) for February per scenario at Lower Caledon (UO_EWR04_I)..... 51

Table 5-25: Evaluated scenarios per component 51

Table 5-26: Physical-chemical ecological consequences of the scenarios..... 52

Table 5-27: Geomorphological and riparian vegetation ecological consequences of the scenarios 53

Table 5-28: Biotic of the scenarios..... 53

Table 5-29: UO_EWR04_Lower Caledon: Ecological consequences 55

Table 5-30: Percentiles and flow (m3/s) for July per scenario at Seekoei (UO_EWR05_I) 58

Table 5-31: Percentiles and flow (m3/s) for March per scenario at Seekoei (UO_EWR05_I)..... 59

Table 5-32: Evaluated scenarios per component 59

Table 5-33: Physical-chemical ecological consequences of the scenarios..... 60

Table 5-34: Geomorphological and riparian vegetation ecological consequences of the scenarios 60
Table 5-35: Biotic consequences of the scenarios 61
Table 5-36: UO_EWR05_I: Seekoei: Ecological consequences 62
Table 5-37: Percentiles and flow (m3/s) for July per scenario at Upper Riet (UO_EWR06_I) 65
Table 5-38: Percentiles and flow (m3/s) for March per scenario at Upper Riet (UO_EWR06_I) 66
Table 5-39: Evaluated scenarios per component 66
Table 5-40: Physical-chemical ecological consequences of the scenarios 67
Table 5-41: Geomorphological and riparian vegetation ecological consequences of the scenarios 67
Table 5-42: Biotic consequences of the scenarios 68
Table 5-43: EWR06_I: Upper Riet: Ecological consequences 70
Table 5-44: Percentiles and flow (m3/s) for July per scenario at Upper Modder (UO_EWR07_I) 73
Table 5-45: Percentiles and flow (m3/s) for February per scenario at Upper Modder (UO_EWR07_I) 74
Table 5-46: Evaluated scenarios per component 74
Table 5-47: Physical-chemical ecological consequences of the scenarios 75
Table 5-48: Geomorphological and riparian vegetation ecological consequences of the scenarios 75
Table 5-49: Biotic consequences of the scenarios 76
Table 5-50: UO_EWR07_I: Upper Modder: Ecological consequences 78
Table 5-51: Percentiles and flow (m3/s) for July per scenario at Lower Kraai (UO_EWR08_I) 81
Table 5-52: Percentiles and flow (m3/s) for March per scenario at Lower Kraai (UO_EWR08_I) 82
Table 5-53: Evaluated scenarios per component 82
Table 5-54: Physical-chemical ecological consequences of the scenarios 83
Table 5-55: Geomorphological and riparian vegetation ecological consequences of the scenarios 83
Table 5-56: Biotic consequences of the scenarios 84
Table 5-57: UO_EWR08_I: Lower Kraai: Ecological consequences 85
Table 5-58: Percentiles and flow (m3/s) for July per scenario at Lower Riet (UO_EWR09_I) 88
Table 5-59: Percentiles and flow (m3/s) for March per scenario at Lower Riet (UO_EWR09_I) 89
Table 5-60: Evaluated scenarios per component 89
Table 5-61: Physical-chemical ecological consequences of the scenarios 90

Table 5-62: Geomorphological and riparian vegetation ecological consequences of the scenarios 90
Table 5-63: Biotic consequences of the scenarios 91
Table 5-64: UO_EWR09_I: Lower Riet: Ecological consequences 92
Table 5-65: Percentiles and flow (m3/s) for July per scenario at Lower Orange (UO_EWR10_I) 95
Table 5-66: Percentiles and flow (m3/s) for February per scenario at Lower Orange (UO_EWR10_I) 96
Table 5-67: Evaluated scenarios per component 96
Table 5-68: Physical-chemical ecological consequences of the scenarios 97
Table 5-69: Geomorphological and riparian vegetation ecological consequences of the scenarios 97
Table 5-70: Biotic consequences of the scenarios 98
Table 5-71: UO_EWR10__I: Lower Orange: Ecological consequences 100
Table 6-1: Table showing the designed capacity use, daily volume of wastewater (million litres per day; ML/day) treated, and Green Drop (GD) score for the wastewater treatment works (WWTW) within the Upper Orange River catchment. The data for 2013 and 2021 GD reports are summarised, with the change from 2013 to 2021 calculated for each parameter. The GD scores <31% (considered by the Department of Water and Sanitation (DWS) to be dysfunctional and in need of critical intervention (DWS, 2022)) are highlighted in red, the WWTW which have shown a decrease in the daily volume of wastewater they treat are highlighted in purple, and the WWTW which have shown a decrease in their GD score from 2013 to 2021 are highlighted in orange. The EWR Intermediate sites that are in the downstream catchment and likely affected by the WWTW discharge are indicated. 104
Table 6-2: Table showing the wastewater chemical, microbiological, physical, and monitoring compliance status (as of October 2023) of the local municipalities in the Upper Orange River Catchment for which there are data in the National Integrated Water Information System (NIWIS; https://www.dws.gov.za/niwis2/wwq2) database. Compliance <50% is highlighted in red. The The EWR Intermediate sites that are likely affected by the wastewater treatment compliance of the municipalities are indicated. 109
Table 7-1: In situ water quality measurements and diatom sampling results 112
Table 8-1: Summary of applicable scenarios per EWR site 118
Table B-10-1: *In situ* water quality measurements and diatom sampling results. 134
Table B-10-2: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC) 135
Table B-10-3: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR02_I: Sterkspruit site. 137
Table B-10-4: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring. 138
Table B-10-5: *In situ* water quality measurements and diatom sampling results. 140

Table B-10-6: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC)...................... 142
Table B-10-7: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR03_I: Upper Orange site. 144
Table B-10-8: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.. 145
Table B-10-9: In situ water quality measurements and diatom sampling results. 147
Table B-10-10: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC)...................... 148
Table B-10-11: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR04_I: Lower Caledon site. 150
Table B-10-12: Table showing the advantages and Limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.. 151
Table B-10-13: *In situ* water quality measurements and diatom sampling results. 153
Table B-10-14: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC)...................... 155
Table B-10-15: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR05_I: Seekoei site. 157
Table B-10-16: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.. 159
Table B-10-17: *In situ* water quality measurements and diatom sampling results. 160
Table B-10-18: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC)...................... 162
Table B-10-19: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR06_I: Upper Riet site. 164
Table B-10-20: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.. 165
Table B-10-21: *In situ* water quality measurements and diatom sampling results. 166
Table B-10-22: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC)...................... 168
Table B-10-23: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR07_I: Middle Modder site. 170
Table B-10-24: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.. 171
Table B-10-25: *In situ* water quality measurements and diatom sampling results. 173

Table B-10-26: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC)...................... 175

Table B-10-27: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR08_I: Lower Kraai site. 177

Table B-10-28: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring... 178

Table B-10-29: *In situ* water quality measurements and diatom sampling results. 180

Table B-10-30: Results of aquatic macroinvertebrate assessment, showing the calclated ecological category (EC; % and summary EC)........................ 182

Table B-10-31: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR01_I: Lower Riet site. 183

Table B-10-32: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring based on previous sampling at the same site (this site was not sampled during this study). 184

Table B-10-33: *In situ* water quality measurements and diatom sampling results. 186

Table B-10-34: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR10_I: Lower Orange site. 188

Table B-10-35: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring... 190

Table B-10-36: *In situ* water quality measurements and diatom sampling results. 191

Table B-10-37: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC)...................... 193

1. INTRODUCTION

1.1 Background

The National Water Act (No. 36 of 1998) (NWA) is founded on the principle that the National Government has overall responsibility for and authority over water resource management for beneficial public use without seriously affecting the functioning and sustainability of water resources. Chapter 3 of the NWA enables the protection of water resources by the implementation of Resource Directed Measures (RDM). As part of the RDM process, an Ecological Reserve must be determined for a significant water resource to ensure a desired level of protection.

The Reserve (water quantity and quality) is defined in terms of (i) Ecological Water Requirements (EWR) based on, the quantity and quality of water needed to protect aquatic ecosystems; water quantity, quality, habitat and biota in the desired state and (ii) Basic Human Needs (BHN), ensuring that the essential needs of individuals dependant on the water resource is provided for. These measures collectively aim to ensure that a balance is reached between the need to protect and sustain water resources while allowing economic development.

The Chief Directorate: Water Ecosystems Management (CD: WEM) of the Department of Water and Sanitation (DWS) is responsible for coordinating all Reserve Determination studies in terms of the Water Resource Classification System (WRCS). These studies include the surface water (rivers, wetlands and estuaries) and groundwater components of water resources.

The Reserve has priority over other water uses in terms of the NWA and should be determined before license applications are processed, particularly in stressed and over utilised catchments. Accordingly, the CD: WEM identified the need to determine the Reserve for the ecosystems (rivers, wetlands and groundwater) of the Upper Orange River catchment in the Orange Water Management Area (WMA 6). The aim is to provide adequate protection for (i) possible hydraulic fracturing (HF) activities, (ii) assessment of various water use license applications, and (iii) evaluation of impacts of current and proposed developments on the availability of water.

1.2 Purpose of this study

It is important to note the following:

- Priority rivers are selected by assessing water use impacts (quantity and quality) to determine the integrated water use index (IWUI) or water stress and (ii) integrated ecological index (IEI) that considers the PES and the ecological importance (EI) and ecological sensitivity (ES) of each sub-quaternary reach. This results in the identification of priority resource units where the EWRs need to be quantified.
- A “high confidence study” refers to a combination of different river level assessments, from desktop extrapolation to intermediate assessments. Furthermore, a wider coverage of the catchment has been undertaken, not only the main stem Orange River

and major tributaries, but inclusive of the smaller tributaries within the catchment. Groundwater and wetland priority resources and their interactions will also be assessed.

Therefore, the purpose of this study is to determine the Reserve (quantity and quality of the EWR and BHN) for priority rivers, wetlands and groundwater areas at a high level of confidence in the Upper Orange Catchment. The results from the study will guide the Department to meet the objectives of maintaining, and if attainable, improving the ecological state of the water resources. The primary deliverable will be the preparation of the Reserve templates for the Upper Orange Catchment, specifying the ecological water requirements and ecological specifications/ conditions for the management of the priority rivers, wetlands and groundwater areas.

1.3 Purpose of this report

The purpose of this report is to provide the processes, approaches and results of step 5 in accordance with the 8-step process as outlined in Regulation 810 (Government Gazette 33541) dated 17 September 2010 (**Figure 1-1**), as well as The Reserve determination process as outlined in the study, "Development of Procedures to operationalise Resource Directed Measures (DWS, 2017)".

i. A description of the process to define the operational scenarios;

ii. The approaches and results of the assessments to determine the ecological consequences of these scenarios for the rivers, and

iii. The approach and results of the socio-economic consequences of the defined scenarios.

Therefore, the report strives to assess the operational flow scenarios to evaluate the ecological consequences to finalise the EWRs that can be met.

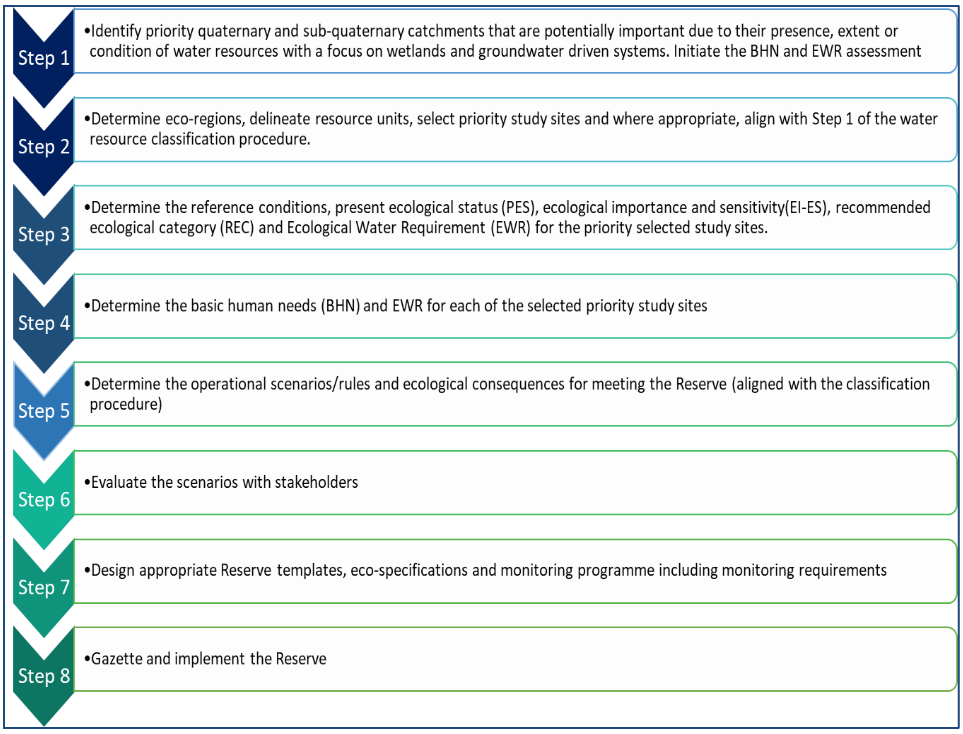


Figure 1-1: Integrated steps for the determination of the Reserve (DWS, 2017)

This report draws on the results from:

- The Eco-categorisation and quantification of EWR processes and reports (see Report No. RDM/WMA13/00/CON/COMP/1223 Volume 1 and Volume 2 (a, b respectively) and Report No. RDM/WMA13/00/CON/COMP/1323).

2. OVERVIEW OF THE STUDY AREA

The study area of the Upper Orange Catchment forms part of the Orange WMA6 (**Figure 2-1**) and includes the main stem Orange River from the Lesotho border to the confluence with the Vaal River at Douglas. The major tributaries of the Orange River include the Kraai, Caledon and Seekoei Rivers. Although the Modder-Riet River drains into the Vaal River, due to their interconnectivity (i.e., water transfers) with the Upper Orange River, are included in this study. The study area consists of 129 quaternary catchments, covering an approximate area of 106 000 km^2. This includes secondary catchments D1, D2, D3 and C5 namely:

I. The Orange River from the Lesotho Border to the Gariep Dam, including the main tributaries: Kornetspruit, Sterkspruit, Stormbergspruit and Brandwaterspruit (catchments D12, D14 and the SA part of D15 and D18);
II. The Caledon River from its headwaters and its tributaries to the Gariep Dam (catchments D21, D22, D23, D24);
III. The Kraai River catchment (catchment D13); and
IV. The Orange River from the Gariep Dam to Marksdrift weir (catchments D31, D33, D34 and D35), just upstream from the confluence with the Vaal River. This includes the Seekoei River (catchment D32) in the south and the Modder-Riet River (catchments C51 and C52) in the north.

The Gariep and Vanderkloof Dams on the main stem Orange River are two of the country's largest reservoirs with main uses for the generation of hydropower, transfers of water and releases for irrigation and other demands, including estuarine requirements, before reaching its confluence with the Vaal River.

The current infrastructure for water use is mainly for irrigation, transfer of water within the study area (Caledon River to Modder River, Vanderkloof Dam to the Riet River, Marksdrift on Orange River to Modder-Riet Rivers) and to other WMAs (e.g., transfer to Great Fish River in the Eastern Cape), domestic use, stock watering and power generation at the Gariep and Vanderkloof Dams. The Bloemfontein metropolitan area is the largest in the study area with smaller towns scattered throughout the catchment. Larger towns include Herscell/ Sterkspruit, Aliwal North, Burgersdorp, Ficksburg, Ladybrand, Botshabelo, Kimberley and Colesberg.

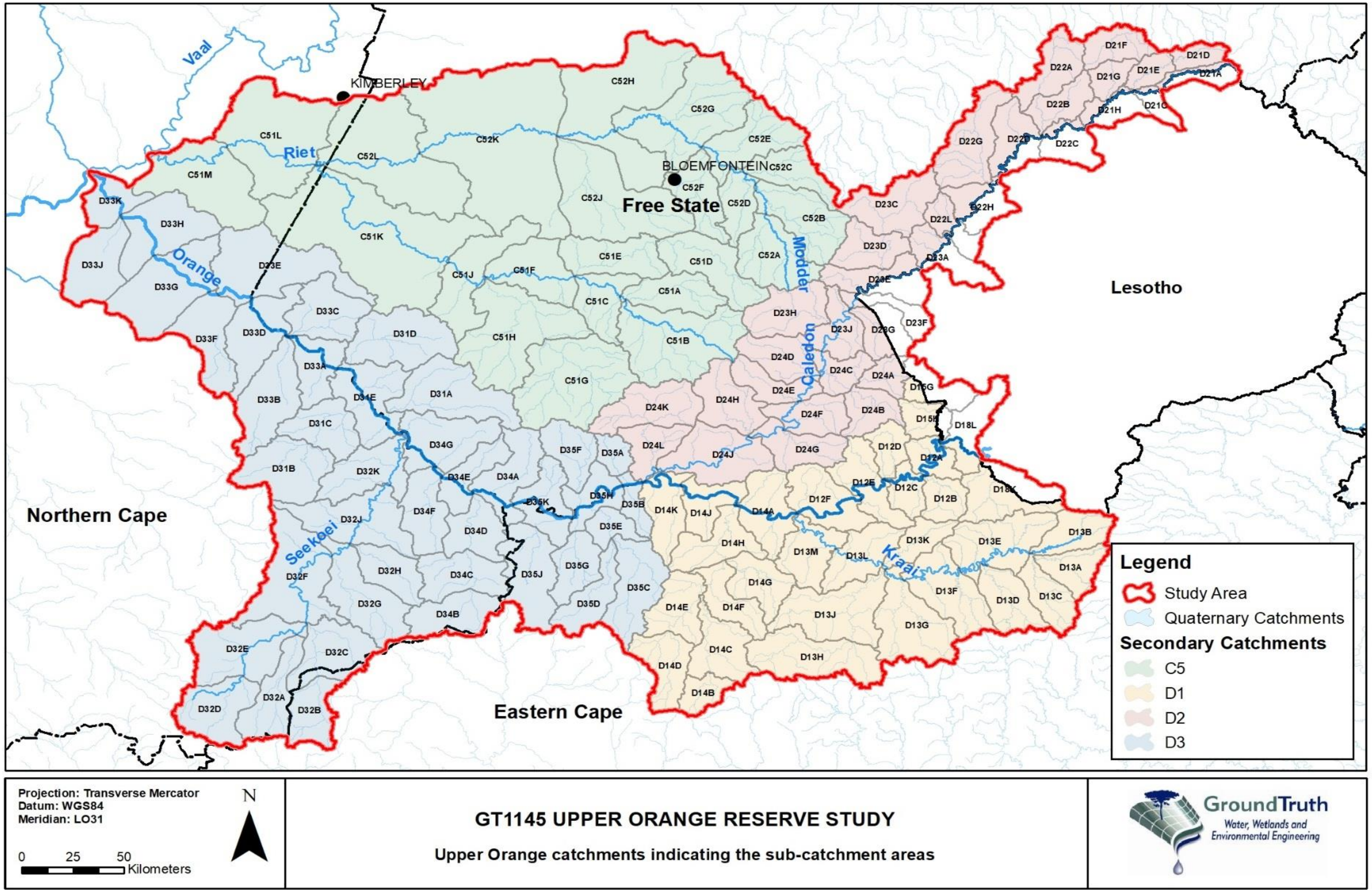


Figure 2-1: Upper Orange Catchment

3. THE EVALUATION OF SCENARIOS WITHIN THE WATER RESOURCE MANAGEMENT PROCESS

A crucial element in the Reserve determination process involves the iterative configuration and evaluation of scenarios. This process entails assessing the outcomes of various ecological protection categories, conservation goals, and anticipated future usage and development to determine the most viable approach for the purpose of this study.

The primary aim of this task has been to determine any consequences if the EWR requirements were not met through the running of the appropriate Water Resources Yield Models. The operational scenarios have taken cognisance of any potential scenarios assessed previously for the Reconciliation Strategy, as well as any other studies, and taking into consideration water transfers from the rivers in the catchment to other catchments (e.g. transfer to Eastern Cape from Gariep Dam) as well as the estuarine requirements in the Lower Orange.

These scenarios were evaluated by the project team in terms of ecological and social consequences. The final scenarios will form the basis for the finalisation of the Reserve as part of step 7.

Further as part of step 5 is an overview of the socio-economic water use in the area. This aspect of the study has been guided by the WRCS Socio-Economic Guidelines (DWAF, 2007), specifically the procedure to describe the present-day socio-economic status of the catchment and community well-being, with a focus on socio-economic water use and socio-cultural importance. The guidelines identify the following relevant aspects:

- Population density figures and related statistics (e.g., urban vs rural, demographics);
- Overview of the economy in terms of the relative contribution of different sectors (e.g. data from Statistics South Africa, Municipal documents such as Integrated Development Plans (IDPs));
- Land-use and related economic activities;
- The current wellbeing of the communities – a description of various aspects of each community that will gives a sense of the levels of financial, physical, human, social and natural capital assets available to those communities (e.g., household characteristics - income category, services and infrastructure, education levels, community cohesion, etc.);
- Description of the way in which water is used currently, informed by a water users analysis based on registered water users information from the WARMS database;
- Description of the aquatic ecosystem goods and service of key importance, particularly those not reflected in the market economy – drawing on the study by Huggins et al. (2010) on the goods and services of the Orange River Catchment. The cultural value of catchments includes their contribution to education, scientific knowledge and the spiritual wellbeing of South Africans (Huggins et al., 2010). Assessment of the socio-cultural value of the catchment reflects a qualitative assessment of how aquatic ecosystems contribute to community wellbeing in the target catchment.

Information and data to inform the description was drawn largely from existing sources (reports, databases, statistics, municipal reports and plans (e.g., IDPs) etc.), supported by a review of existing studies of the Orange River catchment such as the goods and services report (Huggins *et al.,* 2010) as part of the previous assessment of environmental flow requirements for the Orange River Basin. The baseline assessment provides an overall contextual background for the catchment; a more detailed consideration of the socio-economic context of specific parts of the catchment aligned with the EWR sites has been undertaken based on the availability of existing information.

The study is now in the final stages of the Reserve determination process that will inform the setting of ecological specifications.

The scenario evaluation has been finalised and recommended scenarios are proposed.

3.1 Objectives of the scenario evaluation step

The objective of this step is to evaluate scenarios configured. Scenario evaluation has been incorporated into the integrated water resource management process so that a subset of catchment scenarios can be recommended.

The following activities have been undertaken as part of the process:

- Inclusion of the following proposed scenarios:
  - Current scenario (2025) including the key current infrastructure developments in the Upper Orange catchment
  - Future development scenarios
    - A medium-term scenario (2040), and
    - A long-term scenario (2060).
  - Water Resources Planning (WRP) and Water Resource Yield Model (WRYM) analysis and adjustment;
  - Reporting of ecological consequences;
  - Assessment of water quality implications, based on the current scenario;
  - Description of the socio-economic implications;
  - Evaluation of the overall scenario implications for the Upper Orange catchment; and
  - Selection of a subset of recommended scenarios.

3.2 Resource Units delineated in the Upper Orange catchment area

The prioritisation of Resource Units (RU) formed part of Steps 1 and 2 of the integrated steps for the determination of the Reserve (see report RDM/WMA13/00/CON/COMP/0321). These were delineated, the eco-categorisation process followed, and the EWRs quantified for these prioritised RUs for the assurance of the protection of the water resources.

The final Intermediate EWR sites selected per priority Resource Unit for the Upper Orange River catchment is presented in **Table 3-1** and **Figure 3-1** (blue dots).

Furthermore, **Table 3-1** provides the results of the eco-categorisation process to determine the Recommended Ecological Category (REC) which was 1. used to quantify the EWRs at each of the selected sites and 2. to apply the relevant methodology to assess the consequences of the various driver and response components for the selected management scenarios.

Table 3-1: Summary of the selected Intermediate EWR sites for the study area, along with their identified REC

RU	EWR site code	River	Quat	REC
R_RU04	UO_EWR01_I	Middle Caledon	D23A	D
R_RU01	UO_EWR02_I	Sterkspruit	D12B	C/D
R_RU02a	UO_EWR03_I	Upper Orange	D12F	D
R_RU05	UO_EWR04_I	Lower Caledon	D24J	C/D
R_RU06	UO_EWR05_I	Seekoei	D32J	C
R_RU08	UO_EWR06_I	Upper Riet	C51F	C
R_RU09a	UO_EWR07_I	Upper Modder (Sannaspos)	C52G	C
R_RU03	UO_EWR08_I	Lower Kraai	D13M	B/C
R_RU10	UO_EWR09_I	Lower Riet	C51L	B/C
R_RU07	UO_EWR10_I	Lower Orange	D33K	C

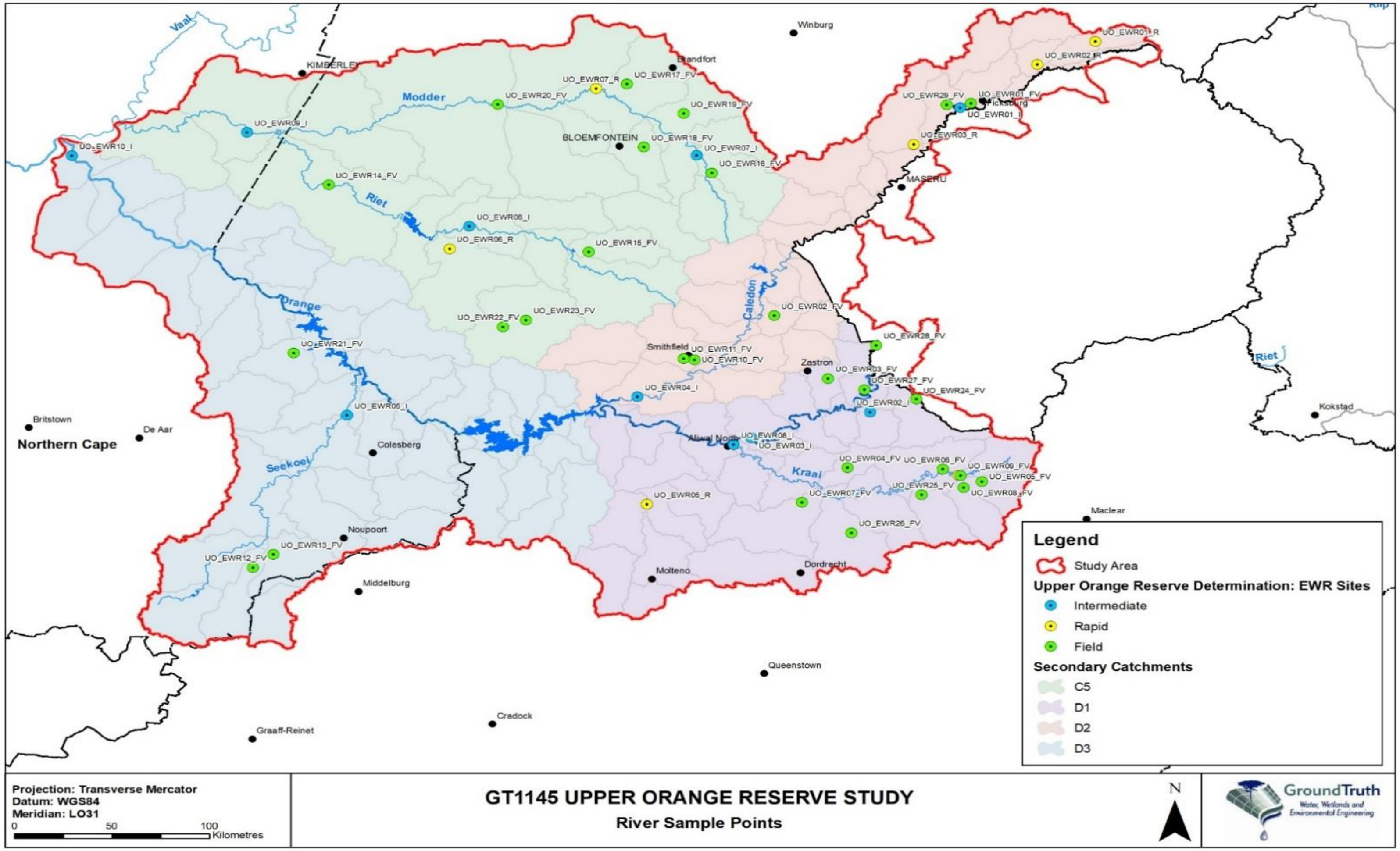


Figure 3-1: EWR sites for the Upper Orange Reserve study

4. WATER RESOURCE PLANNING ANALYSIS

To comprehensively assess the present and future developments within the Upper Orange Catchment, it is imperative to encompass a diverse range of potential scenarios. These scenarios should account for the intentions of the DWS, in addition to other governmental water service entities, water service providers, and the public.

The Upper Orange Catchment's strategic importance is underscored by its substantial water resource infrastructure, most notably the Gariep and Vanderkloof dams, which rank as the country's largest dams and play a pivotal role in the nation's economy. Additionally, the catchment is central to ongoing development planning. As a result, it holds a vital position in the long-term strategies of neighbouring catchments, including the Fish to Tsitsikamma catchment areas. This interconnection involves the transfer of water from the Gariep Dam to the upper reaches of the Great Fish River, notably the Grassridge Dam, primarily for irrigation and domestic usage within the Great Fish River catchment as well as transfers from the Caledon River, Vanderkloof Dam and Orange River at Marksdrift to the Modder/ Riet Rivers that forms part of the Vaal River catchment.

Therefore, management scenarios were identified using the Reconciliation Strategy that was developed by DWA in 2014 for the Orange River as the main source. Any additional scenarios specifically relevant to the ecological function or well-being of the water resources, e.g. the operation of releases from the larger dams was discussed with DWS before finalisation. Proposed dams, as identified in this strategy has initially been used to guide the selection of EWR sites on river reaches downstream of these dams. This enabled the assessment of the ecological consequences of altered flows from the dams and to optimise releases from the dams.

For the final scenario analysis purposes, the most appropriate tool to use was the water Resource Planning Model (WRPM) for the Integrated Vaal-Orange River System as developed for ORASECOM (ORASECOM, 2014). No integrated Vaal-Orange WRYM model exists and due to the linkage between the Upper Orange and the Modder-Riet catchments the only option was to make use of the integrated WRPM model. A historical run version of the integrated WRPM model was previously configured for the analysis of the Orange River Mouth water requirements analysis by WRP Consulting and this version of the model was used as base for the scenario analysis in this study. The primary change made to the historical version of the WRPM was to build in all the Intermediate Reserve Determination Sites, as well as have a few other sites of interest (e.g. below Gariep and Vanderkloof Dams for the purposes of the proposed conceptual flow management plan). Three model configurations were then created for the following development scenarios:

- Present-Day development with and without EWR supply;
- 2040 Development with and without EWR Supply; and
- 2060 Development with and without EWR Supply.

The following changes were made to the historical version of the Integrated Vaal-Orange WRPM model for each of the different scenario:

- Update the entire system's water use; and
- Build in or update the configuration of the planned dams in the catchment, including the current EWR planned for each of the dams and the planned water requirements from the new infrastructure.

4.1 Present Day Scenarios

Literature that was consulted for the scenario establishment included the following:

- The WRPM model used for the 2022 Annual Operating Analysis was used for the scenario analysis, including the latest water requirements and all the Intermediate and Rapid 3 EWR sites have been incorporated into this model; and
- Scenarios were selected from the ORASECOM Integrated Water Resource Management Plan and Reconciliation strategies for the area.

The key present infrastructure developments in the Upper Orange Catchment are highlighted in **Table 4-1** and include the main dams that have been developed in the catchment, together with large water conveyance infrastructure. This list excludes the various local water supply schemes for potable water, industry and irrigation within the catchment developed by the municipalities and farmers.

Table 4-1: Main dams in the catchment

Name	Sub - catchment	Purpose	Volume (ML)	Surface area (km^2)
Major dams				
Gariep	Orange	• Major storage dam • Irrigation • Major Orange-Fish transfer from Gariep Dam to the Fish / Tsitsikamma WMA • Hydropower	5 340 600	352.162
Vanderkloof	Orange	• Major storage dam • Irrigation • Hydropower • The Orange-Riet transfer from downstream Vanderkloof Dam to the Riet River	3 171 300	133.402
Armenia	Caledon	• Small storage dam for irrigation	13 000	3.933
Egmont	Caledon	• Small storage dam for irrigation	9 300	2.442
Welbedacht	Caledon	• Small storage dam • Irrigation • Water transfer for domestic	10 200	10.185

Name	Sub - catchment	Purpose	Volume (ML)	Surface area (km²)
Knellpoort	Modder	• Off-channel storage dam supplementing water supply to Bloemfontein from Caledon River (Caledon-Modder transfer)	130 000	9.854
Rustfontein	Modder	• Small storage dam • Irrigation • Domestic and industrial	72 200	11.585
Mockes	Modder	• Small storage dam • Domestic and industrial	No information	No information
Krugersdrift	Modder	• Small storage dam for irrigation	66 000	18.525
Tierpoort	Riet	• Small storage dam for irrigation	34 000	9.11
Kalkfontein	Riet	• Small storage dam for irrigation	325 100	37.697

The resources of the Upper Orange Catchment are used to support requirements for water in other parts of the country with large transfer schemes both from and within this WMA. These include the following:

- The Orange Fish Transfer from Gariep Dam to the Fish / Tsitsikamma WMA;
- The Orange-Vaal Transfer to the Lower Orange WMA; and
- Transfers within the catchment, occurring from the Orange and Caledon Rivers to the adjacent Modder / Riet catchment (DWA, 2009).

Although not directly within this study area, though do influence the availability of flows within the study area, the following water transfers listed below will be considered:

- Transfers out from the Senqu River (Lesotho Highlands Water Project) through the Katse and Mohale and planned Polihali Dams to the Upper Vaal WMA; and
- Transfer from Muela Dam in Lesotho to the Caledon River is used during droughts to supply water to Maseru and surrounding areas.

Additional to these large developments are numerous irrigation schemes, industrial supply, as well as domestic and rural water supply schemes. The information on these is captured in a range of reports and previous studies, as well as embedded in water resource models for the catchment.

4.2 Future Development Scenarios

Literature and models that were consulted for the future scenario formulation included the following:

- The WRPM model used for the present day scenarios was adjusted to incorporate future infrastructure developments and water demands;
- Scenarios were selected from the ORASECOM Integrated Water Resource Management Plan and Reconciliation strategies for the area as well as large developments planned within Lesotho that will impact on the availability of flows;
- Scenarios selected were developmental scenarios of the water resources and future water requirement projections upstream the EWR sites; and
- Scenarios identified also consider the ecological function or well-being of the water resources, including estuarine requirements (Lower Orange) and climate change impacts.

The main future developments anticipated for the Upper Orange Catchment, including Lesotho, and the associated infrastructure included are summarised in **Table 4-2**. This is based on the above-indicated reports, the Study Team's experience and knowledge of the catchment, as well as through the engagements with the DWS and WRP Consulting Engineers. Refer to **Table 4-3** for a summary of the management scenarios that were evaluated.

Table 4-2: Anticipated and proposed major developments in the Upper Orange Catchment

No.	Development	Scenario inclusion	Estimated commissioning date	Scheme Dimensions	Status	Literature
1	Polihali Dam, Lesotho	2040 and 2060	2029	2322 million m^3 dam in Lesotho. Determined EWR releases included. 411 million m^3/a supply to Vaal for Gauteng Water Requirements	Under construction	Estimated Delivery data: MaM JV Polihali Dam Design and Supervision contract (C3006) July 2023 monthly progress report. EWR Requirements: Instream Flow Requirements for the Senqu River – Final Report. LDHA Contract 6001. Prepared by the Institute of Natural Resources
2	Lesotho off-channel storage irrigation schemes along the Hlotsi and Caledon River	2040 and 2060	Between 2035 and 2040	Three schemes along the Hlotsi and Caledon/Mohakare Rivers (Manka, Tsoili-Tsoili and Likhakeng) and one scheme along the Senqu River (Phamong). Total abstraction from all 4 schemes totals 5.3 million m^3/a. Total irrigation area of 1580 ha.	Will start implementing first scheme by 2024	Personal communication with Mr. J. Bekker and Mr. J. Schroder from AECOM. Analysis based on separate detailed WRYM modelling of the schemes.
3	Makhaleng Dam on the Makhaleng River in Lesotho	2040 and 2060	Unknown, assumed by 2040	Final dam size not determined. Estimated 1218 million m^3/a dam with 185 and 103 million m3/a water use by Botswana pipeline and EWR releases from the dam, respectively.	Prefeasibility Study underway	Personal communication with Mr. M. Maree from WRP Consulting Engineers. Latest WRYM Model configuration for the dam was provided for inclusion in the WRPM
4	Gariep Dam pipeline to Bloemfontein	2040 and 2060	2035	Pipeline directly to Bloemfontein from Gariep dam to make up for shortfall in the supply from the Caledon. 44 million m^3/a by 2040 and 60 million m^3/a by 2060.	Late stages of planning.	Personal communication with Mr. M. Maree from WRP Consulting Engineers.

No.	Development	Scenario inclusion	Estimated commissioning date	Scheme Dimensions	Status	Literature
5	Verbeeldingskraal Dam on the Orange River, upstream of the confluence with the Kraai River	2060	Unknown, assumed by 2040	The estimated 1363 million m3 dam will be built to help regulate the shortfall in yield in the Upper Orange River after the commissioning and full use of Polihali Dam.	Early stages of planning	Personal communication with Mr. M. Maree from WRP Consulting Engineers. Dam configuration details provided and incorporated into WRPM
6	Vioolsdrift Dam on the Lower Orange River upstream from the Orange River Estuary	2060	Unknown, assumed by 2040	The estimated 2217 million m3 dam will be built just before the Orange River Estuary to regulate the flow to the estuary more accurately, with resulting lower releases for losses along the Lower Orange river from Vanderkloof Dam.	Advanced stages of planning	Personal communication with Mr. D. Badenhorst from AECOM.

Table 4-3: Summary description of the management Scenarios

Number	Description
Sc1	Present day without EWR
Sc2	Present day with EWR for REC
Sc3	2040 Polihali, Makhaleng Dam and pipeline to Botswana, Pipeline from Gariep to Bloemfontein, Caledon weirs without EWR
Sc4	2040 Polihali, Makhaleng Dam and pipeline to Botswana, Pipeline from Gariep to Bloemfontein, Caledon weirs with EWR for REC, estuarine requirements
Sc5	2060 Polihali, Makhaleng Dam, Pipeline from Gariep, Caledon weirs, Verbeeldingskraal on upper Orange, Vioolsdrift Dam on lower Orange, without EWR
Sc6	2060 Polihali, Makhaleng Dam, Pipeline from Gariep, Caledon weirs, Verbeeldingskraal on upper Orange, Vioolsdrift Dam on lower Orange, with EWR for REC, estuarine requirements
Sc7	Present day with EWR for REC (Sc2) but with progressive water quality decline

These initial EWR scenarios include the floods and freshets per component (geomorphology, riparian vegetation, fish, macroinvertebrates) as specified by the specialists during the quantification of the EWRs. The ability for these to be released from the dams will need to be reviewed against both the outlet capacities of the dams where releases are required, and the ability for the system to provide these and achieve a balance between environmental protection and socio-economic support and development. This will be conducted as a form of trade-off scenario and the final ecological category (or Target ecological category) will be determined during the Classification phase of the study which has been initiated by DWS recently.

4.3 Climate Change

The impact of climate change (CC) on the yield of the Upper Orange River and Modder-Riet River Catchments were assessed in a 2019 ORASECOM study (ORASECOM, 2019). The study made use of the same system configuration as used as basis for this study. The ORASECOM Study (referred to as the CC Study), evaluated the effects of changes in (a) rainfall and (b) rainfall and evaporation on the behaviour of the Upper Orange and Modder-Riet Systems. The CC Study made use of six (6) selected Global Climate Models (GCMs) and the GCMs were used to predict long-term change in the rainfall and evaporation.

The six Global Climate Models that were downscaled are:

- Australian Community Climate and Earth System Simulator (ACCESS1-0), hereafter referred to as ACC;
- Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3), hereafter referred to as GFD;

- National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5), hereafter referred to as CNR;
- Max Planck Institute Coupled Earth System Model (MPI-ESM-LR), hereafter referred to as MPI;
- Norwegian Earth System Model (NorESM1-M), hereafter referred to as NOR; and
- Community Climate System Model (CCSM4), hereafter referred to as CCS.

These changes were then used in Present Day simulation runs of the WRYM to assess the impact on irrigation water requirements (one of the largest water users) as well as the impact on the historical firm yield of the system.

The CC study showed that there is an increase in irrigation demands for the different catchments and General Circulation Model (GCM) for climate, that range between 5% and 9%, with only one GCM showing a decrease in irrigation demand as shown in **Table 4-4**.

Table 4-4: Global Climate Models for the different sub-catchments in the Upper Orange catchment area

Sub-catchments	GCM (%) difference in irrigation demands					
	ACC	CCS	CNR	GFD	NOR	MPI
Caledon	7%	7%	3%	-6%	5%	8%
Modder	10%	9%	3%	-6%	6%	10%
Upper Orange	5%	9%	2%	-10%	4%	9%
Average	6%	8%	2%	-8%	5%	9%

The effect on long term historical yield of the different GCMs and catchment areas on average compared to observed historical hydro-climatic conditions (considering both rainfall and evaporation) is summarised in **Table 4-5**.

Table 4-5: Effect on long term historical yield of the different GCMs and catchment areas on average compared to observed historical hydro-climatic conditions

Catchment	Average % difference when comparing Climate Change Firm Yield versus Historic Observed Firm Yield
Greater Bloemfontein Water Supply System	15%
Lesotho Highland Water Project	-1%
Makhaleng River Catchment	1%
Orange River	-8%

The relevance of the CC study results to the developed Scenarios in this Study:

- The main difference between the historical and the CC scenario results is the increased irrigation demand. The Upper Orange catchment has significant irrigation schemes which will be affected with higher water requirements. However, most of the irrigation schemes are highly regulated through operations of transfers and quotas/ water use licenses, which will mean that any higher water requirements will have to be dealt with by the irrigators themselves through scaling down of activities, more water efficient irrigation methods or getting alternative resources. There are also no planned increases in the allocation for irrigation throughout the whole of the Orange River catchment. The scenarios developed for this study therefore are still applicable since the impact of this water use will be limited through the regulation and control of schemes' access to water; and
- From a general flow perspective, the Historical Firm Yield shows the impact of CC on the critical drought severity and durations. For the Modder-Riet and Lesotho catchments the Firm Yield of the system improve or stays the same as historically. For the rest of the Orange River there is a significant drop of 8% in the Firm Yield. The CC Study was however based on a near-Present-Day development level and does not include the Polihali, Makhaleng and Verbeeldingskraal Dams which will aim to regulate the system even more and which will compensate for future increases in water use and possibly also climate change. The scenarios developed in this study is therefore perhaps more severe in some cases due to the higher projected water use and number of large new reservoirs planned in the catchments. It is also well understood that climate resilience is helped by more controlling infrastructure (such as dams) that could support each other in times of drought.

5. ECOLOGICAL CONSEQUENCES

The scenario analysis serves as the foundation for evaluating the ecological and socio-economic consequences discussed in the subsequent sections. This process is aimed at appraising the effects of the chosen flow scenarios on ecological categories by anticipating both the drivers and responses in each scenario. These findings, in turn, provide insights that guide the ultimate determination of the ecological category. This may or can be used for the determination of the water resources class within a specific IUA during the Classification phase of the study. Please refer to the subsequent sections for further detail in the approach.

5.1 Approach

The process for assessing the ecological and socio-economic consequences for the seven (7) identified scenarios was undertaken through a series of chronological steps as follows:

- The operational scenarios were modelled and a time series was provided for each scenario at each EWR site. These scenarios encompassed present day conditions, as well as future projections for 2040 and 2060. The hydrological changes associated with each of the identified scenarios as modelled were used as the primary driver of change. The scenario flows were assessed in terms of how the changes in hydrology for the various scenarios will impact on the level of stress being experienced in the system and the state of the various response variables. To aid in the interpretation of the impacts due to hydrological changes, seasonal distribution and flow duration graphs were prepared for the operational scenarios;
- The driver components, specifically geomorphological factors, underwent initial evaluation to gauge their ecological repercussions. These preliminary assessments were then shared with the wider team;
- A close collaboration between the geomorphologist and the riparian vegetation specialist ensued, with a particular focus on flood impacts;
- Utilising the GAI model, the geomorphologist conducted predictions for the ecological categorisation of operational scenarios within specific and relevant sites in the catchment area. The primary emphasis was on the mainstem of the Orange River, given the various impacts on the river system, such as the presence of existing and newly proposed dams and transfer schemes (EWR03 and EWR10);
- Subsequently, the riparian vegetation specialist assessed the effects on marginal and other riparian zones, furnishing this information to specialists to interpret habitat changes for instream biota (i.e., fish and macroinvertebrates). This step preceded the instream biota assessment, given the pivotal role of riparian vegetation in providing critical habitat for some aquatic biota (cover features for fish and increased marginal vegetation availability for macroinvertebrates);
- The riparian vegetation specialist ran the VEGRAI model to predict the ecological category for the operational scenarios across selected and applicable sites within the catchment area;
- Seasonal modelling (wet and dry months) of the biotic consequences for all scenarios, encompassing fish and macroinvertebrates, was undertaken using the Fish Invertebrate Flow Habitat Assessment Model (FIFHA);
- Inclusive, the insights garnered from the assessments of driver responses were used to interpret the overall ecological category for the biota as a consequence of the operational scenarios, both during wet and dry seasons; and

- Evaluation of scenario 7 pertaining to water quality with insights derived from diatom results, macroinvertebrate data and the Green Drop Reports.

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

5.1.1 Water Quality

Water quality was assessed for all the intermediate sites based on the macroinvertebrate assessments and available physical-chemical data (including diatoms). Furthermore, the assessment postulated what changes will arise, if any, under Scenario 2 and Scenario 7 (which is the same as Scenario 2, whereby the EWR flows are implemented, but where water quality conditions likely decline). Refer to **Appendix A** for a summary of how the assessment of water quality in the Upper Orange catchment was conducted, including an analysis of scenario 7 from a water quality standpoint.

Additionally, please consult **Appendix B** for a comprehensive overview of the present status of water quality at each EWR site. This includes *in situ* water quality data, information on diatoms, and macroinvertebrates, all of which are coupled with an analysis of the key factors responsible for the current water quality conditions in the rivers. The above was based on the Eco-categorisation report – volume 1 (No. RDM/WMA13/00/CON/COMP/1223 (a)).

5.1.2 Geomorphology

The scenarios were assessed using GAI for the sites (EWR03 and EWR10) where additional dams will possibly be constructed in the catchment. The dams will result in changes to the freshet and flood flows and longitudinal sediment transport which are the main geomorphological drivers. The sites where smaller weirs will possibly be constructed will not have significant longer-term impact on the flow and sediment regimes and were not assessed using GAI. Similarly, the impact of 'with' and 'without EWR' scenarios were not assessed where there were no significant changes to the freshets and flood magnitudes.

Impacts from sand mining, grazing, browsing, and changes to vegetation cover and sediment supply due to catchment degradation was not assessed as the focus was on water resource development scenarios.

5.1.3 Riparian vegetation

The VEGRAI model was used to re-run the scenarios whereby riparian vegetation is expected to respond to drivers, primarily changes in flows, as determined through the hydrological modelling, as well as geomorphological changes as interpreted by the geomorphologist using the GAI model. This process was only followed for systems where future planned developments would have a significant effect on the flow regime based on the hydrological modelling. For systems that are only expected to experience minor changes in flow, a qualitative interpretation was provided to describe the likely response of riparian vegetation based on the scenarios. Where changes in riparian vegetation are expected to occur, particularly along the marginal zone, then the interpretations provided a basis to infer responses by aquatic biota to the altered provision of habitat.

5.1.4 Biota (fish and macroinvertebrates)

Seasonal modelling of the biotic consequences for all scenarios, encompassing fish and macroinvertebrates, was undertaken using the Fish Invertebrate Flow Habitat Assessment Model (FIFHA). This model, developed by Dr. N. Kleynhans and C. Thirion of the Department of Water and Sanitation's Resource Quality Information Services (RQIS) in 2016, adheres to Eco-categorisation principles, Ecological Category formulation (Kleynhans and Louw, 2007), and the specification of EWR, specifically pertaining to instream flows. The FIFHA model incorporates the following parameters:

- Discharge,
- Average width and depth,
- Different flow-depth velocity classes for fish and inverts,
- Different biotope / substrate,
- Hydrology (Natural, Present day, and Baseflows)
- Various scenario flows,
- Ecological Categories (PES, REC),
- Fish (flow dependent species), and
- Macroinvertebrates (sensitive and flow dependent/ habitat dependent taxon).

Importantly, it should be noted that the FIFHA model has certain limitations. The FIFHA model was infact developed to enable rapid monitoring of water levels related to critical habitats and instream biota requirements through the use of HABFLO and hydrology. It is useful for dry seasons, but for wet seasons, proper baseflow separation is requirements (of which is problematic using monthly flows).

Nevertheless, FIFHA was specifically prescribed in the Terms of Reference for this study and was consequently employed for modelling the scenarios. At certain locations, such as the Upper Orange, Caledon River, and Lower Orange River, the FIFHA model did not yield accurate results due to the aforementioned limitations. As a result, the team reverted to fundamental principles and incorporated additional metrics into their interpretations, based on available data and expert knowledge integration, namely, taking into account increased flows, siltation, erosion, incision, and/or limited habitat availability. Thus the FIFHA was used as a “stop-gap’ approach.

In situations where rheophilic macroinvertebrate taxa, such as Perlidae, were absent due to the lack of their preferred habitat at these sites, alternative indicator taxa was used. These alternative indicators may not be as sensitive because of the limited available habitats and/or their other preferences. When it comes to fish, there are no truly rheophilic species; only semi-rheophilic fish species was used in the FIFHA model for this catchment, which, once again, may not provide the same level of accuracy in assessing the biotic consequences of the scenarios. Therefore, the interpretations are based on the expertise and knowledge of specialists who consider the current characteristics and impacts on the systems, as well as their understanding of the potential consequences resulting from the scenarios.

Furthermore, in this context, the assessment of anticipated changes in water quality resulting from the implementation of various scenarios took into account existing impacts and insights derived from diatom results, macroinvertebrates, and/or other nutrient data on hand. The water quality perspective was an integral part of the consequence assessment, especially for scenario 7.

5.1.5 Socio-economics

The influence on the system drivers and ecological responses of the altered flows to meet the EWR predicted by the various specialists was reviewed in relation to the socio-economic context (as presented in the Socio-Economic Baseline Report, Report No. RDM/WMA13/00/CON/COMP/1123) for the selected scenarios at each site. Important to note is that the socio-economic baseline assessment was undertaken at the local municipality scale and the interpretation of each EWR site is based on the local municipality baseline. The system drivers and response elements reviewed included water quantity, water quality, geomorphology, riparian vegetation, fish and invertebrates.

The likely socio-economic outcomes of the predicted driver and response states between the 'with' and 'without EWR' were considered across five key socio-economic aspects (household vulnerability[1], domestic (treated) water use, subsistence cultivation, commercial irrigated agriculture, and the local economy, using the data and indicators from the baseline socio-economic assessment.

Based on the present socio-economic state (as described in the Socio-Economic baseline report) and the ecological and biophysical consequences predicted by the various specialists for the scenarios, the socio-economic outcomes under the altered flow regimes were qualitatively predicted. A narrative statement was provided for those scenarios where likely outcomes were identified. The indicator levels are described as a range from low to high, based on the magnitude of the indicator for the area relative to the Upper Orange catchment as a whole.

Important to note is that the socio-economic evaluation is based on the predicted driver and state responses at the EWR sites, and, therefore, provides an indication of the socio-economic outcomes for the site and corresponding local municipalities associated with the alternative flow regimes. This does not consider potential socio-economic outcomes related to changes in water quantity/availability upstream to provide the necessary flows to meet the EWR. The flow modelling was interpreted as considering present human water use and growth projects.

[1] Household vulnerability is a composite indicator derived from an integration of indicators on multi-dimensional poverty (SAMPI), population density and reliance on flowing water/stream/river sources for drinking water, to meet basic human needs (as described in the Socio-Economic baseline report).

5.1.6 Determining the ranking of scenarios per EWR site

Scenarios at each EWR site were ranked based on the degree to which the scenarios meet the EWR for the PES of each component, and then overall whether the scenarios would meet the EWR for the REC (Table 5-1). The impact of the scenarios at the different EWR sites were compared to determine a ranking from a system context. It is important to note, that the ranking approach to the scenarios has not been published; instead, it represents an identified and adaptable approach. The approach depends on *four (4)* steps as follows:

- *Step1: The degree to which the scenario meets the PES per component*
  - a. Primarily from the biotic perspective, a structured ranking system was employed, as detailed in **Table 5-1**. This ranking system goes beyond intuitive explanations and incorporates specific criteria to quantify changes in the system resulting from the scenarios.

Table 5-1: Ranking of ecological consequences of the scenarios

Ecological Category	≥PES/ component	½EC < PES/ component	1 EC < PES/ component	>1 EC PES/ component
Colour key	Green	Yellow	Orange	Red

- *Step 2: The relative ecological significance of the sites can be delineated as follows:*
  - a. The significance of an EWR site is directly proportional to the values of PES and/or EIS; in other words, the higher the PES and/or EIS, the greater the ecological importance of the EWR site (DWS, 2014);
  - b. Consideration is given to the conservation importance of a site. Consequently, if an EWR site is situated within a conservation area of notable significance, it will be designated as a pivotal EWR site due to its ecological importance (DWS, 2014);
  - c. The extent of the river reach encompassed by the EWR sites is also a factor in determining their importance. Specifically, the greater the length of the represented river reach, the higher the level of significance attributed to the potential impacts within that scenario (DWS, 2014); and
  - d. The crucial factor determining the ranking of EWR sites in the ecosystem is their relative position and influence on simulated operations. This involves considering factors such as the location (upstream or downstream) in relation to WWTW or other developments, as well as the nature and extent of their influences on the EWR site. The hierarchy of these sites depends on their significance in the modeling context, which determines the primary driver EWR site for "releases" within the model. These key sites can either be the most downstream or have a higher REC (or PES) compared to others, resulting in a greater flow requirement and, consequently, higher ecological importance (DWS, 2014).
- *Step 3: Rank the scenarios in a system context based on assumptions*
  - a. The aggregation of the categories per component per scenario were assessed as to whether the scenario will be met as a whole. If one of the components did not meet their PES by a full category, it was then assumed that overall, the physical and biological components would not meet the REC for that specific scenario for that EWR site.

- *Step 4: Interpretation of Sc7 from a biotic perspective*
  a. The category result for the biota with reference to Sc7 (water quality) was based on expert opinion through assessing the diatom results and the responses from the aquatic macroinvertebrate community, taking into consideration the PES of the overall water quality component. This will apply throughout the report.

5.1.7 Selection of scenarios for evaluation

The management scenarios that were selected are based on actual development options that are considered for the study area and upstream in Lesotho. Thus, some of the rivers will have no changes to flows or minimally impacted and ecological consequences will be the same. A scenario comparison matrix based on the changes in flows was developed to guide the specialists where to focus as it depict a sequence of scenarios for comparison with natural conditions, baseflows and the EWR for REC. It is based on the seasonal hydrographs for the various scenarios and were interpreted where changes occur for wet season (floods) and dry season (baseflows). These hydrographs are included for each of the intermediate sites as part of the ecological consequences results (see **Section 5.2**).

5.2 Ecological Consequences Results

5.2.1 UO_EWR01_I: Middle Caledon

Site Name	UO_EWR01_I	**Prioritised RU**	R_RU04
River	Middle Caledon	**Altitude (m.a.s.l.)**	1526
Latitude	-28.909102	**Longitude**	27.784924
Level 1 EcoRegion	Eastern Escarpment Mountains	**Quaternary catchment-SQ Reach**	D22D-03415
Level 2 EcoRegion	15.01	**DWS, 2014 PES, EI, ES**	C, Moderate, Moderate
Geomorphological zone	F (Lowland)		
Sumary of the Eco-categorisation results			

River	**Middle Caledon**
EWR Site Code	**UO_EWR01_I**
Driver component	**PES**
HAI	C
Diatoms	D
GAI	D
Response component	**PES**
FRAI	D
MIRAI	C
VEGRAI	E
Ecostatus	D/E
EI	Moderate
ES	Moderate
REC	D
AEC	C

Reasons for EcoStatus: Impacts

- Extensive alien invasive plants within the riparian zone;
- Poor habitat availability for both fish and aquatic macroinvertebrates;
- Degraded site with elevated sediment yields from the degrading catchment;
- Alluvial bed with high sediment mobility;
- Trampling along the banks and alien vegetation changing the bank stability and shape; and
- Diatoms used to infer the present physical-chemical state of the system, indicating that the quality is largely driven by pollution from untreated effluent discharge upstream in Ficksburg.

Present EI-ES

- Both remained Moderate.

REC: Mitigations Needed

- The system has perennial flows – limited to no zero flows as per the HAI. The month of October generally have these zero flows.

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-1** below. The flow durations of the scenarios for the Middle Caledon (UO_EWR01_I) for July (dry) and February (wet) are shown in **Table 5-2** and **Table 5-3**. **The 'red' highlighted areas in the tables indicate where the EWR could not be met (deficit – meaning that there is not enough water in the system to meet the EWR).**

It is crucial to note, and this applies across the report, that the tables below do not incorporate natural baseflows. Comparing them with other scenarios that encompass freshets/floods would be inappropriate. To gauge the baseflows, one can consider the 60th to 85th percentile as an indicative measure.

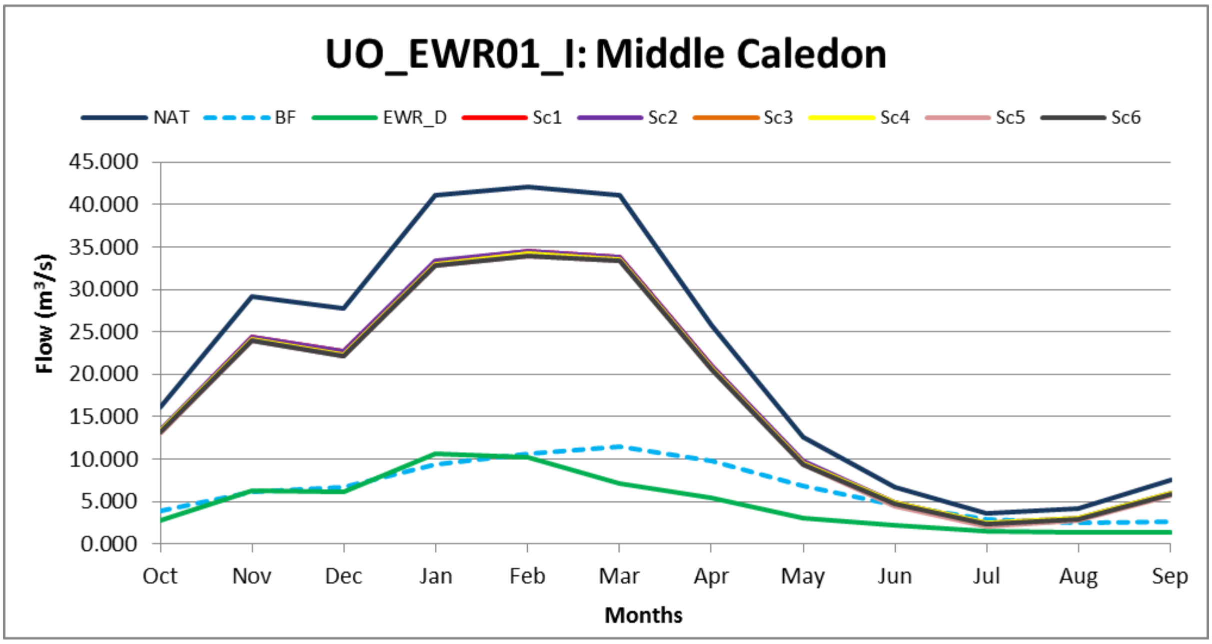


Figure 5-1: Seasonal distribution of scenarios at site UO_EWR01_I: Middle Caledon

All the scenarios show reduced floods in the summer months, as well as reduced baseflows, especially for Sc1 and Sc3.

Table 5-2: Percentiles and flow (m^3/s) for July per scenario at Middle Caledon (UO_EWR01_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_D
0.1	38.859	33.839	33.839	33.658	33.658	33.445	33.445	2.336
1	20.195	17.656	17.656	17.468	17.468	17.255	17.255	2.330
5	10.314	8.456	8.456	8.022	8.022	7.809	7.809	2.325
10	5.919	4.492	4.491	4.189	4.189	3.977	3.977	2.312
15	5.236	3.828	3.828	3.642	3.642	3.501	3.501	2.284
20	4.419	2.635	2.635	2.405	2.404	2.216	2.386	2.249
30	3.352	2.062	2.096	1.983	2.009	1.622	1.844	2.151
40	2.607	1.453	1.682	1.294	1.665	1.067	1.622	1.955
50	2.284	1.105	1.401	1.044	1.378	0.831	1.311	1.682
60	1.928	0.866	1.080	0.733	1.086	0.603	1.066	1.317
70	1.516	0.557	0.813	0.474	0.941	0.452	0.819	1.021
80	1.295	0.346	0.671	0.333	0.693	0.384	0.627	0.760
85	1.190	0.269	0.522	0.268	0.537	0.305	0.481	0.676
90	1.045	0.194	0.436	0.230	0.426	0.238	0.391	0.622
95	0.837	0.131	0.299	0.183	0.291	0.159	0.270	0.588
99	0.664	0.095	0.181	0.113	0.179	0.137	0.159	0.570
99.9	0.571	0.090	0.137	0.109	0.116	0.093	0.095	0.562

Table 5-3: Percentiles and flow (m^3/s) for February per scenario at Middle Caledon (UO_EWR01_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_D
0.1	180.286	158.100	158.100	157.912	157.912	157.699	157.699	24.290
1	177.747	149.861	149.861	149.680	149.680	149.467	149.467	24.279
5	111.930	93.028	93.029	92.843	92.843	92.630	92.629	24.191
10	93.343	79.476	79.477	79.203	79.203	78.990	78.990	23.805
15	87.024	75.320	75.320	75.128	75.128	74.915	74.915	21.566
20	80.340	62.558	62.559	62.328	62.329	62.115	62.116	19.777
30	61.684	46.338	46.337	46.066	46.065	45.853	45.852	16.034
40	37.203	32.078	32.078	31.778	31.778	31.565	31.565	11.415
50	25.844	22.488	22.488	22.226	22.226	22.013	22.013	7.475
60	18.033	14.755	14.755	14.414	14.414	14.257	14.257	4.861
70	10.927	8.796	8.796	8.331	8.331	8.118	8.118	3.064
80	8.736	6.821	6.821	6.473	6.474	6.260	6.261	2.026
85	7.521	5.057	5.057	4.769	4.769	4.671	4.672	1.735
90	5.842	4.252	4.252	3.893	3.893	3.680	3.680	1.636
95	2.884	1.696	1.973	1.641	1.970	1.833	1.958	1.613
99	2.418	1.244	1.505	1.054	1.427	0.872	1.311	1.491
99.9	1.009	0.609	0.635	0.543	0.580	0.506	0.550	0.916

The above tables indicate that the EWR could not be met for most of the time for any of the scenarios in July even the 'with EWR' scenarios show non-compliances. The EWR could be met for most of the time during February.

The scenarios highlighted in grey in **Table 5-4** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC of D for the EWR site. This information is provided in **Table 5-5** to **Table 5-7.** For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

With reference to water quality, it is important to note that **Appendix B** provides a comprehensive overview of the present status of water quality at each EWR site. This includes *in situ* water quality data, information on diatoms, and macroinvertebrates, all of which are coupled with an analysis of the key factors responsible for the current water quality conditions in the rivers. In general, this collective summary provided evidence for the expert opinion regarding Scenario 7, particularly with respect to the anticipated future state of water quality in our waterways. This relevance holds true throughout the entire report.

Table 5-4: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-5: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES*		**Sc2**	**Sc7 (*anticipated further deterioration in water quality*)**

D		In accordance with Figure 5-1, one could expect a maintenance of the water quality of this site.
		• There is a maintenance of the typical summer/wet season volume in the system (and hence flushing/freshets and floods);
		  o In the result, benthic algal growth due to nutrient enrichment, will be scoured out and the system refreshed.
		• However, the low flows during winter/dry season are when the WWTW flows (along with the observed poorly treated WWTW and sewage flows not even getting into the WWTW) contribute a significantly higher proportion of the base flow to this system, making this the most stressed period in terms of water quality.
		  o Again, in the result, a larger proportion of sewage and associated nutrients, bacteria etc., dominating the baseflows of this system.
			Due to the present critical degradation of water quality, it is expected to worsen significantly and reach a critical point in the future.
			
			The net impact will be a significant decline in the health and ability of this system to deliver ecosystem goods and services, principally acceptable water quality and a system able to assimilate polluted water associated with its natural resident biota.
			
			Considering the major reason for declining water quality in the Upper Orange River system is failing WWTWs, worsening water quality is likely to a) allow water borne diseases to become more frequent and persistent, and b) seasonally increased risk for local dependent communities, recreational users, and a high impact for biodiversity associated with this river system.

**Present Ecological State (PES) as per above summary table and throughout report obtained from the Eco-categorisation Report Volume 1 (Report No. RDM/WMA13/00/CON/COMP/1223)*

Table 5-6: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES*		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D		**D**	**D**	**D/E**	**D/E**	**D/E**	**D/E**
The flow changes for Sc1 and Sc2 are not relevant to geomorphological processes, but the proposed weirs (Sc3 to Sc6) can have a small impact on flow and sediment regimes but are unlikely to result in significant changes to the physical habitat, the channel structure or the longer-term availability of sand for sand mining.							
Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
E		**E**	**E**	**E**	**E**	**E**	**E**
Riparian vegetation is not likely to change in response to the flow changes due to insignificant changes in low flows and resultant geomorphological processes. It is unlikely that marginal vegetation will establish given the lack of channel structure and instream habitat, as well as the severe infestation by woody alien vegetation along the banks. As a result, the EC will remain unchanged for Sc1 to Sc6, which will compromise the situation of meeting the REC.							

Table 5-7: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7***
Fish Dry	D		D	C/D	D	C/D	D	D	D/E
Inverts Dry	C		B/C	B	B/C	B	B/C	B	D
Fish Wet	D		A/B	A/B	B	B	B/C	B/C	D/E
Inverts Wet	C		A/B	A/B	B	B	B	B	D

**The category result for the biota with reference to Sc7 (water quality) was based on expert opinion, taking into consideration the PES of the component. This will apply throughout the report.*

Macroinvertebrates

The Middle Caledon is a wide homogenous river composed largely of sand and silt with both banks sandy, steep and highly erodible, coupled with zero marginal vegetation. Habitat diversity for macroinvertebrates was thus very poor in this river system, with only sand and mud as the dominating biotope available for macroinvertebrates. Consequently, the indicator macroinvertebrate selected for this reach that was run in the FIFHA was Caenidae. Caenidae are not a sensitive rheophilic taxon but do have a preference for the fast and very fast fine substrate. The FIFHA analysis was conducted for the months of February and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. Although the proposed weirs in Sc3 to Sc6 may have a small impact on flow and sediment regimes, it is unlikely to result in any significant changes to these critical habitat types. Therefore, the ecological flows will maintain the various aquatic velocity-depth classes and thus habitat will subsequently maintain the expected macroinvertebrate community. Thus, all scenarios would meet both the macroinvertebrate EC and the supply for the REC for this EWR site.

However, it's crucial to emphasise that, at this EWR site, the macroinvertebrate community is not significantly influenced by alterations in flow currently. Instead, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a 'C' or moderately modified using the MIRIA methodology, was water quality. This finding is also substantially corroborated by the diatom results.

With regards to Sc7 whereby there is anticipated further deterioration in water quality. Given that the current state of the aquatic macroinvertebrate community is already moderately modified and responding to poor water quality, as mentioned earlier, it is reasonable to anticipate that the further deterioration and a critical compromise in water quality, which may even result in an increased prevalence of waterborne diseases, will only serve to perpetuate the presence of highly tolerant macroinvertebrates that thrive in conditions characterised by very low water quality within this ecosystem in the future.

Fish

The reach is expected to support very limited cover features from a fish perspective, comprising a sandy/small gravel substrate with laminar flows across the channel expected for much of the hydrological year. Some undercut banks are expected to be present that would provide cover for some fish elements, although critical habitat for spawning, egg development and larvae are not expected to be present due to the high sedimentation rates and lack of suitable spawning substrates. The reach is located within the middle reaches of the Caledon River upstream from Welbedacht Dam which will prevent any movement of fish from the Orange River or the lower parts of the Caledon River. As such, fish species expected to be present include those that will be able to over-winter within Welbedacht Dam or tributaries and undertake seasonal upstream migrations up the Caledon River during the warmer summer rainfall periods when flows increase. Due to the lack of true rheophilic species, the large semi-rheophilic *Labeobarbus aeneus* was selected to act as flow-dependent indicators. While the reach does not have any critical habitat for early-life stages (spawning, egg development & larval nursery area), the reach is likely to be used as a conduit for upstream movement during periods of high flow.

Application of the FIFHA model for the various consequences investigated suggest that although the proposed weirs in Sc3 to Sc6 may have a small impact on flow and sediment regimes, it is unlikely to result in any significant changes to the ecological state of the associated reach of the Caledon River from a flow-depth perspective given that the indicator species does have a wide diversity of habitat preferences and is able to survive within lentic water bodies. However, a further decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted as a result of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-8**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-8: UO_EWR01_Middle Caledon: Ecological consequences

Component	PES	REC		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	D	D		D	D	D/E	D/E	D/E	D/E
Riparian Vegetation	E			E	E	E	E	E	E
Fish*	D			D	C/D	D	C/D	D	D
Macroinvertebrates*	C			B/C	B	B/C	B	B/C	B
EcoStatus	**E**								
Meeting overall REC				√	√	√	√	√	√

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*
**The lowest of the two categories run from FIFHA during the wet and dry seasons were included in this summary table for fish and macroinvertebrates. This applies for all EWR sites throughout this report in the summary chapter.*

Overall, the ranking of the scenarios indicate that all scenarios achieve the REC requirements for this site. However, it must be noted that from a biological perspective, due to the limited habitat availability for biota and sediment deposition, the system may not meet the REC of a D. Moreover, due to the absence of native riparian vegetation and the extensive intrusion of alien invasive plant species, coupled with issues such as bank erosion and collapse, the most viable approach for enhancing the overall riparian vegetation PES at this EWR site and improving its overall PES involves the management and stabilisation of the riverbanks, as well as the removal of invasive plants and the subsequent replanting of indigenous vegetation.

Scenario 7 summary

The physical-chemical state of the system was changed from natural with the introduction of the long-standing developments upstream. The negative impacts of the Ficksburg WWTW were reported as a problem in 2011, suggesting that the associated issues have also been impacting the system over a long period. The poor greendrop scores for

Ficksburg/Fouriesburg (Mashaeng) WWTW in 2021 identified these as a critical ongoing risk to the system stability, and a prohibitive factor to system recovery and improvement.

Thus, in addition to future land use in this catchment area and thus from a water quality perspective, it is predicted to worsen considerably and reach a critical point. Consequently, this will lead to a marked reduction in the overall health and capacity of the ecosystem to provide essential services, primarily in terms of supplying clean water and maintaining the ability to dilute, process, and mitigate the effects of polluted water, in conjunction with its native biota. Moreover, the prevalence of waterborne diseases is expected to become more frequent and enduring. This heightened risk, especially during certain seasons, poses significant challenges for local communities dependent on the river, recreational users, and also has a profound impact on the biodiversity (fish and macroinvertebrates) associated with this river system.

Socio-economic summary

The present socio-economic state indicates a moderate relative incidence of vulnerable households, significant high-value irrigated commercial agriculture with a corresponding relative high contribution of agricultural value add, and a relatively high level of registered water-use from river sources.

The ecological/biophysical analysis and consequences outlined above indicate there is sufficient flow to meet the REC across all scenarios, suggesting there is unlikely to be any changes in the ability of the system to meet the present socio-economic water-use. The water quality situation and Sc7 pose a greater socio-economic risk particularly given the moderate relative incidence of vulnerable households and significant high-value irrigated commercial agriculture.

5.2.2 UO_EWR02_I: Sterkspruit

Site Name	UO_EWR02_I	**Prioritised RU**	R_RU01
River	Sterkspruit	**Altitude (m.a.s.l.)**	1429
Latitude	-30.51784446	**Longitude**	27.36907996
Level 1 EcoRegion	Eastern Escarpment Mountains	**Quaternary catchment- SQ Reach**	D12B-05232
Level 2 EcoRegion	15.01	**DWS, 2014 PES, EI, ES**	C, Moderate, High

Sumary of the Eco-categorisation results

River	**Sterkspruit**
EWR Site Code	**UO_EWR02_I**
Driver component	**PES**
HAI	C
Diatoms	C
GAI	D
Response component	**PES**
FRAI	D/E
MIRAI	D
VEGRAI	D
Ecostatus	D
EI	Moderate
ES	Moderate
REC	C/D
AEC	C

Reasons for EcoStatus: Impacts

- Widespread overgrazing and soil erosion in the catchment elevating fine sediment loads;
- Localised weirs along mainstem trapping coarser sediment;
- Sand mining upstream of the site;
- Trampling, overgrazing and localised alien trees along bars, banks and floodplain;
- Diatoms used to infer the present physical-chemical state of the system, indicating periodic nutrient and salinity increases at the site leading to eutrophication;
- Adjacent to the EWR site, an evaporation sewage pond directly discharging into the system; and
- Sterkspuit WWTW (although located downstream of the EWR site, but along the same sub-quaternary reach) is currently discharging untreated wastewater into the Sterkspruit, largely impairing the Physical-chemical state of this reach and further downstream.

Present EI-ES

- ES decreased from High to Moderate due to reduced sensitive aquatic macroinvertebrate taxa and riparian-wetland vegetation intolerance to water level changes.

REC: Mitigations Needed

- As water quality is the primary driver of this system from a biotic perspective, if this can be improved through various land and catchment management practices, this will provide an opportunity to improve the biotic state of the system, coupled with adequate flows; and
- Maintenance and upgrade of WWTW infrastructure, including the upgrade and functioning of the adjacent maturation pond.
- Informal and illegal sand mining practices to be halted and fines issued to the company partaking in such activities immediately;
- Sediment traps needed to prevent excessive sediment run-off into the river;
- Control and plan surrounding urban development and informal settlements;

- Better management of rubbish dumping facilities and the complete prevention of rubbish dumping within the river;
- Planning design for road network, catchment sediment drains; and
- Town clean up (local municipality to take accountability and responsibility).

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-2**. The flow durations of the scenarios for the Sterkspruit (UO_EWR02_I) for July (dry) and March (wet) are shown in **Table 5-9** and **Table 5-10**. The 'red' highlighted areas in the tables indicate where the EWR could not be met.

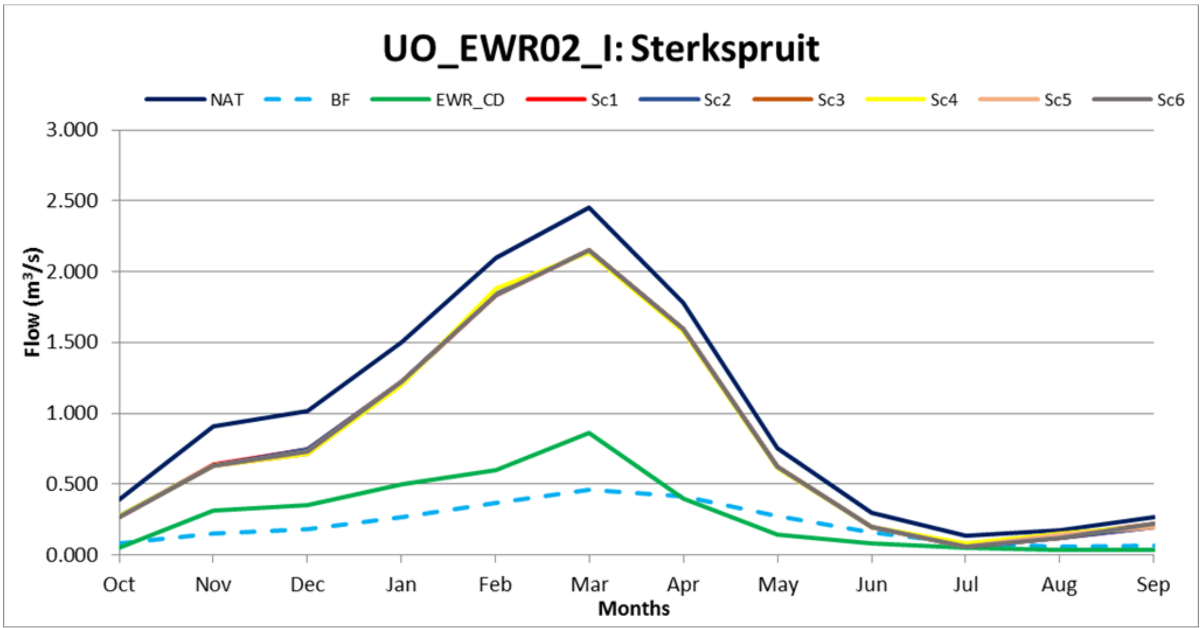


Figure 5-2: Seasonal distribution of scenarios at site UO_EWR02_I: Sterkspruit

All the scenarios show reduced floods in the summer months, as well as reduced baseflows. This is mainly due to the Jozanahoek Dam in the upper catchment with limited releases into the river.

Table 5-9: Percentiles and flow (m^3/s) for July per scenario at Sterkspruit (UO_EWR02_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C/D
0.1	1.030	0.532	0.532	0.544	1.494	0.532	0.532	0.103
1	0.810	0.517	0.517	0.536	0.702	0.517	0.517	0.102
5	0.556	0.240	0.240	0.309	0.359	0.240	0.240	0.101
10	0.360	0.176	0.175	0.191	0.207	0.176	0.175	0.101
15	0.281	0.117	0.118	0.129	0.144	0.117	0.118	0.098
20	0.202	0.060	0.060	0.067	0.088	0.060	0.060	0.095
30	0.131	0.039	0.039	0.039	0.051	0.039	0.039	0.084
40	0.106	0.031	0.033	0.032	0.038	0.031	0.031	0.067

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C/D
50	0.046	0.014	0.025	0.016	0.031	0.014	0.014	0.046
60	0.028	0.008	0.010	0.009	0.012	0.008	0.008	0.025
70	0.018	0.005	0.005	0.006	0.008	0.005	0.005	0.013
80	0.014	0.004	0.004	0.004	0.005	0.004	0.004	0.004
85	0.006	0.002	0.002	0.002	0.002	0.002	0.002	0.003
90	0.005	0.001	0.001	0.002	0.001	0.001	0.001	0.002
95	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001
99	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99.9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5-10: Percentiles and flow (m^3/s) for March per scenario at Sterkspruit (UO_EWR02_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C/D
0.1	21.365	21.207	21.207	21.207	21.207	21.207	21.207	2.156
1	15.538	15.348	15.348	15.348	15.348	15.348	15.348	2.151
5	11.237	11.063	11.063	11.063	11.063	11.063	11.063	2.146
10	6.964	6.120	6.120	6.120	6.103	6.120	6.120	2.127
15	4.363	4.187	4.187	4.187	4.187	4.187	4.187	1.905
20	3.668	3.156	3.156	3.156	3.135	3.156	3.156	1.658
30	2.143	1.752	1.752	1.752	1.752	1.752	1.752	1.364
40	1.133	0.748	0.748	0.748	0.748	0.748	0.748	1.018
50	0.740	0.426	0.426	0.426	0.391	0.426	0.426	0.591
60	0.548	0.298	0.298	0.298	0.260	0.298	0.298	0.365
70	0.436	0.147	0.147	0.147	0.145	0.147	0.147	0.212
80	0.203	0.060	0.060	0.060	0.072	0.060	0.060	0.117
85	0.132	0.039	0.039	0.039	0.049	0.039	0.039	0.095
90	0.074	0.022	0.022	0.022	0.031	0.022	0.022	0.073
95	0.028	0.008	0.008	0.008	0.019	0.008	0.008	0.028
99	0.018	0.005	0.005	0.005	0.007	0.005	0.005	0.018
99.9	0.006	0.001	0.001	0.001	0.005	0.001	0.001	0.006

The above tables indicates that the EWR could not be met for most of the time in any of the scenarios in July. Additionally, the EWR could also not be met during March, indicating the lack of releases from the upstream dam.

The scenarios highlighted in grey in **Table 5-11** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-12** to **Table 5-14**. For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-11: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-12: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
C		One could expect a maintenance of the water quality of this site (**Figure 5-2**). • Similar to the site UO_EWR01_I, at this site there is a maintenance of the typical summer/wet season volume, meaning that the water quality will be reset during the rainfall season as the benthic algal growth from nutrient enrichment will be scoured out and the system reset. • However, the low flows during the winter/dry season will be when the discharge from WWTW contributes a significantly higher proportion of the base flow to this system, resulting in the base / low flow period being when the nutrients, bacteria, and other WWTW associated outputs dominate the water quality in the system.	Due to the present critical degradation of water quality, it is expected to worsen significantly and reach a critical point in the future. The net impact is a significant decline in the health and ability of this system to deliver ecosystem goods and services, principally adequate water quality and a system able to assimilate polluted water associated with its natural resident biota. Considering the major reason for declining water quality in the Upper Orange River system is failing WWTW, worsening water quality is likely to a) allow water borne diseases to become more frequent and persistent, and b) seasonally increase risk for local dependent communities, recreational users, and a high impact for biodiversity associated with this river system.

Table 5-13: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D		**D**	**D**	*Not applicable due to no proposed development on the Sterkspruit*			
The scenarios for the Sterkspruit are of no geomorphological significance as the flows are modelled to be similar to the present day, and there will be no additional barriers to longitudinal sediment connectivity. We assume that all other impacts will remain stable.							
Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D		**D**	**D**	*Not applicable due to no proposed development on the Sterkspruit*			
Assuming non-flow related impacts remain the same (notably sand mining), it is expected that the riparian vegetation will not change under Sc1 and Sc2. Without active riparian management, the site could become more infested by invasive alien plants, in particular Popular and Black Wattle trees.							

Table 5-14: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	D/E		F	F	*Not applicable due to no proposed development on the Sterkspruit*				E/F
Inverts Dry	D		D	D					E
Fish Wet	D/E		D	D					E/F
Inverts Wet	D		C/D	C/D					E
Macroinvertebrates Perlidae was the selected indicator taxon for this reach, as they are a flow dependent taxon, with a preference for fast and very fast course substrate being the critical habitat for this taxon. They further have a preference for >0.6m/s, of which in accordance with the HabFlo for this site, includes a flow of approximately 0.128m^3/s. The FIFHA analysis was conducted for the months of March and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. Overall, both Sc1 and Sc2 during the wet and dry season will meet the macroinvertebrate EC for this EWR site. However, the concern are the deficits (meaning that there is not enough water in the system to meet the EWR) within the system for both Sc1 and Sc2, likely resulting in not meeting the supply during the dry season for the macroinvertebrates (this is where the limitations of the FIFHA arise as per Section 5.1.4 which does not pick up these deficits). For both Sc1 and Sc2 from the 20th percentile to the 80th percentile in July, there is not enough flow in the river to supply the EWR, of which exacerbates into the subsequent months. Thus, perhaps additional water is being removed									

from the system, which may have a consequence on the biota with limited flow. Regardless of having the suitable and available biotopes within the Sterkspruit, these deficits will have a knock-on effect on the quality of the critical habitats for the indicator macroinvertebrate, with the limited required flow over these habitats for the Perlidae to persist and colonise.

However, it is crucial to emphasise that, at this EWR site, the macroinvertebrate community is not significantly influenced by alterations in flow currently. Instead, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a "D" or largely modified using the MIRAI methodology, was water quality. This finding is also substantially corroborated by the diatom results.

With regards to Sc7 whereby there is anticipated further deterioration in water quality. Since the aquatic macroinvertebrate community is already significantly altered due to poor water quality, it's logical to expect that any further decline and a severe compromise in water quality could lead to an increase in waterborne diseases. This would likely sustain the presence of highly tolerant macroinvertebrates thriving in conditions marked by very low water quality in this ecosystem in the future.

Fish

Habitat present within the reach during both the July 2022 and the May 2023 assessments included a variety of velocity-depth classes with a notable dominance of slow-deep and fast-shallow classes, with cover features being substrates (including boulders, cobbles and gravel) and undercut banks. Due to the lack of true rheophilic species, the large semi-rheophilic *Labeobarbus aeneus* was selected to function as flow-dependent indicators, with the reach supporting critical habitat for early-life stages (spawning, egg and embryo development & larval nursery area) for the species. Given the size of the watercourse within the reach as well as the location of the reach within the larger catchment, seasonal movement of fish species for the purpose of spawning was expected. Primary focus in this respect was therefore given the faster flowing velocity-depth classes at the cross-section associated with early life-stages, notably fast-intermediate and fast-shallow. While no slow-deep class was identified at the cross-section for growth of larvae, this class was identified downstream and to a lesser extent upstream of the cross-section.

Analysis of the outputs from the application of the FIFHA model suggests that Sc1 and Sc2 will not impact the ecological state of the fish assemblage to a significant degree during March (relative to present status) from a flow perspective, but prevailing impacts relating to failing sewage infrastructure may well nevertheless impact the ecological state due to loss of dilution capacity. In contrast, both Sc1 and Sc2 were likely to impact the fish assemblage negatively during the low-flow period of July. However, given that seasonal movement into the system is expected for spawning purposes (which takes place during the summer high-flow period), emphasis from a fish perspective should be placed on the suitability of conditions during March rather than July.

However, a further decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted as a result of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish. Deteriorating water quality would furthermore deter *L. aeneus* from moving into the reach during seasonal upstream migrations, with the species instead selecting a tributary of better water quality for spawning purposes.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-15**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site.

Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-15: UO_EWR02_I: Sterkspruit: Ecological consequences

Component	PES	REC	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	D	C/D	D	D				
Riparian Vegetation	D		D	D				
Fish	D/E		F	F				
Macroinvertebrates	D		D	D				
EcoStatus	D							
Meeting Overall REC			**X**	**X**				

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

In summary, the assessment of the two relevant scenarios (Sc1 and Sc2) reveals that neither meets the REC requirements for this site. This is primarily due to the decline in the fish category, attributed to insufficient flow and compromised water quality, evident in both scenarios. Consequently, neither scenario is capable of sustaining the PES EcoStatus or attaining the REC.

Therefore, these scenarios will not meet the EWR owing to the flows which show that not adequate floods or baseflows are coming through due to the Jozanashoek Dam located upstream. In addition, water quality is highly compromised, having a negative effect on the biota. Thus, if the water quality is not going to be improved, this REC will not be achieved.

Scenario 7 summary

The increasing catchment development and poorly maintained sewage infrastructure at the site and upstream threatens to continue to degrade the water quality. The water quality is also highly susceptible to degradation because of the instream sand mining at the site, which threatens to severely compromise the water quality via sediment loading. The WWTW is currently classified at critical risk of failure. It has an effluent compliance of 15%, which means ongoing discharge will continue to degrade the physical-chemical state of the receiving river. The *in situ* water quality results appear to be within TWQR limits with elevated pH. This is likely to change downstream after the WWTW discharges into the river.

Therefore, it is reasonable to predict that the described conditions will deteriorate further and reach a critical stage. The ultimate consequence will be a marked decrease in the overall health and functionality of this ecosystem, particularly in its capacity to provide essential ecosystem services, primarily clean water and the ability to dilute, process, and mitigate the impact of polluted water in collaboration with its indigenous biota. Furthermore, the frequency and persistence of waterborne diseases are likely to increase. This could result in a heightened seasonal risk for local communities that rely on the river, recreational users, and have a substantial impact on the biodiversity (fish and macroinvertebrates) associated with this river system.

Socio-economic summary

The present socio-economic state indicates a high relative incidence of vulnerable households and a predominantly rural population with high relative poverty levels. There are moderate levels of both irrigated commercial agriculture and subsistence agriculture. Per capita GDP for the area is relatively low with the main GDP contributions coming from the Government and Community Services sector and little primary sector value addition.

The ecological/biophysical analysis and consequences outlined above indicate inadequate flow and compromised water quality, suggesting a potential risk to the ability of the system to meet the present socio-economic water-use. This is particularly concerning given the predominantly rural population and high relative poverty levels.

5.2.3 UO_EWR03_I: Upper Orange

Site Name	UO_EWR03_I	**Prioritised RU**	R_RU02a
River	Upper Orange	**Altitude (m.a.s.l.)**	1302
Latitude	-30.652888889	**Longitude**	26.82304963
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D12F-05348
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, High

Sumary of the Eco-categorisation results

River	Upper Orange
EWR Site Code	**UO_EWR03_I**
Driver component	**PES**
HAI	D
Diatoms	C
GAI	C
Response component	**PES**
FRAI	D
MIRAI	C/D
VEGRAI	D
Ecostatus	D
EI	Moderate
ES	Moderate
REC	D
AEC	C/D

Reasons for EcoStatus: Impacts

- Poor habitat availability for both fish and aquatic macroinvertebrates (limited biotopes, alluvial system);
- Widespread overgrazing and soil erosion in the catchment (largely Lesotho and communal land) elevating fine sediment loads;
- Hydrological modification due to upstream impoundments within Lesotho;
- Extensive alien invasive plants within the riparian zone;
- Diatoms were used to infer the present physical-chemical state of the system, indicating heavy organic pollution;
- Elevated nutrient concentrations are expected to be prevalent at the site because of the Sterkspruit discharging untreated sewage upstream; and
- Other contaminants and toxins are also expected to be present at the site given the untreated effluent discharged upstream.

Present EI-ES

- EI decreased from High to Moderate due to riparian-wetland zone habitat integrity class and instream habitat integrity class; and
- ES decreased from High to Moderate due to reduced aquatic macroinvertebrate sensitivity and riparian-wetland vegetation intolerance to water level changes.

REC: Mitigations Needed

- Manage and maintain the EcoStatus.

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-3** below. The flow durations of the scenarios for the Upper Orange (UO_EWR03_I) for July (dry) and February (wet) are shown in **Table 5-16** and

Table 5-17. The 'red' highlighted areas in the tables indicate where the EWR could not be met.

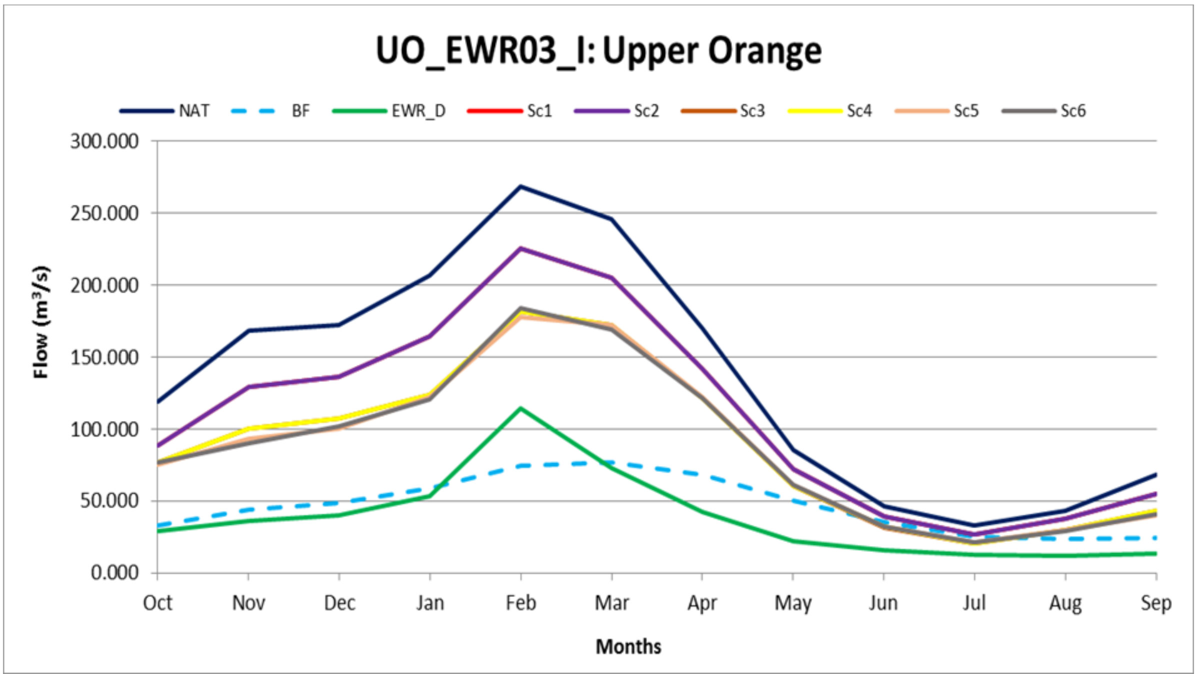


Figure 5-3: Seasonal distribution of scenarios at site UO_EWR03_I: Upper Orange

Sc1 and Sc2 show reduced floods in the summer months that are further reduced in Sc3 to Sc6 due to the proposed Polihali and Verbeeldingskraal Dams. All scenarios show reduced baseflows.

Table 5-16: Percentiles and flow (m^3/s) for July per scenario at Upper Orange (UO_EWR03_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_D
0.1	167.017	128.680	128.680	108.424	108.423	108.954	108.366	18.624
1	153.111	122.640	122.639	91.772	91.771	92.108	86.222	18.624
5	121.242	95.143	95.143	67.766	67.766	66.553	66.553	18.611
10	75.059	65.053	65.053	45.840	45.840	44.848	44.683	18.545
15	61.015	47.186	47.186	35.017	35.017	36.180	34.921	18.411
20	48.777	41.649	41.648	30.511	30.510	32.901	32.868	18.195
30	35.990	28.919	28.918	22.016	22.016	23.628	22.980	17.575
40	22.982	19.410	19.410	15.806	15.806	18.021	18.021	16.003
50	18.551	16.258	16.259	13.212	13.440	12.791	14.589	14.214
60	15.374	13.959	14.013	11.353	11.351	10.885	13.445	11.057
70	12.223	10.225	10.314	8.580	8.623	8.942	10.073	8.835
80	9.059	8.421	8.419	7.220	7.220	6.325	7.494	6.695
85	7.165	7.031	7.106	6.117	6.204	5.447	6.661	5.982
90	6.598	5.701	5.702	4.661	4.964	4.152	5.614	5.495
95	5.908	5.014	5.152	3.998	4.131	2.896	5.179	5.219
99	2.932	3.138	3.159	2.700	2.894	2.069	4.331	2.932

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_D
99.9	2.848	2.551	2.674	2.362	2.869	1.564	3.094	2.847

Table 5-17: Percentiles and flow (m^3/s) for February per scenario at Upper Orange (UO_EWR03_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_D
0.1	1001.244	920.673	920.673	728.350	728.349	727.654	727.654	206.949
1	875.691	772.627	772.627	725.324	725.313	726.334	726.334	206.949
5	711.070	611.777	611.778	526.404	526.404	525.559	525.291	206.937
10	562.898	510.494	510.493	441.747	441.747	440.953	440.953	205.648
15	516.934	443.862	443.862	376.697	376.697	374.522	374.523	191.458
20	470.439	382.324	382.325	280.330	280.301	270.909	270.105	180.968
30	286.068	239.098	239.098	187.760	187.862	185.188	186.834	160.079
40	214.979	178.692	178.692	137.304	137.409	133.168	146.556	139.156
50	174.796	138.820	138.820	110.317	110.605	104.785	117.470	106.945
60	157.113	122.337	122.336	91.962	92.118	88.978	97.928	92.259
70	136.245	100.617	100.617	77.034	77.033	76.077	84.838	72.474
80	105.099	85.176	85.248	63.354	63.424	62.870	68.943	48.805
85	83.165	69.121	69.121	49.466	49.465	48.181	56.397	37.743
90	65.408	53.666	53.666	37.309	37.479	37.272	43.798	30.363
95	42.130	37.660	37.658	28.847	28.847	28.009	27.965	23.134
99	24.164	24.375	24.375	16.288	16.572	11.884	19.844	20.054
99.9	22.328	22.409	22.408	15.653	15.937	11.266	18.356	20.054

The EWR could not be met during the dry months, especially Sc3 and Sc4 when Polihali Dam has been constructed with limited releases of environmental flows (only 12% of natural Mean Annual Runoff (nMAR)). With the construction of Verbeeldingskraal Dam just upstream of the EWR site (Sc5 and Sc6), the EWR could not be met for Sc5, 'without EWR'. The wet season requirements could be met for most of the scenarios.

The scenarios highlighted in grey in **Table 5-18** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-19** to **Table 5-21**. For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-18: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Instream Biota							
Socio-economics							

Table 5-19: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
C		In accordance with **Figure 5-3**, one could expect a maintenance of the water quality of this site. • Like the site UO_EWR01_I, there is a maintenance of the typical summer/wet season volume, meaning that the water quality will be reset during the rainfall season as the benthic algal growth from nutrient enrichment will be scoured out and the system refreshed. • Again, the low flows during the winter/dry season (June – August) will be when the discharge from WWTW contribute a significantly higher proportion of the base flow to this system, resulting in the base / low flow period being when the nutrients, bacteria, and other WWTW associated outputs dominate the water quality in the system.	Due to the current severe degradation of water quality, it is anticipated to deteriorate further, reaching a critical state in the future. This will result in a significant reduction in the health and functionality of the system, impacting its ability to provide ecosystem services, particularly clean water and the capacity to dilute, process, and mitigate polluted water associated with its natural resident biota. The primary cause of declining water quality in the Upper Orange River system is the malfunctioning WWTW. The exacerbation of water quality issues is likely to a) increase the frequency and persistence of waterborne diseases and b) seasonally elevate risks for local communities, recreational users, and have a substantial impact on the biodiversity associated with this river system.

Table 5-20: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		**C/D**	**C/D**	**D**	**D**	**D/E**	**D/E**

Specific impacts as a result of the operational scenario primarily relate to morphological changes, impacts of flow changes on available substrate, embeddedness, inset benches, marginal vegetation etc. Detailed interpretation on these is described below.

(i) Sc3 and Sc4 introduce the construction of Polihali Dam in the upper catchment, with reductions in sediment and flow. Based on the hydrological modelling the freshets will be reduced to some extent, resulting in increased embeddedness as these smaller events will have insufficient shear stress to mobilise and flush fine sediment. Polihali Dam will trap bedload, reducing the input of sand and gravel to the site. This will lead to a moderate reduction in sand supply for sand mining. The GAI score dropped from a 61 (C) to 55 (D), which is a half category change, although in line with the identified REC for the EWR site.

(ii) The proposed Verbeeldingskraal Dam (Sc5 and Sc6) will have a large impact on the sediment regime, trapping most of the suspended sediment and all the sand and gravel bed sediment. The freshet and flood flows are moderately impacted, reducing the channel maintenance processes. Due to the change in longitudinal connectivity, it is envisaged that the current alluvial channel will be starved of bed sediment, resulting in channel incision and associated bank erosion. The bed sediment is likely to coarsen, with less sediment deposited on flood features. This will lead to a large reduction in sand availability for sand mining. The GAI PES score decreased from 61 (C) present day to 42 (D/E), which is a full category change, but a half a category change from the identified REC for the EWR site.

Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D		**D**	**D**	**D**	**D**	**D/E**	**D/E**

The flow and geomorphological response will remain unchanged for Sc1 and Sc2, and as a result the riparian vegetation will remain the same as the PES EC (EC = 54.9, i.e. D category), which will help maintain the REC.

For Sc3 and Sc4 with Polihali Dam being developed in the upper reaches, flood peaks will be reduced and baseflows will become more constant. This will lead to increased wood vegetation and terrestrialisation within the riparian zone, as well as increased dominance of reeds in the marginal zone. The declined supply of sandy substrate will inhibit the dynamic vegetation processes required to sustain marginal vegetation patterns, although it is noted that the marginal vegetation was found to be in a very poor condition during the field surveys. It is expected that the marginal vegetation will improve slightly, the lower banks will remain unchanged, and upper banks will deteriorate slightly resulting in an overall unchanged EC (Sc3 and Sc4 EC = 47.3, i.e. D category).

For Sc5 and Sc6 with Verbeeldingskraal Dam being developed in future just upstream of the EWR site, flood magnitude and frequency will be further reduced, and freshets will become less frequent, adding to the flow impacts from Polihali Dam. The channel incision and bank erosion that is expected to increase will further degrade riparian vegetation, especially along the margins and lower banks. It is expected that the marginal zone will become more degraded, with terrestrial species encroaching more into the upper banks together with an increase in alien vegetation throughout the site. The overall EC will decrease to 40.5 (i.e. D/E category).

Table 5-21: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	D		A	A	A	A	A/B	A	D/E
Inverts Dry	C/D		A	A	A	A	A	A	D
Fish Wet	D		A	A	B	B	B	B	D/E
Inverts Wet	C/D		A	A	B	B	B	A	D

Macroinvertebrateso
The Upper Orange River is a wide homogenous alluvial river characterised by limited habitat diversity (mostly dominated by the gravel, sand and mud biotope) and exposed sandbars along its banks. Marginal vegetation, crucial for macroinvertebrate colonization, is scarce or non-existent in this stretch of the river. Consequently, the selected indicator macroinvertebrate for this area that was run in the FIFHA model was Caenidae. While Caenidae is not particularly sensitive or adapted to fast-flowing water (rheophilic), it does exhibit a preference for fast and very fast fine substrates with varying velocity tolerances ranging from 0.1m/s to 0.6m/s. The FIFHA analysis was conducted for the months of March and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. As a result, all scenarios met the criteria for the macroinvertebrate during these assessment periods.

However, it is worth noting that scenarios Sc3 and Sc4 will face changes when the Polihali Dam in the upper catchment (Lesotho) becomes operational (approximately 2029). This dam will intercept bedload, particularly sand and gravel, which are essential substrates for Caenidae. Additionally, there will be a reduction in downstream flow, primarily affecting the July and October months, with deficits in the system during the 50th percentile to 70th percentile, and later from the 90th percentile to 99/99.9th percentile flow conditions. In the context of riparian vegetation, these changes might lead to slight improvements in marginal vegetation, potentially creating opportunities for macroinvertebrate colonization. During the field surveys for this study, marginal vegetation at this site was notably scarce and limited as a macroinvertebrate biotope (owing to the banks being scoured and channel incised over time).

Regarding Sc5 and Sc6, the proposed Verbeeldingskraal Dam will significantly impact the system by trapping additional sediments, particularly sand and gravel. This will further diminish the critical habitat for the indicator taxon, resulting in habitat degradation and increased bank erosion. These changes will also have a significant negative effect on marginal vegetation, reducing the options for macroinvertebrates that prefer the marginal vegetation for colonisation. The FIFHA model didn't appear to pick these up owing to the limitations of the model, also likely owing to the indicator macroinvertebrate not being as sensitive to flow as other rheophilic taxa, however this is also due to the system having limited biotopes.

However, it iss crucial to emphasise that, at this EWR site, the macroinvertebrate community is not significantly influenced by alterations in flow currently. Instead, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a "C/D' or moderately to largely modified using the MIRIA methodology, was water quality. This finding is also substantially corroborated by the diatom results.

Regarding Scenario 7, where a further decline in water quality is expected, it's pertinent to note that the existing state of the aquatic macroinvertebrate community is already moderately to largely modified and responsive to poor water quality. It is logical to expect that the anticipated further deterioration and a critical compromise in water quality might lead to an increased prevalence of waterborne diseases. This, in turn, would perpetuate the presence of highly tolerant macroinvertebrates thriving in conditions characterized by very low water quality within this ecosystem in the future.

Fish

The reach is expected to support very limited cover features for fish, with sandy/small gravel substrate with laminar flows across the channel expected for much of the hydrological year. Some undercut banks are expected to be present that would provide cover for some fish elements, although critical habitat for spawning, egg development and larvae are not expected to be present due to the high sedimentation rates. The reach is located within the middle reaches of the Orange River upstream from Gariep Dam which will prevent any movement of fish from the lower reaches of the Orange River. As such, fish species expected to be present include those that will be able to over-winter within Gariep Dam or similar deeper water habitats or tributaries and undertake seasonal upstream migrations up the Orange River into Lesotho during the warmer summer rainfall periods when flows increase. Due to the lack of true rheophilic species, large semi-rheophilic *Labeobarbus aeneus and L. kimberleyensis* were selected to function as flow-dependent indicators. The reach does not have any critical habitat (i.e. substrate within differing velocity-depth classes) for early-life stages (spawning, egg development & larval nursery area), thus likely to be used as a conduit for upstream movement during periods of high flow. Primary focus in this respect was given the faster flowing velocity-depth classes, notably fast-intermediate and fast-deep classes Consideration was also given to the availability of slow-deep flows to sustain adults of juvenile fish species.

Application of the FIFHA model for the various scenarios investigated suggest that Sc1, Sc2, Sc3, Sc4, Sc5 and Sc6 are all unlikely to result in any significant changes to the ecological state of the associated reach of the Orange River from a flow perspective given that the indicator species do have a wide diversity of habitat preferences and are able to survive within lentic water bodies. Nevertheless, loss of seasonal high-flow events and/or unseasonal releases flows following the development of various dams proposed under Sc3 to Sc6 (e.g. Polihali Dam, Verbeeldingskraal Dam, etc.) is likely to impact the migratory cues for the indicator fish species, and result in a loss of upstream connectivity and habitat fragmentation.

However, a further decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted as a result of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish. In addition, reduction in water quality, and particularly from failing sewage infrastructure, is likely to increase the periodicity and magnitude of fish kill events, particularly below where impoundments are expected.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-22**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-22: UO_EWR03_I: Upper Orange: Ecological consequences

Component	PES	REC		Sc1	Sc3	Sc3	Sc4	Sc5	Sc6
Geomorphology	C	D		C/D	C/D	D	D	D/E	D/E
Riparian Vegetation	D			D	D	D	D	D/E	D/E
Fish	D			A	A	B	B	B	B
Macroinvertebrates	C/D			A	A	B	B	B	A
EcoStatus	D								
Meeting Overall REC				√	√	**X**	**X**	**X**	**X**

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

Overall, the ranking of the scenarios indicates that only Sc1 and Sc2 achieves the REC requirements. The rest of the scenarios will not achieve the REC or the PES EcoStatus. The flood peaks have been reduced throughout, as well as baseflows during the dry months. With regards to Sc3 and Sc4, they do not receive adequate baseflows due to Polihali Dam in Lesotho, as the dam will only release 12% of the MAR which is of a concern. The proposed Verbeeldingskraal Dam (Sc5 and Sc6), which is relatively close to this EWR site, will have a large impact on the sediment regime, trapping most of the suspended sediment and all of the sand and gravel bed sediment. Therefore, deterioration in both the riparian vegetation and geomorphology is evident in Sc3 to Sc6, ultimately with the potential to have repercussions on the biotic response.

However, it's crucial to highlight that at this site, the biota is influenced not only by flow but also by factors such as sediment deposition, water quality, and restricted habitat availability (not natural owing to dominance of alien invasive plants within the riparian zone and bank erosion/scouring).

Scenario 7 summary

The system currently suffers from compromised water quality due, largely, to sedimentation loading from the upstream sand mining. This has been ongoing for some time, indicating that the system may have stabilised in this compromised state. However, there is the possibility that ongoing sand-mining and no remediation could further degrade the system.

Therefore, it is reasonable to predict that the described observations will deteriorate further and reach a critical stage. The net impact will be a significant decline in the health and ability of this system to deliver ecosystem goods and services, principally clean water and a system able to dilute, process and reduce polluted water associated with its natural resident biota. Water borne diseases are also likely to become more frequent and persistent. There may be a seasonally higher risk for local dependent communities, recreational users, and a high impact for biodiversity (fish and macroinvertebrates) associated with this river system.

Socio-economic summary

The present socio-economic state indicates a low relative incidence of vulnerable households. There is limited subsistence agriculture and little irrigated commercial agriculture. The area falls within the Arid Innovation Region and is classified as vulnerable to changes in water resources. GDP per capita is relatively moderate to low, with the dominant contributions to GDP coming from the Government and Community Services sector.

The ecological/biophysical analysis and consequences indicate inadequate flow and compromised water quality for Sc3 to 6 to meet the REC, which suggests that there may be a risk to the ability of the system to meet socio-economic water-use. However, the low relative incidence of vulnerable households and limited subsistence agriculture and commercial agriculture limits the likely extent of the risk.

5.2.4 UO_EWR04_I: Lower Caledon

Site Name	UO_EWR04_I	**Prioritised RU**	R_RU05
River	Lower Caledon	**Altitude (m.a.s.l.)**	1277
Latitude	-30.28011493	**Longitude**	26.65306029
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D24G-04958
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, High

Sumary of the Eco-categorisation results

River	**Lower Caledon**
EWR Site Code	**UO_EWR04_I**
Driver component	**PES**
HAI	C
Diatoms	D
GAI	C
Response component	**PES**
FRAI	D
MIRAI	D
VEGRAI	D
Ecostatus	D
EI	Moderate
ES	Moderate
REC	C/D
AEC	C/D

Reasons for EcoStatus: Impacts

- Widespread overgrazing and soil erosion in the upper catchment (largely Lesotho and communal land) elevating fine sediment loads;
- Presence of migratory barriers downstream (Gariep Dam, Van Der Kloof Dam) and upstream (Welbedacht Dam);
- Hydrological modification due to presence of Welbedacht Dam catchment activities, including transfers from the Caledon River to the Modder/Riet systems for domestic water use in the larger Bloemfontein area;
- Alien invasive plants within the riparian zone, bare banks; and
- Diatoms used to infer the present physical-chemical state of the system, indicating heavy organic pollution likely from elevated nutrient concentrations. High sodium chloride salinity and especially irrigation return flows.

Present EI-ES

- EI decreased from High to Moderate due to riparian-wetland zone habitat integrity class and instream habitat integrity class; and
- ES decreased from High to Moderate due to reduced fish physical-chemical sensitivity and riparian-wetland vegetation intolerance to water level changes.

REC: Mitigations Needed

- Water use and transfers to be better managed;
- Water quality can be improved (effluent from upstream centres, upstream catchment management practices, implementation of buffer zones);
- Sediment management (overall catchment management – with a focus on Lesotho); and
- Management of alien invasive plant species within the riparian zone.

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-4** below. The flow durations of the scenarios for the Lower Caledon (UO_EWR04_I) for July (dry) and February (wet) are shown in **Table 5-23** and

Table 5-24. The 'red' highlighted areas in the tables indicate where the EWR could not be met.

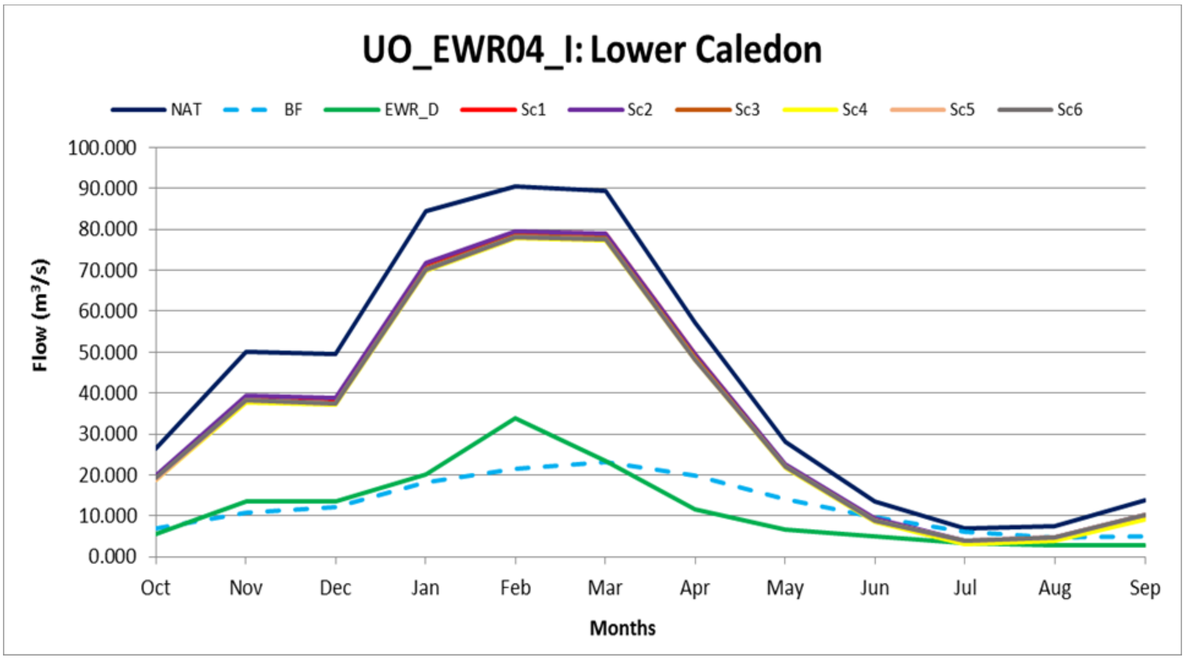


Figure 5-4: Seasonal distribution of scenarios at site UO_EWR04_I: Lower Caledon

All the scenarios show reduced floods in the summer months, as well as reduced baseflows. This is mainly due to the numerous small dams in tributaries and Welbedacht Dam reducing the floods and abstractions for irrigation and transfers to the Modder River for domestic and industrial use in the Greater Bloemfontein area.

Table 5-23: Percentiles and flow (m^3/s) for July per scenario at Lower Caledon (UO_EWR04_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C/D
0.1	63.528	55.731	55.727	55.248	55.232	54.775	54.759	5.332
1	33.756	26.888	26.882	26.024	26.011	25.557	25.544	5.320
5	17.433	10.655	10.639	9.769	9.760	9.322	9.312	5.299
10	14.437	8.053	8.037	7.650	7.631	7.222	7.197	5.272
15	10.919	5.265	5.252	4.902	5.192	4.522	4.553	5.207
20	9.392	4.070	4.235	3.637	4.006	3.447	3.646	5.114
30	7.920	2.856	3.016	2.550	3.014	2.484	2.912	4.889
40	5.031	2.333	2.521	2.221	2.515	1.779	2.496	4.394
50	4.590	1.993	2.307	1.884	2.338	1.342	2.307	3.753
60	3.922	1.562	2.191	1.197	2.222	0.845	2.192	2.904
70	3.278	1.001	1.980	0.738	2.101	0.513	1.974	2.148
80	2.461	0.542	1.465	0.446	1.658	0.311	1.441	1.527
85	2.324	0.372	1.305	0.300	1.375	0.248	1.293	1.314
90	2.113	0.278	1.178	0.191	1.217	0.191	1.178	1.196
95	1.859	0.153	1.001	0.134	1.022	0.134	0.923	1.110
99	1.305	0.095	0.724	0.082	0.696	0.082	0.492	1.068

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C/D
99.9	1.071	0.084	0.559	0.078	0.538	0.078	0.450	1.048

Table 5-24: Percentiles and flow (m^3/s) for February per scenario at Lower Caledon (UO_EWR04_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C/D
0.1	674.728	648.998	648.991	645.081	645.072	643.658	643.712	68.586
1	423.992	408.692	408.665	407.642	407.615	407.065	407.052	68.498
5	300.918	288.134	288.113	287.618	287.597	287.138	287.116	68.443
10	225.431	213.573	213.556	211.936	211.918	211.463	211.445	67.454
15	188.678	171.400	170.672	169.889	168.535	168.599	166.678	62.828
20	169.865	152.782	152.762	152.231	152.209	151.691	151.674	59.423
30	107.207	94.329	94.316	94.045	94.032	93.571	93.558	51.401
40	67.945	54.295	53.831	53.290	53.052	52.558	52.527	43.877
50	41.538	32.608	32.598	31.248	31.054	30.457	30.076	31.093
60	30.713	20.766	21.121	19.949	20.848	19.500	20.414	24.016
70	16.178	7.799	7.851	6.621	7.411	6.235	7.007	15.955
80	12.726	5.236	5.692	4.463	5.493	4.110	4.954	8.565
85	10.860	3.597	4.007	2.891	4.112	2.694	3.413	5.817
90	7.650	1.892	2.819	1.370	2.020	1.172	1.944	4.178
95	4.464	0.920	1.967	0.476	1.900	0.187	1.894	3.690
99	3.143	0.292	1.679	0.032	1.671	0.032	1.669	3.143
99.9	1.170	0.062	0.799	0.031	0.755	0.031	0.737	1.170

The above tables indicates that the EWR could not be met for most of the time in any of the scenarios in July and February. Thus, the system is under severe pressure from a flow perspective and any additional water resource developments in the upper catchments will increase the non-compliance with the EWR.

The scenarios highlighted in grey in **Table 5-25** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-26** to **Table 5-28**. For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-25: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Instream Biota							
Socio-economics							

Table 5-26: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
D		In accordance with **Figure 5-4**, one could expect a decline in the water quality at this site during the winter / low flow periods. • Like the UO_EWR01_I site, this location maintains the typical volume seen in the summer/wet season. This implies that during the rainy season, the water quality will reset, with benthic algal growth from nutrient enrichment being scoured out, resulting in a refreshed system. • The EWR flows at this site mean there's a lower flow from July to August compared to the current baseflow regime. So, with the EWR, WWTW and return flows will likely contribute even more to the baseflows from May to October each year. That means during that period, the water quality is expected to be worse than it is now, with less dilution of the compromised water coming in through WWTW and return flows	Due to the present critical degradation of water quality, it is expected to worsen significantly and reach a critical point in the future. The net impact will be a significant decline in the health and ability of this system to deliver ecosystem goods and services, principally clean water and a system able to dilute, process and reduce polluted water associated with its natural resident biota. Given that the primary cause of deteriorating water quality in the Upper Orange River system is the malfunctioning WWTW, a further decline is expected to a) increase the frequency and persistence of waterborne diseases and b) elevate seasonal risks for local communities, recreational users, and pose a significant threat to the biodiversity linked to this river system.

Table 5-27: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		**C**	**C**	**C**	**C**	**C**	**C**
Due to the significant distance from the proposed weirs and small impact to the geomorphological drivers, changes to the geomorphology is unlikely.							
Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D		**D**	**D**	**D**	**D**	**D**	**D**
Flow impacts are expected to be minor, and geomorphological changes are considered unlikely. As a result, the riparian vegetation is expected to remain in a poor condition (i.e. D category). This will compromise the situation of maintaining the REC in a C/D category, and alien vegetation should ideally be managed to help improve riparian integrity.							

Table 5-28: Biotic of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	D		C	A	C	A	D	A	D/E
Inverts Dry	D		C	C	C/D	B/C	C/D	B/C	D/E
Fish Wet	D		B/C	B	B/C	B/C	C/D	B/C	D/E
Inverts Wet	D		C	B/C	C/D	C	D	C	D/E

Macroinvertebrates
The longitudinal profile of the lower Caledon continues from the upper reaches in that it remains a wide, deep homogenous river, comprised largely of sand and silt and highly erodible banks with limited diversity of marginal vegetation. However, at this particular EWR site, artificial substrate is available as a habitat for the macroinvertebrates as a result of the bridge construction – requiring flow in order to retain the selected flow dependent indicator taxon, being Hydropsychidae. They have a high preference for fast currents of >0.6m/s, although optimal speeds are approximately 0.4m/s, along critical habitats namely fast and very fast course substrate.

Overall, the FIFHA analysis was conducted for the months of February and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. As a result, all scenarios met the criteria for the macroinvertebrate during these assessment periods. This can likely be attributed to the considerable distance from the proposed weirs located upstream of this EWR site, and thus flow impacts are expected to be minor.

However, it is crucial to emphasise that, at this EWR site, the macroinvertebrate community is not significantly influenced by alterations in flow currently. Instead, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a 'D' or largely modified using the MIRIA methodology, was water quality. This finding is also substantially corroborated by the diatom results. Nonetheless, its worth noting that the Hydropsychidae family is not highly responsive to declines in water quality. Therefore, if there are future alterations in flow conditions that fail to meet the requirements of the EWR, this family may no longer persist at the site due to flow alternation, despite the quality of the water.

With regards to Sc7 whereby there is anticipated further deterioration in water quality. Considering the existing condition of the aquatic macroinvertebrate community, which is already significantly altered and responsive to poor water quality, it is logical to expect that any further decline and a critical compromise in water quality might lead to an increased prevalence of waterborne diseases. This would likely perpetuate the presence of highly tolerant macroinvertebrates thriving in conditions characterized by very low water quality within this ecosystem in the future.

Fish

The Lower Caledon River is a wide homogenous river composed largely of sand and silt and both banks are sandy, steep and highly erodible and thus zero marginal vegetation. However, at this particular EWR site, artificial substrate is available as a habitat for fish species as a result of the bridge construction, with suitable habitat available to act as a spawning medium for large semi-rheophilic fish species such as *Labeobarbus aeneus*. This is particularly relevant given that Welbedacht Dam located upstream of the EWR site acts as a barrier for upstream migrations of fish from the Orange River (Gariep Dam). Consequently, critical life stages considered include spawning, egg and embryo development, with juvenile and adult life stages also being considered to a lesser extent, thus fast-shallow and fast-intermediate classes. Slow-deep class is present downstream and upstream of the cross-section, and thus not considered. Nevertheless, egg development success is expected to be impacted by the high sediment loads present within the system (Welbedacht Dam is expected to function as a sink for larger sediment size classes, but fines will pass over the dam).

Application of the FIFHA model for the various consequences investigated suggest that all the proposed scenarios are unlikely to result in any significant changes to the ecological state of the associated reach of the Caledon River from a flow perspective given that the indicator species does have a wide diversity of habitat preferences and is able to survive within lentic water bodies. Nevertheless, the installation of various weirs in the Caledon River system is still likely to result in a loss of upstream connectivity and habitat fragmentation for the fish still present within the system.

However, a further decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted because of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish. In addition, reduction in water quality, and particularly from failing sewage infrastructure, is likely to increase the periodicity and magnitude of fish kill events, particularly below where impoundments are expected.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (**Table 5-29**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-29: UO_EWR04_Lower Caledon: Ecological consequences

Component	PES	REC		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	C	C/D		C	C	C	C	C	C
Riparian Vegetation	D			D	D	D	D	D	D
Fish	D			B/C	B	C	B/C	D	B/C
Macroinvertebrates	D			C	C	C/D	C	D	C
EcoStatus	D								
Meeting Overall REC				√	√	√	√	√	√

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

Overall, the ranking of the scenarios indicate that all scenarios achieve the REC requirements for this site. However, despite the above, it must be noted that the flows are of a concern, both the floods and baseflows, as they don't meet the EWR for all scenarios (refer to Table 5-23 and Table 5-24).

Scenario 7 summary

Overall, water clarity was low at this site because of the regular cattle trampling, unstable banks, and erosion resulting in high suspended solids in the river. This may represent a stabilised, though compromised, system. However, if the anthropogenic pressures intensify, the physical-chemical status of the system can be expected to decline.

Therefore, it is reasonable to predict that the described impacts will deteriorate conditions further and reach a critical stage. The ultimate consequence will be a substantial deterioration in the system's capacity to provide ecosystem goods and services, primarily adequate water quality, as well as its ability to dilute, treat, and alleviate the presence of polluted water linked to its indigenous biota. Additionally, the prevalence of waterborne diseases is expected to increase in frequency and persistence. This heightened risk may pose a seasonal challenge for local communities that rely on the river, recreational users, and it will have a pronounced impact on the biodiversity, including fish and macroinvertebrates, associated with this river system.

Socio-economic summary

The present socio-economic state indicates a low relative incidence of vulnerable households, limited subsistence agriculture and low levels of irrigated commercial agriculture. The area falls within the Arid Innovation Zone and is classified as under threat from limited water availability and classified as vulnerable to changes in water resources. The relative gross value add from agriculture is moderate, with relatively low registered water use from river and stream sources. The local formal economy is relatively small with low per capita GDP.

The ecological/biophysical analysis and consequences outlined above indicate inadequate flow to meet the EWR, which suggests a potential risk to the ability of the system to meet socio-economic water-use. However, the REC is achieved across all scenarios suggesting lower risk of significant changes in ecosystem services, which suggests there are unlikely to be significant associated risks for the present socio-economic state. In addition, the low relative incidence of vulnerable households and limited subsistence agriculture and commercial agriculture limits the likely extent of the socio-economic risk. Baseflows that don’t meet the EWR, however, suggest a potential seasonal challenge for river abstraction for socio-economic use. There are also potentially significant socio-economic risks associated with water quality, linked to the seasonal challenges for local communities (although small) that rely on the river to meet BHN, and recreational users.

5.2.5 UO_EWR05_I: Seekoei

Site Name	UO_EWR05_I	**Prioritised RU**	R_RU06
River	Seekoei	**Altitude (m.a.s.l.)**	1221
Latitude	-30.53390069	**Longitude**	24.96253678
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D32J-05237
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	D, Moderate, Moderate

Sumary of the Eco-categorisation results

River	**Seekoei**
EWR Site Code	**UO_EWR05_I**
Driver component	**PES**
HAI	B/C
Diatoms	C
GAI	C
Response component	**PES**
FRAI	C
MIRAI	C
VEGRAI	B/C
Ecostatus	C
EI	Moderate
ES	Moderate
REC	C
AEC	B/C

Reasons for EcoStatus: Impacts

- Longitudinal fragmentation due to high number of weirs along the system;
- Habitat dominated by bedrock (natural but not preferably for aquatic macroinvertebrates);
- Flow modification due to weirs and abstractions;
- Abundance of non-native (alien) fish species;
- Widespread and intensive grazing and soil erosion elevate fine sediment loads;
- Grazing along banks, but low erosion evident as bank gradient is low, very rocky and well vegetated; and
- Diatoms indicate, elevated electrolyte concentrations.

Present EI-ES

- Both remained Moderate.

REC: Mitigations Needed

- Water quality improvements through controlled irrigation and return flows.

Evaluated scenarios

The seasonal discharge distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-5** below. The flow durations of the scenarios for the Seekoei (UO_EWR05_I) for July (dry) and March (wet) are shown in **Table 5-9** and **Table 5-31.** The 'red' highlighted areas in the tables indicate where the EWR could not be met.

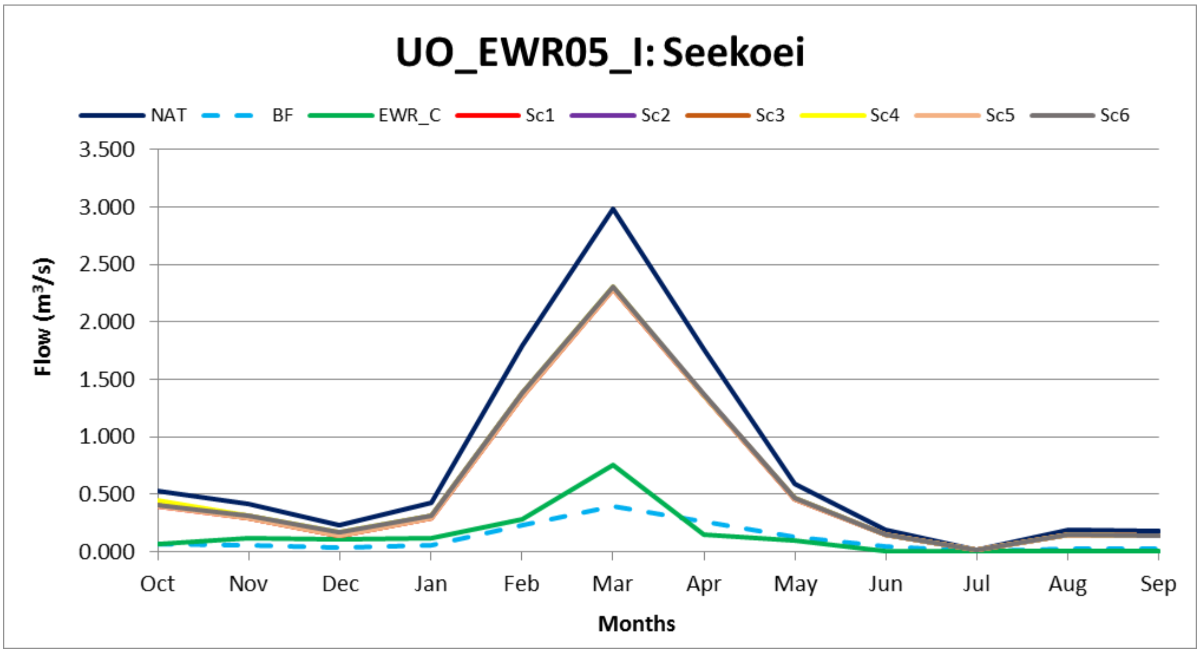


Figure 5-5: Seasonal distribution of scenarios at site UO_EWR05_I: Seekoei

All the scenarios show reduced floods in the summer months, as well as small reductions in baseflows. This is mainly due to the numerous small dams/ weirs for irrigation and stock watering in the upper catchment.

Table 5-30: Percentiles and flow (m^3/s) for July per scenario at Seekoei (UO_EWR05_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	0.476	0.366	0.365	0.366	0.365	0.366	0.365	0.006
1	0.413	0.324	0.324	0.324	0.324	0.324	0.324	0.006
5	0.035	0.023	0.023	0.023	0.023	0.023	0.023	0.006
10	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.005
15	0.003	0.006	0.005	0.006	0.005	0.006	0.005	0.003
20	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.001
30	0.000	0.004	0.004	0.004	0.004	0.004	0.004	0.000
40	0.000	0.003	0.003	0.003	0.003	0.003	0.003	0.000
50	0.000	0.003	0.003	0.003	0.003	0.003	0.003	0.000
60	0.000	0.002	0.002	0.002	0.002	0.002	0.002	0.000
70	0.000	0.002	0.002	0.002	0.002	0.002	0.002	0.000
80	0.000	0.002	0.001	0.002	0.001	0.002	0.001	0.000
85	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000
90	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000
95	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000
99	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000
99.9	0.000	0.001	0.001	0.001	0.000	0.001	0.000	0.000

Table 5-31: Percentiles and flow (m^3/s) for March per scenario at Seekoei (UO_EWR05_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	64.046	50.042	50.042	50.042	50.042	50.042	50.042	3.289
1	37.580	29.264	29.264	29.264	29.264	29.264	29.264	3.278
5	21.507	16.708	16.707	16.708	16.707	16.708	16.707	3.262
10	4.327	3.320	3.319	3.320	3.319	3.320	3.319	3.222
15	2.317	1.756	1.809	1.756	1.808	1.756	1.809	2.317
20	1.287	0.953	0.980	0.953	0.997	0.953	0.997	1.287
30	0.875	0.632	0.630	0.632	0.630	0.632	0.630	0.527
40	0.403	0.263	0.270	0.263	0.276	0.263	0.276	0.276
50	0.258	0.149	0.162	0.149	0.162	0.149	0.162	0.162
60	0.162	0.076	0.114	0.076	0.116	0.076	0.116	0.116
70	0.080	0.025	0.066	0.025	0.066	0.025	0.066	0.080
80	0.027	0.010	0.019	0.010	0.021	0.010	0.021	0.026
85	0.010	0.004	0.008	0.005	0.010	0.004	0.010	0.010
90	0.004	0.002	0.003	0.003	0.003	0.002	0.003	0.004
95	0.001	0.002	0.003	0.002	0.003	0.002	0.003	0.001
99	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000
99.9	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000

The above tables indicates that the EWR could be met for all the scenarios in July. However, some of the flood requirements could not be met, although small deficits.

The scenarios highlighted in grey in **Table 5-32** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-33** to **Table 5-35.** For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-32: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-33: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
C		In accordance with **Figure 5-5**, one could expect a maintenance of the water quality of this site. • Similar to the site UO_EWR01_I, at this site there is a maintenance of the typical summer/wet season volume, meaning that the water quality will be reset during the rainfall season as the benthic algal growth from nutrient enrichment will be scoured out and the system refreshed. • Again, the low flows during the winter/dry season (June – September) will be when the discharge from WWTW contribute a significantly higher proportion of the flows to this system, resulting in the base / low flow period being when the nutrients, bacteria, and other WWTW associated outputs dominate the water quality in the system.	Due to the present degradation of water quality, it is expected it might worsen and reach a critical point in the future. The net impact can be a significant decline in the health and ability of this system to deliver ecosystem goods and services, principally clean water and a system able to dilute, process and reduce polluted water associated with its natural resident biota.

Table 5-34: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		C	C	*Not applicable due to no proposed development on the Seekoei*			
There are no changes to the main drivers, so the geomorphology is unlikely to change as a result of water resource developments.							
EC	**Riparian Vegetation**						
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**

B/C		**B/C**	**B/C**	*Not applicable due to no proposed development on the Seekoei*
There are no changes to flow and geomorphology expected for the EWR site and thus riparian vegetation is expected to remain in a B/C category.				

Table 5-35: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	C		C	C	*Not applicable due to no proposed development on the Seekoei*				C/D
Inverts Dry	C		B	A					C/D
Fish Wet	C		C	B/C					C/D
Inverts Wet	C		C	B/C					C/D

Macroinvertebrates

In theory, there should be no changes to the main drivers, and thus the macroinvertebrate community is unlikely to change because of water resource development and thus the community should remain as moderately modified (category C) for both Sc1 and Sc2. However, the FIFHA analysis was conducted for the months of March and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. Both Sc1 and Sc2 during the dry season and Sc2 during the wet season, will meet the macroinvertebrate EC (as explained above). However, the needs for Sc1 during the wet season will not be met. This is likely owing to the deficits within the system during March from the 15% to the 90% where there is not enough flow in the river to supply the EWR, of which exacerbates into the subsequent months, particularly in May again. As there are no future developments, it may be that additional water is being removed from the system for irrigation, which may have a consequence on the biota with limited flow during the wet period going forward, compromising required critical habitats for the indicator macroinvertebrate (Caenidae) and thus the rest of the assemblage.

It is though crucial to emphasise that, at this EWR site, the macroinvertebrate community is not significantly influenced by alterations in flow currently. Instead, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a “C' or moderately modified using the MIRIA methodology, was water quality. This finding is also substantially corroborated by the diatom results.

With regards to Sc7 whereby there is anticipated further deterioration in water quality. Given that the current state of the aquatic macroinvertebrate community is already moderately modified and responding to poor water quality, as mentioned earlier, it is reasonable to anticipate that the further deterioration and a critical compromise in water quality, which may even result in an increased prevalence of waterborne diseases, will only serve to perpetuate the presence of highly tolerant macroinvertebrates that thrive in conditions characterised by very low water quality within this ecosystem in the future.

Fish

The Seekoei River is characterised by a high density of weirs along the reach which result in significant habitat fragmentation, and which do not have any mechanisms for environmental flow releases and result in the lack of lotic water during dry/low rainfall periods of the year. Despite this, the ecological state of the fish assemblage is regarded as moderately modified and reflects the ability of the fish assemblage to tolerate significant flow-related impacts. As no true rheophilic species are present, the large semi-rheophilic *Labeobarbus aeneus* was selected to function as flow-dependent indicator for the reach of the Seekoei River.

Application of the FIFHA model for Sc1 and Sc2 suggest that these proposed scenarios are unlikely to result in any significant negative changes to the ecological state of the fish assemblage from a flow perspective given that the indicator species do have a wide diversity of habitat preferences and are able to survive within lentic water bodies. Priority from a fish perspective should instead be given to the removal of redundant weirs within the reach and, wherever possible, the installation of fish ladders on weirs that will remain.

However, a further decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted because of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-36**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-36: UO_EWR05_I: Seekoei: Ecological consequences

Component	PES	REC	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	C	C	C	C				
Riparian Vegetation	B/C		B/C	B/C				
Fish	C		C	C				
Macroinvertebrates	C		C	B/C				

Component	PES	REC		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
EcoStatus	C								
Meeting Overall REC				√	√				

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

Overall, the ranking of the scenarios indicates that Sc1 and Sc2 achieve the REC requirements for this site.

Scenario 7 summary

High conductivities are characteristic of this system. The pH was elevated, although still within guidelines. Clarity was low as a result of high suspended solids from upstream, likely as a result of erosion of topsoil. No recent developments that could alter the physical-chemical nature of the system.

Therefore, it is reasonable to predict that the described observations will deteriorate further and reach a critical stage. The ultimate consequence will be a substantial deterioration in the system's capacity to provide ecosystem goods and services, primarily clean water, as well as its ability to dilute, treat, and alleviate the presence of polluted water linked to its indigenous biota. Additionally, the prevalence of waterborne diseases is expected to increase in frequency and persistence. This heightened risk may pose a seasonal challenge for local communities that rely on the river, recreational users, and it will have a pronounced impact on the biodiversity, including fish and macroinvertebrates, associated with this river system.

Socio-economic summary

The present socio-economic state indicates a moderate relative incidence of vulnerable households, low relative levels of subsistence agriculture and moderate to low relative levels of irrigated commercial agriculture. The area falls within the Arid Innovation Zone and classified as vulnerable to changes in water resources. The GDP per capita is relatively low, with little value add from the primary sector.

The ecological/biophysical analysis and consequences outlined above indicate that the REC is achieved across Sc1 and Sc2, suggesting a low risk of significant changes in ecosystem services and therefore low potential socio-economic risk. However, the scenarios show small reductions in baseflows, which may pose a risk to ron-of-river water abstraction, however, the low relative incidence of vulnerable households and limited subsistence agriculture and irrigated commercial agriculture reduces the extent of the risk. The implications of predicted decreasing water quality on the substantial deterioration in the system's capacity to provide ecosystem goods and services, and the increasing prevalence of waterborne diseases, will present significant socio-economic risk particularly for local communities who are reliant on the river, to meet BHN, as well as recreational users.

5.2.6 UO_EWR06_I: Upper Riet

Site Name	UO_EWR06_I	**Prioritised RU**	R_RU08
River	Upper Riet	**Altitude (m.a.s.l.)**	1278
Latitude	-29.53478727	**Longitude**	25.52449567
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	C51F-04071
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, Moderate
Sumary of the Eco-categorisation results			

River	**Upper Riet**
EWR Site Code	**UO_EWR06_I**
Driver component	**PES**
HAI	C
Diatoms	D
GAI	C
Response component	**PES**
FRAI	C
MIRAI	C
VEGRAI	C
Ecostatus	C
EI	High
ES	Moderate
REC	C
AEC	B/C

Reasons for EcoStatus: Impacts

- Widespread grazing and soil erosion elevate fine sediment loads;
- Dams and weirs along tributaries and mainstem trap coarser bed sediment;
- Grazing along banks and some localised erosion evident along banks, but generally well vegetated;
- Presence of non-native fish species; and
- Diatoms indicate heavily polluted waters (organic pollution) with elevated conductivities.

Present EI-ES

- Both remained High, Moderate.

REC: Mitigations Needed

- Water quality improvements through controlled irrigation and return flows.

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-6** below. The flow durations of the scenarios for the Upper Riet (UO_EWR06_I) for July (dry) and March (wet) are shown in **Table 5-37** and **Table 5-38**. The ‘red’ highlighted areas in the tables indicate where the EWR could not be met.

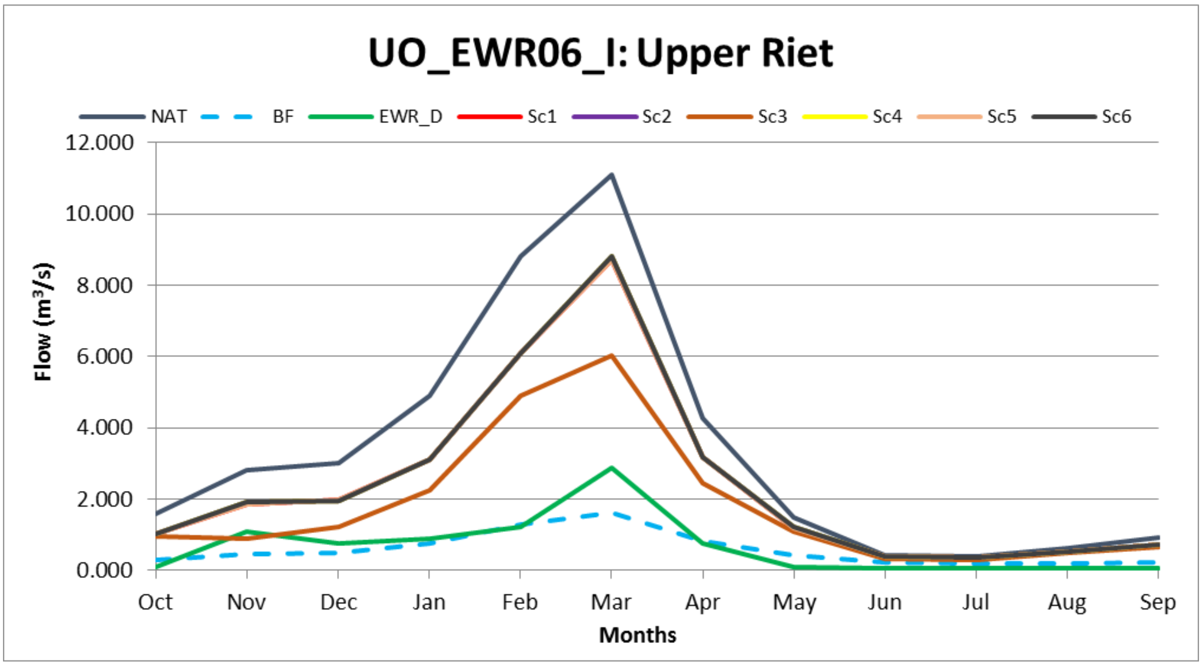


Figure 5-6: Seasonal distribution of scenarios at site UO_EWR06_I: Upper Riet

All the scenarios show reduced floods in the summer months, as well as small reductions in baseflows in the dry months. However, it should be noted that the Upper Riet was changed from a seasonal to a more perennial system due to return flows from upstream water use.

Table 5-37: Percentiles and flow (m^3/s) for July per scenario at Upper Riet (UO_EWR06_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	6.934	6.387	6.387	6.211	6.387	6.387	6.387	0.195
1	5.628	4.807	4.807	4.631	4.807	4.807	4.807	0.193
5	1.402	1.113	1.113	0.937	1.113	1.113	1.113	0.180
10	0.499	0.398	0.398	0.240	0.398	0.398	0.398	0.174
15	0.364	0.283	0.283	0.160	0.283	0.283	0.283	0.143
20	0.290	0.250	0.251	0.146	0.251	0.250	0.251	0.110
30	0.168	0.154	0.153	0.112	0.153	0.154	0.153	0.047
40	0.096	0.110	0.110	0.085	0.110	0.110	0.110	0.015
50	0.068	0.071	0.071	0.067	0.071	0.071	0.071	0.005
60	0.025	0.063	0.063	0.061	0.063	0.063	0.063	0.002
70	0.004	0.060	0.059	0.058	0.059	0.060	0.059	0.001
80	0.000	0.057	0.057	0.055	0.057	0.057	0.057	0.000
85	0.000	0.055	0.055	0.055	0.055	0.055	0.055	0.000
90	0.000	0.049	0.048	0.047	0.048	0.049	0.048	0.000
95	0.000	0.047	0.042	0.042	0.042	0.047	0.042	0.000
99	0.000	0.020	0.020	0.020	0.020	0.020	0.020	0.000
99.9	0.000	0.019	0.019	0.019	0.019	0.019	0.019	0.000

Table 5-38: Percentiles and flow (m^3/s) for March per scenario at Upper Riet (UO_EWR06_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	184.936	166.017	165.974	154.888	165.974	166.017	165.974	11.327
1	133.776	109.340	108.914	97.828	108.914	109.340	108.914	11.295
5	55.760	43.837	43.699	32.613	43.699	43.837	43.699	11.207
10	16.590	12.550	12.549	2.563	12.549	12.550	12.549	10.921
15	12.638	8.248	8.942	1.712	8.942	8.248	8.942	8.584
20	8.423	6.352	6.413	1.556	6.413	6.352	6.413	6.745
30	5.369	3.067	3.307	1.097	3.307	3.067	3.307	1.974
40	3.819	2.242	2.242	0.647	2.242	2.242	2.242	1.054
50	2.787	1.585	1.599	0.215	1.599	1.585	1.599	0.572
60	1.862	0.753	0.754	0.156	0.754	0.753	0.754	0.389
70	0.886	0.494	0.499	0.084	0.499	0.494	0.499	0.335
80	0.607	0.394	0.423	0.000	0.423	0.394	0.423	0.317
85	0.482	0.284	0.336	0.000	0.336	0.284	0.336	0.316
90	0.249	0.190	0.237	0.000	0.237	0.190	0.237	0.249
95	0.091	0.153	0.162	0.000	0.162	0.153	0.162	0.092
99	0.006	0.101	0.102	0.000	0.102	0.101	0.102	0.006
99.9	0.001	0.086	0.089	0.000	0.089	0.086	0.089	0.001

The above tables indicates that the EWR could be met for all the scenarios in July. However, some of the flood requirements could not be met, especially for Sc3 that almost no EWR could be met in full.

The scenarios highlighted in grey in **Table 5-39** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-40** to **Table 5-42**. For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-39: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-40: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
D		In accordance with **Figure 5-6**, one could expect a maintenance of the water quality of this site. • Similar to the site UO_EWR01_I, at this site there is a maintenance of the typical summer/wet season volume, meaning that the water quality will be reset during the rainfall season as the benthic algal growth from nutrient enrichment will be scoured out and the system refreshed. • Again, the low flows during the winter/dry season (June – August) will be when the discharge from WWTW contribute a significantly higher proportion of the base flow to this system, resulting in the base / low flow period being when the nutrients, bacteria, and other WWTW associated outputs dominate the water quality in the system.	Due to the present critical degradation of water quality, it is expected to worsen significantly and reach a critical point in the future. The net impact will be a significant decline in the health and ability of this system to deliver ecosystem goods and services, principally clean water and a system able to dilute, process and reduce polluted water associated with its natural resident biota. Considering the major reason for declining water quality in the Upper Orange River system is failing WWTW, worsening water quality is likely to a) allow water borne diseases to become more frequent and persistent, and b) seasonally increased risk for local dependent communities, recreational users, and a high impact for biodiversity associated with this river system.

Table 5-41: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		**C**	**C**	**C/D**	**C**	*Not applicable*	

The drivers are mostly constant for all scenarios, except for Sc3 where there are small to moderate reductions in the freshet and small flood magnitudes, driving sedimentation and increases in embeddedness and sand bars along the channel.

Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		**C**	**C**	**C/D**	**C**	*Not applicable*	

There are no changes to flow and geomorphology expected for the EWR site, except for Sc3, which shows a noticeable reduction in floods and freshets. As a result, for Sc3 it is expected that the site would experience a slight increase in woody indigenous, alien and terrestrial species with encroachment extending further into the riparian zone. This would lead to a slight decline in EC from 62.3 (i.e. C category) to 59.4 (i.e. C/D category) under Sc3.

Table 5-42: Biotic consequences of the scenarios

Fish and Macroinvertebrates										
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	C		A	A	A/B	A	*Not applicable*		C/D
Inverts Dry	C		A/B	A/B	B/C	A/B			C/D
Fish Wet	C		C/D	C/D	E	B/C			C/D
Inverts Wet	C		C/D	C/D	E	C			C/D

Macroinvertebrates

The upper Riet River has a diversity of macroinvertebrate biotopes available, including both marginal and in-stream aquatic vegetation. The indicator taxon selected for this site included in the FIFHA was Hydropsychidae, being a flow dependent taxon. They have a high preference for fast currents of >0.6m/s, although optimal speeds are approximately 0.4m/s, along the critical habitats of fast and very fast course substrate. The FIFHA analysis was conducted for the months of March and July, representing the wet and dry seasons, respectively, starting from the 0.10th percentile. In accordance with the FIFHA, the ecological flow requirements will be met during the dry season for Sc1 to Sc4, including Sc4 during the wet season. However, there is a concern that the PES of the macroinvertebrates of a C (moderately modified) will not be met for Sc1 to Sc3 during the wet season. Of particular concern is Sc3, where the PES (only considering flow and habitat) is projected to be an E (seriously modified). This is primarily attributed to the zero flows observed in Sc3 from the 80th percentile in the month of March. Furthermore, when comparing this scenario to the EWR of a C, there are major deficits in the system in March from the 10th percentile onwards (thus only flow is available 5% of the time in this month). However, the deficits do alleviate to a certain degree in April to June. Therefore, there may potentially be additional water being removed from the system, which may have a consequence on the biota with limited flow.

Nevertheless, it is important to underscore that alterations in flow did not significantly impact the macroinvertebrate community on this site. Instead, the community displayed noteworthy responses to low to very low requirements for maintaining unaltered physical-chemical conditions. Consequently, the primary factor influencing the macroinvertebrate PES, which was evaluated as 'C' or moderately modified according to the MIRIA methodology, was water quality. This conclusion is further substantiated by the results pertaining to diatoms. However, it is worth noting that even though water quality impairments drive the community's dynamics, a complete absence of flow can still have detrimental effects on the macroinvertebrates.

With regards to Sc7 whereby there is anticipated further deterioration in water quality. Given that the current state of the aquatic macroinvertebrate community is already moderately modified and responding to poor water quality, as mentioned earlier, it is reasonable to anticipate that the further deterioration and a critical compromise in water quality, which may even result in an increased prevalence of waterborne diseases, will only serve to perpetuate the presence of highly tolerant macroinvertebrates that thrive in conditions characterised by very low water quality within this ecosystem in the future.

Fish
The reach of the upper Riet River has a variety of habitat types supportive of a diverse assemblage of fish species, with all velocity-depth classes present, with water column and emergent vegetation providing the primary cover features. Due to the lack of true rheophilic species, large semi-rheophilic *Labeobarbus aeneus* was selected to act as flow-dependent indicators, with the reach likely to support critical habitat for early-life stages (spawning, egg and embryo development & larval nursery area) for the species within selected areas. The presence of Kalkfontein Dam downstream of the EWR site however poses a movement barrier for fish moving from the lower reaches of the system, thus upstream movement is expected to be largely from fish resident in the dam over low-flow periods.

Based on the outputs from the FIFHA model, it was determined that the ecological flow requirements for fish will be met for Sc1, Sc2, Sc3 and Sc4 during July (representing the dry period) as well and for Sc4 during March (representing the wet period). Concern is however raised with respect to Sc1, Sc2 and Sc3 where ecological flow requirements for critical life stages will be reduced or not be met, resulting in a decline in the integrity of the fish assemblage. Sc3 is of particular concern in that the ecological state is likely to diminish to a level that is unsustainable.

A further decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted because of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish. Deteriorating water quality would further likely lead to increased prevalence of fish kill events within the reach.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-43**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-43: EWR06_I: Upper Riet: Ecological consequences

Component	PES	REC	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	C	C	C	C	C/D	C	*Not applicable*	
Riparian Vegetation	C		C	C	C/D	C		
Fish	C		C/D	C/D	E	B/C		
Macroinvertebrates	C		C/D	C/D	E	C		
EcoStatus	C							
Meeting Overall REC			√	√	**x**	√		

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

Overall, the ranking of the scenarios indicate that only Sc3 will not achieve the REC requirements for this site, primarily owing to the biotic component illustrating deterioration (primarily owing to deficits in the system and the flows not meeting the preferences of the selected indicator fish species or macroinvertebrate taxon). Therefore, the baseflows are adequate for all scenarios, the issue lies with the high flows for Sc3. However, with the EWR in Sc4, the flows will meet the REC. Therefore, if the EWR is not implemented, the biota will be negatively modified.

Scenario 7 summary

In terms of the current state of the water quality, turbidity levels may continue to rise in response to increasing sediment supply from erosion upstream. The physical-chemical state was in a declining condition (estimated with moderate confidence). The diatoms illustrated a decline in water quality between surveys, from being classified as moderately modified in July 2022 to poor in May 2023. This may have reflected increasing organic pollution and sedimentation from upstream processes. The pH was elevated, although still within guidelines.

Hence, it is reasonable to anticipate a further decline in the noted conditions, potentially reaching a critical threshold. The ultimate result will be a significant degradation in the system's capability to furnish ecosystem services, primarily in terms of providing clean water and the ability to dilute, process, and ameliorate the presence of polluted water in conjunction with its native biota (assimilative capacity). Moreover, an increased occurrence and persistence of waterborne diseases are expected. This heightened risk may pose seasonal challenges for the local communities dependent on the river, recreational users, and will notably impact the river's biodiversity, including fish and macroinvertebrates.

Socio-economic summary

The present socio-economic state indicates a low relative incidence of vulnerable households, and low population densities. There is little irrigated commercial agriculture at the site (however there is significant high-value irrigated commercial agriculture in other parts of the local municipality), and very limited subsistence agriculture. There is a relatively moderate-high GDP contribution through agricultural at the municipal level. There is relatively high registered water use from rivers and boreholes.

The ecological/biophysical analysis and consequences outlined above indicate there is enough flow to meet the REC across scenarios Sc1, Sc2 and Sc4, suggesting there is unlikely to be any changes in the ability of the system to meet the present socio-economic water-use. However, Sc3 will not achieve the REC requirements primarily owing to deficits in the system and the flows not meeting the preferences for target biotic components. Therefore, if the EWR is not implemented there will likely changes in the ability of the system to meet the present socio-economic water-use.

There is a socio-economic risk associated declining water quality, broadly as a result of a significant degradation in the system's capability to furnish ecosystem services and an increased occurrence and persistence of waterborne diseases.

5.2.7 UO_EWR07_I: Upper Modder (Sannaspos)

Site Name	UO_EWR07_I	**Prioritised RU**	R_RU9a
River	Modder	**Altitude (m.a.s.l.)**	1333
Latitude	-29.160017°	**Longitude**	26.572492°
Level 1 EcoRegion	Highveld	**Quaternary catchment- SQ Reach**	C52B-03819
Level 2 EcoRegion	11.03	**DWS, 2014 PES, EI, ES**	D, Moderate, High

Sumary of the Eco-categorisation results

River	**Upper Modder**
EWR Site Code	**UO_EWR07_I**
Driver component	**PES**
HAI	C/D
Diatoms	D
GAI	D
Response component	**PES**
FRAI	C
MIRAI	D
VEGRAI	D
Ecostatus	D
EI	Low
ES	Moderate
REC	C
AEC	C

Reasons for EcoStatus: Impacts

- Extensive alien invasive plants within the riparian zone;
- Widespread overgrazing and soil erosion elevate fine sediment loads;
- Dams and weirs along tributaries and mainstem trap coarser bed sediment;
- Overgrazing and trampling along banks with widespread erosion evident along banks;
- Presence of non-native fish species;
- Migration barrier (upstream weir); and
- Diatoms used to infer the present physical-chemical state of the system, indicating strong organic and inorganic pollution, arising from urban runoff and poorly treated wastewater from the Botshabelo Township upstream.

Present EI-ES

- EI decreased from moderate to low due to instream migration link class and habitat diversity class.

REC: Mitigations Needed

- As water quality currently is the primary driver of this system from a biotic perspective, if this can be improved through various land and catchment management practices (i.e., WWTW), this will provide an opportunity to improve the biotic state of the system, coupled with adequate flows; and
- Land and catchment management (grazing, trampling, erosion and alien invasive vegetation).

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-7** below. The flow durations of the scenarios for the Upper Modder (UO_EWR07_I) for July (dry) and February (wet) are shown in **Table 5-44** and **Table 5-45**. The 'red' highlighted areas in the tables indicate where the EWR could not be met.

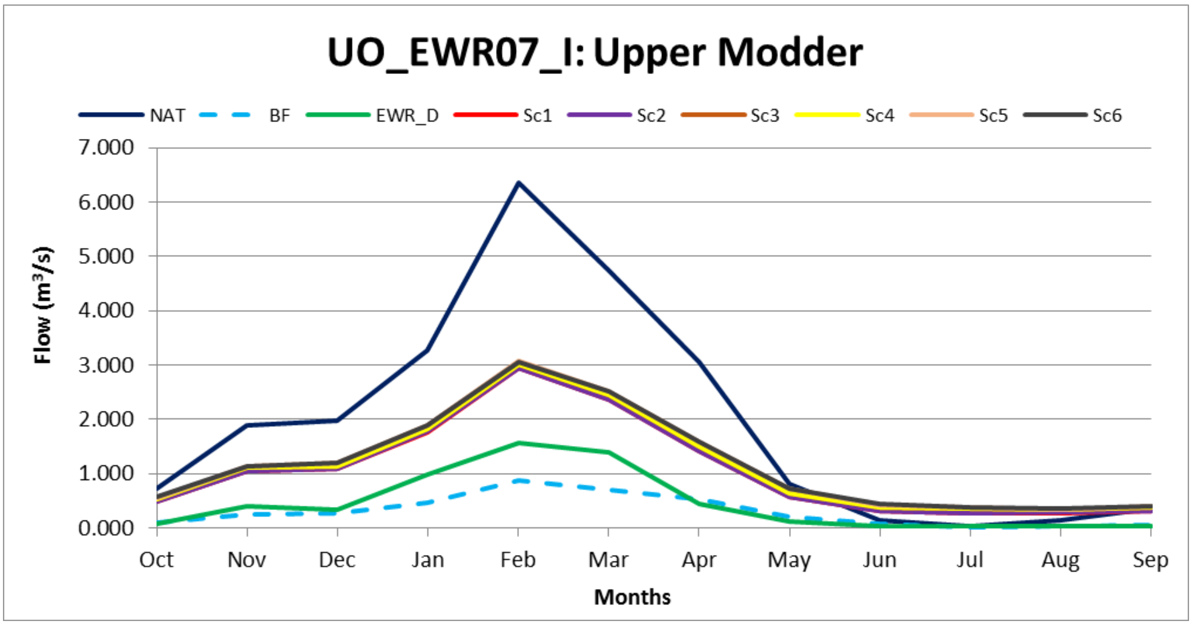


Figure 5-7: Seasonal distribution of scenarios at site UO_EWR07_I: Upper Modder

All the scenarios show reduced floods in the summer months, as the river is dependent on spills from the upstream Rustfontein Dam. Higher baseflows than natural in dry months due to the WWTW upstream that discharges into the Little Modder River. It should be noted that the Upper Modder was changed from a seasonal to a more perennial system due to return flows from upstream WWTW.

Table 5-44: Percentiles and flow (m^3/s) for July per scenario at Upper Modder (UO_EWR07_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	0.548	0.572	0.572	0.675	0.675	0.863	0.863	0.108
1	0.482	0.421	0.421	0.528	0.528	0.696	0.696	0.108
5	0.135	0.338	0.338	0.440	0.440	0.609	0.609	0.104
10	0.101	0.307	0.308	0.414	0.414	0.586	0.587	0.097
15	0.068	0.303	0.303	0.410	0.410	0.575	0.575	0.068
20	0.060	0.299	0.299	0.404	0.404	0.571	0.571	0.060
30	0.034	0.292	0.292	0.395	0.395	0.568	0.568	0.034
40	0.014	0.287	0.287	0.391	0.391	0.369	0.408	0.014
50	0.005	0.285	0.285	0.388	0.388	0.319	0.319	0.005
60	0.000	0.280	0.280	0.381	0.381	0.309	0.310	0.000
70	0.000	0.277	0.277	0.378	0.378	0.302	0.302	0.000
80	0.000	0.276	0.276	0.372	0.372	0.293	0.293	0.000
85	0.000	0.275	0.275	0.263	0.263	0.223	0.225	0.000
90	0.000	0.275	0.275	0.082	0.084	0.041	0.068	0.000
95	0.000	0.164	0.165	0.004	0.027	0.002	0.026	0.000
99	0.000	0.001	0.004	0.001	0.004	0.001	0.003	0.000
99.9	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000

Table 5-45: Percentiles and flow (m^3/s) for February per scenario at Upper Modder (UO_EWR07_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	109.416	41.225	40.917	41.289	40.870	41.580	41.145	4.623
1	52.622	26.285	26.231	26.370	26.296	26.564	26.488	4.578
5	29.701	12.805	12.778	12.907	12.695	13.128	12.874	4.523
10	19.960	8.542	8.509	8.641	8.481	8.843	8.676	4.394
15	10.470	4.402	4.402	4.505	4.505	4.709	4.709	3.942
20	6.307	3.566	3.566	3.371	3.483	3.347	3.347	3.472
30	2.572	1.406	1.407	1.498	1.499	1.621	1.621	2.295
40	2.068	1.015	1.015	1.115	1.115	1.188	1.189	1.262
50	1.274	0.798	0.798	0.828	0.828	0.881	0.881	0.667
60	0.842	0.599	0.599	0.689	0.689	0.754	0.767	0.413
70	0.571	0.501	0.501	0.597	0.597	0.601	0.616	0.339
80	0.262	0.359	0.360	0.459	0.459	0.431	0.432	0.262
85	0.206	0.319	0.340	0.397	0.397	0.322	0.343	0.206
90	0.149	0.276	0.276	0.335	0.334	0.274	0.281	0.149
95	0.108	0.241	0.241	0.164	0.240	0.126	0.203	0.108
99	0.031	0.168	0.170	0.034	0.108	0.034	0.108	0.031
99.9	0.014	0.053	0.059	0.005	0.053	0.005	0.053	0.014

The above tables indicates that the EWR could be met for all the scenarios in July and most of the time for February.

The scenarios highlighted in grey in **Table 5-46** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-47** to **Table 5-49** . For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-46: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-47: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
D		In accordance with **Figure 5-7** one could expect a maintenance of the water quality of this site. • Similar to the site UO_EWR01_I, at this site there is a maintenance of the typical summer/wet season volume, meaning that the water quality will be reset during the rainfall season as the benthic algal growth from nutrient enrichment will be scoured out and the system refreshed. • Again, the low flows during the winter/dry season (May – September) will be when the discharge from WWTW contribute a significantly higher proportion of the base flow to this system, resulting in the base / low flow period being when the nutrients, bacteria, and other WWTW associated outputs dominate the water quality in the system. • Notably, from June to September, Sc2 shows an increase in flows in the system higher than the natural or current flows due to the discharges from the WWTW.	Due to the present critical degradation of water quality, it is expected to worsen significantly and reach a critical point in the future. One could expect the observations above to be further and critically compromised. The net impact of will be a significant decline in the health and ability of this system to deliver ecosystem goods and services, principally clean water and a system able to dilute, process and reduce polluted water associated with its natural resident biota. Considering the major reason for declining water quality in the Upper Orange River system is failing WWTW, worsening water quality is likely to a) allow water borne diseases to become more frequent and persistent, and b) seasonally increase risk for local dependent communities, recreational users, and a high impact for biodiversity associated with this river system.

Table 5-48: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D		**D**	**D**	*Not applicable*			
Despite the PES being lower than the REC, there are no significant geomorphological changes expected for the upper Modder despite the slight reduction in freshet and flood magnitude.							

Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D		**D**	**D**	*Not applicable*			
The EWR for the site is largely met for the range of flows for all scenarios. Flow changes for Sc1 and Sc2 are negligible, and there is only a small reduction in low flows for Sc3 to Sc6 when compared to the present-day flows as produced for Sc1. As a result, no changes in riparian vegetation are expected and the EWR site is expected to remain in a D category, provided other impacts remain unchanged. However, to meet the REC, active riparian management will be required to specifically address livestock impacts and alien vegetation.							

Table 5-49: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	C		-	-	*Not applicable*				D
Inverts Dry	D		-	-					E
Fish Wet	C		A*	A					D
Inverts Wet	D		A/B**	A/B**					E

*Too much flow

Note: The water quality is highly compromised, that this is not a true reflection of the response of the biota, thus interpreted with caution and low confidence.

Macroinvertebrates

This site has a selection of varying aquatic macroinvertebrate biotopes, thus the selected flow dependent indicator taxon at this site, was Hydropsychidae. They have a high preference for fast currents of >0.6m/s, although optimal speeds are approximately 0.4m/s, along critical habitats namely fast and very fast course substrate. Overall, the FIFHA analysis was conducted for the months of February and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. Owing to no future developments on the Modder River, there will be no change to the main drivers in the system, and thus the macroinvertebrate community is unlikely to change as a result of water resource development and thus the community should remain as moderately modified (category C) for both Sc1 and Sc2. In accordance with the FIFHA, the PES of the macroinvertebrates for Sc1 and Sc2 in the wet season was an A category. However, this is merely due to the FIFHA not considering the water quality metric in the model. Nonetheless, it's worth noting that the Hydropsychidae family is not highly responsive to declines in water quality. Therefore, if there are future alterations in flow conditions that fail to meet the requirements of the EWR, this family may no longer persist at the site due to flow alternation, despite the quality of the water.

Water quality at this site was highly compromised by elevated nutrient inputs from upstream. Thus, it is crucial to emphasise that the macroinvertebrate community is not significantly influenced by alterations in flow currently. Instead, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a "D' or largely modified using the MIRIA methodology, was water quality. This finding is also substantially corroborated by the diatom results.

With regards to Sc7 whereby there is anticipated further deterioration in water quality. Given that the current state of the aquatic macroinvertebrate community is already largely modified and responding to poor water quality, as mentioned earlier, it is reasonable to anticipate that the further deterioration and a critical compromise in water quality, which may even result in an increased prevalence of waterborne diseases, will only serve to perpetuate the presence of highly tolerant macroinvertebrates that thrive in conditions characterised by very low water quality within this ecosystem in the future.

Fish

Due to the lack of true rheophilic species, large semi-rheophilic *Labeobarbus aeneus* was selected to function as flow-dependent indicators, with the reach likely to support some critical habitat for early-life stages (spawning, egg and embryo development & larval nursery area) for the species within selected areas during the high flow period, albeit to a marginal extent.

Based on the outputs from the FIFHA model, it was determined that there will be no change to the main drivers in the system particularly given that there are no planned future developments on the Modder River under Sc1 and Sc2. It is thus unlikely that Sc1 and Sc2 will result in any significant changes to the ecological state of the associated reach of the Modder River from a flow-depth perspective, particularly given that the indicator species does have a wide diversity of habitat preferences and is able to survive within lentic water bodies.

However, a further decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be further impacted because of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-50**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-50: UO_EWR07_I: Upper Modder: Ecological consequences

<table>
<tr><th>Component</th><th>PES</th><th>REC</th><th></th><th>Sc1</th><th>Sc2</th><th>Sc3</th><th>Sc4</th><th>Sc5</th><th>Sc6</th></tr>
<tr><td>Geomorphology</td><td>D</td><td rowspan="5">C</td><td></td><td>D</td><td>D</td><td colspan="4" rowspan="4">Not applicable</td></tr>
<tr><td>Riparian Vegetation</td><td>D</td><td></td><td>D</td><td>D</td></tr>
<tr><td>Fish</td><td>C</td><td></td><td>A</td><td>A</td></tr>
<tr><td>Macroinvertebrates</td><td>D</td><td></td><td>A</td><td>A</td></tr>
<tr><td>EcoStatus</td><td>D</td><td></td><td colspan="6"></td></tr>
<tr><td colspan="3">Meeting Overall REC</td><td></td><td>√</td><td>√</td><td colspan="4"></td></tr>
</table>

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

Overall, the ranking of the scenarios indicate that the selected scenarios achieve the REC requirements for this site. However, it is important to note that the flows from all scenario, show reduced floods in the summer months, as the river is dependent on spills from the upstream Rustfontein Dam. Higher baseflows than natural in dry months due to the WWTW upstream that discharges into the Little Modder River.

Scenario 7 summary

In terms of the current state of the water quality, this site was assessed to be experiencing long-term decline of water quality through failing / dysfunctional sewage infrastructure. Notably the DO was among the lowest recorded in the catchment (less than 80%). The impacts from the upstream confluence with the Klein-Modder were likely minimised by dilution from the larger Modder River and the Rustfontein Dam upstream during the wet months. However, the physical-chemical state reflects worsening under the increasing impacts of the upstream Botshabelo Township and WWTW.

Hence, it is reasonable to anticipate a further decline in the observed conditions, potentially reaching a critical threshold. The ultimate result will be a momentous degradation in the system's capability to furnish ecosystem services, primarily in terms of providing clean water and the ability to dilute, process, and ameliorate the presence of polluted water in conjunction with its native biota. Moreover, an increased occurrence and persistence of waterborne diseases are expected. This heightened risk may pose seasonal challenges for the local communities dependent on the river, recreational users, and will notably impact the river's biodiversity, including fish and macroinvertebrates.

Socio-economic summary

The present socio-economic state indicates a moderate relative incidence of vulnerable households, and relatively large urban and smallholder farming communities. There is significant levels of commercial agriculture, but little irrigated agriculture, and moderate levels of subsistence/smallholder agriculture. The local economic development focus areas include agriculture and tourism, and there is a relatively significant gross value addition contribution from the agriculture sector. The main GDP contributors are Government and Community Service Sectors.

The ecological/biophysical analysis and consequences outlined above indicate the selected scenarios (Sc1 and Sc2) achieve the REC requirements for this site, suggesting there is unlikely to be any changes in the ability of the system to meet the present socio-economic water-use. However, there is a socio-economic risk associated with declining water quality, broadly as a result of a significant degradation in the system's capability to furnish ecosystem services and an increased occurrence and persistence of waterborne diseases.

5.2.8 UO_EWR08_I: Lower Kraai

Site Name	UO_EWR08_I	**Prioritised RU**	R_RU03
River	Kraai	**Altitude (m.a.s.l.)**	1298
Latitude	-30.69007°	**Longitude**	26.74157°
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D13M-05442
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, High

Sumary of the Eco-categorisation results

River	**Lower Kraai**
EWR Site Code	**UO_EWR08_I**
Driver component	**PES**
HAI	B
Diatoms	C
GAI	C
Response component	**PES**
FRAI	C
MIRAI	C
VEGRAI	D/E
Ecostatus	C
EI	High
ES	High
REC	B/C
AEC	B

Reasons for EcoStatus: Impacts

- Extensive alien invasive plants within the riparian zone, bare banks;
- Widespread grazing and some soil erosion elevate fine sediment loads;
- Low water bridges and weirs along main stem trapping course sediments and flow modification;
- Localised erosion along left bank due to the weir. Grazing along banks and bars. New inset benches forming along right bank;
- Presence of non-native fish species;
- Migration barrier (upstream weir); and
- Diatoms used to infer the present physical-chemical state of the system, indicating elevated electrolyte concentrations and pollutants.

Present EI-ES

- Both remained High.

REC: Mitigations Needed

- Water quality improvements through land use activities (irrigation, abstraction, return flows) within upstream and adjacent catchment should be managed to prevent degradation of the ecological health of the system and deterioration of the water quality (buffer zones to be implemented); and
- Alien invasive vegetation to be managed.

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-8** below. The flow durations of the scenarios for the Lower Kraai (UO_EWR08_I) for July (dry) and March (wet) are shown in **Table 5-51** and **Table 5-52**. The 'red' highlighted areas in the tables indicate where the EWR could not be met.

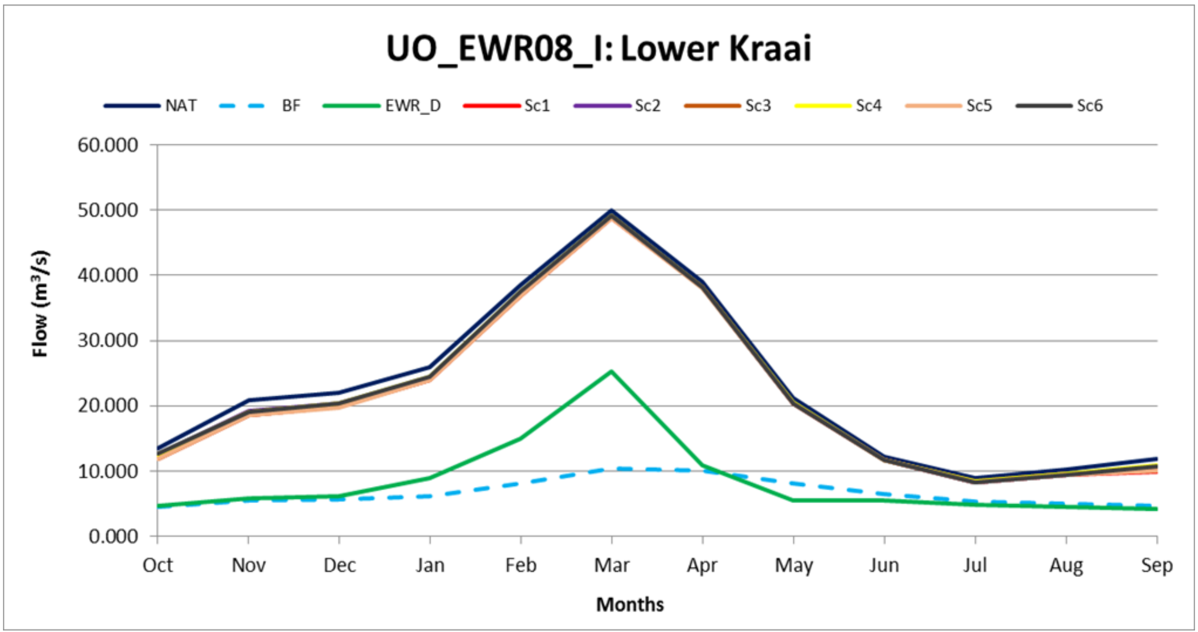


Figure 5-8: Seasonal distribution of scenarios at site UO_EWR08_I: Lower Kraai

All the scenarios show limited reductions in floods and baseflows as the main water use is abstractions for irrigation either directly from the river or from small dams.

Table 5-51: Percentiles and flow (m^3/s) for July per scenario at Lower Kraai (UO_EWR08_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_B/C
0.1	68.554	68.166	68.159	68.166	68.159	68.166	68.159	6.945
1	59.299	58.831	58.825	58.831	58.825	58.831	58.825	6.940
5	21.048	20.549	20.534	20.549	20.533	20.549	20.533	6.915
10	17.190	16.643	16.635	16.643	16.635	16.643	16.635	6.897
15	12.171	11.556	11.551	11.556	11.550	11.556	11.551	6.839
20	11.885	11.362	11.357	11.363	11.357	11.362	11.357	6.789
30	8.693	8.152	8.142	8.152	8.142	8.152	8.142	6.571
40	7.047	6.334	6.332	6.334	6.529	6.334	6.330	6.156
50	6.299	5.661	5.657	5.786	6.049	5.661	5.654	5.595
60	5.071	4.362	4.361	4.362	4.547	4.362	4.361	4.645
70	4.118	3.403	3.393	3.416	3.408	3.403	3.393	3.576
80	3.680	2.987	2.984	2.995	2.989	2.987	2.984	2.403
85	3.185	2.527	2.518	2.583	2.576	2.583	2.518	1.889
90	3.085	2.331	2.331	2.368	2.365	2.368	2.331	1.627
95	2.731	1.983	1.975	1.983	1.971	1.983	1.971	1.337
99	2.256	1.586	1.581	1.586	1.574	1.586	1.574	1.335
99.9	1.943	1.285	1.276	1.285	1.275	1.285	1.275	1.335

Table 5-52: Percentiles and flow (m^3/s) for March per scenario at Lower Kraai (UO_EWR08_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_B/C
0.1	284.494	284.247	284.246	284.247	284.246	284.247	284.246	49.252
1	280.831	280.553	280.552	280.553	280.552	280.553	280.552	49.238
5	177.500	177.068	177.062	177.068	177.062	177.068	177.062	49.118
10	124.528	123.833	123.827	123.833	123.827	123.833	123.827	49.033
15	108.476	107.508	107.506	107.508	107.501	107.508	107.501	46.334
20	80.501	79.832	79.821	79.832	79.821	79.832	79.821	43.673
30	49.254	47.639	47.635	47.629	47.624	47.629	47.624	39.146
40	39.655	38.758	38.740	38.758	38.740	38.758	38.740	34.587
50	22.775	20.977	21.751	20.977	22.239	20.977	22.239	22.775
60	14.169	12.942	13.586	12.942	13.586	12.942	13.586	14.169
70	10.624	8.952	9.589	9.315	9.651	8.952	9.651	10.624
80	8.262	6.770	7.154	6.770	7.405	6.770	7.492	8.262
85	7.191	5.692	6.446	5.692	6.439	5.692	6.439	6.693
90	5.386	3.972	4.334	3.872	4.334	3.972	4.334	4.334
95	2.641	1.303	1.802	1.303	2.122	1.303	2.122	2.641
99	1.051	0.039	0.634	0.039	0.634	0.039	0.634	1.051
99.9	0.885	0.035	0.502	0.035	0.502	0.035	0.502	0.885

The above tables indicates that the EWR could be met most of the time for all the scenarios in July. However, the EWR could not be met for 50% of the time in March.

The scenarios highlighted in grey in **Table 5-53** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-54** to **Table 5-56**. For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-53: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-54: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
C		In accordance with **Figure 5-8**, one could expect that given the natural and Sc2 flows are virtually unchanged, that the water quality would not be impaired significantly during the wet season due to the flushing and dilution of return flows through the higher freshets and flood events.	There may be some marginal deterioration, but with reasonable EWR flows maintained here, the system can sustain the impacts with dilution and internal processing.

Table 5-55: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		**C**	**C**	*Not applicable due to no proposed development on the Lower Kraai*			
There are no significant changes to the main geomorphological drivers for the Kraai River, thus the PES should remain in a C category for Sc1 and Sc2, which is in line with the geomorphology EC, but a half a category less than the sites identified REC of a B/C.							
Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
D/E		**D/E**	**D/E**	*Not applicable due to no proposed development on the Lower Kraai*			
There are no significant changes to flow and geomorphological processes expected for Sc1 and Sc2, and thus riparian vegetation is expected to remain in a D/E category, provided that other impacts remain unchanged. Active riparian management will be required to achieve the REC, focussing on sustainable sand mining and alien vegetation control.							

Table 5-56: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	C		A	A	*Not applicable due to no proposed development on the Lower Kraai*				C
Inverts Dry	C		A	A					C
Fish Wet	C		C	B					C
Inverts Wet	C		C	B					C

Macroinvertebrates
This lower Kraai River has a diversity of macroinvertebrate biotopes, although the marginal vegetation was limited. Perlidae was the selected indicator taxon for this reach, as they are a flow dependent taxon, with a preference for fast and very fast course substrate being the critical habitat for this taxon. They further prefer flow >0.6m/s. The FIFHA analysis was conducted for the months of March and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. Owing to no future developments on the Kraai River, there will be no change to the main drivers in the system, and thus the macroinvertebrate community is unlikely to change as a result of water resource development and thus the community should remain as per their current PES for both Sc1 and Sc2. In accordance with the FIFHA, the PES of the macroinvertebrates had slightly improved to a B category. However, this can be ascribed to the FIFHA not considering the water quality metric in the model.

It is important to note that, the water quality at this site is slightly compromised, likely from nutrients from irrigation return flows, due to algae growth observed, smothering the biotope. The PES of a C for the macroinvertebrate community, in accordance with the MIRAI, was primarily influenced by water quality, as the community exhibited significant responses to low to very low water quality conditions. This was further supported by the diatom results.

In general, given the absence of recent water resource developments near the site that would alter its status over time, Scenario 7 is anticipated to result in marginal deterioration. However, with consistent EWR flows, the system can likely endure the impacts through dilution and internal processing.

Fish
The Lower Kraai reach is considered important for fish movement upstream from the Orange River, with limited spawning habitat present within the immediate reach. Spawning beds are located upstream of the site, but opportunistic spawning is expected to take place following delayed/impeded upstream migration which, during lower flow summer periods, may result in fish kill events. Life stages of importance within the immediate reach will therefore primarily include juvenile and adult stages for large semi-rheophilics, *Labeobarbus aeneus* and *L. kimberleyensis.*

Application of the FIFHA model for the scenarios investigated suggest that Sc1 and Sc2 are unlikely to result in any changes to the ecological state of the associated reach of the Lower Kraai River from a flow-depth, with no development scenarios planned for the river. However, a decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted as a result of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus Saprolegnia, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish. Deteriorating water quality would furthermore deter various fish species from moving into the reach during seasonal upstream migrations.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (**Table 5-57**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-57: UO_EWR08_I: Lower Kraai: Ecological consequences

Component	PES	REC		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	C	B/C		C	C				
Riparian Vegetation	D/E			D/E	D/E				
Fish	C			C	B				
Macroinvertebrates	C			C	B				
EcoStatus	C								
Meeting Overall REC				√	√				

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

Overall, the ranking of the applicable scenarios indicate that all scenarios achieve the REC requirements for this site. However, the only concern is that all the scenarios show limited reductions in floods and baseflows as the main water use is abstractions for irrigation either directly from the river or from small dams.

Scenario 7 summary

There have been no recent water resource developments near the site that would lead its status to change over time. Thus, under Scenario 7, one could expect some marginal deterioration, but with reasonable EWR flows maintained here, the system can sustain the impacts with dilution and internal processing.

Socio-economic summary

The present socio-economic state indicates a moderate to low relative incidence of vulnerable households. Cultivated land is categorised as a small proportion of the land area of the municipality of which a similarly low proportion is commercial irrigated agriculture; however, irrigated agricultural is largely concentrated along the Kraai and Orange rivers including the vicinity of the EWR site. Subsistence agriculture levels are low. The area is located in the Arid Innovation Zone and classified as under threat from limited water availability. The local economic development focus areas in the municipality include agriculture and tourism along with land reform. There are moderate relative levels of gross value addition from the agriculture sector. The main GDP contributors are the Government and Community Service sectors and Wholesale and Trade. Relatively moderate to high levels of the registered water use is abstracted from rivers and streams.

The ecological/biophysical analysis and consequences outlined above indicate the selected scenarios (Sc1 and Sc2) achieve the REC requirements for this site, suggesting there is unlikely to be changes in the ability of the system to meet the present socio-economic water-use. However, the reduction in baseflows and floods may have implications for irrigated agriculture, although the relatively low levels of irrigated agriculture across the municipality limits the likely extent of the risk. There is also unlikely to be a significant socio-economic risk associated water quality, as the ecological system can sustain the impacts with dilution and internal processing.

5.2.9 UO_EWR09_I: Lower Riet

Site Name	UO_EWR09_I	**Prioritised RU**	R_RU10
River	Lower Riet	**Altitude (m.a.s.l.)**	1080
Latitude	-29.026963	**Longitude**	24.512919
Level 1 EcoRegion	Southern Kalahari	**Quaternary catchment- SQ Reach**	C51L-03878
Level 2 EcoRegion	29.02	**DWS, 2014 PES, EI, ES**	D, Very High, High

Summary of the Eco-categorisation results

River	**Lower Riet**
EWR Site Code	**UO_EWR09_I**
Driver component	**PES**
HAI	C
Diatoms	C
GAI	C
Response component	**PES**
FRAI	C
MIRAI	C
VEGRAI	B
Ecostatus	C
EI	Very high
ES	High
REC	B/C
AEC	B/C

Reasons for EcoStatus: Impacts

- Vegetation removal;
- Water quantity (abstraction for irrigation and small impoundments upstream of the site);
- There is degradation in the catchment due to grazing, changes in hillslope-channel connectivity and cropping elevating fine sediment loadings;
- The dams and weirs along the Modder and Riet Rivers trap bedload sediment, reducing coarser habitats at the reach;
- Disturbance along the banks and margins are localised; and
- Diatoms used to infer the present physical-chemical state of the system, indicating high electrolyte content, which is congruent with the historical data at the site. The high electrical conductivities at the site are a result of irrigation return flows from both the Modder and Riet Rivers.

Present EI-ES

- Both remained Very High, High.

REC: Mitigations Needed

- The site is located within Mokale National Park and thus requiring attention to the conservation / environmental needs. It is further a recreational fishing area (Largemouth Yellowfish).

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-9** below. The flow durations of the scenarios for the Lower Riet (UO_EWR09_I) for July (dry) and March (wet) are shown in Table 5-58 and **Table 5-59**. The ‘red’ highlighted areas in the tables indicate where the EWR could not be met.

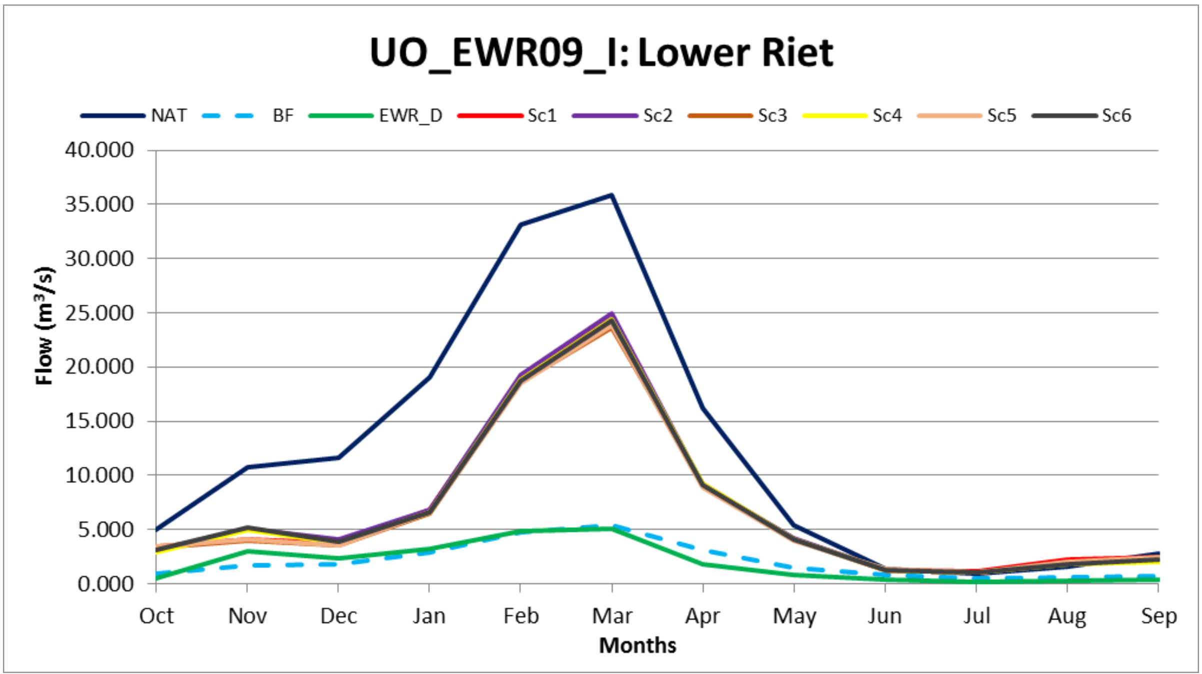


Figure 5-9: Seasonal distribution of scenarios at site UO_EWR09_I: Lower Riet

All the scenarios show reduced floods in the summer months due to numerous dams in the upper catchments and increased baseflows, especially in the dry months as a result of reurn flows from WWTWs and releases from dams for irrigation. It should be noted that the Lower Riet was changed from a seasonal to a more perennial system due to these return flows and constant releases.

Table 5-58: Percentiles and flow (m^3/s) for July per scenario at Lower Riet (UO_EWR09_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR
0.1	18.471	15.783	15.783	15.833	15.833	15.720	15.720	0.856
1	14.816	12.203	12.203	12.252	12.252	12.139	12.139	0.847
5	3.250	1.016	1.003	1.074	1.074	1.024	1.024	0.788
10	1.148	0.914	0.907	0.867	0.862	0.873	0.862	0.771
15	0.871	0.903	0.893	0.805	0.792	0.833	0.792	0.611
20	0.648	0.892	0.885	0.786	0.778	0.792	0.784	0.468
30	0.358	0.816	0.806	0.765	0.753	0.771	0.756	0.208
40	0.241	0.802	0.772	0.744	0.532	0.748	0.551	0.065
50	0.142	0.781	0.556	0.707	0.520	0.730	0.520	0.022
60	0.093	0.750	0.539	0.520	0.520	0.520	0.520	0.009
70	0.046	0.542	0.539	0.520	0.520	0.520	0.520	0.006
80	0.000	0.539	0.539	0.520	0.520	0.520	0.520	0.000
85	0.000	0.539	0.539	0.520	0.519	0.520	0.520	0.000
90	0.000	0.539	0.539	0.520	0.519	0.520	0.519	0.000
95	0.000	0.539	0.539	0.520	0.519	0.520	0.519	0.000
99	0.000	0.539	0.539	0.437	0.001	0.520	0.519	0.000
99.9	0.000	0.539	0.539	0.046	0.000	0.520	0.519	0.000

Table 5-59: Percentiles and flow (m^3/s) for March per scenario at Lower Riet (UO_EWR09_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR
0.1	433.020	418.856	418.856	417.805	417.805	417.611	417.611	18.804
1	371.629	358.783	358.783	358.453	358.453	358.105	358.105	18.735
5	167.007	126.078	125.940	126.032	125.894	126.037	125.898	18.390
10	81.325	54.828	54.846	50.470	50.472	49.042	49.026	17.417
15	41.146	13.423	13.423	13.492	13.492	13.506	13.505	14.499
20	32.097	9.953	9.952	9.012	9.935	9.716	9.831	11.578
30	21.443	5.610	9.489	2.306	8.207	3.421	8.199	5.458
40	14.695	1.877	5.726	1.770	3.908	1.831	3.866	2.546
50	10.805	1.773	2.421	1.757	1.834	1.763	1.893	1.115
60	8.717	1.755	1.827	1.745	1.760	1.750	1.768	0.575
70	5.025	1.742	1.758	1.728	1.731	1.737	1.745	0.404
80	2.811	1.727	1.688	1.673	0.991	1.709	1.508	0.351
85	2.461	1.702	1.063	1.627	0.582	1.662	0.878	0.349
90	1.414	1.613	0.576	1.532	0.421	1.588	0.424	0.349
95	0.258	1.556	0.351	0.958	0.352	1.553	0.351	0.258
99	0.073	0.704	0.262	0.106	0.340	0.855	0.263	0.073
99.9	0.011	0.220	0.115	0.029	0.298	0.484	0.121	0.011

The above tables indicates that the EWR could be met for all the scenarios in July and most of the time for March.

The scenarios highlighted in grey in **Table 5-60** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-61** to **Table 5-63**. For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-60: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-61: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
C		In accordance with **Figure 5-9**, one could expect a maintenance of the water quality of this site. • Similar to the site UO_EWR01_I, at this site there is a maintenance of the typical summer/wet season volume, meaning that the water quality will be reset during the rainfall season as the benthic algal growth from nutrient enrichment will be scoured out and the system refreshed. • Again, the low flows during the winter/dry season (June – August) will be when the discharge from WWTW contribute a significantly higher proportion of the base flow to this system, resulting in the base / low flow period being when the nutrients, bacteria, and other WWTW associated outputs dominate the water quality in the system.	Under Scenario 7, one could expect a similar picture as for Sc2, but a further decrease in the PES, particularly from June to around September where dilution of sewage base flows is at their lowest.

Table 5-62: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		**C**	**C**	**C**	**C**	*Not applicable*	
There are no significant changes to the main geomorphological drivers for the lower Riet River, thus the PES should remain in a C category for all scenarios, although a half a category below the EWR sites identified REC.							

Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
B		**B**	**B**	**B**	**B**	*Not applicable*	
The changes in flow that are expected for the various scenarios are not significant, and the geomorphological processes are likely to remain stable. Thus, riparian vegetation will remain the same as the PES EC, which is half a category above the REC.							

Table 5-63: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	C		A	A	A	A	*Not applicable*		C/D
Inverts Dry	C		A	A	A	A			C/D
Fish Wet	C		C	C	C	C			C/D
Inverts Wet	C		C	C/D	C/D	D			C/D

Macroinvertebrates

Perlidae was the selected indicator taxon for this reach, as they are a flow dependent taxon, with a preference for fast and very fast course substrate being the critical habitat for this taxon. They further prefer flow >0.6m/s. The FIFHA analysis was conducted for the months of March and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. Overall, the ecological flow requirements are met during the dry season for Sc1 to Sc4. However, in the wet season, the changes in flow that are expected for Sc2 to Sc4 will result in a negative response in the macroinvertebrate community due to lower flows. This may be a result owing to the deficits in the system, during the month of March generally between the 15^{th} and 20^{th} percentile, and at times continues until June.

Under Scenario 7, one could expect a further decrease in the PES, owing to additionally compromised water quality from sewage inputs and return flows in the future.

Fish

The Lower Riet reach is considered important for the purpose of upstream movement of fish as well as supporting a strong population of the Near Threatened *Labeobarbus kimberleyensis,* with the reach supporting spawning habitat. Life stages of importance within the immediate reach will therefore primarily include juvenile and adult stages for large semi-rheophilics *Labeobarbus aeneus* and *L. kimberleyensis.*

Application of the FIFHA model for the scenarios investigated suggest that Sc1, Sc2, Sc3 and Sc4 are unlikely to result in any changes to the ecological state of the associated reach of the Lower Riet River from a flow-depth perspective. However, a decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted as a result of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus Saprolegnia, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-64**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-64: UO_EWR09_I: Lower Riet: Ecological consequences

Component	PES	REC		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	C	B/C		C	C	C	C		
Riparian Vegetation	B			B	B	B	B		
Fish	C			C	C	C	C		
Macroinvertebrates	C			C	C/D	C/D	D		
EcoStatus	C								
Meeting Overall REC				√	√	√	**X**		

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*

Overall, the ranking of the scenarios indicates that Sc1 to Sc3 will meet the REC, however there is a concern that Sc4 will not achieve the REC requirements, or meet the EWR for this site, primarily owing to the macroinvertebrate component, illustrating deterioration. This is primarily owing to deficits in the system and the flows not meeting the preferences of the selected indicator macroinvertebrate taxon.

Scenario 7 summary

Under Scenario 7, one could expect a similar picture as for Sc2, but a further decrease in the PES, particularly from June to around September where dilution of sewage and irrigation return flows is at the lowest.

Socio-economic summary

The present socio-economic state indicates a moderate to high relative incidence of vulnerable households, with largely urban settlements and some smallholder farming communities. There is a relatively high percentage of cultivated land, with some commercially irrigated. There is also relatively little subsistence agriculture across the municipality. The area is located in the Arid Innovation Zone and categorised as threatened by limited water availability. The local economic development focus areas include agriculture and agro-processing. The main GDP contributors are Government and Community Service sectors, as well as agriculture, catering and accommodation.

The ecological/biophysical analysis and consequences outlined above indicate selected scenarios (Sc1 to Sc3) achieve the REC requirements for this site. However, deficits in the system and changes in flows indicate that the REC will not be achieved for Sc4. This suggests there will likely be changes in the ability of the system to meet the present socio-economic water-use for Sc4. There is also the risk of significant socio-economic consequences associated with water quality issues and further declines (Sc7), especially for the vulnerable households and local economic growth areas of accommodation, catering and agro-processing), particularly from June to September when dilution of flows is at the lowest.

5.2.10 UO_EWR10_I: Lower Orange

Site Name	UO_EWR10_I	**Prioritised RU**	R_RU07
River	Lower Orange	**Altitude (m.a.s.l.)**	1000
Latitude	-29.14485	**Longitude**	23.691403
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D33K-03723
Level 2 EcoRegion	26.01	**DWS, 2014 PES, EI, ES**	C, High, Moderate

Sumary of the Eco-categorisation results

River	**Lower Orange**
EWR Site Code	**UO_EWR010_I**
Driver component	**PES**
HAI	C/D
Diatoms	D
GAI	C/D
Response component	**PES**
FRAI	B/C
MIRAI	D
VEGRAI	C
Ecostatus	C
EI	Moderate
ES	Moderate
REC	C
AEC	B/C

Reasons for EcoStatus: Impacts

- Flow modification from upstream hydropower discharges;
- Non-native fish species;
- Migratory barriers (Marksdrift Weir);
- Habitat modification for biota as the marginal vegetation has completely been removed due to all the floods and hydropeaking (scouring and sediment deposition); and
- Diatoms used to infer the present physical-chemical state of the system, indicating very electrolyte-rich to brackish water, owing to the irrigation return flows in the system. The return flows appear to be the major physical-chemical driving factor.

Present EI-ES

- EI decreased from High to Moderate mostly due to instream migration link class.

REC: Mitigations Needed

- Gariep and Vanderkloof Dams fulfil a critical role in providing water/power generation to the country; and
- In the current socio-economic situation, flow and dam operation cannot be avoided or altered..

Evaluated scenarios

The seasonal distribution (hydrograph) plot was prepared using the flows provided for the scenarios and is illustrated in **Figure 5-10** below. The flow durations of the scenarios for the Lower Orange (UO_EWR10_I) for July (dry) and February (wet) are shown in **Table 5-65** and **Table 5-66**. The ‘red’ highlighted areas in the tables indicate where the EWR could not be met.

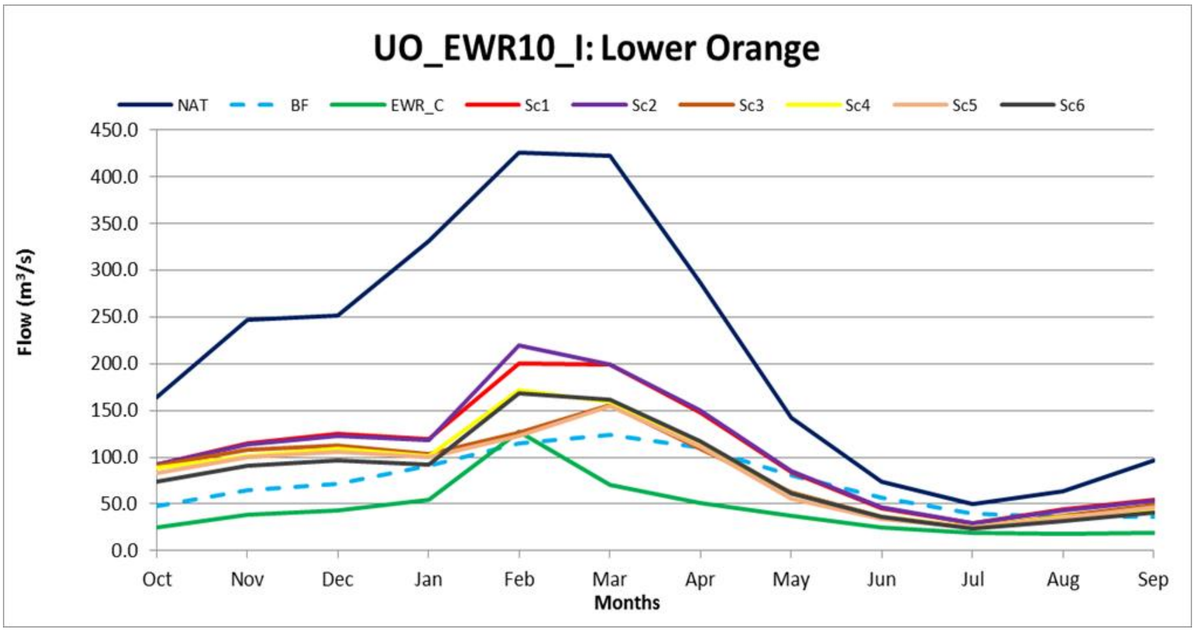


Figure 5-10: Seasonal distribution of scenarios at site UO_EWR10_I: Lower Orange

All the scenarios show reductions in floods and constant baseflows. These are due to the upstream dams reducing floods and releases for irrigation and hydropower (mainly Vanderkloof Dam).

Table 5-65: Percentiles and flow (m^3/s) for July per scenario at Lower Orange (UO_EWR10_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	244.502	150.002	151.000	74.189	64.315	104.800	103.084	26.564
1	233.663	112.874	122.922	62.295	60.561	82.358	65.390	26.564
5	158.037	67.521	67.925	41.059	41.843	50.557	41.821	26.551
10	106.070	47.869	37.758	24.633	26.477	40.163	27.165	26.445
15	94.334	28.440	26.477	24.104	26.476	25.328	26.477	26.297
20	74.864	23.497	26.202	24.014	26.083	24.653	26.282	25.961
30	54.387	23.223	25.267	23.953	25.267	24.482	25.267	25.184
40	36.422	23.183	23.699	23.917	24.124	23.641	23.129	23.170
50	31.620	23.148	23.220	23.808	23.970	21.360	20.728	20.846
60	25.901	23.066	23.174	23.728	23.920	18.518	18.563	16.819
70	20.000	23.002	23.090	23.543	23.749	18.435	18.435	13.861
80	16.467	22.906	22.975	22.165	22.318	18.307	18.132	11.001
85	15.655	22.708	22.878	20.195	20.910	18.165	17.278	10.094
90	13.964	22.245	22.616	18.204	17.429	17.752	15.240	9.556
95	10.991	19.439	21.750	15.762	15.815	16.646	12.901	9.192
99	9.292	17.432	16.508	13.472	10.901	15.926	10.848	8.618
99.9	6.833	17.387	15.178	7.327	10.866	15.857	10.783	6.766

Table 5-66: Percentiles and flow (m^3/s) for February per scenario at Lower Orange (UO_EWR10_I)

Percentiles	Natural	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	EWR_C
0.1	2416.943	2048.669	2019.417	1052.289	987.111	985.159	985.148	220.010
1	2120.283	1469.157	1143.966	1001.171	958.063	955.046	955.043	220.010
5	1176.916	911.961	899.001	570.717	582.422	653.484	579.828	219.989
10	968.540	545.840	444.604	151.402	218.934	177.771	220.951	218.890
15	804.090	298.980	275.903	99.259	204.314	89.309	210.442	202.356
20	699.349	185.083	203.805	75.685	194.469	77.355	196.796	191.840
30	456.034	74.797	183.748	75.606	172.656	76.780	175.534	174.073
40	334.750	74.707	156.501	75.461	154.117	75.546	154.302	154.625
50	252.692	74.592	120.865	75.322	120.865	73.478	120.865	122.681
60	214.709	74.488	105.146	74.940	102.304	59.162	105.146	104.365
70	170.634	74.359	86.772	74.188	84.033	57.783	86.772	86.475
80	133.920	73.864	74.797	70.565	75.624	57.675	67.778	60.909
85	107.124	73.437	74.736	65.626	75.528	57.457	58.842	49.030
90	81.401	72.909	74.687	54.019	75.055	55.185	57.929	41.397
95	65.265	68.131	74.533	42.019	61.028	48.313	57.770	34.849
99	30.945	57.297	71.948	37.618	40.122	42.041	50.817	29.835
99.9	23.998	53.856	61.367	36.100	31.886	41.293	38.818	23.887

The above tables indicates that the EWR could be met most of the time for all the scenarios in July. However, the EWR could not be met in February for all the scenarios, with those scenarios ‘without EWR’ the worst (Sc1, Sc3 and Sc5).

The scenarios highlighted in grey in **Table 5-67** were subsequently chosen by experts for their respective components and assessed. The outcomes of these selected scenarios were then interpreted by comparing them to the REC identified for the EWR site. This information is provided in **Table 5-68** to **Table 5-70**. For more details on the color-coding categories used for scenario comparison with the REC, please refer to Chapter 5.1.6. The REC is color coded according to the DWS EC continuum.

Table 5-67: Evaluated scenarios per component

Component	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
Quality							
Geomorphology							
Riparian Vegetation							
Instream Biota							
Socio-economics							

Table 5-68: Physical-chemical ecological consequences of the scenarios

Physical-chemical			
PES		**Sc2**	**Sc7 (anticipated further deterioration in water quality)**
D		In accordance with **Figure 5-10**, one could expect that during the May to August period, when Sc2 flows dip below the modelled baseflows (primarily due to limited releases for irrigation demands), then the worsening water quality, particularly associated with increasing salinity and conductivity as the dilution effect decreases, will have a severe impact on the biota, especially algae in the system.	During this scenario, one could see a similar picture as per Sc2, although worsening during the dry season and low baseflows and high irrigation demand but also return flows making the salinity conditions worse and with less dilution potential.

Table 5-69: Geomorphological and riparian vegetation ecological consequences of the scenarios

Geomorphology							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C/D		**C**	**C**	**C/D**	**C/D**	**C/D**	**C/D**

The Marksdrift Site is largely impacted by the Vanderkloof and Gariep dams which trap most of the suspended sediment and all of the bedload from the upper and middle catchments. This has led to an armoured channel with reductions in gravel and sand habitat. The damming has also led to large reductions in the freshet and flood flows, leading to channel siltation (from lateral sediment input) increasing embeddedness. No changes are expected for any of the scenarios for sand availability in terms of sand mining.
The scenarios are unlikely to alter the sediment regime as the proposed dams are upstream of the Vanderkloof Dam. The main changes are in terms of the hydrology as follows:

- Sc2: Small improvement in freshets and floods. This will result in small reductions in siltation and embeddedness and improve lateral connectivity with flood features. The GAI score improved from initially 64 (C) to 65 (C).
- Sc3 and 5: Large reductions in freshets and floods. This will result in large increases in siltation and embeddedness. The GAI score was lowered from initially 64 (C) to 60 (C/D).
- Sc4 and 6: Moderate to large reductions in freshets and floods. This will result in moderate to large increases in siltation and embeddedness. The GAI score was lowered from initially 64 (C) to 62 (C/D).

Riparian Vegetation							
PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**
C		**C**	**C/D**	**D**	**D**	**D**	**D**

The flows and geomorphological processes are already impacted by Vanderkloof and Gariep Dams, thus the riparian vegetation has been structured according to less frequent floods of smaller magnitudes and reduced bedloads (gravel and sands) and increased embeddedness due to increased channel siltation (as described above).

- For Sc2 low flows will be similar to present-day flows (i.e. Sc1), while baseflows are expected to increase in late summer, and freshets and floods will decrease slightly. As a result, the riparian zone is expected to experience an increase in reed cover along the lower banks and margins together with increased establishment of woody vegetation (especially on the lower banks) with increased risk of alien vegetation establishing. The modelled VEGRAI score is estimated to decrease from 67.7 (C category) to 57.9 (C/D category).
- For Sc3 and Sc5, the EWR site will experience an overall reduction in flows, particularly low flows, freshets and floods. This will lead to the riparian zones becoming more confined within the channel with encroachment of terrestrial vegetation into the riparian zones, and increased infestation by alien vegetation. Reeds will dominate the margins and lower banks. The modelled VEGRAI score is estimated to decrease further 57.9 (C/D category) to 51.8 (D category).
- Sc4 and Sc6 will experience similar flow changes to Sc3 and Sc5, with the exception of increased baseflows in late summer/early winter. Riparian vegetation, however, is expected to remain the same as for Sc3 and Sc5. The modelled VEGRAI score is expected to improve slightly by unlikely to change by half a category.

Table 5-70: Biotic consequences of the scenarios

Fish and Macroinvertebrates									
	PES		**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**
Fish Dry	B/C		A	A	A	A	A	A	C
Inverts Dry	D		A	A	A	A	A	A/B	D
Fish Wet	B/C		B	A	B	A/B	B	A	C
Inverts Wet	D		A	A	A	A	A/B	A	D

Macroinvertebrates

The Lower Orange River is a wide homogenous river characterised by limited habitat diversity (mostly dominated by the gravel, sand and mud biotope) and limited marginal vegetation owing to sediment deposits. Owing to the site located downstream of both the Vanderkloof and Gariep dams, this site is affected by varying flow regimes daily. The indicator macroinvertebrate selected for this area that was run in the FIFHA model was Leptophlebiidae. Leptophlebiidae, is a flow-dependent taxon, which show the greatest response for moderately-fast flowing water between 0.3 – 0.6m/s, over cobbles, but can tolerate >0.6m/s and in the habitats of gravel, sand, mud. Should flows fall below this target, this taxon will be absent from the macroinvertebrate community. They further have moderate requirement for unmodified physico-chemical conditions. The FIFHA analysis was conducted for the months of February and July, representing the wet and dry seasons, respectively, starting from the 40th percentile. As a result, the changes and/or reductions in flow in the scenarios will not have an impact on the macroinvertebrate responses, as their categories remain in line with their current PES. However, it is important to be aware of the limitations of FIFHA, which does not account for changes in flow patterns, and the fact that the chosen indicator taxon prefers finer substrates. Therefore, the interpretation of these results was approached with caution. Thus, in scenarios Sc3 to Sc6, where these conditions may lead to significant increases in siltation, it would offer more suitable habitat for these taxa. However, other flow dependent taxa that favour high-flows over courser environments (i.e. cobbles) may experience a reduction in their population due to increased sedimentation caused by the flow changes in these scenarios and embeddedness in these habitats which are available along this river reach. This will ultimately influcence the PES of the macroinvertebrate community in that it will be unable to maintain the C category in the long term.

In the future, it is anticipated that the macroinvertebrates will exhibit responses similar to Sc 2. However, this change in their reactions may occur during the dry season and low baseflows, coinciding with high irrigation demand and increased return flows. These factors are likely to worsen salinity conditions and reduce dilution potential, creating favourable conditions for highly tolerant macroinvertebrates that prefer low to very low water quality.

Fish

The reach of the Orange River is expected to support very limited cover features from a fish perspective, comprising primarily a sandy/small gravel substrate with laminar flows across the channel for much of the hydrological year. Some critical habitat for spawning, egg development and larvae is expected to a marginal degree, but the reach is expected to rather act as a conduit for upstream movement. Due to the lack of true rheophilic species, large semi-rheophilic *Labeobarbus aeneus and L. kimberleyensis* were selected to function as flow-dependent indicators. Primary focus in this respect was given the faster flowing velocity-depth classes, notably fast-intermediate and fast-deep classes, although some consideration was given to possible slow-deep class to sustain adult of juvenile fish species.

Application of the FIFHA model for the various consequences investigated suggest that Sc1, Sc2, Sc3, Sc4, Sc5 and Sc6 are all unlikely to result in any significant changes to the ecological state of the associated reach of the Orange River from a flow-depth perspective given that the indicator species do have a wide diversity of habitat preferences and are able to survive within lentic water bodies. Nevertheless, loss of seasonal high-flow events and/or unseasonal releases following the development of various dams proposed under Sc3 to Sc6 is likely to impact the migratory cues for the indicator fish species, and result in a loss of upstream connectivity and habitat fragmentation.

However, a decline in the ecological state of the fish assemblage within the reach is expected with respect to Sc7, with the presence and/or abundance of fish likely to be greatly impacted as a result of increased stress loads. Under such instances of increased stress load, a compromised immune response is often present, making the fish susceptible to opportunistic infections. Infection with oomycetes, particularly of the genus *Saprolegnia*, typically becomes apparent in such fish, and may appear as cotton-wool-like growths on the fins and skin of the fish. In addition, reduction in water quality, and particularly from failing sewage infrastructure, is likely to increase the periodicity and magnitude of fish kill events, particularly below where impoundments are expected.

SUMMARY AND CONCLUSION

Below provides a summary of the quantity, the physical (geomorphology and riparian vegetation)/biological (fish and macroinvertebrates) consequences in comparison to their PES per component and overall meeting the REC per scenario (see **Table 5-71**). Should one or more of the components not meet their PES by a whole category or more, ultimately, that scenario will not meet the requirements of the overall REC for the EWR site. Furthermore, a summary of the consequences from a water quality perspective (Sc7) is provided, and the concluding remarks of the socio-economic consequences.

Biophysical Summary

Table 5-71: UO_EWR10__I: Lower Orange: Ecological consequences

Component	PES	REC		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Geomorphology	C/D	C		C	C	C/D	C/D	C/D	C/D
Riparian Vegetation	C			C	C/D	D	D	D	D
Fish**	B/C			B	A	B	A/B	B	A
Macroinvertebrates**	D			A	A	A	A	A	A
EcoStatus	C								
Meeting Overall REC				√	√	√	√	√	√

**Please refer to Chapter 5.1.6 to denote the category colour coding with accordance to the REC.*
***The PES for the fish and macroinvertebrates (B/C and D respectively), was primarily driven by limited habitat availability and water quality. Thus, the PES of A and A/B from the FIFHA, must be interpreted with caution, as the FIFHA does not take into account water quality and habitat availability, only critical habitat.*

Overall, the ranking of the scenarios indicate that all the selected scenarios achieve the REC requirements for this site. This is likely owing to the site being far downstream from the proposed future developments along the main Orange River. Although the current varying flow regimes and armoured bed, may become exasperated with the additional two dams proposed for Sc3 and Sc4 and Sc5 and Sc6 in the far upper reaches of the Orange River.

Scenario 7 summary

The site is expected to continue to adapt to the temperature and sediment changes along this reach associated with the hydropeaking, with ongoing responses to the continued run-off from adjacent agricultural activities. High salinities are prevalent in the system as a result of agricultural irrigation return flows. Prior to flooding the site had stabilised with these ongoing pressures. Similar to the macroinvertebrates, the site is expected to stabilise at pre-flood conditions.

Thus, one could expect a similar picture for Sc7, as per Sc2, although worsening during the dry season and low baseflows and high irrigation demand but also return flows making the salinity conditions worse and with less dilution potential.

Socio-economic summary

The present socio-economic state indicates a moderate-high relative vulnerability, relatively little small-scale/ subsistence agriculture, but a high to very high proportion of crop cultivation is irrigated. Local GDP is moderate relative to the rest of the catchment, but with a relatively higher value add contribution from agriculture, along with higher relative employment in the formal sector. Recreation related to the Orange River is a feature of the area.

The ecological/biophysical analysis and consequences indicated above indicate there are reductions in floods and constant baseflows across the scenarios, with the EWR not being met in all seasons; this is amplified for those scenarios 'without EWR' (Sc1, Sc3 and Sc5). This suggests a potential risk to the ability of the system to meet socio-economic water-use. This is particularly concerning given the moderate to high relative vulnerability levels and further exacerbated by the water quality situation described above and reduced dilution potential in Sc7. The high salinity levels are also of concern, given the high proportion of irrigated crop production and the risk to crop production of high salinity.

6. WATER QUALITY IN THE UPPER ORANGE CATCHMENT: THE ULTIMATE DRIVER OF CATCHMENT CONDITIONS

It is evident that deteriorated water quality was the driving factor affecting the ecological condition at the sites on most of the streams and rivers in the Upper Orange catchment area. The source of this problem is primarily related to nutrient overload, originating from the various WWTWs and agricultural runoff associated with the towns and cultivation in the catchment. Most WWTW in the catchment are either unmaintained, dysfunctional, or run over-capacity; a problem across most of South Africa (**Table 6-1** and **Table 6-2**).

Only 35 of the 73 WWTWs in the Upper Orange River catchment had data on the volume of wastewater treated per day. The total volume of wastewater according to these 35 was ~194 million L/day. Assuming the volume from the remaining 38 WWTW has a roughly similar value, one can broadly assume that the WWTW in the catchment are discharging ~390 million L/day into rivers in the catchment. As noted for several WWTW in the discussions per site above, this value does not account for the large volumes of wastewater not reaching WWTW where the volume they are processing has decreased between 2013 and 2021, or where they operate well-below capacity[2]. The volume of wastewater (including a huge portion that is only partially, or wholly untreated) entering the rivers can therefore be safely assumed to exceed ~400 million L/day in the Upper Orange River catchment. Considering the amount of missing data for discharge, it is problematic to calculate exactly how the sewage releases contribute to the baseflows at a given site. However, considering the wastewater discharge is equivalent to at least 160 Olympic sized swimming pools per day entering rivers in the catchment, one can be sure that there is a significant contribution of wastewater to baseflows. For reference, 400 million L/day is equivalent to a discharge rate of 4.63 cubic meters per second (m^3/s), a discharge rate approximately four times (~4x) higher than the modelled natural low flows in July for the Lower Riet site (EWR_09_I). This shows how much potential WWTW discharge in the catchment has for contributing to the baseflows in the dry months (Table 6-1 and Table 6-2).

There were comparable data on WWTW discharge rates between 2013 and 2021 for 27 of the WWTW in the catchment. Of these, eight reported decreases in the volume of wastewater treated daily, totalling 5.44 million litres per day less than in 2013. As mentioned above, this is despite the fact that population, urbanisation, and water access trends are consistently upward in South Africa, suggesting that the amount of water being treated should steadily increase over time. Therefore, it is likely that this wastewater, and considerably more, is still being generated but not reaching the WWTW. Consequently, it can be assumed that it is discharging, untreated and unaccounted for, into freshwater systems throughout the catchment, thus compromising water quality throughout.

[2] https://www.dailymaverick.co.za/article/2023-08-10-millions-of-litres-of-poo-a-day-never-even-reach-sas-failing-underserviced-sewage-plants/

The GD scores in 2021 also illustrate the dire wastewater situation in the catchment, and by association the serious water quality issues within the catchment. A total of 26 WWTW, out of the 73, were critically failing and dysfunctional (GD score <31 %), with another 12 very close (GD score < 36 %). The lack of data on discharge (or any data at all in some instances) is also concerning (38 WWTW (52 %) did not have data on the daily volume treated in 2021), since discharge rates from WWTW are a critical component of their performance and impact on the receiving system (Table 6-1 and Table 6-2).

In support of the above, please refer to **Appendix C** for a case study and a letter notification to DWS. This communication pertains to a non-operational WWTW and its connected infrastructure, which, in the past and potentially still today, has been discharging significant volumes of untreated sewage into the natural environment. This discharge has caused, and continues to cause, a considerable decline in the water quality of the receiving system. This degradation directly impacts the Caledon River, a vital tributary of the Orange River, which serves as a critical water source for agricultural, industrial, and domestic use, both for commercial and subsistence purposes. It is essential to recognise that this issue is systemic, extending throughout the Upper Orange catchment area, as elaborated above.

Overall, the river ecosystem is in danger of failing with a loss of biodiversity and ecosystem services, i.e. thus potentially moving into an E or E/F ecological category. It is the mandate and responsibility of DWS to ensure enforcement and accountability within the municipalities that are responsible for these WWTWs (National Water Act, 1998). DWS investigations into this issue are essential to improve and regulate the water quality issues this catchment faces. Management of the water quality status must be regarded as an urgent issue. The current conditions are disastrous for the environment, human needs, the functionality of ecosystem services, and from a health perspective. If not addressed effectively, the current conditions will continue and worsen, resulting in the non-attainment of the REC for the EWR sites.

Table 6-1: Table showing the designed capacity use, daily volume of wastewater (million litres per day; ML/day) treated, and Green Drop (GD) score for the wastewater treatment works (WWTW) within the Upper Orange River catchment. The data for 2013 and 2021 GD reports are summarised, with the change from 2013 to 2021 calculated for each parameter. The GD scores <31% (considered by the Department of Water and Sanitation (DWS) to be dysfunctional and in need of critical intervention (DWS, 2022)) are highlighted in red, the WWTW which have shown a decrease in the daily volume of wastewater they treat are highlighted in purple, and the WWTW which have shown a decrease in their GD score from 2013 to 2021 are highlighted in orange. The EWR Intermediate sites that are in the downstream catchment and likely affected by the WWTW discharge are indicated.

Area and WWTW Details			GD 2013			GD 2021			Change 2013 - 2021			Intermediate EWR Sites
Province	**Local Municipality**	**WWTW Name**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Sites Affected**
Eastern Cape	**Chris Hani**	**Dordrecht**	100.0	1.20	48.7	100.0	2.80	100.0	0.0	1.60	51.3	EWR_08_I, EWR_10_I
		Molteno	100.0	3.46	24.0	50.0	1.35	51.0	-50.0	-2.11	27.0	EWR_10_I
	Joe Gqabi	**Sterkspruit**	110.0	1.10	37.0			39.0			2.0	EWR_02_I, EWR_03_I, EWR_10_I
		Lady Grey Oxidation Ponds	No data									EWR_03_I, EWR_10_I
		Herschel	1.1	0.01	44.0			36.0			-8.0	EWR_03_I, EWR_10_I
		Jamestown	20.0	0.16	49.0	83.0	1.00	68.0	63.0	0.84	19.0	EWR_08_I, EWR_10_I
		Barkly East (old)	67.0	0.40	59.0	44.0	0.32	57.0	-23.0	-0.08	-2.0	EWR_08_I, EWR_10_I
		Barkly East (new)	62.0	0.81	63.0	200.0	1.20	48.0	138.0	0.39	-15.0	EWR_08_I, EWR_10_I
		Burgersdorp Activated Sludge	77.0	1.93	54.0	224.0	5.60	35.0	147.0	3.68	-19.0	EWR_10_I

Area and WWTW Details			GD 2013			GD 2021			Change 2013 - 2021			Intermediate EWR Sites
Province	**Local Municipality**	**WWTW Name**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Sites Affected**
		Venterstad			47.0	45.0	0.45	44.0	45.0		-3.0	EWR_10_I
		Oviston			42.0	100.0	0.20	37.0			-5.0	EWR_10_I
		Aliwal North	73.0	4.02	47.0	138.0	7.59	40.0	65.0	3.58	-7.0	EWR_10_I
Free State	**Dihlabeng**	**Caledonspoort Port of Entry**	No data									EWR_01_I, EWR_04_I, EWR_10_I
		Mashaeng	89.0	1.02	28.0	45.0	0.50	41.0	-44.0	-0.53	13.0	EWR_01_I, EWR_04_I, EWR_10_I
		Clarens	60.0	1.50	49.0	56.0	1.40	52.0	-4.0	-0.10	3.0	EWR_01_I, EWR_04_I, EWR_10_I
		Mautse	36.0	0.18	27.0	17.0	0.34	33.0	-19.0	0.16	6.0	EWR_01_I, EWR_04_I, EWR_10_I
	Kopanong	**Edenburg**			14.0			41.0			27.0	EWR_06_I, EWR_09_I
		Reddersberg			12.0			16.0			4.0	EWR_06_I, EWR_09_I
		Trompsburg	151.0	1.10	13.0			46.0			33.0	EWR_09_I
		Jagersfontein			12.7			14.0			1.30	EWR_09_I
		Fauresmith			34.0			16.0			-18.0	EWR_09_I
		Gariep Dam			34.0			12.0			-22.0	EWR_10_I
		Bethulie			13.0			44.0			31.0	EWR_10_I
		Philippolis			34.0			52.0			18.0	EWR_10_I
		Springfontein			12.0			49.0			37.0	EWR_10_I

Area and WWTW Details			GD 2013			GD 2021			Change 2013 - 2021			Intermediate EWR Sites
Province	**Local Municipality**	**WWTW Name**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Sites Affected**
	Letsemeng	**Koffiefontein**			12.0			29.0			17.0	EWR_09_I
		Oppermans			22.0			26.0			4.0	EWR_09_I
		Jacobsdal			25.0			33.0			8.0	EWR_09_I
		Petrusburg			7.0			61.0			54.0	EWR_09_I
		Luckhoff			26.0			46.0		0.00	20.0	EWR_10_I
	Mangaung	**Vanstadensrus**			8.0	33.0	0.01	17.0			9.0	EWR_04_I, EWR_10_I
		Van Rooyenshek Port of Entry	No data									EWR_04_I, EWR_10_I
		Wepener			0.0	1.0	0.02	21.0			21.0	EWR_04_I, EWR_10_I
		Dewetsdorp			14.0	38.0	0.02	24.0			10.0	EWR_07_I, EWR_09_I
		Botshabelo	50.0	10.00	81.0	110.0	22.00	36.0	60.0	12.00	-45.0	EWR_07_I, EWR_09_I
		Thaba Nchu	75.0	4.50	81.0	70.0	3.50	41.0	-5.0	-1.00	-40.0	EWR_07_I, EWR_09_I
		Welvaart	75.0	4.50	79.0	80.0	4.00	32.0	5.0	-0.50	-47.0	EWR_09_I
		Sterkwater	164.0	18.04	83.0	128.0	25.60	33.0	-36.0	7.56	-50.0	EWR_09_I
		Bloemspruit	116.0	64.96	76.0	120.0	67.20	32.0	4.0	2.24	-44.0	EWR_09_I
		Bloemdustria	33.0	0.30	87.0	56.0	0.50	30.0	23.0	0.21	-57.0	EWR_09_I
		Bainsvlei	70.0	3.5	82.0	76.0	3.80	35.0	6.0	0.3	-47.0	EWR_09_I
		North Eastern Works			0.0	90.0	18.00	32.0	90.0	18.00	32.0	EWR_09_I

Area and WWTW Details			GD 2013			GD 2021			Change 2013 - 2021			Intermediate EWR Sites
Province	**Local Municipality**	**WWTW Name**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Sites Affected**
		Northern Mangaung	33.0	1.98	81.0	38.0	1.90	30.0	5.0	-0.08	-51.0	EWR_09_I
		Soutpan			30.0			0.0			-30.0	EWR_09_I
	Mantsopa	**Hobhouse**			51.0	80.0	0.40	31.0			-20.0	EWR_04_I, EWR_10_I
		Thaba Patchoa			20.0	100.0	1.50	33.0			13.0	EWR_04_I, EWR_10_I
		Maseru Bridge Port of Entry	No data									EWR_04_I, EWR_10_I
		Ladybrand	98.0	4.90	31.0	29.0	5.08	29.0	-69.0	0.18	-2.0	EWR_04_I, EWR_10_I
		Tweespruit			20.0	100.0	0.50	22.0		0.50	2.0	EWR_04_I, EWR_10_I
		Thaba Phatswa										EWR_04_I, EWR_10_I
	Masilonyana	**Soutpan**			30.0			0.0			-30.0	EWR_09_I
		Brandfort	No data									EWR_09_I
		Acornhoek SAPS	No data									EWR_09_I
		Naboomspruit Military Base	No data									EWR_09_I
	Mohokare	**Zastron**			39.0	252.0	2.52	15.0			-24.0	EWR_03_I, EWR_10_I
		Rouxville			25.0	156.0	2.34	24.0			-1.0	EWR_04_I, EWR_10_I
		Smithfield			26.0	73.0	0.73	30.0			4.0	EWR_04_I, EWR_10_I
		Goedemoed Correctional Center	No data									EWR_10_I
	Setsoto	**Ficksburg**	122.0	14.88	12.2			5.0			-7.2	EWR_01_I, EWR_04_I,

Area and WWTW Details			GD 2013			GD 2021			Change 2013 - 2021			Intermediate EWR Sites
Province	**Local Municipality**	**WWTW Name**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Capacity Use (%)**	**Volume Treated (ML/day)**	**GD Score (%)**	**Sites Affected**
												EWR_10_I
		Clocolan	122.0	5.12	24.0			2.0			-22.0	EWR_04_I, EWR_10_I
	Tokologo	**Dealesville**	23.0	0.46	25.0			46.0			21.0	EWR_09_I
Northern Cape	**Emthanjeni**	**Hanover**	16.0	0.27	74.0			18.0			-56.0	EWR_05_I, EWR_10_I
	Renosterberg	**Philipstown**	73.0	0.23	1.0	233.0	0.70	0.0	160.0	0.47	-1.0	EWR_10_I
		Petrusville	66.2	0.44	1.0	157.0	1.10	0.0	90.8	0.66	-1.0	EWR_10_I
		Vanderkloof	131.0	0.24	1.0	150.0	0.30	0.0	19.0	0.06	-1.0	EWR_10_I
	Sol Plaatjie	**Ritchie**	200.0	1.00	55.0			36.0			-19.0	EWR_09_I
		Beaconsfield	130.0	10.40	53.0	104.0	9.36	32.0	-26.0	-1.04	-21.0	EWR_09_I
	Thembelihle	**Hopetown (New)**			62.0			43.0		0.00	-19.0	EWR_10_I
		Hopetown	100.0	0.80	54.0			0.0	-100.0		-54.0	EWR_10_I
	Umsobomvu	**Noupoort**			4.0			18.0			14.0	EWR_05_I, EWR_10_I
		Colesberg	No data									EWR_10_I
		Norvalspont	29.0	0.04	35.0			17.0			-18.0	EWR_10_I

Table 6-2: Table showing the wastewater chemical, microbiological, physical, and monitoring compliance status (as of October 2023) of the local municipalities in the Upper Orange River Catchment for which there are data in the National Integrated Water Information System (NIWIS; https://www.dws.gov.za/niwis2/wwq2) database. Compliance <50% is highlighted in red. The The EWR Intermediate sites that are likely affected by the wastewater treatment compliance of the municipalities are indicated.

Area details		Compliance Component				Intermediate EWR Sites
Province	**Local Municipality**	**Chemical (%)**	**Microbiological (%)**	**Physical (%)**	**Monitoring (%)**	**EWR Sites Affected**
Eastern Cape	**Chris Hani**	65	56	68	45	EWR_08_I, EWR_10_I
	Joe Gqabi	0	0	0	0	EWR_02_I, EWR_03_I, EWR_08_I, EWR_10_I
Free State	**Dihlabeng**	0	0	0	0	EWR_01_I, EWR_04_I, EWR_10_I
	Kopanong	0	0	0	0	EWR_06_I, EWR_09_I, EWR_10_I
	Letsemeng	0	4	58	33	EWR_09_I, EWR_10_I
	Mangaung	63	100	89	78	EWR_04_I, EWR_07_I, EWR_09_I, EWR_10_I
	Mantsopa	59	74	68	100	EWR_04_I, EWR_10_I
	Masilonyana	54	73	86	59	EWR_09_I
	Mohokare	98	99	86	87	EWR_03_I, EWR_04_I, EWR_10_I
	Setsoto	58	33	80	52	EWR_01_I, EWR_04_I, EWR_10_I
	Tokologo	0	0	0	0	EWR_09_I
Northern Cape	**Emthanjeni**	0	0	0	0	EWR_05_I, EWR_10_I
	Renosterberg	0	0	0	0	EWR_10_I
	Sol Plaatjie	31	0	77	69	EWR_09_I
	Thembelihle	33	0	76	41	EWR_10_I
	Umsobomvu	0	42	0	100	EWR_05_I, EWR_10_I

7. CONCEPTUAL FLOW MANAGEMENT PLAN (DOWNSTREAM GARIEP AND VANDERKLOOF DAMS)

7.1 Background and objective

The EWR Quantification Report (No. RDM/WMA13/00/CON/COMP/1323) included an investigation aimed at formulating a conceptual Flow Management Plan (FMP) for the river reaches downstream of Gariep and Vanderkloof Dams due to the impacts of releases for downstream water users and hydropower generation. This report also outlined proposed action plans that encompass immediate measures, short-term strategies (spanning 0 to 5 years), which will be integrated into the Classification and determination of RQO phase, now in its initial stages. Furthermore, the report discusses medium-term plans (covering 5 to 20 years) and long-term strategies (extending beyond 20 years).

The primary objective of this conceptual FMP presented in this report is to evaluate the immediate action plan and gain insights into the significant ecological effects stemming from hydropeaking activities and other releases occurring in the sacrificial zones, between the dams and immediately downstream of the Vanderkloof Dam. This assessment will also consider alterations in flood frequencies. The aim is to offer guidance to the DWS regarding the optimal conditions needed to achieve a more favourable ecological state within the system. This guidance will encompass the appropriate baseflow types and the structure of releases required to enhance the ecological well-being of the ecosystem.

7.2 Data from JBS2 and JBS3

Macroinvertebrate, diatom, and water quality data from JBS2 (ORASECOM, 2015) and JBS3 (ORASECOM, 2022) are available for site code OSEAH_26_15 (site 38 in JBS3). This site was between the Gariep and Vanderkloof Dams, providing an ideal site to estimate the PES downstream of the dams, and the potential effects of flow management changes in the operation of either dam.

7.2.1 Site description:

The Gariep Dam is ~30 km upstream from the site (30.503784 °S, 25.240033 °E) and releases water regularly. Along the reach of river at the site, the river is ~200m wide in some areas and ~50 m wide at the narrowest point. The site is defined by an igneous intrusion that creates a resistant bed layer, slowing and narrowing the river, and creating riffle and rapid habitats with stronger flows, and several braided channels. The area upstream of the rocky intrusion had formed a 200 m wide pool with slower flowing water. The surrounding land was used for agricultural purposes, mostly centre pivot irrigation and grazing land for cattle and sheep. The site had little alluvial sands and sediment deposits, most likely due to the Gariep Dam catching all sediment. The Gariep Dam releases water intermittently for hydro-power generation, increasing flows and creating temporary pools on the bedrock shelves.

7.2.2 Water quality

Water clarity was low to moderate (**Table 7-1**). Microbiological contamination indicates low, with *Escherichia coli* (*E. coli*) levels of between 0.1-1 colony forming units per ml (cfu/ml). The diatoms were observed to be in a C or moderate ecological category at this site. *Nitzschia fonticola* (35%), an indicator of high conductivity and fine sediments, was the most dominant species at the site followed by *Cyclostephanos invisitatus* (23%) an indicator of eutrophic conditions, with a preference for high phosphorus. *Navicula cryptotenelloides* (79%) dominated the JBS2 sample and indicated mesotrophic to eutrophic calcareous conditions. While the diatom community structure changed from JBS2 to JBS3, the indicative species still suggest nutrient issues at the site. This was supported by the %PTV = 35.5 % in JBS3, which indicated some evidence of organic pollution. The lack of deformed cells in JBS2 and JBS3 suggest that the elevated metal concentrations found at the site are likely related to runoff following heavy rains and are not consistent issues in the system (**Table 7-1**).

Table 7-1: *In situ* water quality measurements and diatom sampling results

Water Quality	*In situ water quality parameters*									
***In situ* water quality**		pH	EC[1] (µS/cm)	TDS[2] (g/l)	DO[3] (mg/l)	DO (%)	Clarity (cm)	Temp. (°C)	Salinity (dS/m)	Discharge (m^3/s)
	JBS2 (July 2015)	8.49	12.3	132	-	111.3	-	11.43	-	-
	JBS3 (October 2021)	9.01	13.8	109	-	117.4	44	17.84	-	-
Diatoms*	**Outcomes of diatom survey**									
		no. of species	SPI**	Categorisation (quality)		%PTV***	Deformed cells			
	JBS2 (July 2015)	18	12.7	C (Moderate)		6.8	0			
	JBS3 (October 2021)	18	12.9	C (Moderate)		35.5	0			

[1]EC – Electrical Conductivity | [2]Total Dissolved Solids | [3]Dissolved Oxygen

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*

***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 13-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*

****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from (Kelly, 1998)).*

7.2.3 Macroinvertebrates

The macroinvertebrate PES in JBS2 = C/D (moderately to largely modified), and = C in JBS3 (moderately modified). The SASS5 scores were 95 and 82 for JBS 2 and JBS3, respectively, with 17 taxa found each during both surveys. The ASPT = 5.59 and ASPT = 4.82 in JBS2 and JBS3, respectively. The macroinvertebrate PES at the site suggested the river was in a moderately modified condition. The MIRAI was calculated at 63.2% in JBS3. Flow and hydrological regime alterations due to releases from Gariep Dam were determined as the main impacts in JBS2 and JBS3; emphasis was put on the fact that releases are unseasonal. The majority of the taxa present had preferences for cobbles and GSM, with low to very low requirements for unmodified water quality. Taxa with a preference for standing or slow flowing water were the most impacted.

7.3 Summary of Proposed Action Plans

7.3.1 Immediate

- Identify any immediate sensitivities / critically time sensitive intervention;
- Define short, medium, and long-term goals for flow management going forward to structure activities and actions efficiently; and
- Establish a longitudinal profile of the focal river section.

7.3.2 Short-term

- A desktop synthesis of previous assessments;
- A analyses to assess the social and economic advantages and disadvantages of the current flow regime;
- Use the information from the assessments to design a monitoring network (physical, chemical, and biological aspects, as well as hydraulic and hydrological assessment of the river for the determination of EWRs);
- Working with Eskom, DWS Planning and Regional officials, define the plans for the necessary power generation regime via hydroelectric power generation; and
- **Implement one or both of the proposed flow management changes to improve PES (see Section 7.4)**.

7.3.3 Medium-term

- Continue monitoring
- Generate best practice flow management protocols below large dams;
- Develop hydrological models to simulate environmental outcomes;
- Establish an ideal interim flow management plan;
- Re-evaluate the ecological potential of ‘sacrificial zones’;
- Establish long-term management and monitoring plan; and
- Set attainable desired conditions for the reach, for different flow release scenarios.

7.3.4 Long-term

- Implement the ideal scenario recommended flow management plan;
- Continue monitoring for adaptive management; and
- Retroactively reassess the accuracy of the initial cost-versus-benefit analysis for the interim EWR strategy.

7.4 Proposed flow management changes to improve PES

We acknowledge that the hydro-electric power generation at both the Gariep and Vanderkloof dams will be required for the near future, given the ongoing, severe pressure on power generation in Southern Africa. There may also be limitations to potential flow management changes according to irrigation demand throughout the catchment causing a mismatch between ideal environmental flows and agricultural demand (Ramulifho *et al.,* 2019). However, we foresee two possible changes to the flow management at the dams which may have benefits for the ecosystem health and function of the river reaches below each dam:

Reduced releases during the winter (June, July, and August) months to achieve minimum flows related solely to the necessary hydro-electric power generation.

It is now established that all parts of a river's natural flow regime, including perennial flows, floods, and periods of no or low flow, are important for functionality and river health (Acreman & Dunbar, 2004). Currently, the flows below both the dams do not reach the natural low-to-zero dry season flows that would naturally occur along both reaches of river. Establishing a natural low or no-flow regime in rivers during the natural dry season can be crucial for maintaining the ecological health of the river and its surrounding ecosystem (Steward *et al.,* 2012). As stated by McMahon and Finlayson (2003) "In regulated rivers, the real problem may be 'anti-droughts'– the removal of significant natural low-flow events from the flow pattern."

Reduced or zero flow can significantly alter the physical-chemical properties of water, changing temperature, oxygen levels, and the nutrient profile, among other things. Critically, low or zero flows allow sediment to precipitate out the water column. This increases water clarity and can create or alter critical habitat as suspended solids, often rich in organic matter, settles into newly formed sand banks or within gravel and rocky microhabitats. Low or zero flows also reduce the level of the river, usually exposing river substrates and forming new pool and riffle habitats that can be essential for the breeding or survival of various species (Humphries & Baldwin, 2003; Stromberg *et al.,* 2007). In contrast, low or zero flows can also be vital for establishing natural community dynamics by limiting the survival or proliferation of species not adapted to the natural cycle of high and low or zero flows. During dry periods, species intolerant of low flows are unlikely to persist or proliferate, while those adapted to periodic drought (e.g., those that can survive as eggs, seeds, or spores during dry periods) and low flows may survive (Stromberg *et al.,* 2007).

A specific example in the context of the section of the Orange River between and below the dams would be that establishing a natural low or zero flow regime could be important for establishing a natural cycle for blackfly (*Simulium spp.*) populations. The species of blackfly that becomes prevalent in a reach of river is dependent on the flow conditions (Rivers-Moore *et al.,* 2014; Rivers-Moore & de Moor, 2021). High flows, and the resulting high turbidity, favour *Simulium chutteri* and *S. damnosum*. These species require blood meals from mammals and are typically responsible for the blackfly outbreaks that can have drastic consequences for livestock farming in the region, costing millions per annum for livestock farmers in the region. However, low flows and clear water conditions favour species of blackfly that often occur in lower numbers and survive on avian hosts. As a result, establishing a natural, low or zero flow regime below the dams over the dry months could help control blackfly outbreaks (Rivers-Moore *et al.,* 2014; Rivers-Moore & de Moor, 2021).

The JBS2 and JBS3 data showed issues with disturbance at the site related to the intermittent flow releases from Gariep. Stabilising a minimum flow may help the macroinvertebrate communities recover and settle into a more natural cycle.

Incrementally increasing releases in the spring (September, October, and November) to closer simulate what would be the increasing natural flow regime during that period.

This potential change would be contingent on water being available for release. Any potential benefit would likely be outweighed by the negative ramifications of the dam becoming empty if supply from higher up in the catchment does not arrive in time, or in sufficient amounts, to restore the dam and supply the increased releases.

For environmental flows, there are requirements not only for the volume of water, but for the timing of flows. Ecosystem function is highly dependent on the timing of flow regimes (Greet et al., 2011; Hannaford & Buys, 2012). For example, the onset of high flows triggers fish and other aquatic species to breed (Lytle & Poff, 2004). Increased flows in spring are sometimes required to inundate flood plains at the right time for migratory breeding species such as wading waterfowl. The increased flows often also supply the habitat connectedness necessary for aquatic species or water-borne progeny to travel to and between breeding grounds (Bunn & Arthington, 2002). Riparian and instream vegetation can also be reliant on the timing of increased flows for nutrient cycling processes or for the supply of water required for establishment, flowering, or growing (Greet *et al.,* 2011).

> "In some landscapes, these "initiation flows" kick-start ecological processes such as nutrient cycling and provide key ecological cues for native species, such as upstream migration … and spawning in semiarid rivers. The timing of these first high flows is essential for life-history cues, whereas the magnitude and duration are important for revitalizing the riverscape by reconnecting channel–riparian–floodplain habitats, flushing organic matter and fines from gravel spawning beds, increasing soil moisture, and reactivating exchanges with the hyporheic zone. The timing of wet-season initiation flows should coincide, to the degree possible, with the onset of wet-season precipitation or initial snowmelt runoff."

- Yarnell, *et al.* (2015). Functional flows in modified riverscapes: Hydrographs, habitats and opportunities. *BioScience*, *65*(10), 963–972.

The interaction between the temporal and volume components of flow are illustrated by Yarnell *et al.* (2015) (**Figure 7-1**).

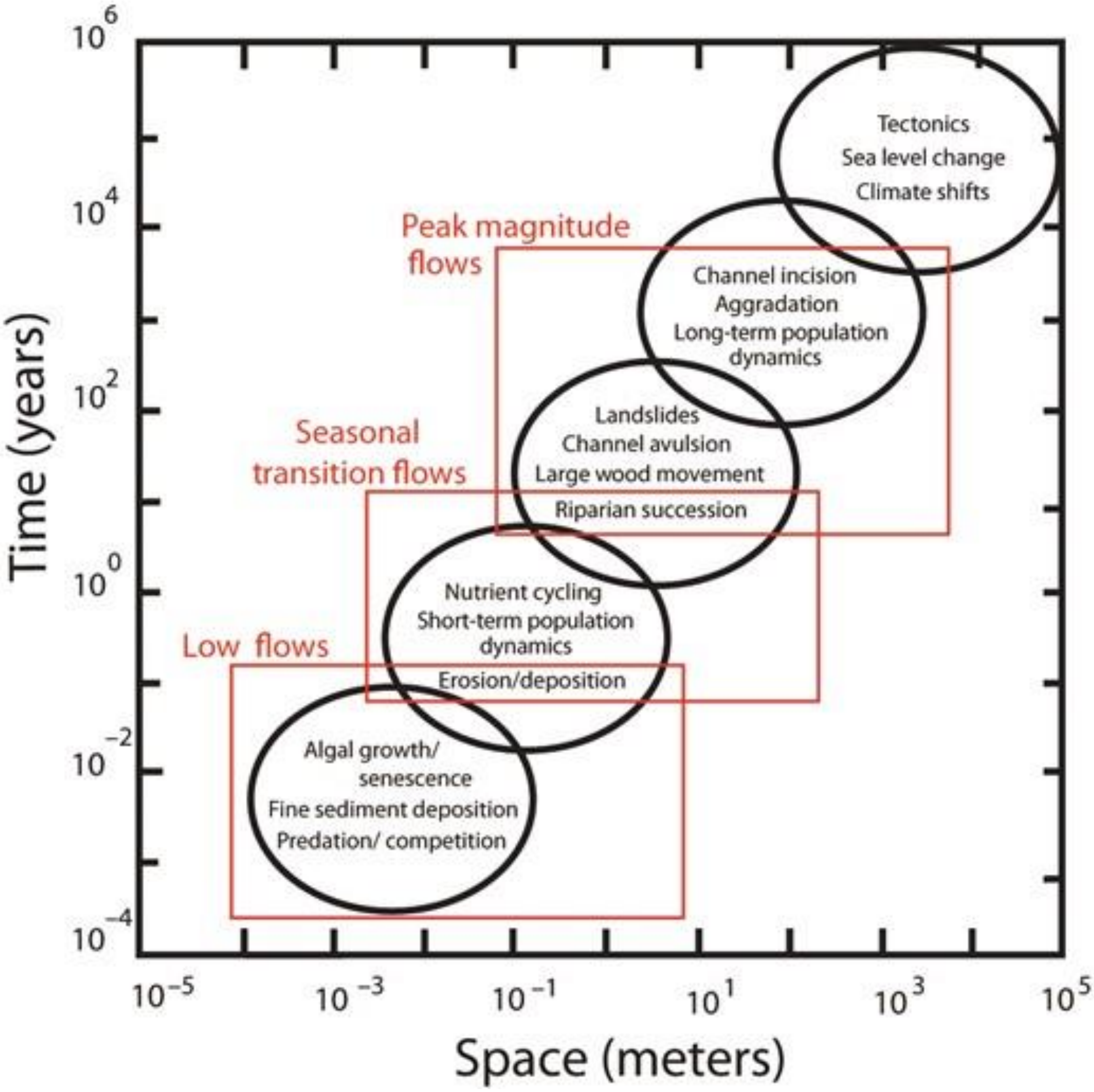


Figure 7-1: "Examples of interrelated physical and ecological riverine processes at varying spatial and temporal scales. Key functional flows supporting specific processes are shown in boxes." – from Yarnell et al. (2015).

The ecological benefits of changing to a more natural flow regime in terms of the timing of the spring increase in flows, could also have benefits far downstream in terms of earlier access to irrigation supply for agriculture. The JBS2 and JBS3 data indicated that the macroinvertebrate community and water quality were impacted by unseasonal flows. Restoring a more natural spring flush may aid in establishing a more natural, seasonal response in the aquatic biota, while reducing disturbance from hydropeaking via a smoother profile of release.

These changes in flow management should be assessed, where possible, in conjunction with frequent monitoring for adaptive management. Flow regimes have been altered for such a long time in most areas of the world by anthropogenic impacts such as dams and hydroelectric power generation that it is not always possible to accurately predict what the ecosystem response will be. However, returning, as far as possible, to natural flow patterns is highly likely to benefit ecosystem health and function. This is especially the case below the Gariep and Vanderkloof dams, which have historically been heavily impacted by drastically altered flow dynamics.

Lastly, it is important to further note the significant ecological concerns related to cheap energy generation crucial for supporting the economy. The primary problem appears to be a heavy reliance on hydropower, which has implications for the sustainability and predictability of energy sources as well as downstream impacts on the aquatic ecosystems. The interpretation involves exploring potential alternatives that could compete with hydropower, aiming to reduce dependency and address associated challenges. The mention of solar energy suggests a consideration for renewable alternatives. The question arises: can solar, or other sources, provide a viable competition to hydropower? This would not only diversify the energy mix but also potentially address the issues associated with hydropower.

The term "cheap energy generation" implies that cost-effectiveness is a key factor in choosing energy sources. The interpretation suggests a need to evaluate the economic feasibility of alternative energy options, considering factors such as installation costs, operational expenses, and long-term sustainability. Furthermore, the notion of restricting releases to meet predictable agricultural and domestic requirements in the medium to long term implies a need for a more stable and reliable energy supply. This brings attention to the challenge of balancing energy generation with the specific needs of sectors like agriculture, emphasising the importance of finding solutions that provide both consistency in power supply and support for essential economic activities.

In summary, there remains a dual concern of diversifying energy sources to reduce reliance on hydropower and ensuring predictability in energy generation to meet the requirements of key sectors, such as agriculture. Exploring and implementing alternative energy options, particularly those that can compete with hydropower, becomes a crucial aspect of addressing these challenges.

8. CONCLUSION

Table 8-1 below provides a summary of which operational flow scenarios can be taken forward following the evaluation of the ecological consequences to finalise the EWRs that can be met.

Table 8-1: Summary of applicable scenarios per EWR site

Site	River	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7
UO_EWR01_I	**Middle Caledon**	√	√	√	√	√	√	X
UO_EWR02_I	**Sterkspruit**	X	X					X
UO_EWR03_I	**Upper Orange**	√	√	√	√	√	√	X
UO_EWR04_I	**Lower Caledon**	√	√	√	√	√	√	X
UO_EWR05_I	**Seekoei**	√	√					X
UO_EWR06_I	**Upper Riet**	√	√	x	√			X
UO_EWR07_I	**Upper Modder**	√	√					X
UO_EWR08_I	**Lower Kraai**	√	√					√
UO_EWR09_I	**Lower Riet**	√	√	√	X			X
UO_EWR10_I	**Lower Orange**	√	√	√	√	√	√	X

Scenario 1 to Scenario 6 (flow scenarios)

All EWR sites will meet all scenarios, with the exception of UO_EWR02_I (Sterkspruit), UO_EWR03_I (Upper Orange), UO_EWR06_I (Upper Riet) and UO_EWR09_I (Lower Riet), which will not meet all scenarios, due to reasons below:

- UO_EWR02_I (Sterkspruit) will not meet either Sc1 or Sc2. This is primarily owing to deterioration in the fish PES owing to inadequate flow and compromised water quality. The flows for both scenarios show that there are not adequate floods or baseflows due to the Jozanashoek Dam located upstream. In addition, water quality is highly compromised, having a negative effect on the biota. Thus, if the water quality is not going to be improved, this REC will not be achieved.

- UO_EWR03_I (Upper Orange) will not meet Sc3 – Sc6 primarily due to the EWR not being met, primarily during the dry months. Scenario 3 and Sc4, will not receive adequate baseflows due to Polihali Dam and the proposed Verbeeldingskraal Dam (Sc5 and Sc6), which is relatively close to this EWR site, will have a large impact on the sediment regime, trapping most of the suspended sediment and all of the sand and gravel bed sediment. Therefore, deterioration in both the riparian vegetation and geomorphology is evident in these scenarios, ultimately having repercussions on the biotic response.

- UO_EWR06_I (Upper Riet) will not meet Sc3 only. This is primarily owing to the biotic component illustrating deterioration (primarily owing to deficits in the system and the flows not meeting the preferences of the selected indicator fish species or macroinvertebrate taxon).

- UO_EWR09_I (Lower Riet) will not meet Sc4 only, also primarily owing to the macroinvertebrate component, illustrating deterioration, due to deficits in the system and the flows not meeting the preferences of the selected indicator macroinvertebrate taxon.

Scenario 7 (water quality)

It is critical to note however, that the Upper Orange catchment area is predominantly influenced by non-flow related patterns in its rivers. Water quality plays a pivotal role, serving as a systemic concern across the catchment, as evidenced by diatom assessments indicating predominantly moderate to severely altered conditions. The root causes of this issue are primarily linked to nutrient overload, stemming from the wastewater treatment works (WWTWs) associated with the towns in the catchment. Unfortunately, most of these WWTWs are either in a state of disrepair, dysfunctional, or have reached or exceeded their capacity. Consequently, this leads to a cascading effect of elevated nutrient levels and eutrophication in the river systems, ultimately resulting in significantly degraded water quality throughout the catchment.

Since water quality is a critical factor influencing water-sensitive aquatic biota, their ecosystems and their biodiversity, these communities are adversely affected compared to reference conditions. Thus, irrespective of the presence or absence of sufficient flow, water quality remains the primary challenge in this catchment area. Furthermore, the river reaches are undergoing severe environmental deterioration due to factors such as extensive sediment deposition (resulting from widespread sand mining and poor land use and management), substantial bank erosion, bank collapse, and the removal of vegetation from the riparian zone, which is being replaced by the encroachment of alien invasive plant species. All these factors contribute to modifications in the riverbed, banks, and channels.

Therefore, it is reasonable to predict that the described observations will deteriorate further and reach a critical stage (Table 8-1 – Sc7) for all sites, except the lower Kraai River. The ultimate consequence will be a marked decrease in the overall health and functionality of this ecosystem, particularly in its capacity to provide essential ecosystem services, primarily clean water and the ability to dilute, process, and mitigate the impact of polluted water in collaboration with its indigenous biota. Furthermore, the frequency and persistence of waterborne diseases are likely to increase. This could result in a heightened seasonal risk for local communities that rely on the river, recreational users, and have a substantial impact on the biodiversity (fish and macroinvertebrates) associated with this river system.

Therefore, in conclusion, while the enhancement of flow rates remains an important objective and a central focus of this study, it is abundantly clear that this alone will not suffice to fully restore the overall health of the aquatic ecosystem in this region. Urgent action is imperative to implement effective water quality management measures aimed at mitigating the adverse consequences of environmental degradation and sedimentation. These stark findings underscore the immediate need to address these issues to protect and preserve the vital ecosystem of the Upper Orange catchment area.

Holistic evaluation of the socio-economic consequences

The current socio-economic conditions in the Upper Orange catchment area vary, with different levels of vulnerability, population density, and economic activities. In some regions, there is a moderate incidence of vulnerable households and a strong focus on commercial agriculture, with high agricultural value addition and water usage from river sources. However, the ecological consequence analysis suggests that the water flow is sufficient to meet current socio-economic water needs, reducing the risk of change. In other areas, there is a high incidence of vulnerable households, low GDP, and limited agriculture, posing a risk to the ability of the system to meet socio-economic water-use due to inadequate flow and compromised water quality. In a few places, there is a low incidence of vulnerable households and limited agriculture, with moderate water use, indicating a potential risk to the ability of the system to meet socio-economic water-use due to inadequate flow and water quality issues. In some regions, the current socio-economic state includes a mix of urban and smallholder farming communities, with a significant focus on agriculture and tourism. The ecological analysis shows that the scenarios meet the requirements for most areas, but there is a socio-economic risk associated with declining water quality and the increased occurrence of waterborne diseases (i.e. Upper Riet and Modder River systems). Finally, in certain areas, there's a mix of urban settlements and smallholder farming communities, with a focus on agriculture and agro-processing. The ecological analysis indicates that some scenarios meet the requirements, but others suggest potential changes in the ability of the system to meet socio-economic water-use, especially regarding water quality and dilution issues.

9. REFERENCES

Acreman, M. C., & Dunbar, M. J. (2004). Defining environmental river flow requirements–a review. Hydrology and Earth System Sciences, 8(5), 861–876. https://doi.org/10.5194/hess-8-861-2004

Bunn, S. E., & Arthington, A. H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management, 30, 492–507. https://doi.org/10.1007/s00267-002-2737-0

Department of Water and Sanitation (DWS). (2013). Green Drop report. https://www.dws.gov.za/Documents/Executive%20Summary%20for%20the%202013%20Green%20Drop%20Report.pdf

DWS. (2014). A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. Compiled by RQIS-RDM: https://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx accessed on.

DWS, (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

DWS, (2023). Development of operating rules for water supply and drought management of stand-alone dams, schemes and integrated systems in the central planning area. Water Supply and Drought Operating Rules for Integrated System: Orange River Project and Greater Bloemfontein Sub-Systems. Report Number P RSA 000/00/24523/4 Operating Year 2023/2024.

DWS. (2022). Green Drop report. https://ws.dws.gov.za/iris/releases/Report_DPW_Rev02_29Mar22_MN%20web.pdf

Greet, J., Webb, A., & Cousens, R. D. (2011). The importance of seasonal flow timing for riparian vegetation dynamics: A systematic review using causal criteria analysis. Freshwater Biology, 56(7), 1231–1247. https://doi.org/10.1111/j.1365-2427.2011.02564.x

Hannaford, J., & Buys, G. (2012). Trends in seasonal river flow regimes in the UK. Journal of Hydrology, 475, 158–174. https://doi.org/10.1016/j.jhydrol.2012.09.044

Humphries, P., & Baldwin, D. S. (2003). Drought and aquatic ecosystems: an introduction. Freshwater Biology, 48(7), 1141–1146. https://doi.org/10.1046/j.1365-2427.2003.01092.x

Kelly, M. G. (1998). Use of the trophic diatom index to monitor eutrophication in rivers. Water Research, 32(1), 236–242.

Lytle, D. A., & Poff, N. L. (2004). Adaptation to natural flow regimes. Trends in Ecology & Evolution, 19(2), 94–100. https://doi.org/10.1016/j.tree.2003.10.002

McMahon, T. A., & Finlayson, B. L. (2003). Droughts and anti-droughts: The low flow hydrology of Australian rivers. Freshwater Biology, 48(7), 1147–1160.

Orange-Senqu River Commission (ORASECOM). (2010). Volume 1: Environmental Flow Requirements Produced for WRP as part of Support to Phase II ORASECOM Basin Wide Integrated Water Resources Management Plan.

ORASECOM, (2014). Integrated Water Resources Management Plan for the Orange-Senqu River Basin. Report Number ORASECOM 020/2014. December 2014.

ORASECOM. 2014. Orange–Senqu River Basin Transboundary Diagnostic Analysis. Report produced by the UNDP–GEF Orange–Senqu Strategic Action Programme. ORASECOM Report 002/2014.

ORASECOM. (2019). Preparation of climate resilient water resources investment strategy & plan and lesotho-botswana water transfer multipurpose transboundary project Component I Climate Change Report. Draft Report number ORASECOM 007/2019.

ORASECOM. 2022. Joint basin survey (JBS) 3: Aquatic ecosystem health (AEH) report. Orange-Senqu River Commission (ORASECOM). Eds. P. M. Graham, G. de Winnaar, & N. B. Pattinson, https://orasecom.org/, 1–227.

ORASECOM. (2022). Preparation of climate resilient water resources investment strategy & plan and lesotho-botswana water transfer multipurpose transboundary project Component III pre-feasibility report phase 1. Report number ORASECOM 014/2019.

Ramulifho, P., Ndou, E., Thifhulufhelwi, R., & Dalu, T. (2019). Challenges to implementing an environmental flow regime in the Luvuvhu River Catchment, South Africa. International Journal of Environmental Research and Public Health, 16(19), 3694. https://doi.org/10.3390/ijerph16193694

Rivers-Moore, N. A., & de Moor, F. C. (2021). Climate-linked freshwater habitat change will have cost implications: Pest blackfly outbreaks in two linked South African rivers. River Research and Applications, 37(3), 387–398.

Rivers-Moore, N. A., Palmer, R. W., & Dallas, H. F. (2014). Assessing the relative culpability of Simulium (Diptera: Simuliidae) species in recent black fly outbreaks along the middle Orange River, South Africa. Canadian Journal of Zoology, 92(6), 505–513.

Steward, A. L., von Schiller, D., Tockner, K., Marshall, J. C., & Bunn, S. E. (2012). When the river runs dry: Human and ecological values of dry riverbeds. Frontiers in Ecology and the Environment, 10(4), 202–209. https://doi.org/10.1890/110136

Stromberg, J. C., Beauchamp, V. B., Dixon, M. D., Lite, S. J., & Paradzick, C. (2007). Importance of low-flow and high-flow characteristics to restoration of riparian vegetation along rivers in arid south-western United States. Freshwater Biology, 52(4), 651–679. https://doi.org/10.1111/j.1365-2427.2006.01713.x

Yarnell, S. M., Petts, G. E., Schmidt, J. C., Whipple, A. A., Beller, E. E., Dahm, C. N., Goodwin, P., & Viers, J. H. (2015). Functional flows in modified riverscapes: Hydrographs, habitats and opportunities. BioScience, 65(10), 963–972. https://doi.org/10.1093/biosci/biv102

10. APPENDICES

Appendix A – Method of assessing water quality in the Upper Orange Catchment – a reiteration

Historic information availability to inform determination of PES and PES trends

The availability of historical data on the water quality, diatoms, and aquatic macroinvertebrates based on previous assessments at any point in time prior to the current surveys was assessed for each site.

The desktop assessment of water quality data revealed gaps in the data available for reference and recent conditions at the EWR sites. Several data sources were used to collate information of the current and historical Physical-chemical state of the assessed river systems and associate catchments. The DWS Resource Quality Information Services (RQIS) website was the obvious first choice used to obtain data from the country-wide DWS monitoring network.

Most of the data obtained from RQIS did not show reference / baseline conditions as most of it was collected after major impacts had been introduced in the catchments. Additionally, a lack of consistent monitoring has resulted in years' worth of gaps in the data and no recent data. This posed a challenge to assessing the current physical-chemical state of the system (see Table for DWS site information and RQIS data obtained during desktop assessment). Additional data received from the DWS Free State Regional Office was interrogated to obtain more recent information. Other data sources were also sought for information including local conservation bodies, literature and experts who have done work in the area.

Table A1: DWS site information and RQIS data obtained during desktop assessment for water quality.

River	DWS Site ID	Latitude	Longitude	No of entries	Start Year - Year End
Seekoei (I)*	D32_101829	-30.5342	24.96194	465	1981-2019
Upper Riet** (I)	C51_189023	-29.5759	25.71075	30	2011-2015
Upper Modder (I)	C52_90811	-29.1603	26.57333	788	1987-2018
Upper Modder (I)	MS2/SW08/C5C5MODD-SANNA	-29.1603	26.57333	13	2017-2023
Lower Riet (I)	C51_189020	-29.0378	24.62481	28	2012-2015
Lower Riet (I)	C51_90835	-29.0333	23.98333	986	1990-2018
Lower Riet (I)	RS5	-29.0412	24.59838	8	2017-2023
Lower Orange (I)	D33_101824	-29.1617	23.69639	1397	1966-2018

River	DWS Site ID	Latitude	Longitude	No of entries	Start Year - Year End
Wonderboomspruit (R)***	D14_101788	-31.0008	26.35306	966	1967-2018
Little Caledon (R)	D2LCAL-EWR02	-28.6114	28.30194	5	2021-2022
Brandwater/Groot (R)	D2GROO-FARM1	-28.6806	28.13972	4	2022

**(I): Intermediate*
*** Site 25km upstream in different SQ Reach*
****(R): Rapid Level 3*

The paucity in data limited our ability to assess site reference conditions confidently and accurately. Consequently, the Physical-chemical driver Assessment Index (PAI) could not be used for determining the physical-chemical category since it is data dependent. The diatom results obtained from the 2022 and 2023 river surveys were used to infer the reference condition and the current status of the river systems in question for the following reasons:

- Long environmental memory: Analyses of diatom fossil records allow for the reconstruction of the history of water quality in an area. This is useful in assessing the changes in water over time and possibly infer the reference/natural state of the system in question;
- Diverse species composition: Diatom communities exhibit extensive species diversity. Each species has unique preferences and tolerances to specific physical-chemical changes in their environment. By analysing diatom communities, it is possible to identify which physical-chemical properties have deviated from natural and are driving the physical-chemical status currently observed in the system in question;
- Indicators of nutrient enrichment: Nutrient enrichment is one of the leading contributors to impaired water quality in the catchment. This is largely due to the mismanaged wastewater treatment works, which discharge poorly and, in some cases, untreated wastewater into watercourses. Certain diatom species are known to be good indicators of eutrophic water bodies. Therefore, these species can be used for identifying river systems with elevated nutrient concentrations;
- Sensitivity to pollutants: Diatoms are good indicators of inorganic pollution in river systems such as heavy metal pollution; and
- Rapid assessment and monitoring: Diatom sampling is relatively easy, quick and ultimately cost effective (based on the integrated water quality picture that can be achieved with the results), and often in the absence of other water quality information. This allows for an effective and holistic assessment of water quality. It is acknowledged though that the analytical/ID skills need are limited.

In the absence of an adequate dataset to assess reference and current physical-chemical state, diatoms were assumed to be an adequate replacement for inferring reference and current information on the physical-chemical status of the system.

Combined, these sets of data provided a picture of the natural state of each EWR site and how the current state has deviated from reference conditions.

Site description and evaluation

Each site was qualitatively evaluated in-field by experts in terms of 1) the state of the site, culminating in a summary description of each site relating to its PES, and 2) the advantages and Limitations of its suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring, and 3) the major impacts on the status of the site. Satellite imagery, Geographic Information System (GIS) and Green Drop (GD) data were also used to identify the catchment-scale drivers of the physical-chemical state of the systems in question.

A profile of WWTW (Figure A1) and agriculture in the catchment upstream of the site was also developed (Figure A10), given that WWTW discharge and agricultural runoff are probably the primary contributors to water quality impairment within this part of the catchment. The catchment of each site was assessed in terms of which WWTW were likely to contribute to the water quality at the site (and their volume and quality contributions, particularly in terms of base flow contributions). The WWTW profiles were generated based on the 2013 (DWS, 2013) and 2021 (DWS, 2022) GD reports. The GD score is a cumulative score based on a weighted calculation of various parameters, including some unrelated to the quality of the water treatment such as financial performance. Therefore, a poor GD score does not necessarily mean that the WWTW treatment is as poor as the score suggests, while a decent score does not necessarily imply that treatment functions well. Therefore, the GD scores were supplemented by what data were available from the National Integrated Water Information System (NIWIS) database on the water monitoring, physical, chemical, and microbial compliance for local municipalities to develop a fuller picture of the status of WWTW in the catchment above each site.

The agricultural profile for the catchment above the site was determined by assigning a 500m buffer on either side of the river and determining the land-use within that buffer for 50km upstream of the site along the main river and major tributaries (i.e., 50km upstream in all directions along rivers, accounting for land use 50km upstream along all major water courses contributing to water quality at the site). The land use data were based on the most recent Department of Forestry, Fisheries, and the Environment (DFFE) dataset (https://egis.environment.gov.za/sa_national_land_cover_datasets). As such, land use data were not available for the Kingdom of Lesotho. This meant that the full profile of land use 50km upstream of EWR sites EWR_01_I and EWR_02_I could not be fully assessed. It was assumed, based on local knowledge and expert experience, that the agricultural profile in Lesotho primarily consisted of primarily rangeland practices which contribute to sedimentation, but generally not to return flows or nutrient loading via intensive cropping practises. This agricultural profile was not designed to be comprehensive, only to provide an estimate of the agricultural signal in the catchment of each site to determine broad scale potential cultivation impacts (Figure A2, Figure A3 and Table A2).

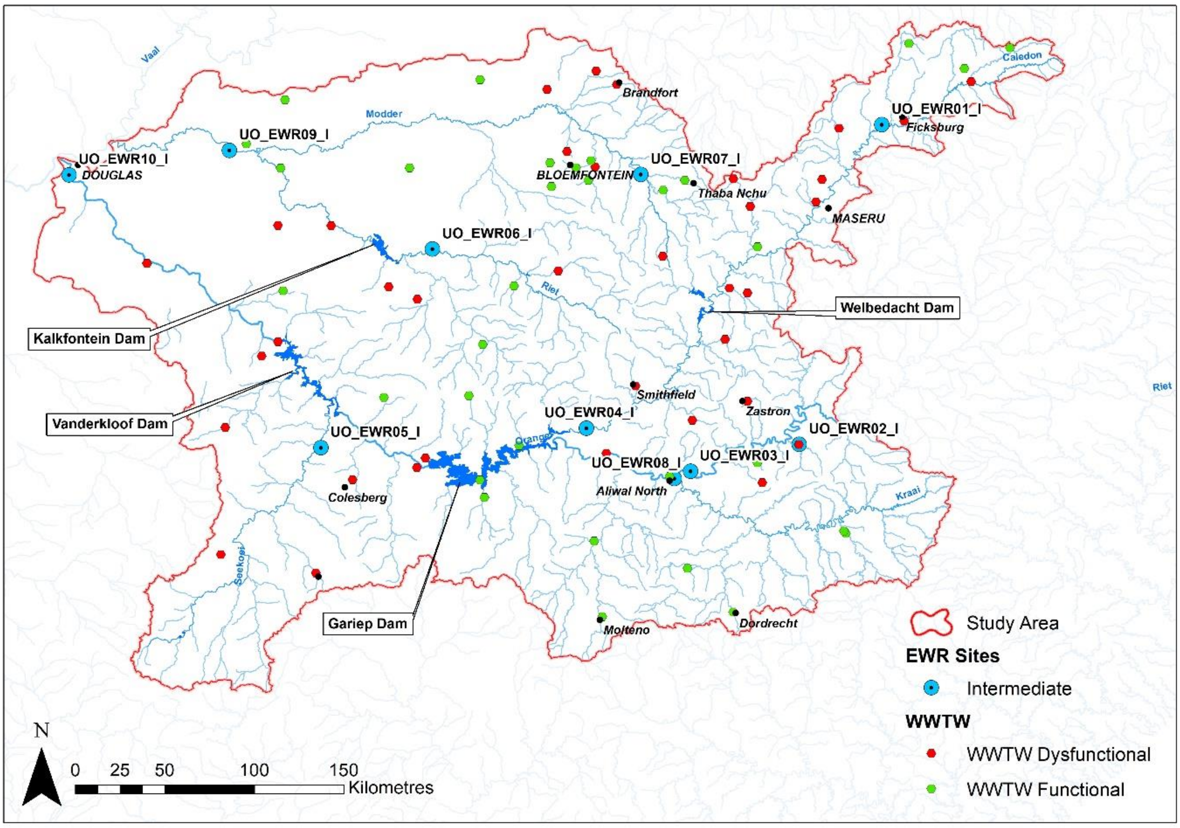


Figure A1: Figure showing the rivers and intermediate ecological water reserve (EWR) sites within the Upper Orange River catchment. Wastewater treatment works (WWTW) within the catchment are indicated, with those with 2021 Green Drop (GD) scores <31 % (those critically failing and dysfunctional) shown in red.

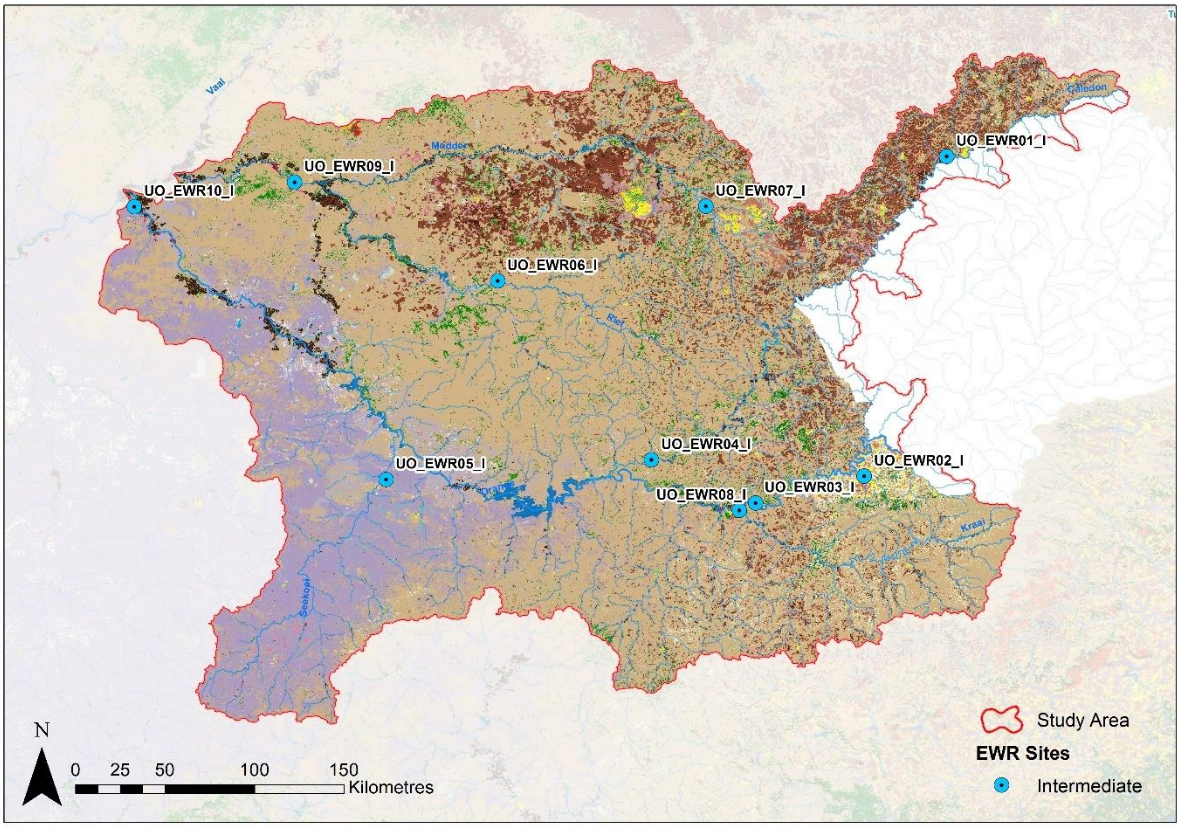


Figure A10: Land-use and land cover profile within the catchment according to most recent (2020) land-use dataset available from the Department of Forestry, Fisheries, and the Environment (DFFE; https://egis.environment.gov.za/sa_national_land_cover_datasets). Land use data were not available for the parts of the Upper Orange River catchment within the Kingdom of Lesotho. For a detailed legend explaining colours, see Figure A3 below.

Figure A3: Legend explaining the colour coding for different land uses within the Upper Orange River catchment

Table A2: Percentage agricultural land use in the catchments upstream of each intermediate ecological water reserve (EWR) site. Land use was calculated for a 500m buffer either side of the river for 50km upstream (or until a major impoundment – impoundments were considered 'reset' points for water quality impacts from upstream) of the site along all major tributaries and the main river. Percentages are shown by dryland and irrigated crops

	Land Use (%)			Land Use Area (m^2)		
Intermediate EWR Site	**Drylands Cultivation**	**Irrigated Cultivation**	**Total Cultivation Upstream**	**Drylands Cultivation**	**Irrigated Cultivation**	**Total Area Upstream**
EWR_01_I	26.72	0.82	27.54	146939	4519	549874
EWR_02_I	0.00	0.00	0.00	0	0	167304
EWR_03_I	5.23	0.53	5.76	42802	4360	818610
EWR_04_I	8.32	4.96	13.28	59511	35475	715247
EWR_05_I	0.89	0.48	1.37	5396	2942	608900
EWR_06_I	2.70	1.56	4.27	20084	12132	754841

	Land Use (%)			Land Use Area (m^2)		
Intermediate EWR Site	**Drylands Cultivation**	**Irrigated Cultivation**	**Total Cultivation Upstream**	**Drylands Cultivation**	**Irrigated Cultivation**	**Total Area Upstream**
EWR_07_I	3.72	0.13	3.85	17742	610	476832
EWR_08_I	9.08	3.59	12.67	77082	31452	856696
EWR_09_I	10.83	21.46	32.29	36760	81253	365492
EWR_10_I	0.85	6.20	7.05	1919	14030	226308

Appendix B – Concise discussion and summary of the water quality assessments at the Intermediate EWR sites in the Upper Orange River Catchment

UO_EWR01_I: Middle Caledon

Information availability

There was some data over the last decade for the macroinvertebrates and physical-chemical state of the system. However, no historical diatom data were available (Table B-1).

Table B-1: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR01_I: Middle Caledon site.

Water quality component	Historical information sources available
Macroinvertebrates	• PESEIS (2014). • Previous study conducted on the lower Caledon in Cal_EWR2** (2021). • May 2023 (this study).
Diatoms	• May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022). • NCMP data DWS Site C2 (2017 to 2023, n=6).

***Stassen et al., 2021*

Description of reference conditions

Macroinvertebrates:

The reference taxa expected to be found at the site based on assessments of other rivers in EcoRegion Level 2 were: Aeshnidae, Ancylidae, Baetidae, Caenidae, Ceratopogonidae, Chironomidae, Coenagrionidae, Corixidae, Dytiscidae/Noteridae, Elmidae, Gomphidae, Gyrinidae, Haliplidae, Hydraenidae, Hydrophilidae, Leptophlebiidae, Libellulidae, Muscidae, Naucoridae, Notonectidae, Planorbinae, Pleidae, Potamonautidae, Simuliidae, Tipulidae, Tricorythidae, Veliidae/Mesoveliidae.

Physical-chemical:

Reference physical-chemical data for the site were not available.

Site Description

The reach was partly confined with a deeply incised channel. The width was approximately 50m, homogenous with some inundated sandbars along the channel. The riverbed was composed largely of sand and silt and both banks are sandy, steep and highly erodible. Habitat diversity for biota was poor and the water was turbid except during low baseflows. The area surrounding the site was a mix of settlements, grazing areas and small-scale croplands. The

Lesotho side was heavily overgrazed and eroded contributing to the already high fine sediment load and evidence of sediment deposition.

Biotopes available for macroinvertebrates were dominated by sand and silt, with small gravel deposits over the sandy substrate. Marginal vegetation was mostly absent owing to erosion of inset benches and lower banks along both banks. There were no Stones-in-Current (SIC) or Stones-Out-Of-Current (SOOC).

Site evaluation

The site was characterized by poor conditions for diatoms and macroinvertebrate assessments (Table B-2).

Table B-2: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring

Advantages	Limitations
• None.	• Wide homogenous channel. • Limited aquatic biotopes – dominated by muddy substrate. • No marginal vegetation. • Excessive bank erosion and undercut banks. • High suspended sediment concentration (highly turbid waters).

Site impacts

The impacts on the sites were primarily settlements, cattle grazing areas, small-scale croplands, alien invasives (*Acacia dealbata, Salix sp., Populus sp., Robinia pseudoacacia)*, cultivation, vegetation removal, and macroplastics (plastics/litter) along both banks.

Wastewater:

Within the catchment likely to be affecting the water quality at the EWR_01_I site, there were five WWTW with at least partial data. Notably, the Ficksburg WWTW was functioning at 22% over capacity in 2013, though there are no capacity use data for 2021 – if anything the volume treated is likely to have increased due to population growth. The Mashaeng and Clarens WWTW have both recorded *decreases* in the volume of wastewater treated (528.5 thousand L/day and 100 thousand L/day, respectively), from 2013 to 2021. The decreases are despite the fact that all urban areas in South Africa have shown upward trends in both population and access to water. The overall GD scores are all <52%, with the Ficksburg WWTW showing a GD score of just 5%, indicating that it is dysfunctional and critically failing (DWS, 2022). Examination of Google Earth time lapse imagery also shows that sewage does not get to the Mashaeng WWTW in Fouriesburg. Rather, the sewage discharges directly into local rivers via broken sewage reticulation infrastructure, which would have affected this EWR site (See

Appendix Y for a letter submitted to the DWS on the failing state of the Mashaeng WWTW in 2023).

The municipalities governing the catchment likely to affect the site, and which had data available, were the Dihlabeng and Setsoto local municipalities. The Dihlabeng municipality recorded zero monitoring, and scored zero across the board for compliance in chemical, microbiological, and physical parameters. This does not imply that it scored zero for compliance for these parameters, only that there was zero monitoring leading to zero data on the NIWIS database. The Setsoto municipality scored only 52 for monitoring, and reported 33 for microbiological compliance in its wastewater management.

Agriculture:

The agriculture upstream of the site showed the second highest percentage of agricultural land use of all the intermediate sites (27.5%). Most of the cultivation was rainfall-fed dryland crops (26.7%, 97% of the agricultural land use), compared to intensively irrigated crops. Cultivation is typically associated with artificial or organic fertilizer use, as well as erosion and run-off from irrigation or rainfall. Consequently, this site is likely to show a strong signal of nutrient enrichment, with potential flow impacts from abstraction, associated with the high percentage of agriculture upstream.

In-situ water quality and diatoms

The dominant diatom species at the site were:

- *Achnanthidium sp.:* These have a preference for moderate to good quality waters.
- *Craticula molestiformis (Hustedt) Lange-Bertalot:* A cosmopolitan species generally found in electrolyte rich and often heavily polluted water (including sewage effluent).
- *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin:* These species are generally tolerant of strong pollution, indicator of industrial organic pollution.
- *Navicula symmetrica Patrick:* A cosmopolitan species that occurs in eutrophic and electrolyte-rich water since it is tolerant of strongly organically polluted water.
- *Nitzschia sp.:* A generalist species that is tolerant of siltation and moderate pollution.

The SPI = 8.6 indicated poor water quality, the %PTV = 24.9% indicated some evidence of organic pollution, and the number of deformed cells was >2%, potentially indicated harmful pollutants within the water column (Table B-10-1). The *in situ* water quality results are shown in Table B-10-1.

Table B-10-1: *In situ* water quality measurements and diatom sampling results.

Water quality component	***In situ water quality parameters***								
In situ water quality	pH (pH units)	Electrical conductivity (EC; µS/cm)	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)
	8	218.6	0.19	9.1	84.2	26	11.7	0.14	17.19 & 1.73
Diatoms*	*Outcomes of diatom survey*								
	no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	58	8.6	D (Poor)	24.9	2.25				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*
***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*
****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = C (64.4%; moderately modified), for flow and no-flow conditions:

During the May 2023 survey, a total of 10 macroinvertebrate taxa were recorded. The key taxa that characterised this site in terms of abundance and sensitivity included Baetidae >2spp, Caenidae, Chironomidae, and Hydropsychidae 1 spp. Except for Baetidae >2spp. These taxa generally exhibit a preference for slow-flowing to standing water and the GSM biotope and a low to very low requirements for unmodified physical-chemical conditions. These taxa therefore reflect the modifications at the site arising from reduced flows caused by upstream impoundments and water abstraction. The SASS5 scores were 55 and 47 (average SASS5 =

51) and the ASPT were 5 and 4.7 (average ASPT = 4.9) across the July 2022 and May 2023 surveys, respectively. These indicate a community of largely tolerant taxa and an absence of taxa sensitive to disturbance.

Diatoms / Physical-chemical PES = D (largely modified), for no-flow conditions:

Due to the lack of sufficient monitoring data, diatoms were used to infer the physical-chemical PES of the system. The poor PES indicated by the diatom community supported the macroinvertebrate assessment, again reflecting the high sedimentation and upstream WWTW effluent pollution.

Drivers of macroinvertebrate PES

The moderate PES indicated by the macroinvertebrate assessment showed water quality modification due to high sedimentation loads (upstream catchment activities, highly erodible soils and steep eroded banks) and upstream pollution related primarily to untreated effluent discharge from the poorly functioning WWTW in Ficksburg and the high percentage of agriculture upstream of the site. The site was also primarily alluvial, expansive and uniform with limited biotopes for aquatic macroinvertebrates. The prevailing biotope primarily consisted of mud and sand, interspersed with small pockets of gravel. There was a lack of marginal vegetation owing to eroded banks and sediment deposition. This habitat modification was also reflected in the moderate macroinvertebrate PES, with the dominant macroinvertebrate species only coming from mud and pockets of gravel.

Overall, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a 'C' or moderately modified using the MIRIA methodology, was water quality (Table B-4). This finding is also substantially corroborated by the diatom results.

Table B-10-2: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	70.2	0.321	22.564	2	90		
Habitat	81.0	0.357	28.912	1	100		
Water quality	38.9	0.304	11.823	3	85		
Connectivity and seasonality	70.0	0.018	1.250	4	5		
EC						64.549	**C**

PES Trends

Macroinvertebrates were in a stable condition (estimated with low confidence).

Assuming the primary catchment-scale impacts remain unchanged, the macroinvertebrate community health is unlikely to deteriorate over time because of proposed abstraction. However, this is subject to EWR flows being met.

The diatom / physical-chemical state was stable (estimated with moderate confidence).

The physical-chemical state of the system was changed from natural with the introduction of the long-standing developments upstream. The negative impacts of the Ficksburg WWTW were reported as a problem in 2011, suggesting that the associated issues have also been impacting the system over a long period. The poor GD scores for Ficksburg/Fouriesburg (Mashaeng) WWTW in 2021 identified these as a critical ongoing risk to the system stability, and a prohibitive factor to system recovery and improvement.

UO_EWR02_I: Sterkspruit

Information availability

There were some data over the last decade for the macroinvertebrates and physical-chemical state of the system. However, no historical diatom data were available (Table B-10-3).

Table B-10-3: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR02_I: Sterkspruit site.

Water quality component	Historical information sources available
Macroinvertebrates	• River Eco-status Monitoring Programme (REMP) river database (macroinvertebrate data). • PESEIS (2014). • July 2022 and May 2023 (this study).
Diatoms	• July 2022 and May 2023 (this study).
Physical-chemical	• GD Reports on the Sterkspruit WWTW that discharges downstream but within same SQ reach as the monitoring site (2011, 2013 and 2021).

Description of reference conditions

Macroinvertebrates: momentous

The reference taxa expected to be found at the site were: Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Perlidae, Baetidae 1sp, Baetidae 2spp, Caenidae, Leptophlebiidae, Oligoneuridae, Coenagrionidae, Lestidae, Aeshnidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Notonectidae, Pleidae, Veliidae, Ecnomidae, Hydropsychidae 1sp, Pisuliidae, Dytiscidae, Elmidae, Gyrinidae, Haliplidae, Hydraenidae, Hydrophilidae, Athericidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Empididae, Muscidae, Simuliidae, Tabanidae, Ancylidae, Lymnaeidae, Physidae, Corbiculidae, Sphaeridae, Unionidae.

Physical-chemical:

Reference physical-chemical data for the site were not available. Diatom data were used to infer the reference condition at the site. The diatom results indicated periodic nutrient and salinity increases at the site. Lower nutrient concentrations and salinities are expected to prevail at the site under reference conditions.

Site Description

The site is located downstream from the town of Sterkspruit and Hershell, but just upstream of the Sterkspruit sewage maturation pond. The valley setting was confined, with cobbles, boulder and bedrock forming riffles and pools. The river was ~5m to 10m wide (macro channel 30m wide) with some bed and channel modifications, erosion on both banks, and cattle trampling and grazing. Biotopes available for macroinvertebrates included SIC, SOOC and slated/fractured bedrock, along with Gravel, Sand, Mud (GSM) and limited marginal vegetation, owing to undercut banks and vegetation die-back during both surveys. There was moderate algae content and very high macroplastics in-stream, including domestic plastic (nappies).

During the May 2023 survey, the water was turbid, likely owing to recent rainfall events resulting in sediment loading. Furthermore, there was extensive sand mining taking place, particularly at the EWR site itself, both in-channel and just above the site. Moreover, mountain cutting activities were taking place to clear foundations for settlements (see Eco-categorisation Report for images. Report No. RDM/WMA13/00/CON/COMP/1223 (a)).

Site evaluation

The site was characterized by good instream habitat for diatoms and macroinvertebrate assessments, with the exception of marginal vegetation (Table B-10-4).

Table B-10-4: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• SIC, SOOC and GSM available. • Varying flow velocities.	• Limited marginal vegetation owing to undercut banks and no instream aquatic vegetation. • Some bank erosion.

Site impacts

The impacts on the sites were primarily upstream construction and bridge collapse, localised and upstream sand mining, the upstream town of Sterkspruit and Hershell, alien invasives (*Acacia dealbata, Salix sp., Populus sp., Robinia pseudoacacia)*, cattle trampling and grazing, and macroplastics (plastics/litter). Both marginal and non-marginal zones were severely impacted by sand mining operations at various points across the site, with additional impacts from rubbish dumping, livestock grazing/tramping, invasive alien plants (IAPs), bank erosion/collapse and sediment deposition. There was near-zero agriculture proximate to the river anywhere upstream of the site, so agriculture was not expected to have any significant impact on water quality at the site.

Wastewater:

Within the catchment likely to be affecting the water quality at the EWR_02_I site, there was only one WWTW with at least partial data. The Sterkspruit WWTW has been performing very poorly over the course of monitoring, registering a GD score of 37 % in 2013, and 39 % in 2021. The WWTW was also recorded to be operating at 10 % over capacity in 2013, although no data were reported for the volume being treated in 2021, so no estimate of capacity use can be made.

The only municipality likely to affect the site was the Joe Gqabi local municipality. This municipality is registered as scoring zero for monitoring, and zero for compliance in chemical, microbiological, and physical parameters. This indicates a lack of any data, and likely severe problems with wastewater management in the catchment above the site, which is likely to have a strong effect on water quality.

In-situ water quality and diatoms

The dominant diatom species at the site in July 2022 was:

- *Cocconeis placentula var. euglypta (Ehrenberg) Grunow*: This species indicates nutrient and salinity increases (eutrophication).

The dominant diatom species at the site in May 2023 were:

- *Cocconeis placentula var. euglypta (Ehrenberg) Grunow.*
- *Navicula amphiceropsis Lange-Bertalot & Rumrich:* Associated with anthropogenic pollution such as nutrients and electrolytes, usually related to nearby livestock farming.

The dominant diatom species downstream of the evaporation pond adjacent to the EWR site in May 2023 was:

- *Cocconeis placentula var. euglypta (Ehrenberg) Grunow.*

At the EWR site in 2023, the SPI = 11.8 suggested good water quality, %PTV = 22.0 % indicated some evidence of organic pollution, and the number of deformed cells was <2%, suggested little to no harmful pollutants within the water column (Table B-10-5)). The *in situ* water quality results are shown in (Table B-10-5).

Table B-10-5: *In situ* water quality measurements and diatom sampling results.

Water quality component		***In situ water quality parameters***								
***In situ* water quality**	*Assessment*	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)
	Survey 1 (July 2022)	8.7	168	0.138	11.1	108.7	60	14.2	0.10	0.618
	Survey 2 (May 2023) at EWR site	7.8	102.6	0.09	9.7	102.6	2.5	10.9	0.07	0.996
	Survey 2 (May 2023) downstream of maturation pond	7.8	97.8	0.08	9.7	88.1	2.5	10.9	0.06	-
Diatoms*		*Outcomes of diatom survey*								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	Survey 1 (July 2022)	17	12.1	C (Moderate)	19.8	0.75				
	Survey 2 (May 2023) at EWR site	33	11.8	C (Moderate)	22.0	1.25				

Water quality component		In situ water quality parameters								
	Survey 2 (May 2023) downstream of maturation pond	29	13.9	C (Moderate)	13.3	1.75				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*

***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*

****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = D (49.4 %; largely modified), for no-flow conditions:

During the July 2022 and May 2023 surveys, a total of 15 and 14 taxa were recorded respectively, resulting in a community of 19 taxa. The community mostly comprised taxa with a preference for standing water and the stones biotope, as well as taxa with low to very low requirements for unmodified physical-chemical conditions. In the July 2022 sampling, taxa sensitive to flow and water quality were recorded, including Perlidae, Baetidae >2spp and Trichorythidae. However, none of these taxa were recorded in May 2023; only Baetidae 2spp was recorded, as well as one individual of Athericidae. The SASS5 scores were 85 and 71 (average SASS5 score = 78) and the ASPT were 5.7 and 5.1 (average of 5.4) for the July 2022 and May 2023 surveys, respectively. These indicated the community was mostly composed of tolerant taxa (Dickens and Graham, 2002).

A high number of the taxa expected to be present with a high frequency of occurrence under reference conditions were absent. The taxa which were expected but not sampled mostly preferred moderately fast flowing water and the stones biotope, as well as sensitivity to changes in water quality, flow, and habitat.

The poor PES indicated by the macroinvertebrate assessment suggested that there has been substantial change or loss of natural habitat, biota and basic ecosystem functions.

Physical-chemical PES = C (moderately modified), for no-flow conditions:

Because of the lack of physical-chemical data for the sites, diatoms were used to infer the physical-chemical PES. The diatoms indicated periodic nutrient and salinity increases at the site leading to eutrophication. This was primarily linked to the poor Sterkspuit WWTW infrastructure, both discharging untreated wastewater into the Sterkspruit River from the WWTW, but also likely not collecting sewage from the town, which would be entering the river at various places upstream. The dumping of litter and rubbish from the town could also lead to poor water quality and nutrient loading.

Drivers of macroinvertebrate PES

Comparing the structure of the macroinvertebrate community between July 2022 and May 2023 suggested that the macroinvertebrate community responded to degrading water quality between the assessments.

During the May 2023 survey, in-channel sand mining at and upstream of the site appeared to be increasing. The river just upstream of the site had become a dumping area for the town of Sterkspruit. The WWTW was completely dysfunctional, and likely represents poor sewage infrastructure in the entire town upstream of the site, impacting the site despite the fact that the WWTW outlet was downstream of the site. The SIC and SOOC biotopes were also largely unavailable to the majority of macroinvertebrates due to algal smothering (likely relating to nutrient loading). Consequently, the change in the macroinvertebrate community is indicative of deteriorating water quality related to anthropogenic activities upstream and at the site.

Overall, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a "D' or largely modified using the MIRIA methodology, was water quality (Table B-10-6). This finding is also substantially corroborated by the diatom results.

Table B-10-6: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	60.7	0.327	19.878	2	90		
Habitat	49.5	0.291	14.409	3	80		
Water quality	38.3	0.364	13.932	1	100		
Connectivity and seasonality	60.0	0.018	1.091	4	5		
EC						49.310	**D**

PES Trends

Macroinvertebrates were in a declining / stable condition (estimated with moderate confidence).

There was evidence of ongoing catchment development at, and upstream, of the site, which is predicted to contribute to increasing deterioration at the site. The water quality is also likely to continue to deteriorate due to unmaintained upstream and adjacent sewage infrastructure. However, these impacts have been in the system for some time; the WWTW has been dysfunctional as far back as 2011 (earliest record of impacts potentially predate this record). Therefore, the already degraded state of the system may have stabilised at a poor state and remain there until remediation efforts are introduced.

The physical-chemical state in decline (estimated with moderate confidence).

Similar to the macroinvertebrate PES trend, the increasing catchment development and poorly maintained sewage infrastructure at the site and upstream threatens to continue to degrade the water quality. The water quality is also highly susceptible to degradation because of the in-stream sand mining at the site, which threatens to severely compromise the water quality via sediment loading. The WWTW is currently classified as critical risk. It has an effluent compliance of 15%, which means ongoing discharge will continue to degrade the physical-chemical state of the receiving water river. The *in situ* water quality results appear to be within TWQR limits with elevated pH. This is likely to change downstream after the WWTW discharges into the river.

UO_EWR03_I: Upper Orange

Information availability

There were some data over the last decade for the macroinvertebrates and physical-chemical state of the system. However, no historical diatom data were available (Table B-10-7).

Table B-10-7: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR03_I: Upper Orange site.

Water quality component	Historical information sources available
Macroinvertebrates	• PESEIS (2014). • REMP river database. • July 2022 (this study).
Diatoms	• July 2022 and May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022).

Description of reference conditions

Macroinvertebrates:

The reference taxa expected to be found at the site were: Turbellaria, Oligochaeta, Hirudinea, Atyidae, Perlidae, Baetidae 2spp, Caenidae, Leptophlebiidae, Trichorythidae, Coenagrionidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Hydrometridae, Naucoridae, Hydropsychidae 2spp, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Empididae, Muscidae, Simuliidae, Tabanidae.

Physical-chemical:

Reference physical-chemical data for the site were not available. Diatom results were used to infer the reference condition at the site. The diatom results indicated heavy organic pollution at the site. Lower nutrient concentrations are expected to be prevalent under reference condition at the site, and with no input from upstream sources.

Site Description

The site is located ~8 km upstream from the confluence of the Kraai River. The site was characterised by a partly confined valley setting with terraces and narrow flood benches along both banks with an incised channel. The river was ~120m wide with a homogenous sand bed channel, limited habitat diversity, and exposed sand bars along the right bank. The surrounding area was mostly agriculture with small-scale croplands and grazing areas. There was intense in-stream sand mining both downstream and upstream of the site. The macrochannel was sandy with steep, highly erodible fine sand and silt banks. Both banks showed recent erosion along the lower margins, removing inset benches. There were thickets of alien *Salix sp*. and *Populus* sp. on both sides of the riverbanks. However, it is likely these trees were aiding in stabilising the macro channel banks to limit lateral migration. The water was turbid, and the riverbed dominated by a featureless sand bed.

The biotopes available for macroinvertebrates were only sand and mud, with no gravel or any stones to sample. Marginal vegetation comprised fallen down tree debris.

Site evaluation

The site was characterized by a lack of marginal vegetation, or instream gravel or stones biotopes for sampling. There were limited habitats available for sampling for either diatoms or macroinvertebrates (Table B-10-8).

Table B-10-8: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• Water availability.	• Wide, deep, homogenous channel. • Limited aquatic biotopes – dominated by mud. • No marginal vegetation, high erosion and undercut banks. • High suspended sediment concentration (highly turbid waters).

Site impacts

The impacts on the sites were primarily upstream intense sand mining, cattle grazing and trampling areas, small-scale croplands, and reduced flows due to the dams in Lesotho and abstractions for irrigation. The proposed dam upstream represents a strong potential future influence.

Wastewater:

Within the catchment likely to be affecting the water quality at the EWR_01_I site, there were five WWTW with at least partial data. The Sterkspruit WWTW is in the catchment of this site, with a similar potential effect as discussed for EWR_02_I above. Two other WWTW have GD score data for this catchment – the Herschel and Zastron WWTW. These have also been consistently performing poorly, recording GD scores <44 % in 2013 and 2021. The Zastron WWTW recorded a GD score of just 15 % in 2021, indicating that it is dysfunctional and critically failing (DWS, 2022). What is also concerning was that the Herschel WWTW were operating at only 1% capacity in 2013, reporting no data on the volume being treated in 2021.

This was likely indicative of severe lack of sewage capture and reticulation issues, with sewage not reaching the WWTW to be treated at all, and hence the raw untreated sewage going directly to the nearest river channel and into the main stem river.

The municipalities governing the catchment likely to affect the site, and which had data available, were the Joe Gqabi and Mohokare local municipalities. As reported for site EWR_02_I above, the Joe Gqabi local municipality recorded zero for compliance in all parameters. The Mohokare municipality has reported fairly good numbers for compliance across all parameters regarding wastewater management.

Agriculture:

The agriculture upstream of the site showed a notable percentage of agriculture (5.8%), comprising mostly dryland, rain-fed cultivation (5.23%). This raises potential, though limited, for abstraction and nutrient loading from fertilizer run-off to affect the site.

In-situ water quality and diatoms

The dominant diatom species at the site in July 2022 was:

- *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*: This species is tolerant of strong pollution and an indicator of industrial organic pollution.

The dominant diatom species at the EWR site in May 2023 were:

- *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin.* Comment on species tolerance as above.
- *Mayamaea atomus var. permitis (Hustedt) Lange-Bertalot:* Very tolerant of organic pollution.

At the EWR site in 2023, the SPI = 10.9 suggested moderate water quality, %PTV = 36.5 % indicated some evidence of organic pollution, and the number of deformed cells was <2%, suggested little to no harmful pollutants within the water column (Table B-10-9). The *in situ* water quality results are shown in Table B-10-9.

Table B-10-9: *In situ* water quality measurements and diatom sampling results.

Water quality component		*In situ water quality parameters*								
***In situ* water quality**	*Assessment*	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (mS/m)	Discharge (m^3/s)
	Survey 1 (July 2022)	8.8	155	0.150	10.7	93.0	27	9.0	0.11	41.000
	Survey 2 (May 2023) at EWR site	8.3	139.4	0.120	8.9	82.1	12	11.7	0.09	81.596
Diatoms*		*Outcomes of diatom survey*								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	Survey 1 (July 2022)	16	9.2	C (Moderate)	83.1	0.5				
	Survey 2 (May 2023) at EWR site	30	10.9	C (Moderate)	36.5	0				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*

***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*

****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = C/D (60.6%; moderately to largely modified), for no-flow conditions:

Unfortunately, due to inclement weather including heavy rain and lightning, sampling could not be conducted during the May 2023 survey. Therefore, the interpretation provided is solely based on a single survey conducted in July 2022.

Several taxa were expected, but absent during sampling, from the assemblage. These included the Atyidae, Hydracarina, Aeshnidae, Corduliidae, Elmidae, and Hydraenidae, which have varying preferences for velocity and habitat conditions but all share a moderate requirement for modified physical-chemical conditions.

The modified to largely modified PES reflected that the system was large, deep, and homogenous, with limited aquatic biotopes for sampling (dominated by mud in an alluvial bed) that are related to anthropogenic changes to flow and water quality. The 10 taxa recorded in July 2022 primarily indicated a preference for standing water and muddy substrate, with low to very low requirements for unmodified physical-chemical conditions.

During the July 2022 sampling, the SASS5 score was 46 and the ASPT was 4.6 indicating the community was mostly composed of tolerant taxa (Dickens and Graham, 2002).

Physical-chemical PES = C (moderately modified), for no-flow conditions:

The PES of the physical-chemical system was estimated from the diatom results, due to the lack of physical-chemical data. The diatoms indicated heavy organic pollution, diverging from a natural state which would be expected to have lower natural nutrient and sedimentation levels.

Drivers of macroinvertebrate PES

Overall, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a "C/D' or moderately to largely modified using the MIRIA methodology, was water quality (Table B-12). This finding is also substantially corroborated by the diatom results.

Table B-10-10: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	66.0	0.254	16.762	3	80		

	Metric results					EC	
Habitat	57.1	0.317	18.141	1	100		
Water quality	51.3	0.302	15.486	2	95		
Connectivity and seasonality	80.0	0.127	10.159	4	40		
EC						60.548	**C/D**

PES Trends

Macroinvertebrates were in a stable condition (estimated with moderate confidence).

Habitat availability remains naturally poor along this reach, thus no improvement to biotopes to improve the integrity or diversity of the macroinvertebrate community.

The physical-chemical state was stable/declining (estimated with moderate confidence).

The system suffers from compromised water quality due, largely, to sedimentation loading from the upstream sand mining. This has been ongoing for some time, indicating that the system may have stabilised in this compromised state. However, there is the possibility that ongoing sand-mining and no remediation could further degrade the system.

UO_EWR04_I: Lower Caledon

Information availability

There was some data over the last decade for the macroinvertebrates and physical-chemical state of the system. Diatom data were available from JBS2 and JBS3 which had site OSEAH 26_08 at the same location as this EWR site (Table B-10-11).

Table B-10-11: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR04_I: Lower Caledon site.

Water quality component	Historical information sources available
Macroinvertebrates	• REMP river database. • PESEIS (2014). • ORASECOM EFR C5 (2010). • July 2022 and May 2023 (this study).
Diatoms	• JBS2 and JBS3 site OSAEH 26_08 (2015 and 2021). • July 2022 and May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022).

Description of reference conditions

Macroinvertebrates:

The reference taxa expected to be found at the site were: Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Perlidae, Baetidae >2spp, Caenidae, Leptophlebiidae, Trichorythidae, Coenagrionidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Hydrometridae, Naucoridae, Notonectidae, Pleidae, Veliidae, Corydalidae, Hydropsychidae >2spp, Dytiscidae, Elmidae, Gyrinidae, Haliplidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Muscidae, Simuliidae, Syrphidae, Tabanidae, Ancylidae, Lymnaeidae, Unionidae.

Physical-chemical:

Reference physical-chemical data for the site were not available. Diatom results were used to infer the reference physical-chemical state of the site. Diatom results indicated that the site was heavily contaminated with organic pollution, while JBS 2 (2015) diatom results suggested elevated chloride concentrations. Lower nutrient and chloride concentrations are expected to be prevalent at the site under reference conditions.

Site Description

The site is just downstream of the N6 road bridge between Rouxville and Smithfield. The water transfer from the Caledon River to the Knellpoort Dam and the Welbedacht Dam are ~100km upstream. The surrounding land use was extensive sheep farming with localised irrigation from the Caledon River. High silt loads in this river were causing significant problems for local farmers with “fines” (silt, clay and sand) clogging the soil pores and preventing water penetration.

The site was characterised by an unconfined low gradient reach. The channel was relatively straight and incised into the surrounding landscape with narrow flood features. The banks were steep and lined with alien invasive trees and annuals. *Salix sp.* and *Populus sp.* trees dot the riverbanks from the waterline to ~10 m from the water. The river at this site was approximately 50-70m wide and defined by a couple of basaltic intrusions diagonally across the river creating a narrow (~5m wide) resistant bedrock shelf and providing the key geomorphic structure. Coarse material (boulder and cobble sized) was introduced from the bridge construction. This created a series of localised set of concrete shelves under the bridge, as well as boulder and cobble shoots, runs and riffles directly downstream of the bridge. Otherwise the system was broadly dominated by finer alluvial sands and silts from active upstream erosional processes.

The SIC and GSM biotopes were available for sampling during both surveys in this study. There was limited SOOC and no marginal vegetation present owing to undercut banks, vegetation die-back, and erosion.

Site evaluation

The site had some key habitats for sampling (i.e., SIC and SOOC) at varying flow velocities. However, the GSM and vegetation biotopes were limited or absent, with high flows, erosion, and high sedimentation hampering habitat and sampling (Table B-10-12).

Table B-10-12: Table showing the advantages and Limitations of the site’s suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• SIC, SOOC. • Varying flow velocities.	• Limited GSM biotope. • Limited to no marginal vegetation or instream aquatic vegetation. • High velocity flows. • High turbidity. • Bank erosion.

Site impacts

The impacts on the sites were primarily agriculture, abstraction and irrigation, cattle grazing and trampling, local water abstraction just upstream of the site, artificial habitats (as a result of construction material from the bridge), bank erosion, and riparian alien invasives.

Wastewater:

Within the catchment above the EWR_04_I site, there were 17 WWTW with at least partial data. All these WWTW had GD scores <52 % in both 2013 and 2021, showing a dismal performance for all of them through space and time. Notably, eight of the WWTW (Van Stadensrus, Wepener, Ladybrand, Tweespruit, Rouxville, Smithfield, Hlohlolwane (Clocolan), and Ficksburg) all reported GD scores <31 % in 2021 (almost all also reporting <31 % in 2013 as well), indicating that they are dysfunctional and critically failing (DWS, 2022), and have been so for at least a decade.

It is also worrying that some of these WWTW are operating far below (Van Stadensrus at 33 %, Wepener at 1 %, Ladybrand at 29 %, Mashaeng at 45 %, and Mautse at 17%) or above (Rouxville at 156 %) their designed capacity. These figures suggest that there is a severe sewage reticulation issue for most of the WWTW in the catchment, and that the wastewater facilities at Rouxville are severely undersized to deal with their catchment. So, raw sewage not arriving at the WWTW (likely to be entering directly and untreated into the rivers) and secondly, poorly treated due to system under-capacitated and entering the local water courses. In both cases, the result is likely that large volumes of untreated wastewater are entering streams and rivers mostly unaccounted for.

The municipalities governing the catchment likely to affect the site, and which had data available, were the Mangaung, Mantsopa, Mohokare, Setsoto, and Dihlabeng local municipalities. As reported for sites above, the Dihlabeng local municipality recorded zero for compliance in all parameters, the Setsoto performed fairly but with poor microbiological compliance, and the Mohokare municipality reported fairly good numbers for compliance across all parameters. The Mangaung and Mantsopa municipalities also reported fair compliance performance.

Overall, the picture of wastewater management above the site in the catchment at large, including treatment and reticulation, shows a serious and urgent problem with wastewater in the catchment above this site. With that said, the site itself is likely only directly affected by the three WWTW downstream of the Welbedacht dam.

Agriculture:

The site was characterised by the third largest agricultural profile upstream (13.28 %), with a large proportion irrigated (4.96 %). This raises considerable potential for abstraction for irrigation and nutrient loading from fertilizer run-off to affect the site. Large areas of dryland cultivation are also prone to erosion and sedimentation of streams and rivers.

In-situ water quality and diatoms

The dominant diatom species at the site in July 2022 was:

- *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*: This species is tolerant of strong pollution and an indicator of industrial organic pollution.

The dominant diatom species at the EWR site in May 2023 were:

- *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin.*
- *Fistulifera saprophila (Lange-Bertalot & Bonik) Lange-Bertalot*: Some of the most pollution tolerant diatoms - indicate organic pollution (sewage) or are associated with organic detritus.

At the EWR site in 2023, the SPI = 6.4 indicating poor water quality, %PTV = 91.4 % indicating the site was heavily contaminated with organic pollution, while the number of deformed cells was <2%, suggesting little to no harmful pollutants within the water column (Table B-10-13). The *in situ* water quality results are shown in Table B-10-13.

Table B-10-13: *In situ* water quality measurements and diatom sampling results**.**

Water quality component		***In situ water quality parameters***								
In situ water quality	*Assessment*	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)
	Survey 1 (July 2022)	8.7	259.0	0.200	10.1	87.9	27	9.2	0.18	14.190
	Survey 2 (May 2023) at EWR site	8.4	217.4	0.200	9.2	83.5	11.5	10.8	0.14	38.451
Diatoms*		*Outcomes of diatom survey*								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				

Water quality component		***In situ water quality parameters***									
	Survey 1 (July 2022)	23	7.9	D (Poor)	67.2	2.25					
	Survey 2 (May 2023) at EWR site	16	6.4	D (Poor)	91.4	1.5					

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*
***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*
****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = C (64.4%; moderately modified), for flow and no-flow conditions:

The habitat in this reach of the Caledon River was primarily comprised of sand and mud, with artificial SIC and SOOC owing to the construction of the bridge. In the absence of the bridge and erosion, this section of the river would have consisted mainly of GSM and marginal vegetation, without a stone biotope. There were sampling limitations due to very high flow velocities, which may have affected the community sampled.

The macroinvertebrate assemblage recorded in July 2022 and May 2023 comprised species that primarily prefer very fast-flowing water conditions, cobbles (from the artificial substrate), GSM, and mostly low to very low physical-chemical conditions. Those taxa expected to occur at a high frequency of occurrence, but were absent from the assemblage, included Caenidae, Coenagrionidae, Libellulidae, Gerridae, Naucoridae, Veliidae, Dytiscidae, Hydrophilidae, Ceratopogonidae, Unionidae, Atyidae, Leptophlebiidae, Aeshnidae, Corduliidae, and Elmidae. These taxa have a moderate requirement for unmodified physical-chemical conditions and preference for vegetation, suggesting the PES is deteriorated from the natural condition.

The SASS5 scores were 28 and 41 (average SASS5 score = 35) and the ASPT were 4.0 and 4.6 (average of 4.3) for the July 2022 and May 2023 surveys, respectively. These indicated the community was mostly composed of tolerant taxa (Dickens and Graham, 2002).

Physical-chemical PES = D (largely modified), for no-flow conditions:

Due to the lack of data to perform the PAI, the physical-chemical PES was estimated using diatom results. The diatom data indicated heavy organic pollution at the site, resulting from elevated nutrient concentrations and which was congruent with the assessment of WWTW performance. Diatom results from May 2023 were also congruent with high sodium chloride salinity and especially irrigation return flows (*Pseudostaurosiropsis geocollegarum*).

Drivers of macroinvertebrate PES

During both surveys, the main impact at this site was the extensive sediment deposition along the banks, resulting from the absence of marginal vegetation. This reiterated the same findings from the JBS3 survey at this site in 2021. The introduction of artificial substrate through the construction of the bridge provided opportunities for variable flow and stones habitat-dependent taxa to colonise the system, as evidenced by the presence of abundant Trichorythidae in particular. These taxa would not have occurred naturally.

the primary factor shaping the macroinvertebrate PES, which was assessed as a 'D' or largely modified using the MIRIA methodology, was water quality (Table B-10-14). This finding is also substantially corroborated by the diatom results.

Table B-10-14: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	57.5	0.327	18.832	2	90		
Habitat	48.1	0.291	14.000	3	80		
Water quality	32.2	0.364	11.720	1	100		
Connectivity and seasonality	80	0.018	1.455	4	5		
EC						46.01	**D**

PES Trends

Macroinvertebrates were in a stable condition (estimated with low confidence).

There have been no recent upstream developments that would lead to change.

The physical-chemical state was declining / stable (estimated with low confidence).

Water clarity was low at this site because of the cattle trampling, unstable banks, and erosion resulting in high suspended solids in the river. This may represent a stabilised, though compromised, system. However, if the anthropogenic pressures intensify, the physical-chemical status of the system can be expected to decline.

UO_EWR05_I: Seekoei

Information availability

There were some data over the last decade for the macroinvertebrates within the system. No historical diatom data were available. Physical-chemical data extended back to 1981 in the NCMP database, supplemented by the GD data on discharge quality from WWTW in the system (Table B-10-15).

Table B-10-15: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR05_I: Seekoei site.

Water quality component	Historical information sources available
Macroinvertebrates	• REMP river database. • PESEIS (2014). • July 2022 and May 2023 (this study).
Diatoms	• July 2022 and May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022). • NCMP data (1981 – 2018, n = 465).

Description of reference conditions

Macroinvertebrates:

The reference taxa expected to be found at the site were: Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Perlidae, Baetidae >2spp, Caenidae, Leptophlebiidae, Trichorythidae, Coenagrionidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Hydrometridae, Naucoridae, Notonectidae, Pleidae, Veliidae, Hydropsychidae 2spp, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Empididae, Ephydridae, Muscidae, Simuliidae, Tabanidae, Ancylidae, Bulinae, Lymnaeidae, Unionidae.

Physical-chemical:

Reference Physical-chemical conditions for the site were determined using DWS data (site D3H015Q01, 1981 to 1989, n =245).

- pH: The reference data reflected a 5th percentile of 7.1 pH units and a 95th percentile of 9 pH units, falling outside the DWA (2008) benchmark for Natural (0) rating. The Natural (0) rating for the site was therefore adjusted, such that the Natural (0 rating for the site was (≥ 7.1 and ≤ 9 pH units).

- EC: Reference site data indicated elevated conductivities at this site, with the 95th percentile = 144.85 mS/m. These elevated conductivities are largely driven by the catchment wide erosion/weathered geological material.
- Temperature: No historical temperature records were available for the site. DWA (2008) benchmark tables were used for a low confidence, qualitative assessment of temperature reference condition.
- Clarity: There were no reference clarity / turbidity records available. The reference condition was taken as that qualitatively described in the DWA (2008) benchmark tables.
- Oxygen: No dissolved oxygen records were available for this site. DWA guideline benchmark tables (2008) have been used to characterise the site's reference condition.
- TIN: The reference data indicated that the 50th percentile for TIN was 0.09 mg/l, which fell within the DWA (2008) Natural (0) rating benchmark of 0.25 mg/l. The DWA (2008) benchmark for TIN was used.
- PO_4: The reference data indicated that the 50th percentile for PO4 was 0.03 mg/l, which fell outside of the DWA (2008) Natural (0) rating benchmark of 0.005 mg/l. The Natural (0) rating for the site was benchmarked at $PO_4 \leq 0.03$ mg/l.
- Fluoride: In terms of the toxics listed within the DWA (2008) rating tables, only fluoride was monitored. The 95th percentile for fluoride was calculated as 0.62 mg/l which fell within the DWA (2008) benchmark table.

<u>Site Description</u>

The site is located off a large cross over bridge off a district road R369, approximately 40km northwest from Colesberg and approximately 60km downstream of the Karoo Gariep Nature Reserve.

The reach was relatively unconfined, with the river incised into the valley floor. Flood features were narrow and the river pattern was straight to sinuous, with bedrock, boulder, cobble and gravel and finer habitats available at the site. The site continued to have high baseflows following the floods prior to assessment. There are various upstream dams and weirs along the river reach. These attenuated floods and reduced sediment accretion at the site, resulting in various islands of *Phragmites sp*. both instream and on the banks. Downstream of the weir, the site was dominated primarily by metamorphic sandstone with igneous intrusions forming the bedrock layer and small pockets of GSM along the reach. The bedrock was blanketed by algae and silt. Both instream and marginal vegetation were present for sampling macroinvertebrates.

<u>Site evaluation</u>

The site had varying flow velocities and marginal vegetation for sampling. However, there were limited other biotopes to sample and turbid waters. Moreover, the site was modified by a bridge at the site, as well as flow alterations due to weirs (Table B-10-16).

Table B-10-16: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• Marginal and instream aquatic vegetation present. • Varying flow velocities.	• Limited biotopes – dominated by bedrock • Just downstream of a weir (inundation upstream and flow modification downstream) • High turbid waters • High silt content • Bed modification owing to the bridge at the site.

Site impacts

The impacts on the sites were primarily dams and weirs, game and livestock farming, localised cultivation on terraces, and the bridge at the site. The agricultural profile upstream of the site was relatively minimal, suggesting a reduced impact of cultivation on flow or water quality at the site.

Wastewater:

Within the catchment likely to be affecting the water quality at the EWR_05_I site, there were only two WWTW with at least partial data – the Hanover and Noupoort WWTW. The GD scores for these WWTW were both 18 % in 2021, indicating they are both dysfunctional and critically failing (DWS, 2022). The Noupoort WWTW had a GD score of just 4 % in 2013, showing the severe issues there are long-standing. The GD score at the Hanover WWTW was 74 % in 2013, showing a drastic decline in the status of the WWTW over the last decade. Both the WWTW were lacking data on the volume they treat per day in 2021. However, 2013 data showed that the Hanover WWTW was at only 16 % of its designed capacity. This again shows that there are likely issues with reticulation in the network, with sewage not reaching the WWTW before ending up in streams, rivers, and groundwater.

The municipalities governing the catchment likely to affect the site, and which had data available, were the Emthanjeni and Umsobomvu local municipalities. The Emthanjeni municipality reported zeros for all compliance parameters, while the Umsobomvu municipality reported zeros for chemical and physical compliance, as well as poor (42 %) performance for microbiological compliance. However, Umsobomvu at least reported 100 % compliance on monitoring.

Overall, similar to other EWR sites, the WWTW in the catchment upstream are functioning dismally, and likely contributing to severe contamination of streams and rivers.

In-situ water quality and diatoms

The dominant diatom species at the site in July 2022 were:

- *Cocconeis pediculus Ehrenberg*: An epiphytic species in waters of moderate to high electrolyte content, including brackish conditions.
- *Nitzschia dissipata (Kützing) Grunow*: A cosmopolitan species found in waters of moderate to high electrolyte content. The species is not present in waters of low electrolyte content.

The dominant diatom species at the EWR site in May 2023 were:

- *Cocconeis pediculus Ehrenberg.*
- *Nitzschia frustulum (Kützing) Grunow*: A species with a preference for high conductivity and heavy agriculture. Typically very tolerant of pollution.
- *Pseudostaurosiropsis geocollegarum (Witkowski & Lange-Bertalot) Morales*: Indicators of high sodium chloride salinity and especially irrigation return flow.
- *Staurosirella pinnata (Ehrenberg) Williams & Round*: Often occurs attached to sand grains. Usually found in clean waters (tolerating mild pollution and only slight organic pollution), with moderate to high electrolyte content and a pH >7 pH units.

At the EWR site in 2023, the SPI = 10.3 indicated moderate water quality, %PTV = 14.6 % indicated the site was free from organic pollution, and the number of deformed cells was <2%, suggesting little to no harmful pollutants within the water column (Table B-10-17). The *in situ* water quality results are shown in Table B-10-17.

Table B-10-17: *In situ* water quality measurements and diatom sampling results.

Water quality component		***In situ water quality parameters***								
	Assessment	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO;	DO (%)	Clarity (cm)	Temperature	Salinity (dS/m)	Discharge (m^3/s)
In situ water quality	*Survey 1 (July 2022)*	8.8	695	0.600	11.1	99.2	30	9.8	0.49	1.155
	Survey 2 (May 2023) at EWR site	8.5	580	0.500	10.0	91.2	25	11	0.39	1.671
Diatoms*		*Outcomes of diatom survey*								

Water quality component		In situ water quality parameters								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	Survey 1 (July 2022)	44	12.4	C (Moderate)	11.2	0.25				
	Survey 2 (May 2023) at EWR site	40	10.3	C (Moderate)	14.6	0.75				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*

***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*

****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = C (67.2%; moderately modified), for flow and no-flow conditions:

During the July 2022 and May 2023 surveys, 21 and 20 taxa were recorded, respectively, resulting in a total community of 30 taxa. The community represented moderately modified conditions, showing a significant change or loss of natural habitat, biota, and basic ecosystem functions.

Some GSM habitat was present at the site, but SIC was absent, and SOOC limited. The dominant biotopes at the site were bedrock and marginal and aquatic vegetation. The community mainly consisted of taxa with a low to very low requirement for pristine physical-chemical conditions, and a preference for standing water and the vegetation biotope. Absent taxa, which were expected to have occurred at high frequency, included Aeshnidae, Leptophlebiidae, Trichorythidae, Libellulidae, and Elmidae. Atyidae, Corduliidae, and Dixidae were also absent, all of which have a preference for moderately unmodified physical-chemical conditions and the SIC biotope. Other absent taxa included Gomphidae, Hydrometridae, and Unionidae. Physidae was recorded during the July 2022 survey, although not in May 2023. Physidae do not form part of the reference conditions due to their status as alien invasive species. Hence, monitoring should be conducted to ensure their population remains at low abundances.

The SASS5 scores were 97 and 89 (average SASS5 score = 93) and the ASPT were 4.6 and 4.5 (average of 4.5) for the July 2022 and May 2023 surveys, respectively. These indicated the community was mostly composed of tolerant taxa (Dickens and Graham, 2002).

Physical-chemical PES = C (moderately modified), for no-flow conditions:

Diatom results were used to infer the physical-chemical PES of the system. The diatoms indicated elevated electrolyte concentrations. High conductivities have been recorded at this site as far back as the early 1980s because of high erosion upstream. During both surveys, a significant amount of filamentous algae was observed at the site, indicating nutrient enrichment and compromising water quality.

<u>Drivers of macroinvertebrate PES</u>

The PES was primarily driven by poor water quality at the site. Habitat was also a strong driver, given that the habitat was dominated by bedrock (not an ideal biotope for macroinvertebrates), with heavy sedimentation causing siltation covering the other available biotopes. Flow also affected the PES, considering the areas downstream of the weir would experience unnatural flow patterns.

Overall, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a “C' or moderately modified using the MIRIA methodology, was water quality (Table B-10-18). This finding is also substantially corroborated by the diatom results.

Table B-10-18: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	73.8	0.340	25.054	2	90		
Habitat	68.8	0.264	18.160	3	70		
Water quality	59.2	0.377	22.331	1	100		
Connectivity and seasonality	90.0	0.019	1.698	4	5		
EC						67.24	**C**

PES Trends

Macroinvertebrates were in a stable condition (estimated with moderate confidence).

There have been no recent upstream developments that would lead to change.

The physical-chemical state was in a stable condition (estimated with moderate confidence).

High conductivities are characteristic of this system. The pH was elevated, although still within guidelines. Clarity was low as a result of high suspended solids from upstream, likely as a result of erosion of topsoil. No recent developments that could alter the physical-chemical nature of the system.

UO_EWR06_I: Upper Riet

Information availability

There were some data over the last decade for the macroinvertebrates within the system. No historical diatom data were available. Physical-chemical data extended back to 2011 in the GD Reports (regarding the WWTW discharge status within the system) and in the NCMP database (Table B-10-19).

Table B-10-19: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR06_I: Upper Riet site.

Water quality component	Historical information sources available
Macroinvertebrates	• REMP river database. • PESEIS (2014). • July 2022 and May 2023 (this study).
Diatoms	• July 2022 and May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022). • NCMP data (2011 – 2018, n = 29).

Description of reference conditions

Macroinvertebrates:

The reference taxa expected to be found at the site were: Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Baetidae >2spp, Caenidae, Oligoneuridae, Trichorythidae, Coenagrionidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Naucoridae, Notonectidae, Pleidae, Veliidae, Hydropsychidae >2spp, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Muscidae, Simuliidae, Tabanidae, Tipulidae, Ancylidae, Lymnaeidae, Planorbinae, Corbiculidae, Sphaeridae.

Physical-chemical:

Historical physical-chemical data at the site date back to 2011, which was not far enough back in time to reflect the reference conditions at the site. Therefore, the reference physical-chemical condition of the site was inferred from diatom data. The diatom data indicated the site was prone to eutrophic conditions and high phosphorus concentrations. However, the site would be free from organic pollution under natural conditions.

Site Description

This site is in the upper reaches of the Riet River, upstream of the Kalkfontein Dam Nature Reserve and ~20km upstream of the confluence of the Kromellenboog. Upstream of this site are the DWS REMP and JBS3 sites C5RIET-IFR03 and 26_10, respectively. The Riet River is a main tributary of the Vaal River and flows in a western direction. The site is located just downstream of a low water cross-over bridge, where log jams have occurred upstream of the bridge, impeding the hydraulics of the river, as well as inundation of the system upstream.

The reach was largely unconfined, with the macro channel incised into the gently sloping hillslopes. The channel was approximately 40m wide and had a straight to sinuous macro channel pattern, with a braided low flow channel pattern owing to in-stream vegetated and gravel islands. These formed braids have resulted in small streams running through the instream islands with rocky habitat for macroinvertebrates.

The substrate at the site was dominated by gravel and cobbles, as well as a section of bedrock along the left side of the channel. The increased flows allowed aquatic grass to establish in the deep runs of the river. Marginal vegetation was abundant and comprised reeds, grasses and sedges. Bank erosion from cattle trampling was evident, more so along the right bank, along with undercut banks.

Site evaluation

The site had various habitats and flow velocities for sampling. However, the waters had high sediment loads and some areas had flow velocities too high for effective sampling (Table B-10-20).

Table B-10-20: Table showing the advantages and limitations of the site’s suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• Variety of aquatic biotopes available. • Varying flow velocities.	• Highly turbid waters • Very fast flow over the SIC biotope limited effective sampling.

Site impacts

The impacts on the sites were rural developments, and game and livestock farming. There was some potential for agricultural effects, with cultivation accounting for 4.3 % of land use proximate to the rivers upstream of the site. However, the signal would be relatively small compared to the potential for wastewater, as noted below.

Wastewater:

Within the catchment likely to be affecting the water quality at the EWR_06_I site, there were just two WWTW with at least partial data – the Edenburg and Reddersburg WWTW. These two WWTW lacked data on the volume of wastewater they treat per day. However, the GD scores show that both were critically failing in 2013 (GD scores both < 15 %), and that the Reddersberg WWTW was still in extremely poor condition in 2021 with a GD score of 16 %.

The only municipality governing the catchment likely to affect the site, and which had data available, was the Kopanong local municipality. This municipality reported zeros for all compliance parameters. Cumulatively, the GD scores and lack of any compliance suggest severe issues with wastewater in the catchment, potentially contributing to severe water quality issues at the EWR site.

<u>In-situ water quality and diatoms</u>

The dominant diatom species at the site in July 2022 were:

- *Cyclostephanos invisitatus (Hohn & Hellerman) Theriot, Stoermer & Hakans*: This species is wide-spread and common in the summer. It is often found in nutrient-rich waters.
- *Fragilaria biceps (Kützing) Lange-Bertalot*: A cosmopolitan taxon often found in mesotrophic to eutrophic waters.

The dominant diatom species at the EWR site in May 2023 was:

- *Nitzschia frustulum (Kützing) Grunow:* A species with a preference for high conductivity and heavy agriculture. Generally, very tolerant of pollution.

At the EWR site in 2023, the SPI = 6.2 indicated poor water quality, %PTV = 94.0 % indicated the site was heavily contaminated with organic pollution, while the number of deformed cells was <2%, suggesting little to no harmful pollutants within the water column (Table B-10-21). The *in situ* water quality results are shown in Table B-10-21.

Table B-10-21: *In situ* water quality measurements and diatom sampling results.

Water quality component		***In situ water quality parameters***									
In situ water quality	*Assessment*	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)

Water quality component		***In situ water quality parameters***								
	Survey 1 (July 2022)	8.8	486	0.449	9.9	97.4	22	9.5	0.34	4.217
	Survey 2 (May 2023) at EWR site	8.3	557	0.495	8.98	81.3	13	11	0.37	12.405
Diatoms*		*Outcomes of diatom survey*								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	Survey 1 (July 2022)	31	19.3	C (Moderate)	16.6	1				
	Survey 2 (May 2023) at EWR site	20	6.2	D (Poor)	94.0	0.5				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*

***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*

****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = C (62.6%; moderately modified), for no-flow conditions:

During the surveys conducted in July 2022 and May 2023, a total of 14 and 19 macroinvertebrate taxa were recorded, respectively. This resulted in a cumulative total of 25 taxa for the last hydrological year (July 2022 - May 2023).

The aquatic macroinvertebrate community at the site predominantly exhibited preferences for low to very low water quality, stones and vegetation biotopes, and standing water. Only two sensitive taxa, Leptophlebiidae and Pyralidae, were recorded, both of which prefer moderate to high water quality, cobbles, and fast to very fast flowing water. Several taxa expected at high frequencies of occurrence, but which were absent from the community, included Hydracarina, Baetidae >2spp, Trichorythidae, Aeshnidae, Hydropsychidae >2spp, and Elmidae. These families all have a preference for moderate to high water quality conditions. It is worth noting that the abundance of Simuliidae recorded in July 2022 (D abundance) decreased, with no Simuliidae recorded during the May 2023 survey. This decline may be attributed to the system being reset following the floods in February 2023, which caused habitat scouring.

The SASS5 scores were 65 and 102 (average SASS5 score = 84) and the ASPT were 4.6 and 5.4 (average of 5.0) for the July 2022 and May 2023 surveys, respectively. These indicated the community was mostly composed of tolerant taxa (Dickens and Graham, 2002).

Physical-chemical PES = D (largely modified):

Due to the lack of historical physical-chemical data, the physical-chemical PES of the site was inferred from the diatom data. The diatoms indicated heavily polluted waters (organic pollution) with elevated conductivities.

Drivers of macroinvertebrate PES

The largest driver of the PES was the compromised water quality due to irrigation from adjacent and upstream agriculture, as well as erosion causing high sediment inputs.

The primary factor influencing the macroinvertebrate PES, which was evaluated as 'C' or moderately modified according to the MIRIA methodology, was water quality (Table B-10-22). This conclusion is further substantiated by the results pertaining to diatoms.

Table B-10-22: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*

	Metric results					EC	
Flow modification	68.8	0.304	20.889	3	85		
Habitat	73.0	0.321	23.470	2	90		
Water quality	47.1	0.357	16.833	1	100		
Connectivity and seasonality	80.0	0.018	1.429	4	5		
EC						62.62	**C**

PES Trends

Macroinvertebrates were in a stable condition (estimated with moderate confidence).

No recent water resource developments suggest that the condition should be stable. However, turbidity levels may continue to rise in response to increasing sediment supply from erosion upstream.

The physical-chemical state was in a declining condition (estimated with moderate confidence).

The diatoms illustrated in a decline in water quality between surveys, from being classified as moderately modified in July 2022 to poor in May 2023. This may have reflected increasing organic pollution and sedimentation from upstream processes. The pH was elevated, although still within guidelines.

UO_EWR07_I: Upper Modder (Sannaspos)

Information availability

There were some data over the last decade for the macroinvertebrates within the system. Diatom data from JBS2 and JBS3, which had the site OSEAH 11_18 at the same location as this EWR site, were available. Physical-chemical data extended back to 1987 in the NCMP database, supplemented by GD data over the last decade for the WWTW in the system (Table B-10-23).

Table B-10-23: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR07_I: Middle Modder site.

Water quality component	Historical information sources available
Macroinvertebrates	• REMP river database. • DWS REMP site further upstream (C5MODD-SANNA) (quarterly monitoring). • PESEIS (2014). • JBS2 and JBS3 site OSAEH 11_18 (2015 and 2021). • July 2022 and May 2023 (this study).
Diatoms	• JBS2 and JBS3 site OSAEH 11_18 (2015 and 2021). • July 2022 and May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022). • NCMP data (1987 – 2018, n = 788).

Description of reference conditions

Macroinvertebrates:

The reference taxa expected to be found at the site were: Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Baetidae >2spp, Caenidae, Trichorythidae, Coenagrionidae, Lestidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Naucoridae, Notonectidae, Pleidae, Veliidae, Hydropsychidae >2spp, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Muscidae, Simuliidae, Tabanidae, Tipulidae, Ancylidae, Lymnaeidae, Planorbinae, Corbiculidae, Sphaeridae.

Physical-chemical:

Historical data (from 1987) for the site indicated substantial fluctuation of physical-chemical properties over time. The earliest available data, therefore, did not represent the reference conditions at the site, especially with the upstream Botshabelo Township established in 1979. Therefore, diatom data were used to infer the reference physical-chemical conditions at the site. Diatom data indicated strong organic and inorganic pollution. Under reference conditions, lower nutrient concentrations are expected to be present at the site, especially with the absence of the impacts from Botshabelo and Thaba Nchu WWTW upstream.

Site Description

The site is located ~30km east of Bloemfontein off the N8, along the upper reaches of the Modder River. The site is ~13 km downstream of Rustfontein Dam. It is impeded by two railway crossings and a large bridge. Furthermore, a gauging weir is located just upstream of the site.

The reach was largely unconfined and characterised by gentle hillslopes and an incised channel with narrow flood features. Both banks are heavily eroded owing to recent flooding, flow modifications and cattle trampling. The site was bedrock-controlled, with silty banks and introduced coarser bed material. Gravel and sand bars were present downstream of the site. The river width varied from B-15m in places, with inundation just upstream of the weir. Much of the instream substrate, downstream of the weir, comprised riffles with artifical loose SIC and some SOOC. However, bedrock was the dominant substrate from the bridge and further downstream. There was GSM habitat, but marginal vegetation was limited because of undercut banks and vegetaion die back during winter (representative of the season). Sedimentation was present downstream of the weir, forming a back-eddie along the sandbank allowing algae to proliferate on the rocks at the river's edge.

At the time of the May 2023 survey, the system was recovering/resetting from a recent flood event that registered a peak discharge of approxmately 60m^3/s two days prior. This had an impact on the macroinvertebrate community and meant the SIC biotope could not be accessed during this survey.

Site evaluation

The site had various flow velocities for sampling. However, the upstream weir made sections of the site too deep to sample and altered flow regimes downstream. The site also had limitations for sampling varied biotopes given the bedrock domination, high sedimentation, and limited vegetation (Table B-10-24).

Table B-10-24: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• Varying flow velocities.	• Upstream weir resulting in inundation upstream and too deep to access, and flow modifications downstream • The site is bedrock-controlled with silty banks and introduced coarser artifical bed material. • High turbidity.

	• Limited marginal vegetation owing to extensive bank erosion from cattle grazing, trampling.

Site impacts

The impacts on the sites were the upstream dams and weirs, WWTW discharges, localised livestock trampling and grazing, and upstream industry. Land uses in the catchment included urbanisation and industrial activities. The Modder River also supplies water to several urban areas including Bloemfontein, Botshabelo (upstream), and Thabu Nchu, although this is supplemented to a large degree by water from the Caledon River via the Caledon - Modder River Government Water Scheme (CMRGWS). From an agricultural perspective, cultivation accounts for a relatively small proportion of the land use upstream of the site (3.85%), suggesting that large scale agricultural impacts are unlikely. Though localised cultivation and run-off can always affect the water quality over short timescales at a site.

Wastewater:

Within the catchment likely to be affecting the water quality at the EWR_07_I site, there were three WWTW with at least partial data. All these WWTW had GD scores <41 % in 2021, with the Dewetsdorp WWTW recording a GD score of 24 %, indicating that it is dysfunctional and critically failing (DWS, 2022). The Botshabelo and Thaba Nchu WWTW showed huge decreases in their GD scores (reductions of 45 % and 40 %, respectively), showing concerning declines in their status over the last decade.

The Mangaung municipality was the only one in the catchment likely to affect the site, and which had data available. As reported for sites above, the Mangaung municipality reported fairly good numbers for compliance across all parameters. However, the difference between the impression given by the GD scores and the compliance reported on the NIWIS database raises the need for closer investigation, since most compliance and monitoring is self-reported. A closer look at the data reveals that the data reported on NIWIS for Mangaung includes data mostly from a Nedbank private works which is reported to run with excellent compliance. The Mangaung municipality WWTW shows consistently poor performance, likely accounting for the disparity, and again highlighting the municipal issues with wastewater management.

In-situ water quality and diatoms

The dominant diatom species at the site in July 2022 were:

- *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*: Tolerant of strong pollution, indicator of industrial organic pollution.
- *Fragilaria biceps (Kützing) Lange-Bertalot*: A cosmopolitan taxon often found in mesotrophic to eutrophic waters.

The dominant diatom species at the EWR site in May 2023 were:

- *Nitzschia frustulum (Kützing)* Grunow: A species with a preference for high conductivity and heavy agriculture. Typically very tolerant of pollution.
- *Gomphonema parvulum (Kützing) Kützing*: Indicative of a high load of fine sediment.
- *Navicula veneta Kützing*: A cosmopolitan, species common in heavily eutrophicated, electrolyte-rich to brackish water. Very pollution tolerant, often the dominant species in industrially impacted waters.
- *Nitzschia palea (Kützing) W.Smith*: A cosmopolitan and very commonly occurring species found in eutrophic and very heavily polluted to extremely polluted waters with moderate to high electrolyte content.

At the EWR site in 2023, the SPI = 6.3 indicated poor water quality, %PTV = 30.0 % indicated some evidence of organic pollution, but the number of deformed cells was 0%, suggesting little to no harmful pollutants within the water column (Table B-10-25). Notably, the percentage of deformed cells in the July 2022 assessment was 8.75%, indicating extreme deformities and cause for concern. The *in situ* water quality results are shown in Table B-10-25.

Table B-10-25: *In situ* water quality measurements and diatom sampling results.

Water quality component		***In situ water quality parameters***								
	Assessment	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)
In situ water quality	*Survey 1 (July 2022)*	8.4	459	0.419	8.70	76.6	52	9.9	0.32	0.673
	Survey 2 (May 2023) at EWR site	8.0	155.7	0.140	9.65	86.2	6.5	10.4	0.10	9.180
Diatoms*		*Outcomes of diatom survey*								

Water quality component		***In situ water quality parameters***								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	Survey 1 (July 2022)	34	5.6	D (Poor)	73.1	8.75				
	Survey 2 (May 2023) at EWR site	20	6.2	D (Poor)	94.0	0.5				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*
***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*
****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = D (50.0%; largely modified), for flow and no-flow conditions:

The available biotopes for aquatic macroinvertebrates in this stretch mainly consist of bedrock, artificial SIC and SOOC, GSM, and some marginal vegetation. During the July 2022 survey, flows were sufficient, allowing for accessible sampling of biotopes. However, the May 2023 survey was hindered by flooding caused by recent rainfall events, resulting in limited access to GSM and marginal vegetation. A total of 10 taxa were recorded during both surveys for this study. However, over the last hydrological year, a total of 14 taxa were documented at this site (including those sampled during JBS3).

The PES shows there has been a substantial change or loss of biota and fundamental ecosystem functions. The assemblage comprised species with low to very low requirement for unmodified physical-chemical conditions, irrespective of habitat or flow conditions. The only taxon with a moderate sensitivity to flow, habitat, and water quality recorded in the last hydrological year was the Baetidae >2spp. Sensitive taxa that were absent, but expected at high frequencies of occurrence, from the assemblage during the last hydrological year included Hydropsychidae >2 spp (during the survey only 1 species was recorded) and Trichorythidae. Other taxa that were absent included Aeshnidae, Elmidae (associated with cobbles), and Atyidae (associated with vegetation). These taxa typically prefer moderate water quality, which explains their absence. Furthermore, Atyidae, Caenidae, Gomphidae, Gerridae, Notonectidae, Veliidae, Dytiscidae, and Culicidae were absent. These taxa generally favour standing water. However, as this site is located just downstream of a gauging weir, flow conditions are frequently regulated. During the May 2023 survey, noticeably higher flows eliminated standing water habitats.

The SASS5 scores were 40 and 38 (average SASS5 score = 39) and the ASPT were 4.0 and 3.6 (average of 3.8) for the July 2022 and May 2023 surveys, respectively. These indicated the community was mostly composed of tolerant taxa (Dickens and Graham, 2002).

Physical-chemical PES = D (largely modified), for no-flow conditions.

The physical-chemical PES at the site was inferred from the diatom data. The diatoms indicated strong organic and inorganic pollution.

Drivers of macroinvertebrate PES

The largely modified PES was driven most strongly by poor water quality. The water was highly turbid and polluted with nutrients from urban runoff and poorly treated wastewater from the Botshabelo township upstream. The modified PES was also driven by loss of habitat, mostly from cattle trampling and overgrazing, as well as bank erosion, leading to an absence of vegetation. Moreover, the site was mainly dominated by bedrock, with high sediment loads smothering the SIC and SOOC habitats. Artificial habitats provided additional substrate for macroinvertebrates to colonise, moving the assemblage further away from what would be expected under natural conditions. The site also suffered from channel and flow modifications resulting from the weir and various bridges at the site, as well as the upstream dam.

Overall, the community showed significant responses to low to very low requirements for unaltered physical-chemical conditions. As a result, the primary factor shaping the macroinvertebrate PES, which was assessed as a “D' or largely modified using the MIRIA methodology, was water quality (Table B-10-26). This finding is also substantially corroborated by the diatom results.

Table B-10-26: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	47.3	0.291	13.761	3	80		
Habitat	59.1	0.327	19.330	2	90		
Water quality	43.6	0.364	15.847	1	100		
Connectivity and seasonality	60.0	0.018	1.091	4	5		

	Metric results					EC	
EC						50.03	**D**

PES Trends

Macroinvertebrates were in a declining condition (estimated with moderate / high confidence).

There appeared to be ongoing, worsening pressures at a catchment level leading to a long-term decline of water quality at the site. The strongest contributor was estimated to be the upstream failing / dysfunctional sewage infrastructure.

The physical-chemical state was in a declining condition (estimated with moderate confidence).

The site was assessed to be experiencing long-term decline of water quality through failing / dysfunctional sewage infrastructure. Notably the DO was among the lower recorded in the catchment (less than 80%). The impacts from the upstream confluence with the Klein-Modder were likely minimised by dilution from the larger Modder River and the Rustfontein Dam upstream during the wet months. However, the physical-chemical state reflects worsening under the increasing impacts of the upstream Botshabelo township and WWTW.

UO_EWR08_I: Lower Kraai

Information availability

There were some data over the last decade for the macroinvertebrates and physical-chemical state of the system. Diatom data from JBS2 and JBS3, which had site OSEAH 26_11 at the same location, were available (Table B-10-27).

Table B-10-27: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR08_I: Lower Kraai site.

Water quality component	Historical information sources available
Macroinvertebrates	• REMP river database, including REMP site further upstream (D2KRAA-ALIWA) (quarterly monitoring). • PESEIS (2014). • JBS2 and JBS3 site OSAEH 26_11 (2015 and 2021). • ORASECOM EFR K7 (2010). • July 2022 (this study).
Diatoms	• JBS2 and JBS3 (2015 and 2021). • July 2022 and May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022).

Description of reference conditions

Macroinvertebrates:

The taxa expected at the site under natural conditions were: Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Perlidae, Baetidae >2spp, Caenidae ,Leptophlebiidae, Oligoneuridae, Polymitarcyidae, Prosopistomatidae, Trichorythidae, Chlorocyphidae, Coenagrionidae, Lestidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Naucoridae, Nepidae, Notonectidae, Pleidae, Veliidae, Hydropsychidae 1sp, Hydropsychidae >2spp, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Muscidae, Simuliidae, Tabanidae, Tipulidae, Ancylidae, Lymnaeidae, Planorbinae.

Physical-chemical:

Historical physical-chemical data for the site were not available. The diatom results were used to infer the reference physical-chemical state of the site. The diatom results indicated the site was strongly polluted, with evidence of elevated electrolyte concentrations. Lower electrolyte concentrations are expected to be prevalent in the system under reference conditions.

Site Description

This site is at the same location as JBS3 site OSEAH 26_11 and the DWS REMP site D1KRAA-ALIWA. The site is immediately downstream of a causeway / bridge which is frequently used by farmers. There is a sluice gate on the right end of the bridge – which can be closed in times of drought or should the Orange River dry up. This functions in pooling the river upstream of the bridge for basic human needs support. During both the July 2022 and May 2023 survey, the baseflows were higher than expected for the time of year as a result of the high rainfall during the latter part of summer.

The reach had a partly confined valley setting, straight to wandering channel form and pool-riffle sequences. The channel was incised with narrow flood features. At the site the river was free flowing, ~30 m wide, and had a range of biotopes. There was a solid igneous bedrock base with riffles and runs below the causeway. There was considerable filamentous algae coverage over the SIC biotopes. Most of the river in the area had deeper, slow flowing pools with various sections of riffles and pools downstream of the bridge, providing a range of habitats. All biotopes for macroinvertebrates were present, although vegetation was limited by undercut banks, vegetation die back, and erosion.

Site evaluation

All the biotopes, at varying velocities, were available at the site for macroinvertebrate and diatom sampling. However, river morphology limited the instream and marginal vegetation biotopes, algal smothering limited the availability of the SIC biotope to macroinvertebrates, and flooding rendered some areas inaccessible for sampling (Table B-10-28).

Table B-10-28: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• A variety of aquatic biotopes • Varying flow velocities.	• Limited marginal vegetation - owing to undercut banks and bank erosion along the banks. • No instream aquatic vegetation. • Low water bridge at site resulting in inundation upstream – too deep to access and some bed modification downstream near the sluice gate. • Algae smothering SIC biotope (nutrients).

Site impacts

The impacts on the sites were agriculture, cattle activity, irrigation, and the upstream causeway / weir. The main land use in the area is agriculture with several centre pivot irrigation fields close to the river immediately upstream. *Salix sp.* line the banks both upstream and downstream. The flood debris line is ~3 m above the water level indicating large volumes passing through during flood events.

Wastewater:

Within the catchment there were four WWTW likely to be affecting the water quality at the EWR_08_I site, with at least partial data. All four WWTW showed GD scores >48 % in 2013 and 2021. The Dordrecht WWTW was notable in that it showed a dramatic increase in GD performance, increasing from 49 % in 2013, to 100 % in 2021, one of only three in the country to achieve that score. The main concern with the WWTW in the catchment would be that the Barkley East new works were operating at 200% capacity in 2021, double the designed use. This may contribute to its poor GD performance, and for poorly treated wastewater entering the freshwater systems in the catchment, ultimately impacting the site.

The Chris Hani and Joe Gqabi municipalities were those in the catchment likely to affect the site, and which had data available. As reported for sites above, the Joe Gqabi lacked any compliance data for any parameter, which suggests issues with at least monitoring and reporting.

Agriculture:

The site was characterised by the fourth largest agricultural profile upstream (12.67 %), with a considerable proportion irrigated (3.6 %). As stated above, this raises considerable potential for abstraction for irrigation and nutrient loading from fertilizer run-off to affect the site. Large areas of dryland cultivation are also prone to erosion and sedimentation of streams and rivers.

<u>In-situ water quality and diatoms</u>

The dominant diatom species at the site in July 2022 was:

- *Gomphonema pumilum*: A species indicative of highly polluted water, high electrolytes, and some siltation.

The dominant diatom species at the EWR site in May 2023 was:

Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin: A species tolerant of strong pollution and indicative of industrial organic pollution.

At the EWR site in 2023, the SPI = 9.8 indicated moderate water quality, %PTV = 62.2 % indicated heavy contamination with organic pollution, while the number of deformed cells was <2 %, suggested little to no harmful pollutants within the water column (Table B-10-29). The *in situ* water quality results are shown in Table B-10-29.

Table B-10-29: *In situ* water quality measurements and diatom sampling results

Water quality component		***In situ water quality parameters***								
In situ water quality	*Assessment*	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)
	Survey 1 (July 2022)	8.6	218	0.2	10.1	87.7	68	9.1	0.15	17.300
	Survey 2 (May 2023) at EWR site	8.3	139.4	0.1	8.9	82.1	12	11.7	0.09	19.030
Diatoms*		*Outcomes of diatom survey*								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	Survey 1 (July 2022)	34	13.8	C (Moderate)	7.8	0				
	Survey 2 (May 2023) at EWR site	31	9.8	C (Moderate)	62.2	1.75				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*

***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*

****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute* *significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = C (65.4%; moderately modified), for flow and no-flow conditions:

In the July 2022 survey, a total of 14 taxa were recorded. Unfortunately, high flows and flooding prevented the DWS from conducting their routine REMP sampling at this site last year. Nevertheless, there is substantial macroinvertebrate data available, allowing for confident interpretation.

Most of the taxa recorded were those with a preference for moderately fast flowing and standing water, cobbles, and a combination of varying water quality conditions. Taxa recorded in July 2022 that were sensitive to flow and water quality included Hydracarina, Perlidae, Baetidae >2spp, Leptophlebiidae, Trichorythidae, Aeshnidae, Elmidae, and Dixidae. However, several taxa sensitive to flow and water quality were absent from the community despite being expected to occur at high frequencies under natural conditions. These included Atyidae, Oligoneuridae, Chlorocyphidae, Lestidae, Corduliidae, Hydropsychidae >2spp, and Hydraenidae.

The SASS5 score was 87 and the ASPT was 6.2 in July 2022, indicating a predominance of tolerant taxa (Dickens and Graham, 2002). However, it is important to note the presence of some sensitive taxa.

Physical-chemical PES = C (moderately modified), for no-flow conditions.

The physical-chemical PES was inferred from the diatom results. The diatoms indicated that the physical-chemical PES was characterised by elevated electrolyte concentrations and pollutants.

Drivers of macroinvertebrate PES

The site offered a variety of biotopes and flow velocities which supported diverse aquatic macroinvertebrate communities. However, the presence of undercut banks limited the growth of marginal vegetation in this area, reducing the presence of taxa dependent on vegetation. The habitat had also been modified for macroinvertebrates by algal growth, likely related to nutrient loading from agriculture return flows, smothering the SIC biotope. There was also modification related to inundation from the upstream weir. The flow was altered from the natural state by abstraction for intensive irrigation upstream.

Overall, a PES of a C for the macroinvertebrate community was recorded, in accordance with the MIRAI, and which was primarily influenced by water quality, as the community exhibited significant responses to low to very low water quality conditions (Table B-10-30). This was further supported by the diatom results.

Table B-10-30: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	73.5	0.327	24.055	2	90		
Habitat	62.4	0.364	22.699	1	100		
Water quality	59.0	0.291	17.164	3	80		
Connectivity and seasonality	80.0	0.018	1.455	4	5		
EC						65.37	**C**

<u>PES Trends</u>

Macroinvertebrates were in a stable condition (estimated with moderate / high confidence).

The trend was stable given that the catchment processes appeared to be relatively established and buffered. This was evidenced by the consistent macroinvertebrate PES from JBS2 (2015), through to JBS3 (2021) and eventually to this study. The site is under constant pressure from abstraction and nutrient loading related to WWTW return flows and agricultural practices upstream.

The physical-chemical state was in a stable condition (estimated with moderate confidence).

There have been no recent water resource developments near the site that would lead its status to change over time.

UO_EWR09_I: Lower Riet

Information availability

There were some data over the last decade for the macroinvertebrates within the system. Diatom data from JBS3, which had the site OSEAH 29_5 at the same location as this EWR site, were available. Physical-chemical data extended back to 1970 in the NCMP database, supplemented by GD data over the last decade for the WWTW in the system (Table B-10-31).

Table B-10-31: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR01_I: Lower Riet site.

Water quality component	Historical information sources available
Macroinvertebrates	• REMP river database, including REMP site (C5RIET-DEKRA) – last dataset was in 2020. • SANParks monitoring site (data obtained 2022). • PESEIS (2014). • JBS3 ORASECOM site OSAEH 29_5 (2021). • Vaal comprehensive study (Vaal_EWR19) (2019).
Diatoms	• JBS3 ORASECOM site OSAEH 29_5 (2021).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022). • NCMP data (1970 to 2017, n= 724).

Description of reference conditions

Macroinvertebrates:

Reference conditions were based on DWS REMP (C5RIET-DEKRA). The taxa expected under reference conditions were: Porifera, Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Perlidae, Baetidae >2spp, Caenidae, Heptageniidae, Leptophlebiidae, Oligoneuridae, Prosopistomatidae, Trichorythidae, Chlorocyphidae, Chlorolestidae, Coenagrionidae, Lestidae, Platycnemididae, Protoneuridae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Hydrometridae, Naucoridae, Nepidae, Notonectidae, Pleidae, Veliidae, Ecnomidae, Hydropsychidae >2spp, Polycentropodidae, Psychomyiidae, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Athericidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Empididae, Ephydridae, Muscidae, Simuliidae, Tabanidae, Tipulidae, Ancylidae, Bulinae, Lymnaeidae, Planorbinae, Thiaridae, Corbiculidae, Sphaeridae and Unionidae.

Physical-chemical:

Historical physical-chemical data indicated high salt concentrations linked to irrigation return flows from the Riet River Irrigation Scheme. Therefore, the reference condition was determined from the diatom data. The diatoms indicated elevated electrolyte concentrations and turbidity. Lower electrolyte concentrations are expected to have been prevalent at the site under reference conditions.

Site Description (based on previous surveys)

The site is downstream of the Modder River confluence and the small farming town of Modderrivier. There are two dams upstream, the Krugersdrif Dam on the Modder River (~140 km upstream), north of Bloemfontein, and the Kalkfontein Dam (~80 km upstream) on the Riet River SSE of Koffiefontein. The site is in the Mokala National Park with intensive irrigation of crops upstream on the banks of both the Modder and the Riet Rivers.

At the most recent assessment (not from this study), the river was approximately 40-50 m wide with turbid waters. The site was along a confined reach of the Riet system and was largely controlled by bedrock. The channel was straight to wandering with localised anastomosing sections. Sand bars were present along the pools. Inset benches and flood features were narrow with no flood plain. The bedrock formed steeper riffles and rapids interspersed by long pools. Boulders, cobble and gravel were present along the riffles and rapids, with fine sediment or bedrock dominating the pools.

Site evaluation

The site was not evaluated in this study. A site evaluation based on previous sampling at the site indicated that the site was bedrock-controlled with *Phragmites sp.* reeds along the river banks at the time of sampling (2021; Table B-10-32).

Table B-10-32: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring based on previous sampling at the same site (this site was not sampled during this study).

Advantages	Limitations
• Site located within a Nature Reserve.	• The stream bed is dominated by bedrock with limited GSM. The banks lined with Phragmites sp. (ORASECOM, 2023a).

Site impacts

The impacts on the site were upstream settlements, agriculture, cattle activity, irrigation, and the upstream large dams and numerous abstraction weirs.

Wastewater:

The EWR_09_I site had the second largest number of WWTW, for which there were data, in the catchment upstream that may have bearing on the site's water quality. Of these, ten had GD scores <31 % in 2021, indicating they are dysfunctional and critically failing (DWS, 2022). A further nine were <36 %, showing that most of the WWTW in the catchment are experiencing severe issues and critically failing. The pattern of ten WWTW showing drops in their GD scores of >40 % from 2013 to 2021 is particularly concerning, demonstrating a trend of dramatic worsening in performance over the last decade.

There is also a lack of data from many of the WWTW in the catchment in terms of the volume of wastewater treated, which are critical data for assessing the impact of the WWTW to river flow and water quality. However, from the data there are, there is evidence that several of the works are operating far above capacity (Sterkwater at 164 % capacity and Ritchie at 200 % capacity in 2013), while many have *decreased* the volume treated in 2021 (Sterkwater and Beaconsfield showing 36 % and 26 % reductions in daily volumes treated, respectively). Cumulatively, the reductions in volume treated (for the few WWTW with comparable volume data between 2013 and 2021) amounted to 2.62 million L/day less being treated at four WWTW that showed reductions.

There are six municipalities in the catchment likely to affect the site, and which had data available. The Kopanong and Mangaung municipalities have been discussed above. The Letsemeng municipality recorded poor monitoring compliance (33 %), zero compliance for the chemical parameter, and just 4 % for the microbiological. Masilonyana reported fair compliance across the board, with 100% microbiological compliance. The Tokologo municipality reported zero compliance for all parameters, showing a lack of any data. Sol Plaatjie reported fair monitoring and physical compliance, though chemical compliance was poor (31 %) and microbiological compliance was reported as zero percent.

Overall, the status of WWTW in the catchment above the site suggest serious issues with wastewater management that are likely to severely compromise the water quality in the system.

Agriculture:

The site was characterised by the largest agricultural profile upstream (32.3 %), with the largest proportion irrigated (21.5 %) by a considerable margin. The huge agricultural profile above the site makes it highly likely that the water quality at the site will show a strong signal related to nutrient loading and erosion associated with intensive irrigated agriculture especially.

In-situ water quality and diatoms

The dominant diatom species at the site in July 2022 was:

- *Gomphonema pumilum*: A species that indicates strongly polluted water, high electrolytes, and some siltation.

The dominant diatom species at the EWR site in May 2023 was:

- *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin:* Tolerant of strong pollution, and an indicator of industrial organic pollution.

At the EWR site in 2023, the SPI = 9.8 indicated moderate water quality, %PTV = 62.2 % indicated heavy contamination with organic pollution, while the number of deformed cells was <2 %, suggesting little to no harmful pollutants within the water column. The *in situ* water quality results are shown in Table B-10-33.

Table B-10-33: *In situ* water quality measurements and diatom sampling results**.**

Water quality component		***In situ water quality parameters***								
In situ water quality	*Assessment*	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)
	JBS3 (October 2021)	8.8	321	0.112	10.1	-	12	20.5	-	-

PES (Results used and interpreted from JBS3)

Macroinvertebrate PES = C (65.4%; moderately modified), for flow and no-flow conditions:

The Lower Riet River was not surveyed for this study. Information from the Vaal comprehensive study (Vaal_EWR19), JBS3 conducted in 2021 (ORASECOM, 2023a), and the DWS REMP site (C5RIET-DEKRA) were used in place of a survey. Based on REMP, JBS1 (2010), and JBS3 (2021), the aquatic macroinvertebrate community consistently exhibited moderate modification (PES = C). However, JBS2 (2015) indicated slightly better conditions (PES = B/C). Previous assessments found that the taxa most affected were those that preferred very fast flowing and standing water. Taxa with low preferences for unmodified water quality were less affected. The JBS3 assessment of the site found a SASS5 score of 120 and an ASPT of 6, indicating a predominance of tolerant taxa (Dickens and Graham, 2002).

Physical-chemical PES = C (moderately modified), for no-flow conditions:

The most recent physical-chemical data for the site were from RQS records ending in 2018, which did not reflect the current conditions at the site. The diatom results indicated high electrolyte content, which was congruent with the historical data at the site. The high electrical conductivities at the site are likely a result of irrigation return flows from the Riet River Irrigation Scheme.

<u>Drivers of macroinvertebrate PES</u>

In JBS3, water quality, habitat, and flow modification were similarly impacted at the site. The higher flows during JBS3 compared to JBS2 resulted in reduced sampling effort, leading to minor differences in category assignments during those surveys (ORASECOM, 2023a). The water quality at the site was estimated to be largely affected by nutrient enrichment from the upstream agriculture and town. Eutrophication was evident at the site, with algal growth on the bedrock and boulder habitats and filamentous algae in the water column.

<u>PES Trends</u>

The PES trend for the macroinvertebrates and physical-chemical condition was unclear.

Due to the high flows at the time of the JBS3 assessment, it was difficult to determine PES trends. However, it was likely that the trend would be stable, since no significant changes are apparent in the system over the course of the last decade of monitoring.

Similar to measurements at other sites low down in the Upper Orange River catchment, previous site observations have indicated turbid water, suggesting high suspended solids and low clarity in the system. Elevated pH was also recorded in the JBS3 survey.

UO_EWR10_I: Lower Orange

Information availability

There were some data over the last decade for the macroinvertebrates within the system. Diatom data from JBS3, which had the site OSEAH 26_3 at the same location as this EWR site, were available. Physical-chemical data extended back to 1966 in the NCMP database, supplemented by GD data over the last decade for the WWTW in the system (Table B-10-34).

Table B-10-34: Table indicating the availability of historical information on the macroinvertebrates, benthic diatoms, and physical-chemical water conditions for the UO_EWR10_I: Lower Orange site.

Water quality component	Historical information sources available
Macroinvertebrates	• REMP river database. • PESEIS (2014). • JBS3 ORASECOM site OSAEH 26_3 (2021). • May 2023 (this study).
Diatoms	• JBS3 ORASECOM (2021). • May 2023 (this study).
Physical-chemical	• GD Reports (2011, 2013, 2021 and 2022). • JBS3 ORASECOM (2021). • NCMP data (1966 to 2018, n = 1397).

Description of reference conditions

Macroinvertebrates:

The taxa expected under reference conditions were: Porifera, Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Baetidae >2spp, Caenidae, Heptageniidae, Leptophlebiidae, Prosopistomatidae, Trichorythidae, Chlorocyphidae, Coenagrionidae, Lestidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Naucoridae, Nepidae, Notonectidae, Pleidae, Veliidae, Ecnomidae, Hydropsychidae >2spp, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Ephydridae, Muscidae, Simuliidae, Tabanidae, Ancylidae, Lymnaeidae, Thiaridae, Corbiculidae and Sphaeridae.

Physical-chemical:

Reference condition for the site was determined using the DWS RQS data for site D3H008Q01 (1967 to 1980, n =163).

- pH: The reference data indicated that the 5th percentile was 6.7 pH units and the 95th percentile was 8.0 pH units. These values both fell within the Natural (0) rating according to DWA (2008). Therefore, the DWA (2008) Natural (0) rating for pH was used.
- EC: The reference data indicated that the 95th percentile for the site was 27.34 mS/m, which fell within the 30 mS/m Natural (0) benchmark according to DWA (2008).
- Temperature: No historical temperature records were available for the site. DWA (2008) benchmark tables were used for a low confidence, qualitative assessment of temperature reference condition.
- Clarity: There were no clarity / turbidity records available for reference condition assessment. Reference condition was taken as that qualitatively described in the DWA (2008) benchmark tables.
- Oxygen: No dissolved oxygen records are available for this site. DWA guideline benchmark tables (2008) have been utilised to characterise the site's reference condition.
- TIN: Reference data indicated a 50th percentile of 0.16 mg/l, which fell within the DWA (2008) Natura (0) rating of 0.25 mg/l.
- PO_4: The reference data indicated a 50th percentile 0.014 mg/, which fell outside of the DWA (2008) Natural (0) rating of 0.005 mg/l. Consequently, the natural PO_4 rating of the site was benchmarked at $PO_4 \leq 0.014$.
- Fluoride: In terms of the toxics listed within the DWA (2008) rating tables, only fluoride was monitored. The 95th percentile for fluoride was calculated as 0.29 mg/l which fell within the DWA (2008) benchmark table.

Site Description

This EWR site is located approximately 13km south-west of Douglas, 12km upstream of the confluence with the Vaal River and 2.5km downstream of Marksdrift weir. Vanderkloof Dam is located approximately 175km upstream, with Gariep Dam positioned further upstream (approximately 55km upstream of Vanderkloof Dam).

It was defined by an incised macro-channel of ~160m wide. The channel had a straight to sinuous platform with pool-riffle and poolrapid reach types. The riffles had cobble and gravel sediment, with bedrock and boulders forming the rapids. The pools were longer than the riffles and had sand bars and lateral bars in places. Islands had formed on bedrock with sedimentary coverings. The banks were steep due to the incised nature of the river and composed of fine silt and sand.

Up until 2020, the site was characterised by several small to medium islands covered by dense reeds and sedges, with a braided network of pools and runs. These channel features had become covered by sediments deposited during recent floods. The active channel was more confined to the mainstem, with the exception of two side channels along the left bank. The aquatic macroinvertebrate biotopes included SIC, SOOC and GSM. All marginal vegetation had been removed by recent floods, although there was evidence of pockets of reeds beginning to establish.

Site evaluation

The site had some variability in habitat for sampling. However, the site was largely homogenous and lacked vegetation for sampling. The boulders were also generally armoured, impeding sampling (Table B-10-35).

Table B-10-35: Table showing the advantages and limitations of the site's suitability for assessment of water quality via diatom and aquatic macroinvertebrate biomonitoring.

Advantages	Limitations
• SIC, SOOC and GSM habitats were present. • Small pocket of boulders.	• Wide homogenous channel. • Limited aquatic biotopes – dominated by muddy substrate. • Boulders highly embedded. • No marginal vegetation – bare banks. • High sediment deposition.

Site impacts

The impacts on the sites were agriculture, cattle activity, irrigation, and the changed flow regime due to releases from upstream dams for water use in the lower Orange River and estuarine requirements. The primary land-use in the surrounds was irrigated agriculture/cultivation, principally centre pivots and peacan nut orchards. Water is also abstracted and pumped from the Orange River at Marksdrift and transferred to Douglas Weir on the Vaal River, which is 23.5km upstream of the confluence. This water transfer scheme is used mainly for irrigation and to improve the water quality in the lower Vaal River.

Wastewater:

The EWR_10_I site had the most WWTW, for which there were data, in the catchment upstream. This included 46 WWTW across 13 municipalities. Many of these have been discussed above. Notably, 21 of these had GD scores <31 % in 2021, indicating a huge problem with dysfunctional and critically failing WWTW in the catchment (DWS, 2022).

Of these, ten had GD scores <31 % in 2021, indicating they are dysfunctional and critically failing (DWS, 2022). A further nine were <36 %, showing that most of the WWTW in the catchment are experiencing severe issues and critically failing. The pattern of ten WWTW shows drops in their GD scores of >40 % from 2013 to 2021 is particularly concerning, showing a trend of dramatic worsening in performance over the last decade.

According to NIWIS, several of the municipalities did not have compliance data, reporting zero across all parameters. However, the picture across the catchment was that where there were data, the compliance was very low, signalling a serious, systematic failure in wastewater management, including treatment and reticulation. This is likely to compromise water quality throughout the catchment, causing nutrient loading and eutrophication, in addition to various other associated negative effects.

However, the upstream large dams of Vanderkloof and Gariep, would have provided some reset and processing of these inputs of poorly performing WWTW and sewage return flows. As such it will only really be the remaining WWTW downstream of the last large dam, Vanderkloof, that would have had the potential to significantly impact on the water quality picture. As such these were assessed accordingly as they affect this lower Orange site.

Agriculture:

The land use upstream of the site showed that cultivation made up approximately 7 % of the land use proximate to rivers in the catchment, most of which was irrigated (6.2 %). As such, there is likely to be a significant signal of agricultural impacts on water quality throughout the catchment, particularly through irrigation water return flows.

In-situ water quality and diatoms

The dominant diatom species at the species at the EWR site in May 2023 was:

- *Nitzschia liebetruthii Rabenhorst*: A cosmopolitan species found in very electrolyte-rich to brackish water.

At the EWR site in 2023, the SPI = 7.8 indicated poor water quality, %PTV = 80.3 % indicated heavy contamination with organic pollution, but the number of deformed cells was 0 %, suggesting little to no harmful pollutants within the water column (Table B-10-21). The *in situ* water quality results are shown in Table B-10-21, with the high conductivity congruent with the dominance of the above diatom species.

Table B-10-36: *In situ* water quality measurements and diatom sampling results.

Water quality component		***In situ water quality parameters***								
In situ water quality	*Assessment*	pH (pH units)	Electrical conductivity	Total dissolved solids (TDS; g/l)	Dissolved oxygen (DO; mg/l)	DO (%)	Clarity (cm)	Temperature (°C)	Salinity (dS/m)	Discharge (m^3/s)

Water quality component		*In situ water quality parameters*								
	Survey 2 (May 2023) at EWR site	8.17	217.5	0.18	9.64	91.9	24	13.2	0.14	63.71
Diatoms*		*Outcomes of diatom survey*								
		no. of species	SPI**	Categorisation (quality)	%PTV***	Deformed cells				
	Survey 2 (May 2023) at EWR site	29	7.8	D (Poor)	80.3	0				

**Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2.*
***Specific Pollution sensitivity Index (SPI; >17: A-high water quality; 1B-17: B-good water quality; 9-13: C-moderate water quality; 5-9: poor water quality; and <5: E seriously modified water quality (adapted from Eloranta & Soininen, 2002)).*
****The percentage of pollution tolerant valves (%PTV; <20: site free from organic pollution; 21-40: some evidence of organic pollution; 41-60: Organic pollution likely to contribute significantly to eutrophication; and >61: Site is heavily contaminated with organic pollution (adapted from Kelly, 1998)).*

PES

Macroinvertebrate PES = D (50.4%; largely modified), for flow and no-flow conditions:

During the May 2023 survey, a total of 7 taxa were recorded, all of which exhibited a preference for low to moderate water quality, cobbles, and varying hydraulic conditions. All biotopes were accessible for sampling, except for marginal vegetation, which was completely absent. Consequently, it was unsurprising that taxa with a high preference for vegetation, such as Coenagrionidae, Belostomatidae, Dytiscidae, and Lymnaeidae, were not recorded. There was also an absence or low abundance of flow-dependent taxa, such as Baetidae (only 1 species recorded), Leptophlebiidae, and Elmidae (only 1 individual recorded), indicating the influence of water level fluctuations prior to sampling. Oligochaeta and Gomphidae were also absent, with just 1 individual of Corbiculidae recorded in the sand-dominated substrate, showing the sand habitats were also disturbed. There was generally a noticeable impact on the macroinvertebrate community, characterised by low diversity and abundance of expected families.

The SASS5 scores were 82 and 46 (average SASS5 score = 64) and the ASPT were 5.13 and 6.6 (average of 5.9) for the July 2022 and May 2023 surveys, respectively. These indicated the community was mostly composed of tolerant taxa (Dickens and Graham, 2002).

The results of this survey represent a significant change from previous surveys conducted by DWS REMP, as well as the JBS3 survey in 2021 (prior to the major La Nina floods), where the macroinvertebrate community consistently exhibited moderately modified conditions (PES = C).

Physical-chemical PES = D (largely modified), for no-flow conditions.

The physical-chemical PES at the site was inferred from the diatom results, since the RQS data only went up to 2018. The diatoms indicated very electrolyte-rich to brackish water, likely as a result of the irrigation return flows in the system which appeared to be the major physical-chemical driving factor. Historical data also showed that salinities in the system started increasing in the mid-1990s, corresponding with the increase in irrigated agriculture/cultivation in the area.

Drivers of macroinvertebrate PES

Flow modification was the primary driver of the MIRAI category of a D – largely modified (Table B-10-37). Generally, fluctuations in flow at this site are related to hydro-peaks caused by hydropower operations, as well as upstream abstraction activities and agricultural practices near Douglas. However, the primary effect on the 2023 survey in this study was the flood event that proceeded sampling. The flood was responsible for removing the marginal vegetation habitat, significant sediment deposition and the formation of sandbars, and disruption of the GSM habitats. There was insufficient time for recolonisation before sampling. The hydropeaking may also be responsible for constant flux that never allows the system to recover from flooding events.

Table B-10-37: Results of aquatic macroinvertebrate assessment, showing the calculated ecological category (EC; % and summary EC).

	Metric results					**EC**	
Aquatic macroinvertebrate metric	*Score*	*Weight*	*Weighted score*	*Metric Rank*	*% Metric Weight*	*EC (%)*	*EC*
Flow modification	47.9	0.357	17.122	1	100		
Habitat	49.0	0.304	14.885	3	85		
Water quality	53.7	0.321	17.267	2	90		

	Metric results					**EC**	
Connectivity and seasonality	60.0	0.018	1.071	4	5		
EC						50.35	**D**

PES Trends

Macroinvertebrates were in a stable condition (estimated with moderate confidence).

The PES trend was considered stable, since no new water resource impacts were envisaged. Once the continuous flood signal from the rains recedes, the site is expected to recover to a state similar to that recorded in previous assessments (PES = C) and remain stable at that level.

The physical-chemical state was in a stable condition (estimated with moderate confidence).

The site is expected to continue to adapt to the temperature and sediment changes along this reach associated with the hydropeaking, with ongoing responses to the continued run-off from adjacent agricultural activities. High salinities are prevalent in the system as a result of agricultural irrigation return flows. Prior to flooding the site had stabilised with these ongoing pressures. Similar to the macroinvertebrates, the site is expected to stabilise at pre-flood conditions.

Appendix C – Case study on the water quality issues in the Upper Orange Catchment