DEPARTMENT OF WATER AND SANITATION

Chief Directorate: Water Ecosystems Management

DETERMINATION OF WATER RESOURCE CLASSES AND ASSOCIATED RESOURCE QUALITY OBJECTIVES IN THE UPPER ORANGE RIVER CATCHMENT

ECOLOGICAL WATER REQUIREMENTS REPORT WP 11422

Study Report No.

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TERMINOLOGY AND ABREVIATIONS

Acronym	Description
BAEN	*Labeobarbus aeneus*
BBM	Building Block Methodology
BF	Baseflows
BHN	Basic Human Needs
BKIM	*Labeobarbus kimberleyensis*
DRIFT	Downstream Response to Imposed Flow Transformation
DRM	Desktop Reserve Model
DWS	Department of Water and Sanitation
EC	Ecological Category
EI	Ecological Importance
ES	Ecological Sensitivity
EWR	Ecological Water Requirements
F	Flow
FCS	Fast coarse sediment
FD	Fast deep
FFS	Fast fine sediment
FI	Fast Intermediate
FMP	Flow Management Plan
FRAI	Fish Response Assessment Index
FS	Fast shallow
FVS	Fast very shallow

Acronym	Description
GAI	Geomorphology Assessment Index
GSM	Gravel, Sand, Mud
HAI	Hydrology Assessment Index
HABFLO	Habitat Flow
HEC-RAS model	Hydrologic Engineering Centre-River Analysis System
HFSR	Habitat Flow Stressor Response
IHI	Integrated Habitat Integrity: instream
IUA	Integrated Unit of Analysis
JBS	Joint Basin Survey
Km^2	Square kilometres
LSR	large semi-rheophilic
MAR	Mean Annual Run-off
mg/L	Milligrams per litre
m.a.s.l	Meters above sea level
MIRAI	Macroinvertebrate Response Assessment Index
mS/m	Milli Siemens per meter
m^3/s	Cubic metres per second
NAT	Natural
NF	Non-flow
nMAR	natural Mean Annual Run-off
PAI	Physico-Chemical Assessment Index
PES	Present Ecological State
PRS	Present day

Acronym	Description
PTV	Pollution Tolerant Valves
ppt	Part per trillion
REC	Recommended Ecological Category
REMP	River Eco-Status Monitoring Programme
SADI	South African Diatom Index
SCS	Slow coarse sediment
SD	Slow deep
SIC	Stones-In-Current
SFS	Slow fine sediment
SoNAR	Sound navigation and ranging/ sonic navigation and ranging
SPI	Specific Pollution Index
SS	Slow shallow
SVS	Slow very shallow
SQ	Sub-quaternary
TDI	Trophic Diatom Index
TIN	Total Inorganic Nitrogen
UAV	Unmanned Aerial Vehicle
VEGRAI	Riparian vegetation assessment index
VFCS	Very fast coarse sediment
VFFS	Very fast fine sediment
VSFS	Very slow fine sediment
VSCS	Very slow coarse sediment
WEM	Water Ecosystems Management

Acronym	Description
WMA	Water Management Area
WRCS	Water Resource Classification System
WRYM	Water Resource Yield Model
WRPM	Water Resource Planning Model
WWTW	Wastewater Treatment Works
°C	Degrees Celsius
%	Percentage
%MAR	Percentage mean Annual Runoff

EXECUTIVE SUMMARY

The Chief Directorate: Water Ecosystems Management (WEM) of the Department of Water and Sanitation (DWS) initiated a study for the determination of Water Resource Classes and associated Resource Quality Objectives in the Upper Orange River catchment in October 2023.

The purpose of this study is to coordinate the implementation of the determination of water resource classes and associated resource quality objectives for all significant water resources as part of implementing the Water Resource Classification System (WRCS) in the Upper Orange River catchment.

The determination of the water resource classes is necessary to facilitate a balance between protection and use of water resources. In determining the class, it is important to recognise that different water resources will require different levels of protection which requires due consideration of the social and economic needs of competing interests by all who rely on the water resources. The classification process is applied taking account of the local conditions, socio-economic imperatives, and system dynamics within the context of the catchment, and in the case of the Upper Orange River catchment, will consider aspects related to the Lower Orange River catchments as well as the Vaal River System, as they are all integrated. The process will therefore also require a wide range of complex trade-offs to be assessed and evaluated.

The purpose of this report is to set out the results of the quantification of ecological water requirements (EWR) and describes the approaches, methods and models used to determine the EWR for priority rivers in the Upper Orange River catchment, at sites selected per Integrated Unit of Analysis (IUA). These determinations are at various levels of detail as described in volume 3 of the RDM methodology of 1999 (DWAF, 1999). Where available and applicable, information from the recently completed Reserve study, based on site visits undertaken in October 2021, July 2022 and April/ May 2023 (DWS, 2023), has been used and updated with new information from field surveys undertaken In October 2024.

In addition, a 2-D hydraulic survey was undertaken at EWR site UO_EWR10_I to provide the ecologists with enhanced contextual data, enabling more informed decisions in quantifying the EWR for this site. The flows used July to October maintenance low flows of 30.0 m^3/s, February maintenance low flows of 63.9 m^3/s, drought flows with a minimum of 8.900 m^3/s for April to December and 25.0 m^3/s for January to March, and floods and freshets of 65 m^3/s, 155 m^3/s and 550 m^3/s. A hydraulic survey was also undertaken at a site between the two dams that will inform the Flow Management Plan (FMP) that was put forward during the Reserve study.

Table E-1: Summary of sites selected per IUA for the scenarios assessment

IUA		EWR sites to be used for scenarios	River	QC	Level	Coordinates		PES	REC	nMAR ($10^6 m^3$)	Catchment area (km^2)
						Latitude	Longitude				
1	**Golden Gate**	UO_EWR 01_R	Little Caledon	D21D	Rapid	-28.557796	28.405709	C	B/C	25.9	252
2	**Caledon/ Leeu River**	UO_EWR 01_I	Middle Caledon	D22D	Intermediate	-28.9089	27.785	E	D	674.0	5 185
3	**Caledon River**	UO_EWR 04_I	Lower Caledon	D24G	Intermediate	-30.436136	26.299258	D	C/D	1 353.6	18 544
4	**Kraai River**	UO_EWR 08_I	Kraai	D13M	Intermediate	-30.69007	26.74157	C	B/C	719.0	9 354
5	**Upper Orange River**	UO_EWR03_I	Upper Orange	D12F	Intermediate	-30.652793	26.823213	D	D	4 259.5	27 578
6	**Gariep Dam**	UO_FMP	Orange	D34E	Field verification	-30.503677	25.200574	D*	D*		
7	**Seekoei River**	UO_EWR05_I	Seekoei	D32J	Intermediate	-30.534359	24.962895	C	C	24.3	8 319
8	**Vanderkloof Dam**	UO_EWR10_I	Orange	D33K	Intermediate	-29.16202	23.695944	C	C	6 674.2	99 297
9	**Upper Modder River**	UO_EWR07_I	Upper Modder	C52B	Intermediate	-29.160017	26.572492	D	C	61.0	1 696
10	**Modder-Riet Rivers**	UO_EWR06_I	Upper Riet	C51F	Intermediate	-29.535065	25.52457	C	C	105.2	5 247
		UO_EWR09_I	Lower Riet	C51L	Intermediate	-29.03842	24.50283	C	B/C	373.8	33 785

Table E-2: Summary of overall EWR outcomes per EWR site per IUA

River	Little Caledon	Middle Caledon	Lower Caledon	Kraai	Upper Orange	Orange River	Seekoei	Orange	Upper Modder	Upper Riet	Lower Riet
EWR Site Code	UO_EWR 01_R	UO_EWR 01_I	UO_EWR 04_R	UO_EWR 08_R	UO_EWR 03_I	FMP site	UO_EWR 05_I	UO_EWR 10_I	UO_EWR 07_I	UO_EWR 06_I	UO_EWR 09_I
IUA	1	2	3	4	5	6	7	8	9	10	
Driver Component	PES	PES	PES	PES	PES	PES	PES	PES	PES	PES	PES
Integrated Habitat Integrity: instream (IHI)	B	C	C	B	D	Not assessed	B/C	C/D	C/D	C	C
Integrated Habitat Integrity: riparian (IHI)	B	D	C	C	C	Not assessed	C	C/D	D	C	C
Response Components	PES	PES	PES	PES	PES	PES	PES	PES	PES	PES	PES
Diatoms (SPI)	C	D	D	C	C	C	C	D	D	D	C
Fish (FRAI)	D	D	D	C	D	C/D	C	B/C	C	C	C
Macroinvertebrates (MIRAI)	D	C	D	C	C/D	C	C	D	D	C	C
Riparian Vegetation (VEGRAI)	B/C	E	D	D/E	D	D	B/C	C	D	C	B
EcoStatus	C	E	D	C	D	D	C	C	D	C	C
Ecological Importance (EI)	High	Moderate	Moderate	High	Moderate	High	Moderate	Moderate	Low	High	Very High
Ecological Sensitivity (ES)	High	Moderate	Moderate	High	Moderate	High	Moderate	Moderate	Moderate	Moderate	High
Recommended Ecological Category (REC	B/C	D	C/D	B/C	D	D	C	C	C	C	B/C

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1 INTRODUCTION

1.1. Background

The Chief Directorate: Water Ecosystems Management (WEM) of the Department of Water and Sanitation (DWS) is presently undertaking a study to determine Water Resource Classes and associated Resource Quality Objectives in the Upper Orange River catchment which falls within the Vaal-Orange Water Management Area (WMA 04).

Water Resource Classification, the Reserve and Resource Quality Objectives (RQOs) are protection-based measures that make up Resource Directed Measures (RDM), the protection principles contained in Chapter 3 of the National Water Act (Act No. 36 of 1998). Resource Directed Measures are intended to ensure comprehensive protection of all water resources. Protection relates to the quantity and quality (overall health) of the water resource. An important consideration in the determination of RDM is that they should be technically sound, scientifically credible, practical, and affordable. Once the water resource class and the Reserve have been established, RQOs are determined to give effect to those water resource classes and the Reserve. The DWS has progressively set water resource classes for all significant water resource systems in South Africa to ensure their protection and sustainable use and the Orange River System (ORS) is the last system that requires classification and setting of RQOs.

The Upper and Lower River catchments studies are being undertaken separately, however in parallel, with continuous liaison.

1.2. Study Objective

The main objective of this study is to coordinate the implementation of the determination of water resource classes and associated resource quality objectives for all significant water resources in the Upper Orange River catchment within the Vaal-Orange Water Management Area (WMA04) as described in the revised reconfiguration that was gazetted as part of the National Water Resources Strategy 3 (NWRS3) under Gazette Notice 49225, dated 1 September 2023, in accordance with the Water Resource Classification System (WRCS)(DWA, 2010), and determine the associated RQOs for the prioritised units.

This is aimed at facilitating the management and regulation of water resources to ensure efficient and sustainable use, a balance between protection and use, while maintaining ecological integrity and specifically maintaining or improving the present ecological state (PES) of the water resources, in the Upper Orange River catchment.

Appropriate integration with water resource planning and management processes, as well as cooperation among stakeholders, will be key success factors in setting the water resource classes and RQOs. The outcomes of the process will result in the protection framework for the catchment that will guide actions, interventions, and needs, to ensure a sustainable water resource system that is able to balance water use and protection.

1.3. Purpose of this Report

This report relates to the quantification of ecological water requirements (EWR) and describes the approaches, methods and models used to determine the EWR for priority rivers in the Upper Orange River catchment, at selected sites. These determinations are on the various levels of detail as described in volume 3 of the RDM methodology of 1999 (DWAF, 1999). Where available and applicable, information from the recently completed Reserve study (DWS, 2023) have been used and updated with new information from field surveys undertaken in October 2024.

2 STUDY AREA AND EWR SITES

The study area is the Upper Orange River catchment and comprises the Upper Orange and part of the Vaal River catchments within the Vaal-Orange Water Management Area (WMA04).

The Upper Orange River catchment comprises four sub-catchments stretching across the Northern Cape, Free State and Eastern Cape provinces and across three ecoregions, the Eastern Escarpment Mountains, Nama Karoo and Highveld (Figure 1):

- The Caledon River from its headwaters and its tributaries to the Gariep Dam (Secondary catchment D2)
- The Orange River from the Lesotho Border to the Gariep Dam, including the main tributaries namely Kornetspruit, Sterkspruit, Stormbergspruit and Brandwaterspruit, and the Kraai River catchment (D1 secondary catchment), and
- The Orange River from the Gariep Dam, through Vanderkloof Dam to Marksdrift weir, just before the confluence with the Vaal River, including the Seekoei River in the south (D3 secondary catchment), and
- The Modder-Riet River (main tributaries of the Vaal River system) in the north (C5 secondary catchment). Although the Modder/Riet rivers are tributaries to the Vaal River, this catchment and related sub-systems are seen as part of the Orange River System due to transfers and support from the Orange to the Modder/Riet catchment.

The sub-catchments, associated rivers, catchment areas and quaternary catchments are listed in Table 1 and illustrated in Figure 1.

Table 1: Sub-catchment areas of the Upper Orange River catchment

Secondary Catchment	Tertiary Catchment	Quaternary catchments	Main River/(s)	Catchment area[(1)] (km^2)	
				Gross	Net
C5	C51	C51A – H, C51J - M	Fouriespruit, Ruisterspruit, Ospoortspruit, Kromellemboogspruit, Rietspruit	17 449	12 166
	C52	C52A – H, C52J - L	Wildebeesspruit,	17 366	8 572

Secondary Catchment	Tertiary Catchment	Quaternary catchments	Main River/(s)	Catchment area[(1)] (km^2)	
				Gross	Net
			Sepane River, Osspruit, Modder River		
D1	D12	D12A - F	Winnaarspruit, Kromspruit, Wilgespruit	2 967	2 967
	D13	D13A – H; D13J - M	Bell River, Langkloofspruit, Dierspruit, Wasbankspruit, Holspruit, Skulpspruit, Kraai River	9 354	9 354
	D14	D14A – H, D14J and K	Orange River	6 145	6 145
	D15	Portions of D15G and H	Makhaleng River (lower reaches shared with Lesotho), Unnamed tributaries	846	846
	D18	Portion of D18L and K	Tele River (shared with Lesotho), Blikana River	1 545	1 545
D2	D21	D21D, D21E, D21F, D21G, portion of D21A and D21H	Caledon River Little Caledon River	1 659	1 659
	D22	D22A, D22B, portions of D22C and D22D, D22G, portions of D22H and D22J	Meulspruit, Brandwater/ Groot River, Rantsho River, Mopeli River	4 369	4 369
	D23	Portion of D23A, E, F and G; D23C, D23D, D23H, D23J	Montsoane River, Maseng River, Tsoaning River Leeu River, Retspruit	4 910	4 910
	D24	D24A – G, D24H, D24J - L	Witspruit, Wilgeboomspruit, Grahamstadspruit, Slykspruit, Edon River, Skulpspruit	6 614	6 614
D3	D31	D31A - E	Berg River, Orange River,	4 910	4 396
	D32	D32A – H, D32J and K	Seeikoei River	9 081	9 081
	D33	D33A – D33K	Orange River	9 598	3 404

Secondary Catchment	Tertiary Catchment	Quaternary catchments	Main River/(s)	Catchment area[(1)] (km^2)	
				Gross	Net
	D34	D34A - G	Orange River	5 020	5 020
	D35	D35A – H, D35J and K	Brandspruit, Brakspruit, Bossiespruit, Suurbergspruit, Orange River	5 638	5 638

[1]WR2012 data

The Caledon River (also called the Mohokare River along the Lesotho/ South Africa border) forms the north-western boundary of Lesotho with South Africa and is the first major tributary of the Orange River with their confluence in the upper reaches of the Gariep Dam. Other large tributaries that contribute to the flow in the Upper Orange River catchment are the Makhaleng (although only the lower reaches within South Africa) and Kraai rivers. Although the Seekoei River has a large catchment, the runoff is very low as it forms part of the drier Karoo area.

The Modder and Riet rivers, tributaries of the Vaal River are also part of the study area due to the interconnectedness of these systems through water transfers.

The main storage dams in the Upper Orange River catchments are the Gariep and Vanderkloof dams on the Orange River. Smaller dams in the study area are the Welbedacht Dam in the Caledon River, Rustfontein, Mockes, and Krugersdrift Dams in the Modder River with the Tierpoort and Kalkfontein Dams in the Riet River. The Gariep Dam, Vanderkloof Dam, Orange-Fish Tunnel, Orange Vaal transfer canal and Orange-Riet Canal system are all part of the Orange River Project.

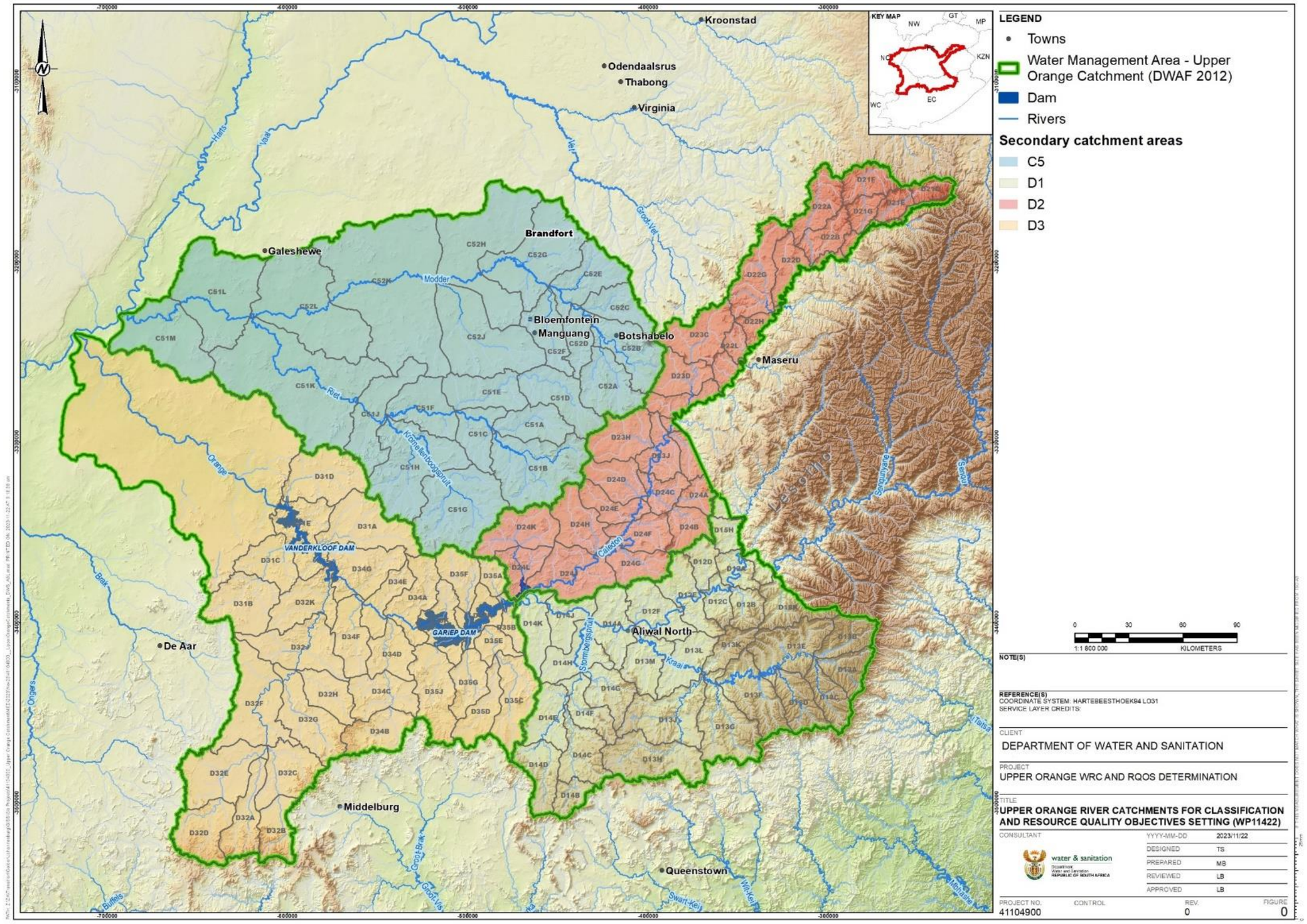


Figure 1: Upper Orange River catchment – Study Area extent and Locality (South African Portion)

The surveys included for the various levels of assessment are defined in Table 2. The Ecological Water Requirements sites (EWR) included in the Reserve study (DWS, 2023) are listed in Table 3, and illustrated in Figure 2 and comprise:

- 10 Intermediate sites
- 6 Rapid III sites,
- 25 Field verification sites, and
- Recommendations for the Flow Management Plan for the reach between Gariep and Vanderkloof dams have also been included.

Table 2: EWR Surveys per level of assessment

Surveys undertaken	Intermediate	Rapid III	Field verification	Desktop
Dry season survey	X	X		
Post-wet season survey	X			
Desktop PES/EI/ES from previous studies			X	
Hydraulics	X	X	X	
Fish	X	X	X	
Macroinvertebrates	X	X	X	
Riparian vegetation	X			
Rapid Habitat Integrity Assessment		X		
Geomorphology	X			
Hydrology	X	X	X	X
Water quality	X			
Diatoms	X	X		
Habitat Flow Stressor Response (HFSR) depending on specific conditions at the EWR site	X			
Desktop Reserve Model		X	X	X
Desktop PES/EI/ES, JBS3 or previous Reserve studies				X

Table 3: Final EWR sites per IUA in the Upper Orange River Catchment

EWR site code	River	Quaternary	Latitude	Longitude	Level
IUA 1: Golden Gate					
UO_EWR01_R	Little Caledon	D21D	-28.557796	28.405709	Rapid III
IUA 2: Caledon/ Leeu River					
UO_EWR01_I	Middle Caledon	D22D	-28.909102	27.784924	Intermediate

UO_EWR02_R	Brandwater (Groot)	D21G	-28.68034	28.139926	Rapid III
UO_EWR03_R	Mopeli	D22G	-29.101205	27.570751	Rapid III
UO_EWR01_FV	Meulspruit	D22B	-28.8857	27.83494	Field verification
IUA 3: Caledon River					
UO_EWR04_I	Lower Caledon	D24G	-30.436136	26.299258	Intermediate
UO_EWR10_FV	Skulpspruit	D24H	-30.2344	26.51134	Field verification
UO_EWR09_FV	Groenspruit	D24H	-30.24119	26.56130	Field verification
UO_EWR02_FV	Witspruit	D24C	-30.00826	26.928315	Field verification
UO_EWR16_FV	Slykspruit	D24L	-30.393003	26.120925	Field verification
UO_EWR22_FV	Tele	D18K	-30.448588	27.582337	Field verification
UO_EWR23_FV	Upper Orange	D12A	-30.398757	27.342987	Field verification
IUA 4: Kraai River					
UO_EWR04_R	Upper Kraai	D13E	-30.85179	27.77689	Rapid III
UO_EWR08_I	Lower Kraai	D13M	-30.69007	26.74157	Intermediate
UO_EWR04_FV	Karringmelkspruit	D13K	-30.811765	27.266497	Field verification
UO_EWR05_FV	Bokspruit	D13A	-30.811765	27.266497	Field verification
UO_EWR06_FV	Holspruit	D13J	-30.995316	27.056639	Field verification
UO_EWR07_FV	Sterkspruit, tributary of the Kraai	D13C	-30.917621	27.800753	Field verification
UO_EWR08_FV	Bell	D13B	-30.852601	27.786557	Field verification
UO_EWR17_FV	Langkloofspruit	D13D	-30.954126	27.606129	Field verification
UO_EWR18_FV	Wasbankspruit	D13G	-31.15554	27.284442	Field verification
IUA 5: Upper Orange River					
UO_EWR03_FV	Gryskopspruit	D12D	-30.339629	27.176878	Field verification
UO_EWR02_I	Sterkspruit	D12B	-30.5178445	27.3690799	Intermediate
UO_EWR03_I	Upper Orange	D12F	-30.6528889	26.8230496	Intermediate
UO_EWR24_FV	Makhaleng	D15G	-30.16412	27.398251	Field verification

UO_EWR05_R	Wonderboomspruit	D14E	-31.005262	26.341938	Rapid III
IUA 6: Gariep Dam					
Field visit site in Oct 2024	Orange River between Gariep and Vanderkloof dams	D34E	-30.503677	25.200574	Hydraulics
IUA 7: Seekoei River					
UO_EWR05_I	Seekoei	D32J	-30.534359	24.962895	Intermediate
IUA 8: Vanderkloof Dam					
UO_EWR10_I	Lower Orange	D33K	-29.16202	23.695944	Intermediate
IUA 9: Upper Modder River					
UO_EWR07_I	Upper Modder (Sannaspos)	C52B	-29.160017	26.572492	Intermediate
UO_EWR06_R	Middle Modder (Soetdoring)	C52H	-28.807191	26.109695	Rapid III
UO_EWR13_FV	Osspruit	C52E	-28.93917	26.511411	Field verification
UO_EWR14_FV	Hondeblaf	D31C	-30.205138	24.71803	Field verification
IUA 10: Modder-Riet Rivers					
UO_EWR06_I	Upper Riet	C51F	-29.535065	25.52457	Intermediate
UO_EWR09_I	Lower Riet	C51L	-29.03842	24.50283	Intermediate
UO_EWR26_FV	C51L	Lower Riet	-29.005676	23.942121	Field verification
UO_EWR11_FV	Fouriespruit	C51A	-29.671211	26.074393	Field verification
UO_EWR12_FV	Renoster	C52F	-29.11632	26.328701	Field verification
UO_EWR15_FV	Tributary of VanZylspruit	C51G	-30.031203	25.786463	Field verification
UO_EWR19_FV	Lower Modder	C51K	-28.89166	25.656445	Field verification
UO_EWR20_FV	Upper Kromellenboog	C51G	-30.066282	25.681056	Field verification
UO_EWR21_FV	Lower Kromellenboog	C51H	-29.65360	25.43507	Field verification

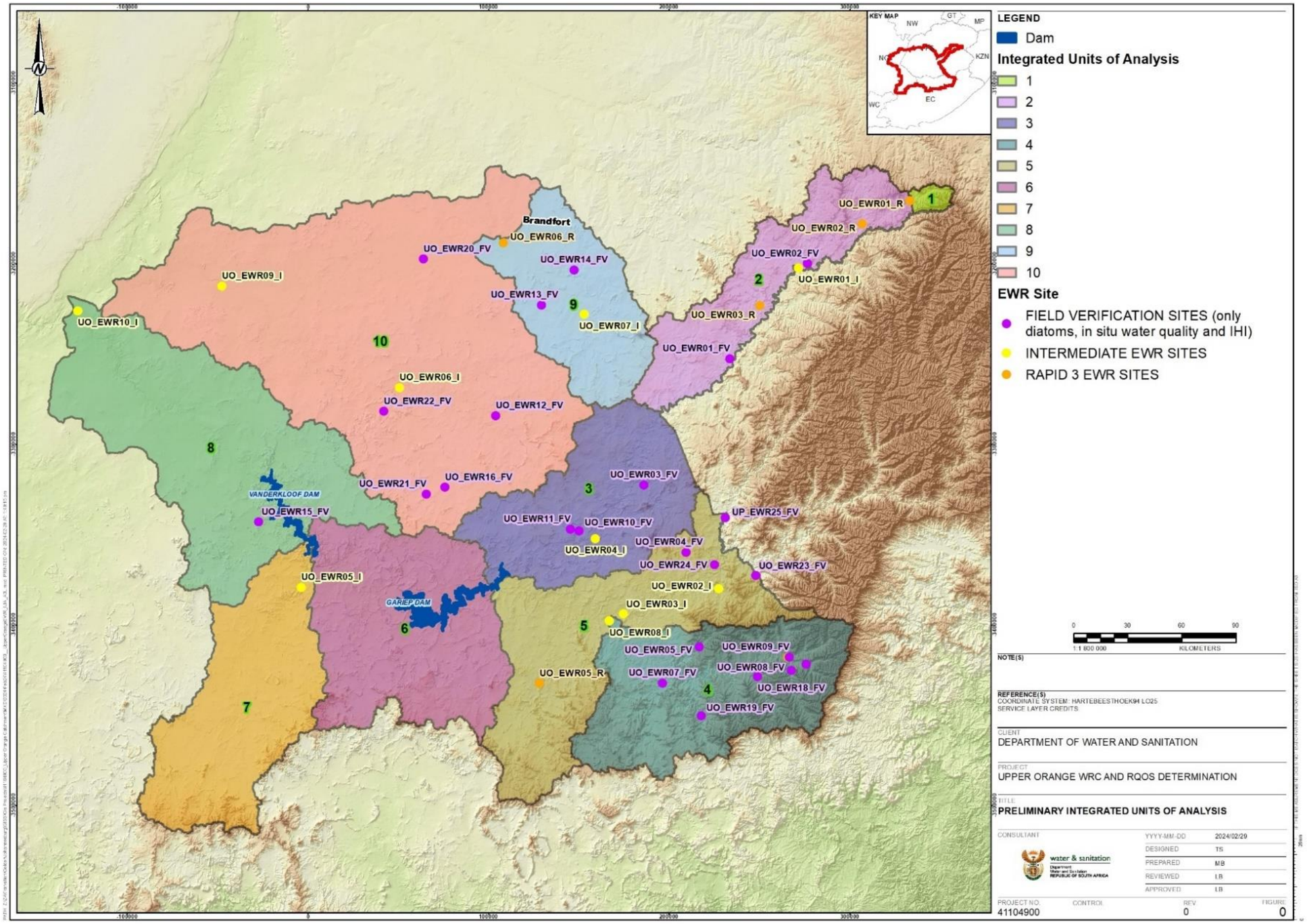


Figure 2: Location of EWR sites per IUA in the Upper Orange River catchments

2.1. Approach to EWR Quantification

The assessments undertaken for the High Confidence Reserve Study completed in February 2024 were used. The quantification of the ecological water requirements for the Reserve study included:

- Existing data for the EWR sites,
- Information collected through field surveys during October 2021, July 2022 and April/ May 2023,
- Results from the Eco-categorisation process (Present Ecological State (PES), Ecological Importance (EI), Ecological Sensitivity (ES) and Recommended Ecological Category (REC)),
- Habitat Flow Stressor Response (HFSR) and Desktop Reserve Model (DRM)/ Revised DRM within SPATSIM for the integration of data produced from the surveys and Eco-categorisation to quantify the EWRs. The most applicable approach was selected depending on the specific conditions at the EWR site and impacts in the upper catchments,
- Results from the hydraulic modelling (cross-sectional profile and discharge) to evaluate the requirements; and
- Baseflow separation undertaken for the intermediate and Rapid III sites using the approach developed by Smakhtin (2001). This provides an indication of the groundwater contribution to surface flows without the influence of high flows (freshets and floods) and assists the ecologists with the setting of baseflows (maintenance low) for the rivers.

In October 2024, a Rapid III survey, which included a 2-D hydraulic survey and the collection of diatoms and physico-chemical water quality samples, was undertaken at the existing EWR site UO_EWR10_I (Orange River at Marksdrift). The aim of the 2-D hydraulic survey was to provide ecologists with enhanced contextual data, enabling more informed decisions in quantifying the EWR for this site.

Furthermore, diatoms and physico-chemical water quality samples were also collected at a site (UO_EWR26_FV) located downstream of UO_EWR09_I in the lower Riet River at co-ordinates: -29.005676; 23.942121 and a new site on the Vaal River, UO_EWR27_FV at co-ordinates: -29.051455; 23.766012. Although this site is in the Vaal catchment, the water quality data will be valuable for understanding the inflows into the Lower Orange Catchment area from the Vaal River.

Additionally, hydraulic data was collected at a site between the Gariep and Vanderkloof Dams at coordinates: -30.50367; 25.200574. The results from this survey will inform the Conceptual Flow Management Plan produced during the Upper Orange Reserve determination (Report No. RDM/WMA13/00/CON/COMP/1323).

Table 4 summarises the eco-categorisation results for EWR sites in the Upper Orange River catchment.

Table 4: Summary of eco-categorisation results for EWR sites in the Upper Orange River catchment

EWR site	Quaternary	River	Latitude	Longitude	PES	EI	ES	REC	Level
IUA 1: Golden Gate									
UO_EWR01_R	D21D	Little Caledon	-28.557796	28.405709	C	High	High	B/C	Rapid III
IUA 2: Caledon/ Leeu River									
UO_EWR01_I	D22D	Middle Caledon	-28.909102	27.784924	E	Moderate	Moderate	D	Intermediate
UO_EWR02_R	D21G	Brandwater (Groot)	-28.68034	28.139926	C	High	Moderate	B/C	Rapid III
UO_EWR03_R	D22G	Mopeli	-29.101205	27.570751	D	Moderate	Moderate	C/D	Rapid III
UO_EWR01_FV	D22B	Meulspruit	-28.8857	27.83494	D	Moderate	Moderate	D	Field verification
IUA 3: Caledon River									
UO_EWR04_I	D24G	Lower Caledon	-30.436136	26.299258	D	Moderate	Moderate	C/D	Intermediate
UO_EWR10_FV	D24H	Skulpspruit	-30.2344	26.51134	C	Moderate	Moderate	C	Field verification
UO_EWR09_FV	D24H	Groenspruit	-30.24119	26.56130	C/D	Moderate	Moderate	C	Field verification
UO_EWR02_FV	D24C	Witspruit	-30.00826	26.928315	C/D	Moderate	Moderate	C	Field verification
UO_EWR16_FV	D24L	Slykspruit	-30.393003	26.120925	B/C	Moderate	Moderate	B/C	Field verification
UO_EWR22_FV	D18K	Tele	-30.448588	27.582337	C	Moderate	Moderate	C	Field verification
UO_EWR23_FV	D12A	Upper Orange	-30.398757	27.342987	C/D	High	Moderate	C	Field verification
IUA 4: Kraai River									

EWR site	Quaternary	River	Latitude	Longitude	PES	EI	ES	REC	Level
UO_EWR04_R	D13E	Upper Kraai	-30.85179	27.77689	D	Moderate	Moderate	C/D	Rapid III
UO_EWR08_I	D13M	Lower Kraai	-30.69007	26.74157	C	High	High	B/C	Intermediate
UO_EWR04_FV	D13K	Karringmelkspruit	-30.811765	27.266497	B	Very high	High	B	Field verification
UO_EWR05_FV	D13A	Bokspruit	-30.811765	27.266497	B/C	Moderate	High	B	Field verification
UO_EWR06_FV	D13J	Holspruit	-30.995316	27.056639	C	High	Moderate	C	Field verification
UO_EWR07_FV	D13C	Sterkspruit, tributary of the Kraai	-30.917621	27.800753	C	Moderate	High	B/C	Field verification
UO_EWR08_FV	D13B	Bell	-30.852601	27.786557	B/C	Moderate	High	B	Field verification
UO_EWR17_FV	D13D	Langkloofspruit	-30.954126	27.606129	B/C	High	High	B	Field verification
UO_EWR18_FV	D13G	Wasbankspruit	-31.15554	27.284442	C	Moderate	High	B/C	Field verification
IUA 5: Upper Orange River									
UO_EWR03_FV	D12D	Gryskopspruit	-30.339629	27.176878	C	Moderate	Moderate	C	Field verification
UO_EWR02_I	D12B	Sterkspruit	-30.5178445	27.3690799	D	Moderate	Moderate	C/D	Intermediate
UO_EWR03_I	D12F	Upper Orange	-30.6528889	26.8230496	D	Moderate	Moderate	D	Intermediate
UO_EWR24_FV	D15G	Makhaleng	-30.16412	27.398251	C/D	Moderate	Moderate	C/D	Field verification
UO_EWR05_R	D14E	Wonderboomspruit	-31.005262	26.341938	B/C	Moderate	High	B	Rapid III

EWR site	Quaternary	River	Latitude	Longitude	PES	EI	ES	REC	Level
IUA 6: Gariep Dam									
Field visit site in Oct 2024	D34E	Orange River between Gariep and Vanderkloof dams	-30.503677	25.200574					Hydraulic survey Inform FMP
IUA 7: Seekoei River									
UO_EWR05_I	D32J	Seekoei	-30.534359	24.962895	C	Moderate	Moderate	C	Intermediate
IUA 8: Vanderkloof Dam									
UO_EWR10_I	D33K	Lower Orange	-29.16202	23.695944	C	Moderate	Moderate	C	Intermediate
IUA 9: Upper Modder River									
UO_EWR07_I	C52B	Upper Modder (Sannaspos)	-29.160017	26.572492	D	Low	Moderate	C	Intermediate
UO_EWR06_R	C52H	Middle Modder (Soetdoring)	-28.807191	26.109695	D	High	Moderate	C/D	Rapid III
UO_EWR13_FV	C52E	Osspruit	-28.93917	26.511411	B/C	High	Moderate	B/C	Field verification
UO_EWR14_FV	D31C	Hondeblaf	-30.205138	24.71803	B	Low	Moderate	B	Field verification
IUA10: Modder-Riet River									
UO_EWR06_I	C51F	Upper Riet	-29.535065	25.52457	C	Moderate	Moderate	C	Intermediate
UO_EWR09_I	C51L	Lower Riet	-29.03842	24.50283	C	Very high	High	B/C*	Intermediate
UO_EWR26_FV	C51L	Lower Riet	-29.005676	23.942121	TBA	TBA	TBA	TBA	Field verification (additional)

EWR site	Quaternary	River	Latitude	Longitude	PES	EI	ES	REC	Level
UO_EWR11_FV	C51A	Fouriespruit	-29.671211	26.074393	C	Moderate	Moderate	C	Field verification
UO_EWR12_FV	C52F	Renoster	-29.11632	26.328701	D/E	Moderate	Moderate	D	Field verification
UO_EWR15_FV	C51G	Tributary of VanZylspruit	-30.031203	25.786463	C	High	Moderate	C	Field verification
UO_EWR19_FV	C51K	Lower Modder	-28.89166	25.656445	C/D	Very high	High	C	Field verification
UO_EWR20_FV	C51G	Upper Kromellenboog	-30.066282	25.681056	B	Moderate	Moderate	B	Field verification
UO_EWR21_FV	C51H	Lower Kromellenboog	-29.65360	25.43507	C	Moderate	Moderate	B/C	Field verification

3 DATA COLLECTION AND MODELLING

3.1. One-dimensional (1D) Hydraulic Modelling (Reserve determination study, 2023)

During the site visits undertaken in October 2021, July 2022 and April/ May 2023 (for the Reserve determination study) and recently during October 2024 (this study), the following activities were undertaken at the selected sites. It is important to note that the 1-D hydraulic modelling was not re-done at the Upper Orange EWR sites, except for the site located between the Gariep and Vanderkloof Dams, as recommended within the FMP in the Upper Orange Reserve determination study. At this site the following were undertaken:

- EWR site cross section was selected
- A survey of the cross-sectional profile of the EWR site was conducted
- Longitudinal water slope was surveyed
- Discharge was measured
- GPS co-ordinates of the site were captured; and
- EWR site photographs were taken.

A 2-D hydraulic modelling was undertaken at EWR site UO_EWR10_I, as a supplement to this study. More information on the 2-D hydraulic modelling is described in Chapter 3.2). The 2-D hydraulic survey was undertaken to provide the ecologists with enhanced contextual data, enabling more informed decisions in quantifying the EWR for this site. In addition, a hydraulic survey was also undertaken at a site between the two dams.

The hydraulic data collected at all the sites, including updated hydraulic data at the above-mentioned sites, is listed in Table 5. It should be noted that the discharges during both the surveys, especially the dry season surveys in July 2022, were much higher than expected (above average) due to increased baseflows because of continuous high rainfall throughout the previous summer and autumn. Further, the flows at the EWR site UO_EWR10_I was very high during the October 2024 survey as releases for downstream water use in the lower Orange had been initiated.

Table 5: Hydraulic data measured for the Upper Orange catchment EWR sites

EWR site	Survey date	River	Discharge Q (m^3/s)	Maximum flow depth (m)
INTERMEDIATE SITES				
UO_EWR01_I	21 July 2022	Middle Caledon	1.726	0.39
	29 May 2023		17.19	0.77
UO_EWR02_I	6 July 2022	Sterkspruit	0.618	0.26

EWR site	Survey date	River	Discharge Q (m^3/s)	Maximum flow depth (m)
	30 May 2023		0.996	0.33
UO_EWR03_I	8 July 2022	Upper Orange	41.0	1.0
	30 May 2023		81.6	1.97
UO_EWR04_I	11 July 2022	Lower Caledon	14.19	0.68
	31 May 2023		35.36	0.97
UO_EWR05_I	12 July 2022	Seekoei	1.155	0.26
	31 May 2023		1.671	0.36
UO_EWR06_I	13 July 2022	Upper Riet	4.217	0.93
	01 June 2023		12.405	1.1
UO_EWR07_I	12 July 2022	Upper Modder	0.673	0.31
	02 June 2023		9.18	0.9
UO_EWR08_I	7 July 2022	Lower Kraai	17.3	0.9
	April 2023		19.03	1.1
UO_EWR09_I	Not surveyed	Lower Riet	Results from Vaal comprehensive Reserve study and JBS3 used, stable cross-section	
UO_EWR10_I	02 June 2023	Lower Orange	63.71	1.79
RAPID III SITES				
UO_EWR01_R	4 July 2022	Little Caledon	0.425	0.36
UO_EWR02_R	4 July 2022	Brandwater (Groot)	0.648	0.215
UO_EWR03_R	5 July 2022	Mopeli	0.808	0.28
UO_EWR04_R	9 July 2022	Upper Kraai	2.325	0.45
UO_EWR05_R	11 July 2022	Wonderboomspruit	1.129	0.39

EWR site	Survey date	River	Discharge Q (m^3/s)	Maximum flow depth (m)
UO_EWR06_R	14 July 2022	Middle Modder	2.257	0.65
FLOW MANAGEMENT PLAN *(site between Gariep and Vanderkloof Dam)*				
FMP1	4 October 2024	Orange	40.0	2.5

Modelling was conducted using the measured data, as well as two modelled points to develop stage discharge curves. The following data was required in the use of the modelling:

- y (maximum flow depth)
- n (resistance coefficient)
- S (slope)
- Q (discharge)
- A (area), and
- WP (wetted perimeter).

The measured and modelled data are shown in Table 6.

Table 6: Hydraulic data used to extend observed rating data at the EWR sites

EWR site	River	Discharge, Q (m^3/s)	Maximum flow depth (m)	Manning's resistance, *n*	Surface Slope, *S* (m/m)	Ave. Velocity, V (m/s)
INTERMEDIATE SITES						
UO_EWR01_I	Middle Caledon	1.726	0.39	0.0537	0.002	0.316
		17.19	0.77	0.0331	0.002	0.819
UO_EWR02_I	Sterkspruit	0.618	0.26	0.0247	0.008	0.951
		0.996	0.33	0.0257	0.008	0.958
UO_EWR03_I	Upper Orange	41.0	1.0	0.0268	0.0004	0.524
		81.6	1.97	0.0726	0.0004	0.360
UO_EWR04_I	Lower Caledon	14.19	0.68	0.0908	0.011	0.683
		35.36	0.97	0.0575	0.011	1.217

EWR site	River	Discharge, Q (m^3/s)	Maximum flow depth (m)	Manning's resistance, *n*	Surface Slope, *S* (m/m)	Ave. Velocity, V (m/s)
UO_EWR05_I	Seekoei	1.155	0.26	0.1353	0.017	0.283
		1.671	0.36	0.1781	0.017	0.309
UO_EWR06_I	Upper Riet	4.217	0.93	0.0491	0.001	0.373
		12.405	1.1	0.0403	0.001	0.48
UO_EWR07_I	Upper Modder	0.673	0.31	0.0623	0.006	0.458
		9.18	0.9	0.0384	0.006	1.495
UO_EWR08_I	Lower Kraai	17.3	0.9	0.1394	0.011	0.508
		19.03	1.1	0.1496	0.011	0.588
UO_EWR09_I	Lower Riet	Not measured	-	-	-	-
UO_EWR10_I	Lower Orange	63.71	1.79	0.1485	0.002	0.327
RAPID III SITES						
UO_EWR01_R	Little Caledon	0.425	0.36	0.3768	0.025	0.191
UO_EWR02_R	Brandwater (Groot)	0.648	0.215	0.0273	0.008	0.872
UO_EWR03_R	Mopeli	0.808	0.28	0.0288	0.0029	0.577
UO_EWR04_R	Upper Kraai	2.325	0.45	0.0390	0.0046	0.682
UO_EWR05_R	Wonder-boomspruit	1.129	0.39	0.0811	0.0153	0.627
UO_EWR06_R	Middle Modder	2.257	0.65	0.1068	0.0028	0.236
FLOW MANAGEMENT PLAN *(site between Gariep and Vanderkloof Dam)*						
FMP1	Orange	40	2.5	0.5465	0.047	0.54

The depth/discharge relationship (Hirschowitz, *et al*., 2007) was determined using the following equation:

$$y = aQ^b + c \quad (1)$$

Where: y is the maximum depth, Q is the discharge (m^3/s) and a, b and c are coefficients. The coefficients used in equation (1) are shown in Table 7.

Table 7: Regression coefficients in equation (1)

EWR site	River	Regression coefficients		
		a	b	c
INTERMEDIATE SITES				
UO_EWR01_I	Middle Caledon	0.33	0.2947	0
UO_EWR02_I	Sterkspruit	0.3111	0.3534	0
UO_EWR03_I	Upper Orange	0.1915	0.4347	0
UO_EWR04_I	Lower Caledon	0.2236	0.4115	0
UO_EWR05_I	Seekoei	0.2492	0.4429	0
UO_EWR06_I	Upper Riet	0.5802	0.2744	0
UO_EWR07_I	Upper Modder	0.3528	0.4135	0
UO_EWR08_I	Lower Kraai	0.3495	0.3655	0
UO_EWR09_I	Lower Riet	-	-	-
UO_EWR10_I	Lower Orange	0.4715	0.321	0
RAPID III SITES				
UO_EWR01_R	Little Caledon	0.5020	0.3820	0
UO_EWR02_R	Brandwater (Groot)	0.2627	0.4781	0
UO_EWR03_R	Mopeli	0.3089	0.4132	0
UO_EWR04_R	Upper Kraai	0.3387	0.3332	0
UO_EWR05_R	Wonderboomspruit	0.3720	0.3960	0

EWR site	River	Regression coefficients		
		a	b	c
UO_EWR06_R	Middle Modder	0.5002	0.3163	0
FLOW MANAGEMENT PLAN *(site between Gariep and Vanderkloof Dam)*				
FMP1	Orange	0.5409	4123	0

The cross-sectional views of the EWR sites per river, stage discharge relationships developed from the modelling and the detailed output tables are available electronically.

The confidence rating in the hydraulic modelling results for the EWR sites ranges from 0 = none to 5 = high and is indicated in

Table 8.

Table 8: Confidence in the hydraulic modelled results

EWR site	River	Limits of measured discharge range (m^3/s)	Confidence rating for discharge range		Comments
		$Q_{measured}$	$Q < Q_{measured}$	$Q > Q_{measured}$	
INTERMEDIATE SITES					
UO_EWR01_I	Middle Caledon	17.19	4	2	Slope of river is very flat and wide, and site located in slow moving water, therefore hydraulics under high flow conditions can be unpredictable.
UO_EWR02_I	Sterkspruit	0.996	3	2	
UO_EWR03_I	Upper Orange	41	3	2	Slope of river is very flat and wide, therefore hydraulics under high flow conditions can be unpredictable. One set of data used for modelling.
UO_EWR04_I	Lower Caledon	35.359	4	2	Site located close to bridge which might affect hydraulics under high flow conditions.
UO_EWR05_I	Seekoei	1.671	3	2	Site located close to bridge which might affect hydraulics and measured points are too close together.
UO_EWR06_I	Upper Riet	12.405	3	2	Slope of river is very flat, therefore hydraulics under high flow conditions can be unpredictable. Site located just downstream of a bridge.

EWR site	River	Limits of measured discharge range (m^3/s)	Confidence rating for discharge range		Comments
		$Q_{measured}$	$Q < Q_{measured}$	$Q > Q_{measured}$	
UO_EWR07_I	Upper Modder	9.18	3.5	2	Site located underneath bridge which may influence hydraulics under high flow conditions.
UO_EWR08_I	Lower Kraai	17.3	3.5	2	Weir located upstream of the site may affect hydraulics under high flow conditions. By-wash area will activate under high flow conditions.
UO_EWR09_I	Lower Riet	-	-	-	
UO_EWR10_I	Lower Orange	63.71	3	2	Slope of river is very flat and wide, and site located in slow moving water, therefore hydraulics under high flow conditions can be unpredictable.
RAPID III SITES					
UO_EWR01_R	Little Caledon	0.425	3	2	One set of data captured. Upstream bridge may influence hydraulics under high flow conditions
UO_EWR02_R	Brandwater (Groot)	0.663	3	2	One set of data captured. Site located close to bridge which might affect hydraulics under high flow conditions
UO_EWR03_R	Mopeli	0.808	2	2	One set of data captured. Site located in slow moving water, therefore hydraulics under varying conditions may be unpredictable

EWR site	River	Limits of measured discharge range (m^3/s)	Confidence rating for discharge range		Comments
		$Q_{measured}$	$Q < Q_{measured}$	$Q > Q_{measured}$	
UO_EWR04_R	Upper Kraai	2.325	2	2	One set of data captured.
UO_EWR05_R	Wonderboomspruit	1.129	3	2	One set of data captured.
UO_EWR06_R	Middle Modder	2.257	2	2	One set of data captured.
FLOW MANAGEMENT PLAN ***(site between Gariep and Vanderkloof Dam)***					
FMP1	Orange	40	1	1	Site is located between two dams therefore there is no natural flow regime. One set of historical data used for modelling.

3.2. Two-dimensional (2D) Hydrological Modelling

For the first time in these studies, a 2-D hydraulic model was developed at the existing EWR site UO_EWR10_I. The following outlines the approach to this innovative method of hydraulic surveying and modelling

3.2.1. Data collection and modelling

Habitat simulation models such as Habitat Flow (HABFLO), developed by Hirschowitz and colleagues in 2007, typically use the 1D data gathered during these cross-sectional surveys to link physical habitat characteristics at a specific point in a river to suitability for target species. However, using a single cross-section to inform habitat models in this way is limited because a single 1D cross-section usually does not accurately represent the hydraulic characteristics of an entire river reach. Consequently, the habitat simulations derived from 1D cross-section data can potentially have a low level of confidence for informing the hydraulic component for E-flow assessments.

The use of a two-dimensional (2D) hydraulic model to inform a E-flow assessment provides a higher level of confidence for the hydraulics and habitat availability component as the river is modelled at a reach level as compared to a single cross section (1D model). Modelling a river reach more accurately depicts the various available habitat classes which are critical in determining the EWR. The Hydraulic Engineering Centre's River Analysis System (HEC-RAS) hydraulic model was used to develop a 2D model of the river depth and velocity over an entire reach at the EWR site UO_EWR10_I on the Upper Orange River.

The following activities were undertaken during the site visit in order to collect the required data to build the 2D model for the site:

- Elevation data of the riverbanks was captured using a photogrammetry survey with an Unmanned Aerial Vehicle (UAV)
- Elevation data of the riverbed was captured by means of carrying out a SoNAR (sound navigation and ranging/ sonic navigation and ranging) bathymetric survey
- Discharge data was collected from the gauging weir located upstream of the site
- Substrate types; and
- EWR site photographs were taken.

The hydraulic data collected during the site visit is listed in **Table 9**.

Table 9: Hydraulic data measured at EWR site UO_EWR10_I (Marksdrift) on the Upper Orange River

EWR site	Survey date	Discharge Q (m/s)³
UO_EWR10_I	03 October 2024	98

The inputs required in the setup and running of the 2D hydraulic model are described in the following sections.

3.2.2. Terrain Elevation Data

For any 2-dimensional surface flow modelling exercise, an elevation model of the terrain to be assessed is required. A photogrammetry survey of the site was conducted using a drone and the data was used to generate high resolution imagery of the site and elevation data of the riverbanks. The imagery of the site is shown in Figure 3.

The bathymetric survey was conducted to survey the riverbed using a SoNAR device attached to a boat. The two sets of elevation data were processed and stitched together to generate an elevation model. The elevation model is shown in Figure 4.

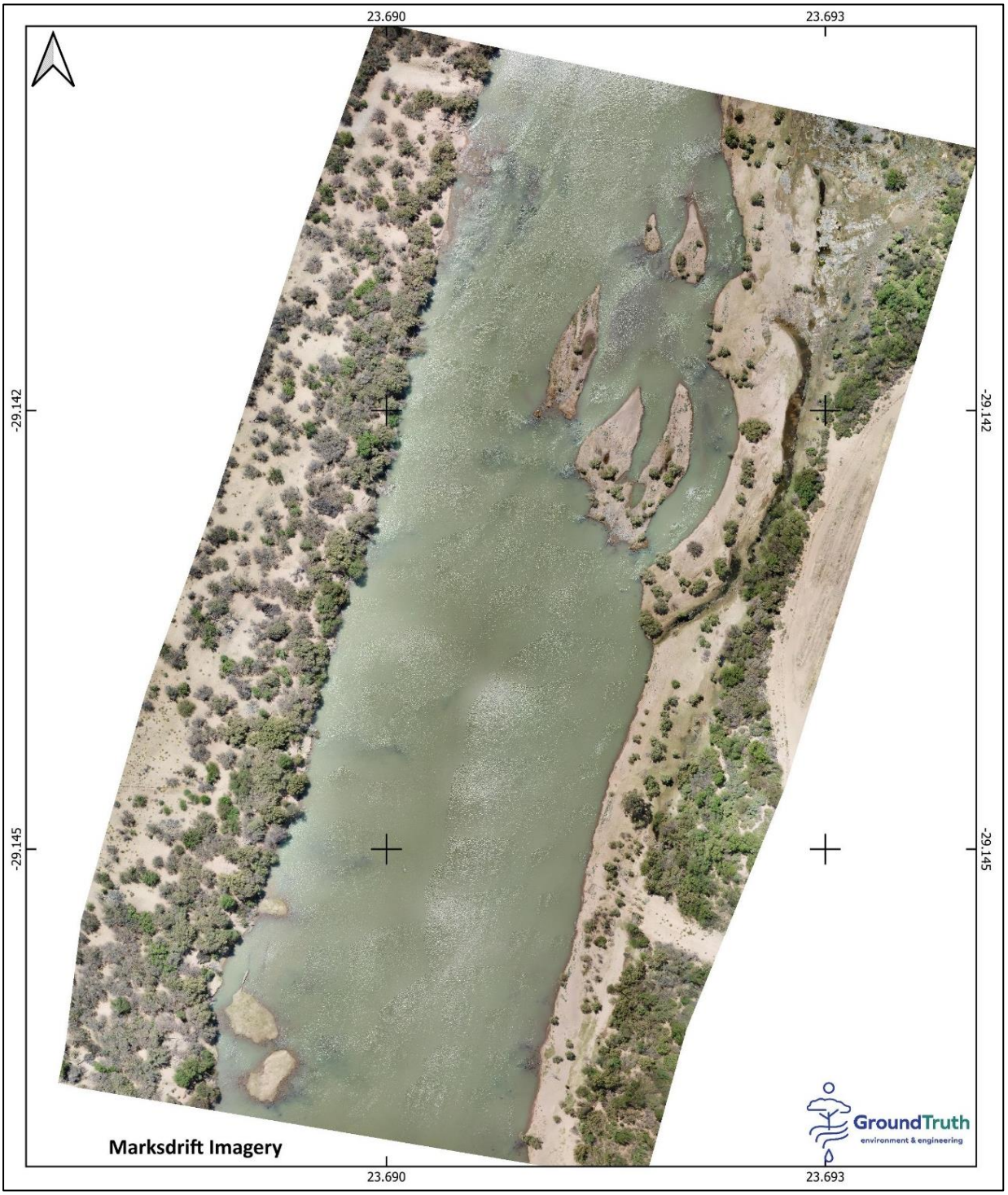


Figure 3: Imagery generated from drone survey of UO_EWR10_I site

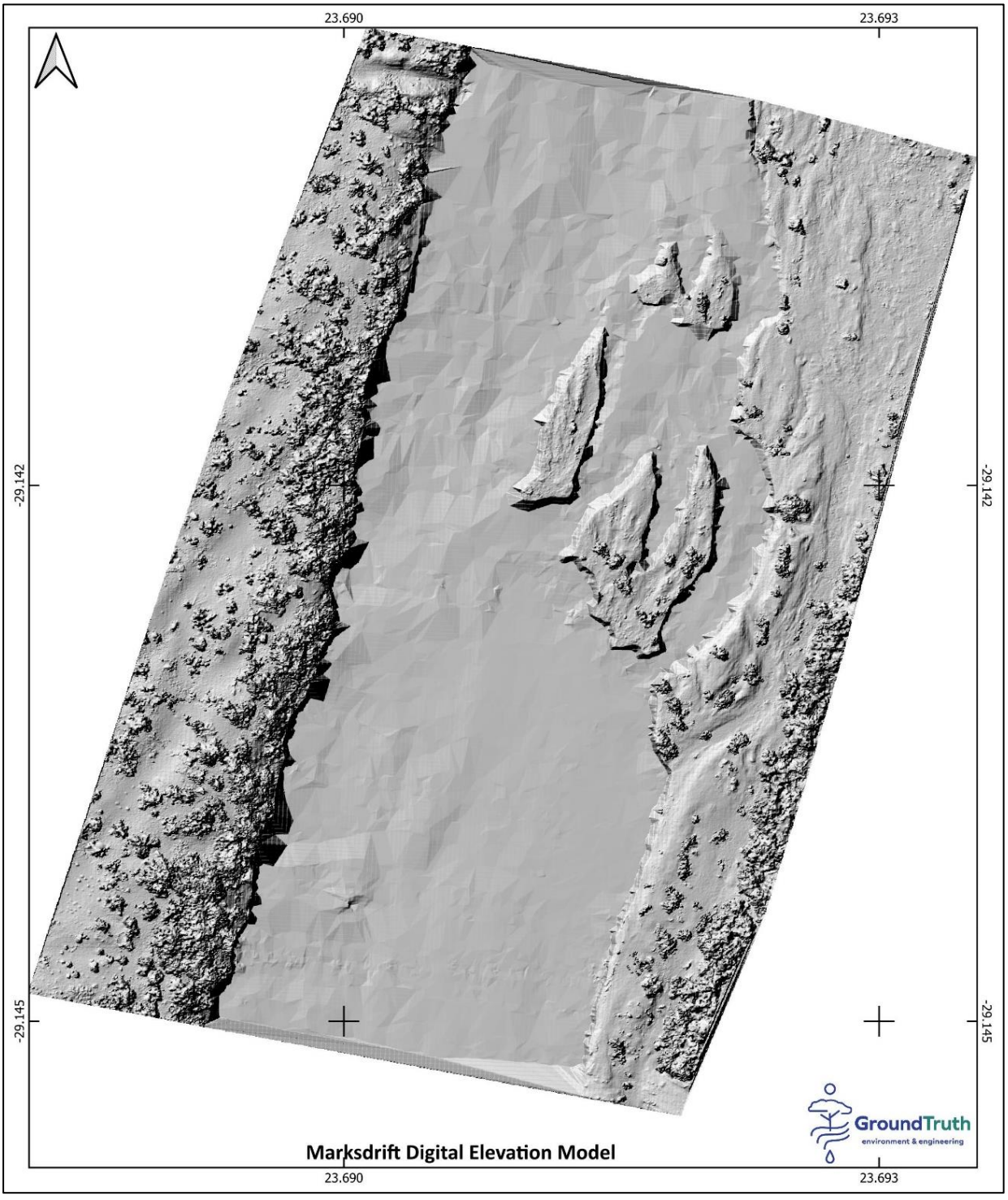


Figure 4: Elevation model generated from drone and bathymetric survey of UO_EWR10_I site

3.2.3. Hydraulic Roughness Coefficients and Flow Data

The Manning's n roughness coefficients required for the modelling were determined by assessing the onsite vegetation, substate types on both the riverbanks and riverbed, and Ven te Chow's tables on roughness coefficients (Chow *et al*, 1988). The land cover categories and values are provided in Table 10.

Table 10: Selected Manning's n-values per description class

Channel type and description	Manning's n value
Major stream (irregular and rough section)	0.035 – 0.1
Sand	0.055
Rock	0.035
Pasture (short grass)	0.03
Thick brush (medium to dense)	0.1
Trees (heavy stand of timber)	0.1

The model setup requires inlet and outlet boundary conditions. The inlet conditions used the 'stepped' straight line hydrographs which were generated using discharge data collected from the Marksdrift gauge to simulate multiple steady flows through the river reach. The outlet boundary conditions were based on a normal depth. The friction slopes inputted into the model were determined using the elevation model.

3.2.4. Understanding the Results

The depth and velocity layers generated by the HEC-RAS model were used in the HEC-RAS RASter calculator to create a habitat distribution map for the modelled flows from the stepped hydrograph, using the HABFLO habitat classes for fish and aquatic invertebrates (substrate types were mapped from infield observations).

The depth and velocity outputs from HEC-RAS for different flow values were used to generate the HABFLO habitat distributions for a range of different river discharge (Q) values for different depth and velocity values of the river reach. The HABFLO habitat classes for fish are shown in **Table 11** and the HABFLO habitat classes for invertebrates are shown in

Table 12.

Table 11: HABFLO fish habitat classes

Habitat Class	Abbreviation	Velocity (m/s)	Depth (m)
Slow very shallow	SVS	0.0 – 0.3	0.0 – 0.1
Slow shallow	SS	0.0 – 0.3	0.1 – 0.5
Slow deep	SD	0.0 – 0.3	0.5 - 10
Fast very shallow	FVS	0.3 – 10	0.0 – 0.1
Fast shallow	FS	0.3 – 10	0.1 – 0.2
Fast Intermediate	FI	0.3 – 10	0.2 – 0.3

Habitat Class	Abbreviation	Velocity (m/s)	Depth (m)
Fast deep	FD	0.3 – 10	0.3 - 10

Table 12: HABFLO invertebrate habitat classes

Habitat Class	Abbreviation	Velocity (m/s)	Substrate
Very slow coarse sediment	VSCS	0.0 – 0.1	Coarse
Slow coarse sediment	SCS	0.1 – 0.3	Coarse
Fast coarse sediment	FCS	0.3 – 0.6	Coarse
Very fast coarse sediment	VFCS	0.6 - 10	Coarse
Very slow fine sediment	VSFS	0.0 – 0.1	Fine
Slow fine sediment	SFS	0.1 – 0.3	Fine
Fast fine sediment	FFS	0.3 – 0.6	Fine
Very fast fine sediment	VFFS	0.6 - 10	Fine

The habitat distribution layers for both fish and invertebrates were generated for a range of flow values. These layers were used to create models to estimate the habitat distributions for each of these flow values. The data that was previously collected at the site for the 1D modelling was used to verify the 2D modelling results to better calibrate the model. A statistical comparison between the measured and modelled values for the observed discharge values (64m³/s on the 6th of June 2023 and 98m³/s on the 2nd of October 2024) was carried out and the error between the modelled and simulated data were found to be low.

The flow depth, fish and invertebrate habitat availability at the EWR site developed from the 2D modelling are shown in Figure 5, Figure 6 and Figure 7.

The confidence rating in the hydraulic modelling results for EWR site UO_EWR10_I, ranges from 0=none to 5=high and is indicated in Table 14

Table 8.

Table 13: Confidence in the hydraulic modelled results for UO_EWR10_I in the Orange River

Limits of measured discharge range (m^3/s)	**Confidence rating for discharge range**	
$Q_{measured}$	**$Q < Q_{measured}$**	**$Q > Q_{measured}$**
98	3	2
Comment: Slope of the river is very flat and wide, therefore hydraulics under low flow and high flow conditions can be unpredictable. 1 set of 2D data captured for the site. More modelling of the site and different flows is required to increase the confidence in the model.		

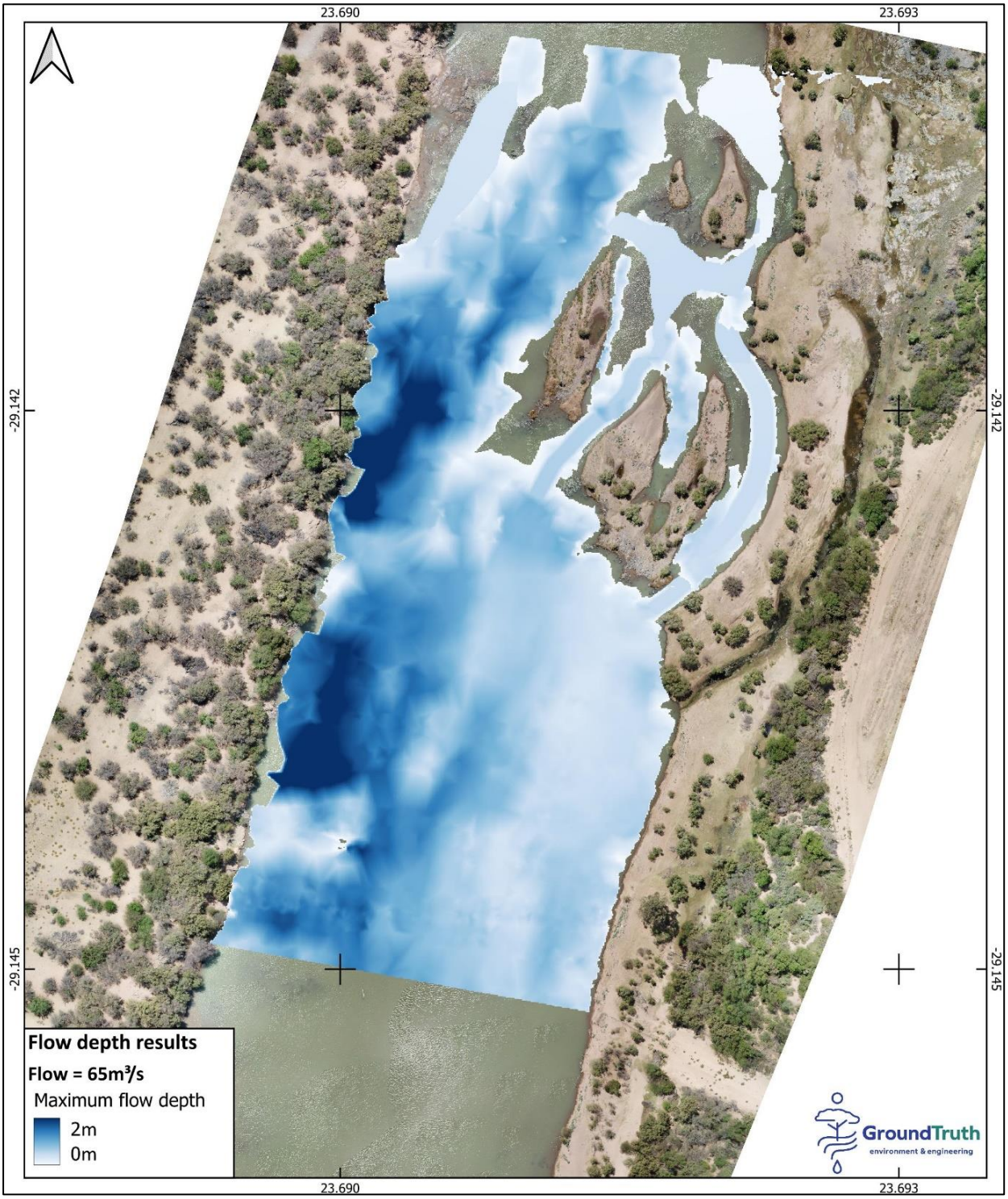


Figure 5: Flow depth HEC-RAS result layer for 65m^3/s at UO_EWR10_I

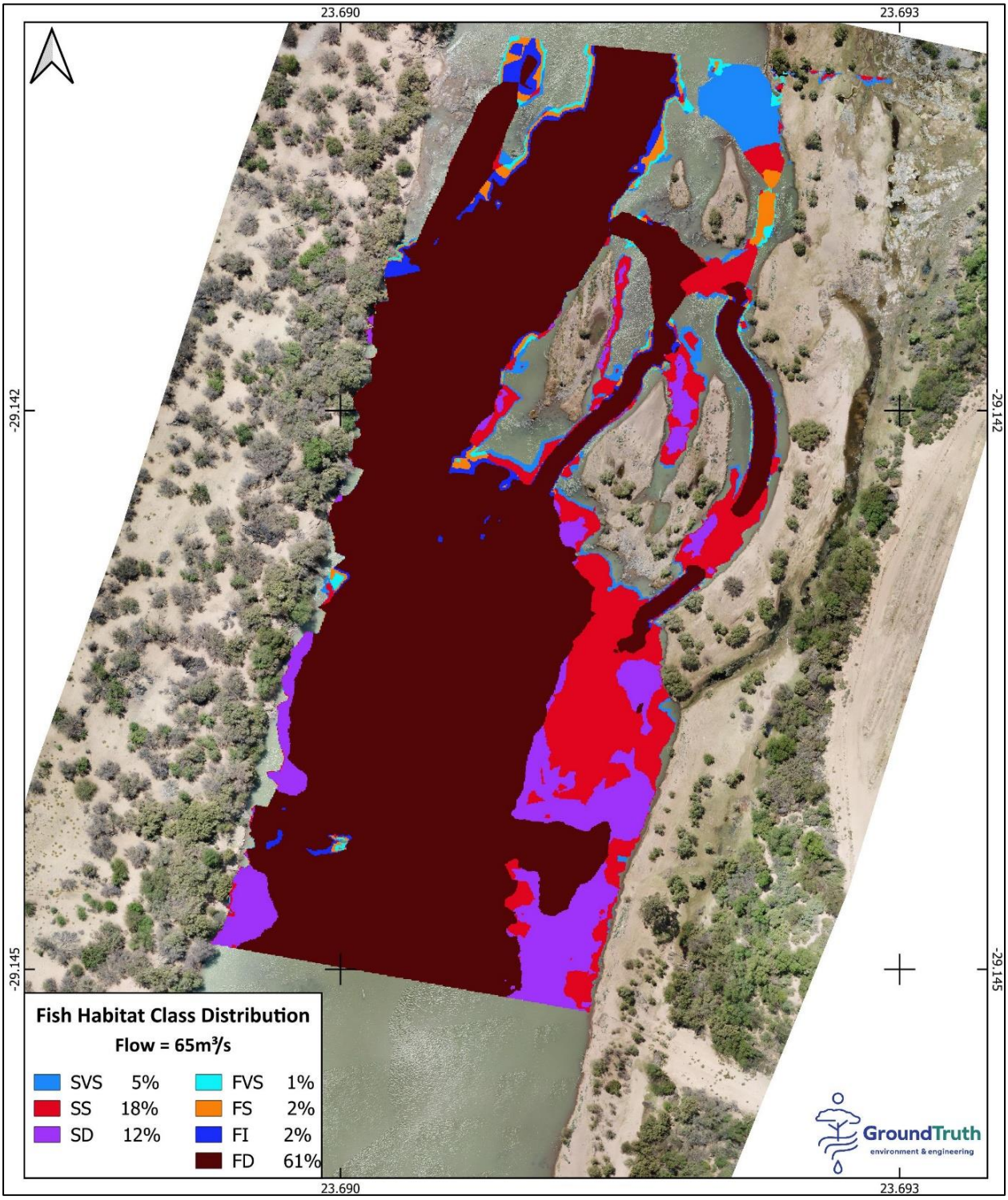


Figure 6: Visual distribution of fish habitat classes for 65m^3/s at UO_EWR10_I

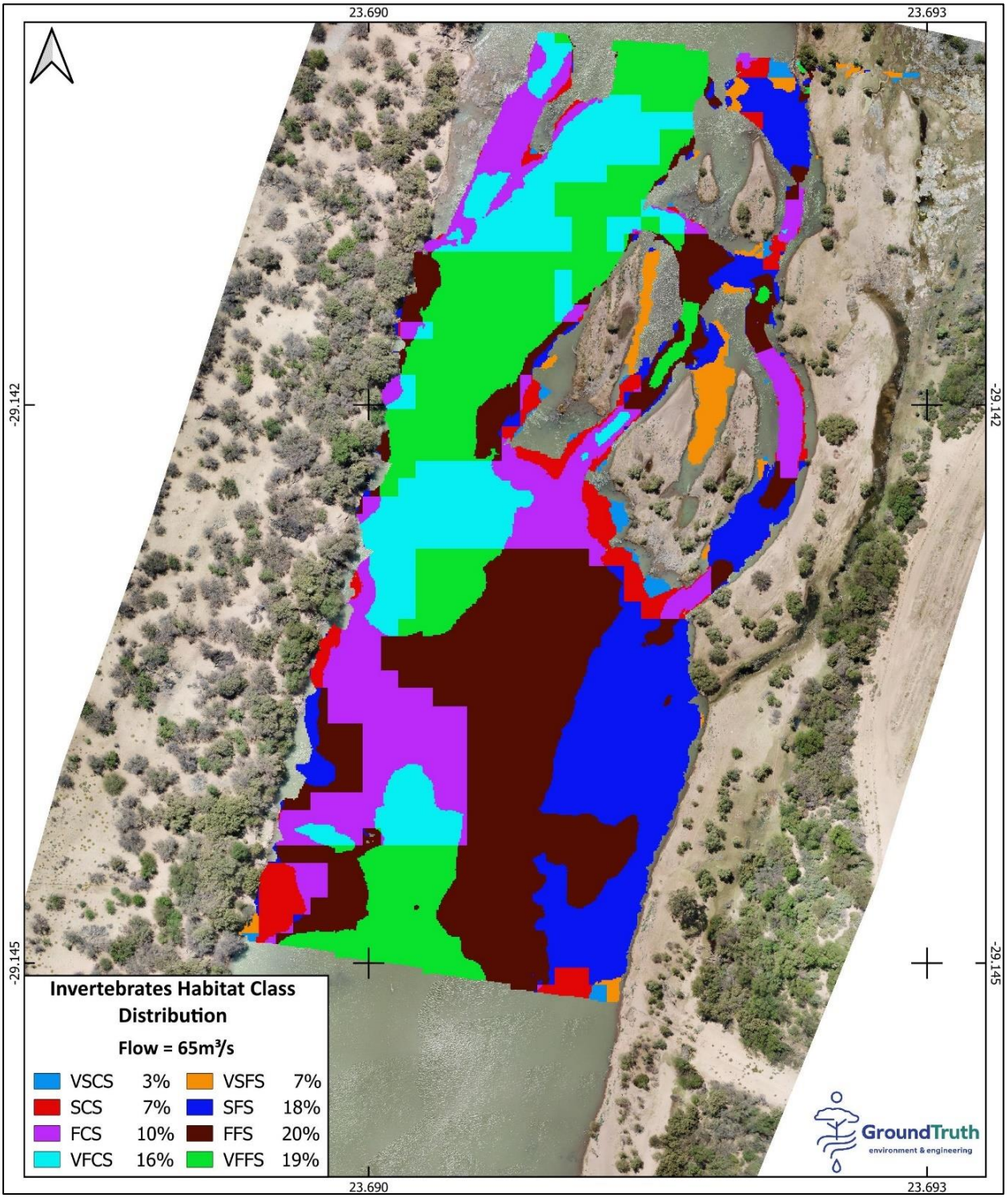


Figure 7: Visual distribution of invertebrate habitat classes for 65m^3/s UO_EWR10_I

3.3. Hydrological data

The natural hydrology as used in the WRYM and WRPM models for the Integrated Vaal-Orange Water Supply System originates from several studies including:

- Vaal River Systems Analysis Updated Study (1994)
- Lesotho Highlands Pre-Feasibility Study (1985)
- Orange River Systems Analysis (1993)
- Review of the Lesotho Highlands Hydrology by the Institute of Hydrology (1994)
- Vaal Augmentation Planning Study (1994)
- Lower Orange River Management Study (1995)
- Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse (2007)
- The original natural hydrology record period was from 1930 to 1994 and was extended in a comprehensive study up to 2004: Support to Phase 2 of the ORASECOM basin-wide Integrated Water resources Management Plan – extension of hydrological records by ORASECOM.
- WR2012 hydrology for the Modder/ Riet system to provide the most up to date information for and ensure the modelling of the transfers between the Orange/ Caledon and Modder/ Riet Rivers are based on the same record period.

The natural flow time series obtained from these studies were used and adjusted by catchment area to obtain the natural flows at the EWR sites. Thus, during the generation of the natural hydrology for Reserve determination studies, the position of the EWR sites is determined in relation to the natural hydrology timeseries' representative catchment areas. The natural hydrology timeseries are then scaled by area to approximate the natural flows at the sites. Care was also taken to ensure that existing infrastructure in the model network were considered in determining the area scaling to be consistent with the current model's configuration and to ensure that Present Day flows to be generated are representative. Present day flows are based on the water use demands in the most recent WRPM model (2023/ 2024) as was used for the 2023 Annual Operating Analysis.

Table 14 provides the approximate catchment areas and natural MAR (nMAR) for the EWR sites for the period 1920 to 2004. The final natural time series per EWR site will be provided electronically to DWS. UO_EWR26_FV is not included in Table 14 as it relates only to the water quality analysis undertaken in October 2024.

Table 14: Natural MAR per EWR site in the Upper Orange River catchment

EWR site	River	Latitude	Longitude	Quaternary Catchment	nMAR ($10^6 m^3$)	Catchment area (km^2)
INTERMEDIATE SITES						
UO_EWR01_I	Middle Caledon	-28.9089	27.785	D22D	674.0	5 185
UO_EWR02_I	Sterkspruit	-30.517806	27.369058	D12B	30.7	293
UO_EWR03_I	Upper Orange	-30.652793	26.823213	D12F	4 259.5	27 578
UO_EWR04_I	Lower Caledon	-30.436136	26.299258	D24G	1 353.6	18 544
UO_EWR05_I	Seekoei	-30.534359	24.962895	D32J	24.3	8 319
UO_EWR06_I	Upper Riet	-29.535065	25.52457	C51F	105.2	5 247
UO_EWR07_I	Upper Modder	-29.160017	26.572492	C52B	61.0	1 696
UO_EWR08_I	Lower Kraai	-30.69007	26.74157	D13M	719.0	9 354
UO_EWR09_I	Lower Riet	-29.03842	24.50283	C51L	373.8	33 785
UO_EWR10_I	Lower Orange	-29.16202	23.695944	D33K	6 674.2	99 297
RAPID III SITES						
UO_EWR01_R	Little Caledon	-28.557796	28.405709	D21D	25.9	252
UO_EWR02_R	Brandwater/ Groot	-28.68034	28.139926	D21G	56.0	700

EWR site	River	Latitude	Longitude	Quaternary Catchment	nMAR (10^6m^3)	Catchment area (km^2)
UO_EWR03_R	Mopeli	-29.101205	27.570751	D22G	49.4	950
UO_EWR04_R	Upper Kraai	-30.85179	27.77689	D13E	200.9	1 525
UO_EWR05_R	Wonderboomspruit	-31.005262	26.341938	D14E	25.9	1 336
UO_EWR06_R	Middle Modder	-28.807191	26.109695	C52G	113.7	6 000
FIELD VERIFICATION SITES						
UO_EWR01_FV	Meulspruit	-28.885731	27.834944	D22B	63.6	457
UO_EWR02_FV	Witspruit	-30.00826	26.928315	D24C	21.7	979
UO_EWR03_FV	Gryskopspruit	-30.339629	27.176878	D12D	7.5	139
UO_EWR04_FV	Karringmelkspruit	-30.811765	27.266497	D13K	25.9	211
UO_EWR05_FV	Bokspruit	-30.88469	27.884557	D13A	60.4	409
UO_EWR06_FV	Holspruit	-30.995316	27.056639	D13J	36.9	2 311
UO_EWR07_FV	Sterkspruit, tributary of Kraai	-30.917621	27.800753	D13C	47.6	517
UO_EWR08_FV	Bell	-30.852601	27.786557	D13B	72.5	533
UO_EWR09_FV	Groenspruit	-30.24119	26.5613	D24H	5.02	215

EWR site	River	Latitude	Longitude	Quaternary Catchment	nMAR (10^6m^3)	Catchment area (km^2)
UO_EWR10_FV	Skulpspruit	-30.23444	26.51134	D24H	7.8	333
UO_EWR11_FV	Fouriespruit	-29.671211	26.074393	C51A	13.8	560
UO_EWR12_FV	Renoster	-29.11632	26.328701	C52F	7.9	485
UO_EWR13_FV	Os-spruit	-28.93917	26.511411	C52E	8.6	650
UO_EWR14_FV	Hondeblaf	-30.205138	24.71803	D31C	2.0	1 231
UO_EWR15_FV	Tributary of VanZylspruit	-30.031203	25.786463	C51G	1.9	73
UO_EWR16_FV	Slykspruit	-30.393003	26.120925	D24L	5.1	1 285
UO_EWR17_FV	Langkloofspruit	-30.954126	27.606129	D13D	43.8	572
UO_EWR18_FV	Wasbankspruit	-31.15554	27.284442	D13G	16.5	248
UO_EWR19_FV	Lower Modder	-28.89166	25.656445	C52K	156.8	7 580
UO_EWR20_FV	Upper Kromellenboog	-30.066282	25.681056	C51G	9.3	367
UO_EWR21_FV	Lower Kromellenboog	-29.6536	25.43507	C51H	85.1	3 466
UO_EWR22_FV	Tele	-30.448588	27.582337	D18K	142.3	920
UO_EWR23_FV	Upper Orange	-30.398757	27.342987	D12A	4 115.1	24 850
UO_EWR24_FV	Makhaleng	-30.16412	27.398251	D15G	524.5	2 998

3.4. Quantification of EWRs

The quantification of the EWRs used the following approaches to calculate the requirements for the REC at the EWR sites:

i. Habitat Flow Stressor Response (HFSR) for selected intermediate sites (further detail below);
ii. Verification of the Desktop Reserve Model (DRM) (SPATSIM, version 2.12) for the Rapid III and at specific intermediate sites where increased flows or water quality were the main impacts (e.g. Upper Modder). These EWR flow data were converted to hydraulic conditions (i.e., depths and flow velocities at discharges measured in m^3/s) using a hydraulic model and evaluated by the ecologists through the verification of the drought and base flows (maintenance flows). Where the modelled requirements were ecologically judged not to be adequate to provide the envisaged protection, the model was adjusted to satisfy such requirements; and
iii. Desktop Reserve Model (DRM)/ Revised DRM for the field verification sites.

The HFSR is based on the approach developed by IWR S2S, 2004 and O'Keeffe et al., 2002 and replaced the Building Block Methodology (BBM) from King and Louw, 1998 and was used to determine the baseflows. The approach to set freshets and floods is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and BBM and was used in several high confidence Reserve determination studies, including the intermediate study on the Mvoti, Umkomazi and Umgeni Rivers.

The HFSR approach is to set stress indices for the aquatic biota namely fish and macroinvertebrates. The stress index describes the effects of flow reduction on flow dependant biota (semi-rheophilic fish species (refers to a species that requires fast flowing water habitat during life stage(s)) or guilds and macroinvertebrates), or life stages and is determined by first assessing the response of habitat to a flow reduction. The habitat flow index is described separately for fish and macroinvertebrates as an instantaneous response of habitat to flow in terms of a stress of 0 to 10. The 0 stress represents optimum habitat with the maximum natural base flow, while a stress of 10 is indicative of zero/no flow.

The second step is to determine the biota stress index which describes the instantaneous response of biota to change in habitat (and therefore flow) in terms of the 0 to 10 stress indices. Important to note the change of critical habitat at each stress level (as described in the habitat stress index) and which is then related to the response of biotic indicator species/taxon. Similarly, a stress of a 0 represents optimum critical habitat (for that indicator species/taxon), therefore providing no stress to the biota and which assemblage abundances are high under these conditions. A stress of 10 is where there is zero critical habitat thus negatively responded to by the indicator species/taxon. Thus, the stress index therefore describes the habitat conditions and biota response at a range of low flows. The stress-flow relationship for the fish and macroinvertebrates will obviously differ owing to their differences in their responses/ requirements/ preferences/ tolerances to the same flows.

The fish and macroinvertebrate stress indices are then used to convert natural, present-day and EWR flow time series to a stress time series. The stress time series is converted to a stress duration curve for the highest (wet) and lowest (dry) flow months. This subsequently provides the specialists with the information of how much the stress has changed from natural under present conditions due to changes in flow. It would follow that if flow has decreased from natural, stress would increase and vice versa. If specialists did not agree with the levels of stress under natural conditions based on their knowledge of the indicator species, the stress indices were further refined. Essentially, the aim is to ensure the persistence of the indicator species/taxon, as then the rest of the biotic community will persist.

Additionally, freshets and annual floods were specified for the intermediate and Rapid III sites taking the release capacities of dams (where available) into consideration. These freshets were adjusted where required when higher than the release capacities of the dams.

These EWR results for the recommended ecological categories were then used to produce the final Ecological Reserve quantity results in the format of an assurance table or EWR rule curves. These curves specify the frequency of occurrence relationships of the flow requirements for each month of the year. The tables thus specify the % of time that defined flows should equal or exceed the flow regime required to satisfy the ecological Reserve.

4 ECOLOGICAL WATER REQUIREMENTS QUANTIFICATION

The data from the High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange Catchment: WP11343, and the situation assessment, has indicated that the following sites are relevant for the catchments scenarios and trade-off assessments that will be undertaken (Table 15). These are detailed in the section to follow. Data for the other EWR sites assessed as part of the Reserve study, and additional data for the sites discussed below are available in the following reports:

- RDM/WMA13/00/CON/COMP/1223 (a): Eco-Categorisation Report – Volume 1
- RDM/WMA13/00/CON/COMP/1223 (b): Eco-Categorisation Report – Volume 2
- RDM/WMA13/00/CON/COMP/1323: Quantification of Ecological Water Requirements Report

Table 15: EWR sites identified for use in this study per IUA

IUA		EWR sites to be used for scenarios	River	PES	REC
1	**Golden Gate**	UO_EWR 01_R	Little Caledon	C	B/C
2	**Caledon/ Leeu River**	UO_EWR 01_I	Middle Caledon	D/E	D
3	**Caledon River**	UO_EWR 04_I	Lower Caledon	D	C/D
4	**Kraai River**	UO_EWR 08_I	Kraai	C	B/C
5	**Upper Orange River**	UO_EWR03_I	Upper Orange	D	D
6	**Gariep Dam**	Site added below Gariep Dam for FMP	Orange	D*	D*
7	**Seekoei River**	UO_EWR05_I	Seekoei	C	C
8	**Vanderkloof Dam**	UO_EWR10_I	Orange	C	C
9	**Upper Modder River**	UO_EWR07_I	Upper Modder	D	C
10	**Modder-Riet Rivers**	UO_EWR06_I	Upper Riet	C	C
		UO_EWR09_I	Lower Riet	C	B/C

** Ecostatus/PES from the JBS3 - retained the PES as the REC as it is flow driven which can't change*

4.1. IUA 1: Golden Gate

4.1.1. UO_EWR01_R: Little Caledon

The selected EWR site located downstream from the town of Clarens along an incised floodplain reach (Figure 8), was assessed on the 4th of July 2022 as part of the high confidence Reserve determination (DWS, 2023) on a Rapid III level.

River	Little Caledon	**Altitude (m.a.s.l.)**	1 692
Latitude	-28.557796°	**Longitude**	28.405709°
Level 1 EcoRegion	Eastern Escarpment Mountains	**Quaternary catchment-SQ Reach**	D21D - 03094
Level 2 EcoRegion	15.03	**DWS, 2014 PES,**	C
Geomorphological zone	E (Lower Foothills)	**EI**	High
		ES	High
Components sampled: Fish, aquatic macroinvertebrates, IHI, *in situ* water quality, diatoms, cross-section, discharge			

Figure 9 shows site photographs. Localised channel modification and bank modification are evident. Farm road/bridge crossing, along and immediately upstream a causeway/bridge which is frequently used by farmers and cattle crossing the river. Both banks show localised erosion. No large upstream dams. The river is approximately 5m wide and has a range of biotopes for both macroinvertebrates and fish. For macroinvertebrates the following biotopes are available: marginal vegetation, Stones-In-Current, Stones-Out-of-Current (SIC, SOOC) and Gravel, Sand, Mud (GSM). For fish the following biotopes are available: , Slow Deep (SD), Slow Shallow (SS) and Fast Shallow (FS). The marginal vegetation is limited owing to steep undercut banks and vegetation die-back. There is much in-stream vegetation debris creating additional habitat for biota. The riparian vegetation zone is modified primarily owing to agriculture/croplands encroachment, although thickets of *Phragmites australis* and *Salix sp*. also occur within the zone. Just downstream of the bridge there is a section of riffles and runs downstream of the causeway. There are upstream deep pools with a meandering channel. During the July 2022 survey for the Reserve study, the flows were higher than expected for the dry season owing to enhanced baseflows due to a very wet and late rainfall season.

The main land use in the area is agriculture, croplands and cattle trampling and grazing. Alien *Salix* trees line the banks both upstream and downstream, facilitating erosion along both banks. The site impacts include:

- Seasonal abstraction
- Agriculture

- Cattle trampling and grazing
- Upstream town of Clarens (possible water quality impacts from WWTW)
- Upstream Clarens golf course, potential source of pesticides, fertilisers, and
- Stream crossings and bridges.

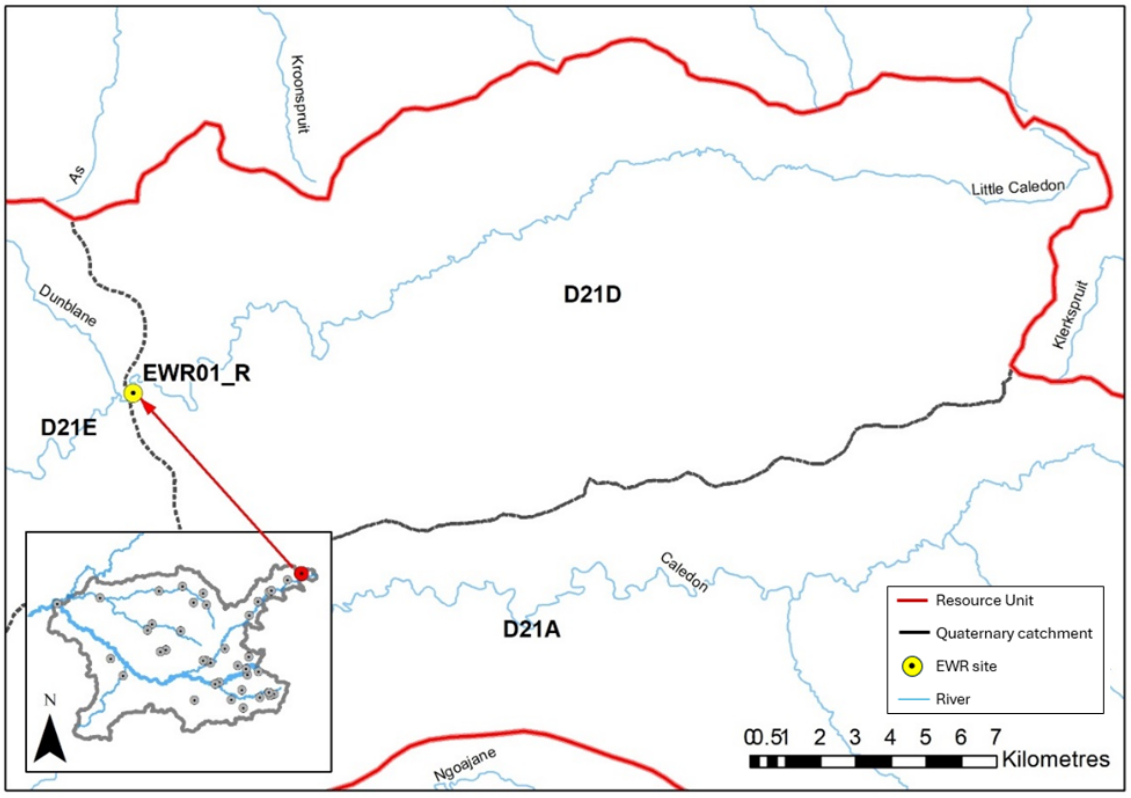


Figure 8: UO_EWR01_R site locality in relation to the study area (DWS, 2023)

Figure 9: Site photographs of Little Caledon, UO_EWR01_R, during the survey (July 2022)

Summary results (DWS, 2023)

WATER QUALITY AND FLOW (In situ)	
Parameter	**Survey (July 2022)**
pH	8.6
Electrical Conductivity (mS/cm)	24.6
Total Dissolved Solids (mg/l)	247
Dissolved Oxygen (mg/l)	12.7
Dissolved Oxygen % (%)	103.6
Clarity (cm)	87
Temperature (°C)	6.6
Salinity (ppt)	0.18
Discharge (m^3/s)	0,425

Diatoms:				
No. species	**SPI****	**Categorisation (quality)**	**%PTV*****	**%Deformed cells******
16	10.5	C (Moderate)	66.8	2.5
Dominant Species	*Mayamaea atomus var. permitis (Hustedt) Lange-Bertalot*			
Preference	Very pollution tolerant – organic pollution			

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 16.

Table 16: Reference Conditions for UO_EWR01_R (DWS, 2023)

Component	Description of Reference Conditions
Fish	*Enteromius oraniensis* ; *Labeobarbus aeneus*
Macroinvertebrates	Porifera; Turbellaria; Oligochaeta; Hirudinea; Potamonautidae; Atyidae; Hydracarina; Perlidae, Baetidae >2spp; Caenidae; Leptophlebiidae; Heptageniidae, Trichorythidae; Chlorolestidae; Coenagrionidae; Aeshnidae; Gomphidae; Belostomatidae; Corixidae; Gerridae; Hydrometridae; Notonectidae; Pleidae; Veliidae; Ecnomidae; Hydropsychidae 2spp; Philopotamidae; Psychomyiidae; Hydroptilidae; Leptoceridae; Pisuliidae, Dytiscidae; Elmidae; Gyrinidae; Hydraenidae; Hydrophilidae; Psephenidae, Athericidae; Ceratopogonidae; Chironomidae; Culicidae; Dixidae; Empididae, Muscidae; Simuliidae; Tabanidae; Tipulidae; Ancylidae; Physidae, Planorbinae, Corbiculidae and Sphaeridae.
Physico-chemical	Historical physical-chemical data for the site could not be obtained. Diatom data were used to infer the reference physical-chemical condition at the site.

Component	Description of Reference Conditions
	The diatom data indicated that the site is heavily contaminated with organic pollution. This likely arise from the Clarens WWTW upstream. The town of Clarens was established in 1912 and the impacts on the physical-chemical state of the system probably deteriorated since then. Lower nutrient concentrations and overall organic pollution are expected to have been prevalent at the site prior to the impacts of WWTW.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 17.

Table 17: PES per component for EWR site and EcoStatus

Component	PES category & score	Flow/ non-flow	Explanation
Fish	D (50.4%)	NF	• Alien fish species (*Oncorhynchus mykiss*) – not recorded, but collection records with likely predation impact on native fish and macroinvertebrates • Decrease in marginal vegetation which acts a spawning substrate as well as provides cover for fry • Downstream dams preventing seasonal migration of *Labeobarbus aeneus*
Macroinvertebrates	D (57.75%)	NF / F	• Combination of both flow and non-flow (SIC, pools driving the community • Higher than usual baseflows (F) • Limited vegetation biotope (NF)
Habitat Integrity: Instream*	B (85%)	NF / F	• Water abstraction and irrigation • Channel modification (bridges) • Physico-chemical • Algae growth • Erosion
Habitat Integrity: Riparian*	B (85%)	NF	• Vegetation removal (trampling, wood harvesting) • Alien vegetation • Bank erosion
ECOSTATUS	C (65.04%)		

*** Refer to Appendix E of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report- VOLUME 2 for the IHI results*

The overall EcoStatus was categorised as a C category. This was mostly owing to the fish component being in a category D (alien species, decrease in spawning substrate and cover features and downstream dams preventing seasonal migration of *Labeobarbus aeneus*) from the

Caledon River. The macroinvertebrates were recorded in a category D (limited habitat availability, particularly limited instream and marginal vegetation owing to vegetation die-back and undercut banks – although seasonally driven) (Table 18). The fish community responded to some degree to flow conditions and physical-chemical conditions. The main driver affecting the macroinvertebrate assemblages was water quality and decreased habitat availability, followed by flow modification.

It is suggested that the REC of a B/C can be achieved, should the proposed mitigation measures/recommendations (mainly water quality improvements) be assessed and applied.

Table 18: Overall EcoStatus assessment for UO_EWR01_R

River	Little Caledon
EWR Site Code	UO_EWR01_R
Driver Component	PES
Integrated Habitat Integrity: instream (IHI)	B
Integrated Habitat Integrity: riparian (IHI)	B
Response Components	PES
Diatoms	C
Fish (FRAI)	D
Macroinvertebrates (MIRAI)	D
EcoStatus	C
Ecological Importance (EI)	High
Ecological Sensitivity (ES)	High
Recommended Ecological Category (REC)	B/C

The EWR for the Little Caledon River were determined for a REC of a B/C. The EWR flow data from the DRM was converted to hydraulic conditions at the EWR site (i.e., depths and flow velocities at discharges measured in m^3/s) using a hydraulic model. The maintenance flows were examined for July and March. July is the month with the lowest average flow (i.e., base-flow) and March is the month with the highest average flow conditions (according to the natural flows).

Together with the site photographs and rating relationships (flow depth versus discharge) from the hydraulic model, water levels proposed by the DRM for drought and maintenance low flows were assessed in terms of the habitat and biotic requirements. The site-specific flow requirements were based mainly on the velocity and habitat requirements of flow-sensitive aquatic macroinvertebrates.

The discharge at the EWR site during the survey on 4 July 2022 was 0.425 m^3/s and was used as reference to adjust the recommended EWRs (Figure 10). It should be noted that the baseflows were very high during the survey because of the continual high rainfall during the summer months.

The consensus reached by the aquatic ecologists was that the recommended flows for both July and March did not provide adequate velocities and availability of instream habitats for the macroinvertebrates. The maintenance low flows were adjusted to ensure increased velocity for those flow dependent and present macroinvertebrates, as well as provided additional critical habitats namely fast course substrate and/or very fast course substrate (being the stones biotope). Furthermore, flows were increased with the aim to improve velocity depth classes and activate additional fast intermediate critical habitat, and to further provide additional cover features for the fish. Therefore, the recommended flows (drought and maintenance) were adjusted as follows:

(i) Maintenance low flows:

July - Adjusted from 0.066 m^3/s to 0.115 m^3/s

March - Adjusted from 0.172 m^3/s to 0.297 m^3/s

(ii) Drought flows:

A minimum of 0.045 m^3/s for the drier months (July to November) and 0.067 m^3/s for the wet months.

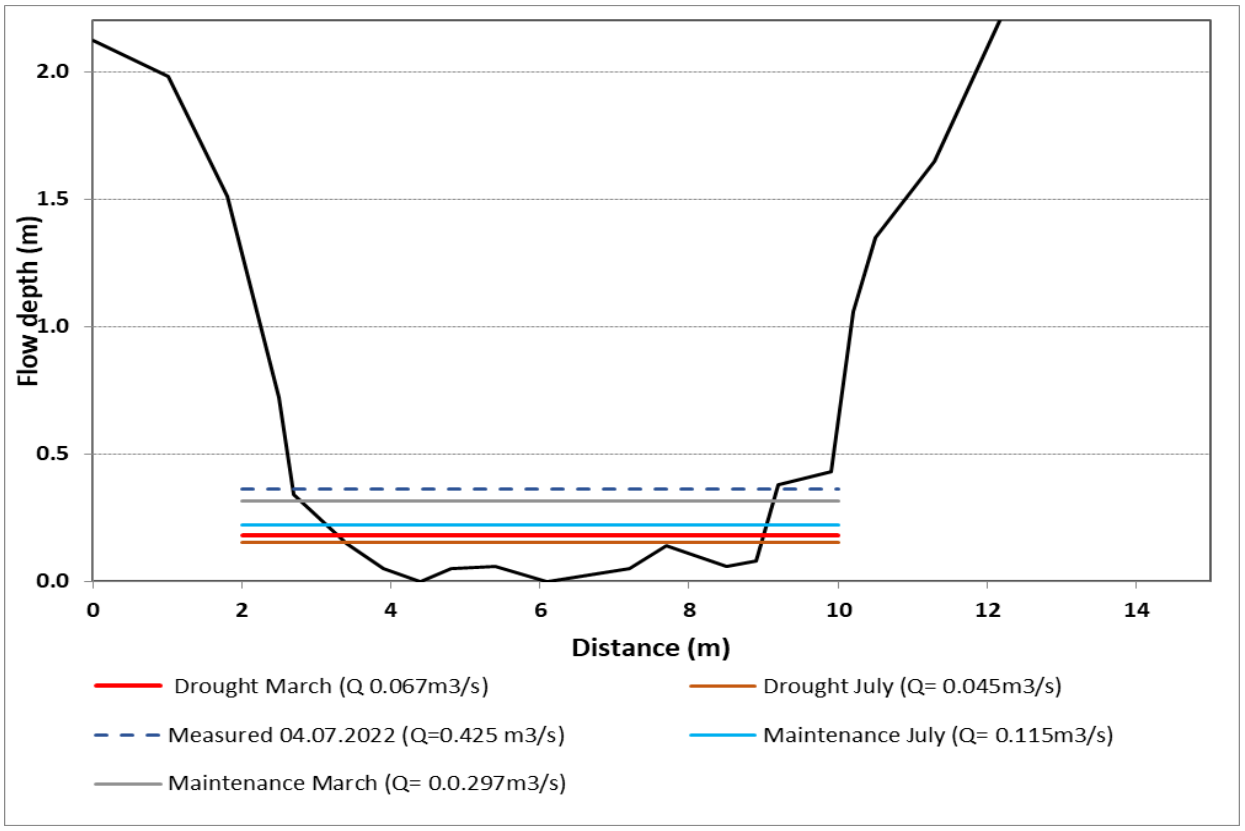
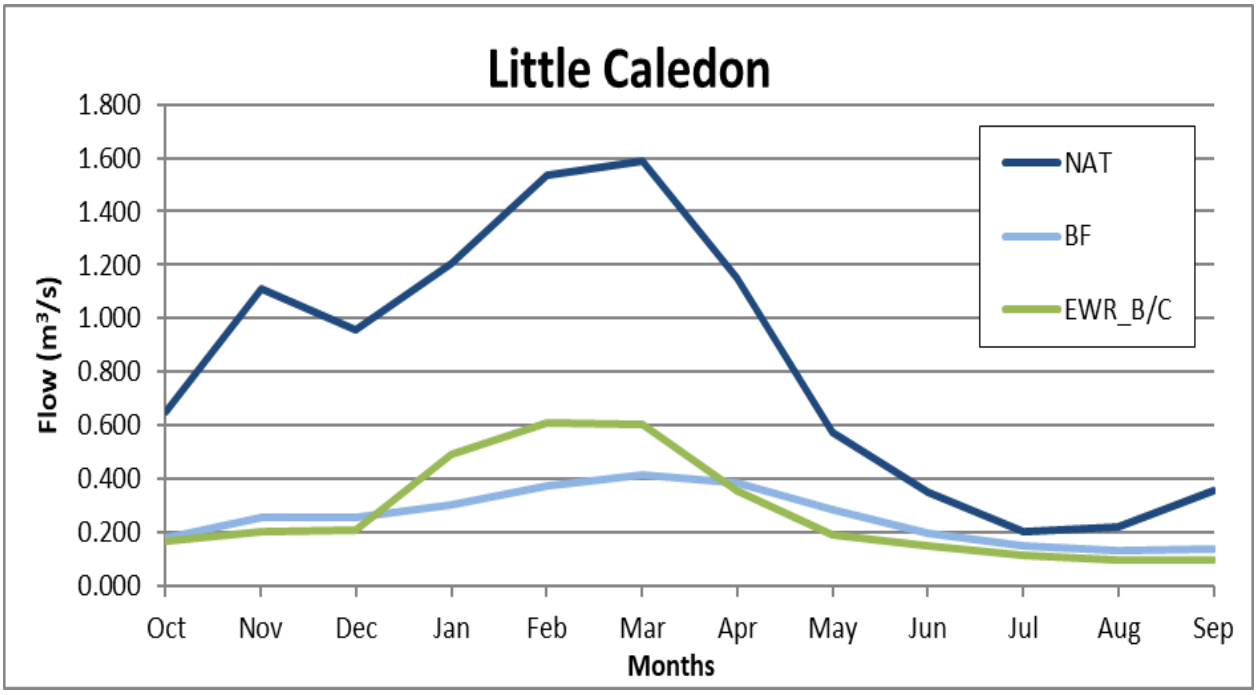


Figure 10: Water levels on cross-section of UO_EWR01_R in the Little Caledon River in D21D

The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 19, the final EWR for the Little Caledon River at the EWR site is summarised in Table 20 and presented in Figure 11.

Table 19: Little Caledon - Freshets and flood requirements for implementation

Months	Freshets		Floods	
	m^3/s	days	m^3/s	days
October	3	2		
November	1.5	2		
December	1.5	2		
January	1.5	2	7	2
February	1.5	2	7	2
March	1.5	2	7	2
April	3	2		



NAT-Natural flows, BF-Baseflows, EWR-Ecological Water Requirements

Figure 11: Monthly hydrograph indicating final EWR for UO_EWR01_R in D21D

Table 20: Little Caledon - Summary of the final EWR results (flows in million m³ per annum) for UO_EWR01_R

Quaternary Catchment	D21D
River	Little Caledon
Recommended Ecological Category	B/C
nMAR at EWR site	25.9
Total EWR	10.154 (39.20 %MAR)
Maintenance Low flows	5.981 (23.09 %MAR)
Drought Low flows	1.919 (7.41 %MAR)
Maintenance High flows	4.173 (16.11 %MAR)
Overall confidence	Moderate

4.2. IUA 2: Caledon/ Leeu River

4.2.1. UO_EWR 01_I : Middle Caledon

The selected EWR site just upstream and downstream of the confluence with the Rantsho River and Meulspruit respectively, near Ficksburg (Figure 12: UO_EWR01_I site locality) was assessed on an intermediate level on the 29th of May 2023 as part of the high confidence Reserve determination (DWS, 2023).

River	Middle Caledon	**Altitude (m.a.s.l.)**	1 526
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,**	C
Geomorphological zone	F (Lowland)	**EI**	Moderate
		ES	Moderate
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

The reach is partly confined with a deeply incised channel. The width is approximately 50m, homogenous with some inundated sandbars along the channel. The riverbed is composed largely of sand and silt and both banks are sandy, steep and highly erodible. Habitat diversity for biota is poor and the water is often very turbid when not low baseflows. The surrounding area is a mix of settlements, grazing areas and small-scale croplands. The Lesotho side is 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 relatively absent owing to erosion of inset benches and lower banks along both banks. There are no Stones-in-Current (SIC) or Stones-Out-Of-Current (SOOC). For fish, the flow-depth velocity classes available were only Fast-Deep (FD) and Fast-Shallow (FS) habitats.

The riparian zone is defined by a deeply incised macro-channel with steep banks that are infested by invasive alien trees (IAPs), notably Black Locust (*Robinia pseudoacacia*) on the right bank and Poplar (*Populus canescens*) and Wattle (Acacia deacurrens) on the left bank, interspersed by Weeping Willow (*Salix babylonica*). Few indigenous species (~6 spp.) were recorded. The marginal zone was largely inundated by high baseflows, and the lower banks are devoid of vegetation. The riparian vegetation is also heavily impacted by bank erosion, footpaths and livestock trampling, and litter snagged in vegetation and scattered along the banks highlights a solid waste problem upstream. Site impacts include:

- Settlements
- Cattle grazing areas
- Small-scale croplands
- Alíen invasives (*Acacia dealbata, Salix sp., Populus sp., Robinia pseudoacacia)*
- Cultivation
- Vegetation removal, and
- Macrophytes and plastics/ litter along both banks.

Figure 12 shows the site locality in quaternary catchment D22D and Figure 13 shows photographs taken during the Reserve study in May 2023 (DWS, 2023).

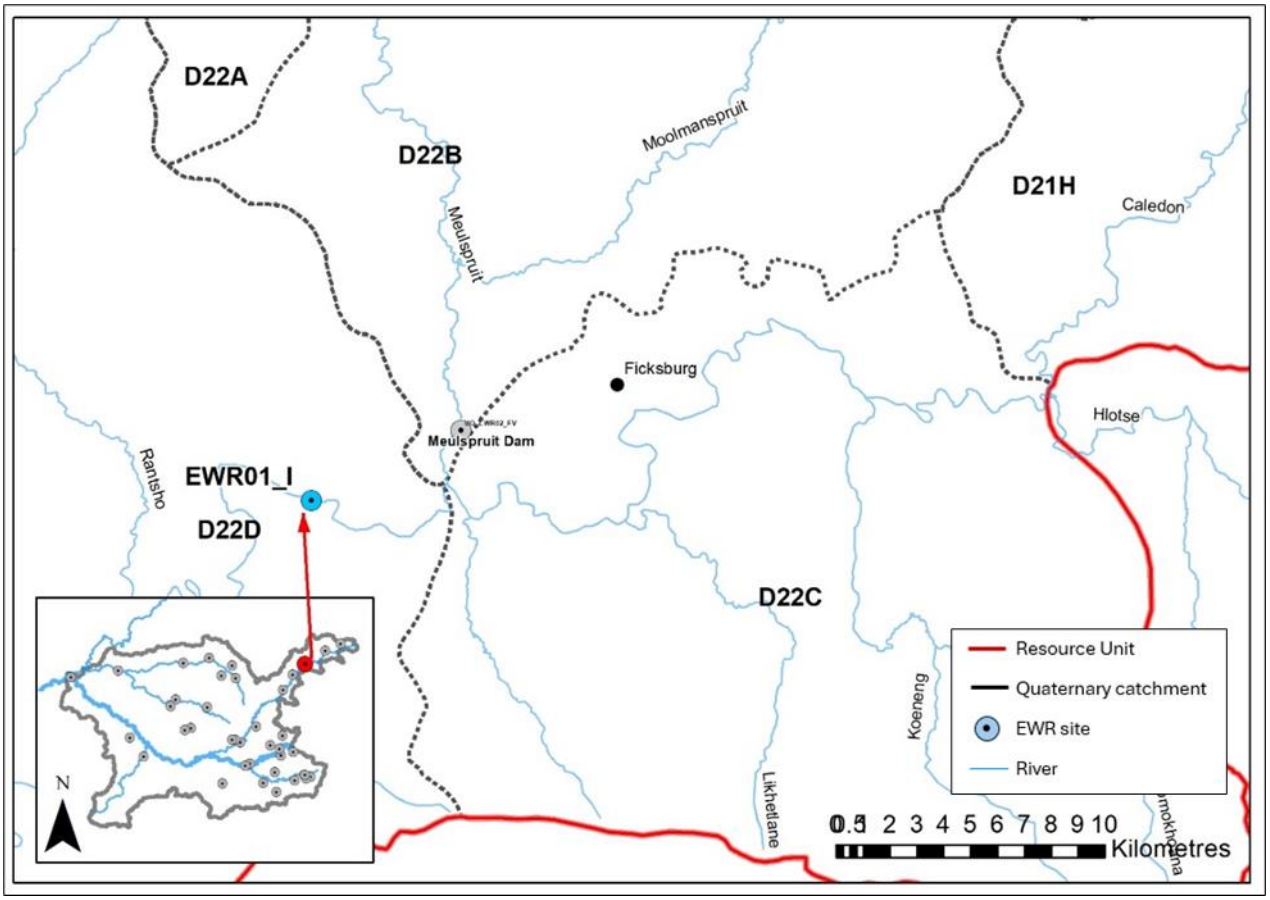


Figure 12: UO_EWR01_I site locality

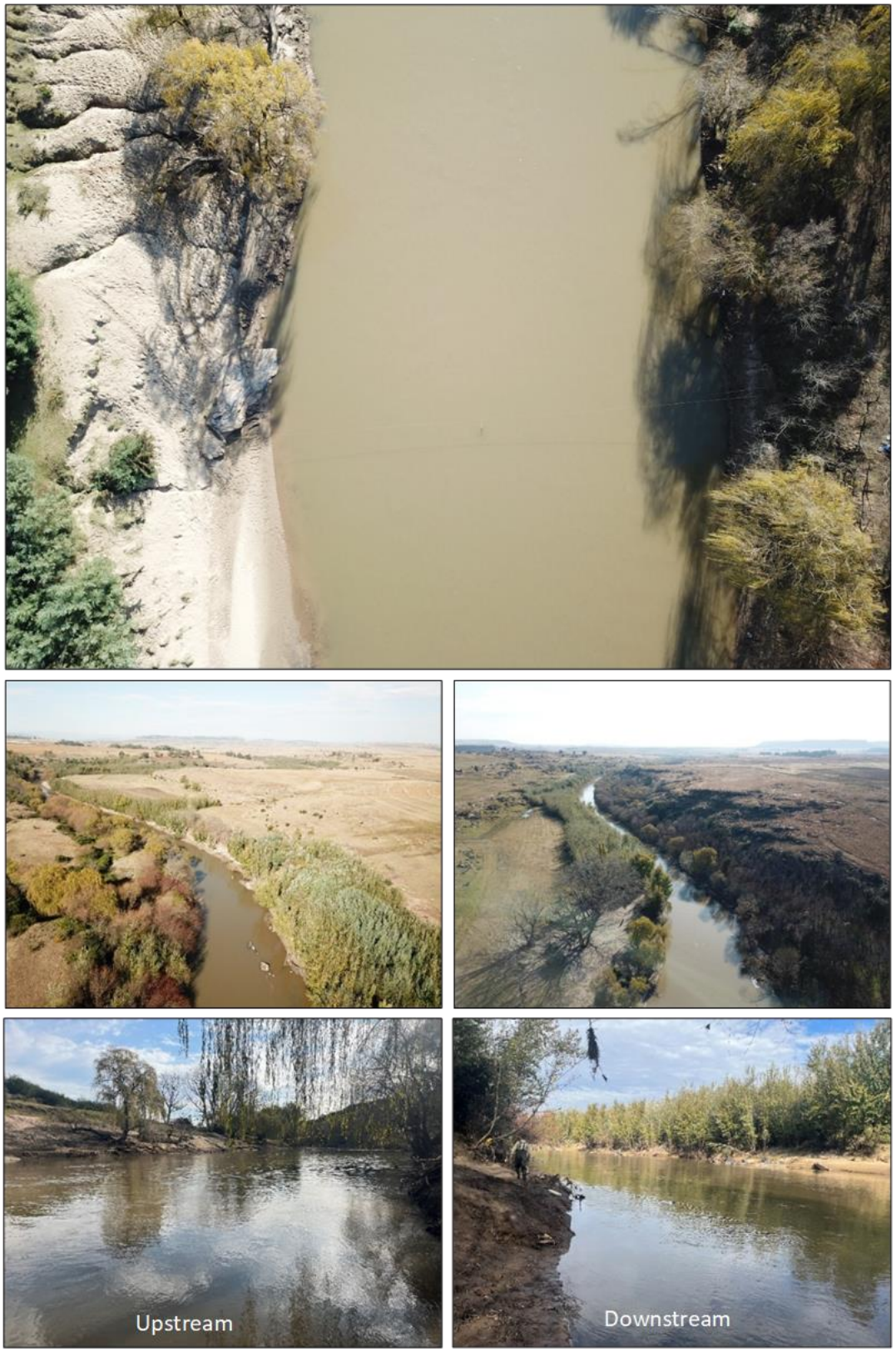


Figure 13: Site photographs for UO_EWR01_I during May 2023 (DWS, 2023)

Summary results (DWS, 2023)

WATER QUALITY AND FLOW (in situ)	
Parameter	**Survey (May 2023)**
pH	8.0
Electrical Conductivity (mS/cm)	21.9
Total Dissolved Solids (mg/l)	190
Dissolved Oxygen (mg/l)	9.1
Dissolved Oxygen % (%)	84.2
Clarity (cm)	26
Temperature (°C)	11.7
Salinity (ppt)	0.14
Discharge (m^3/s)	17.190 m^3/s and 1.73 m^3/s (July 2021, from a previous study)

Diatoms*				
No. species	**SPI****	**Categorisation (quality)**	**%PTV*****	**%Deformed cells********
58	8.6	D (Poor)	24.9	2.25
Dominant Species		1. *Achnanthidium sp.*		
		2. *Craticula molestiformis (Hustedt) Lange-Bertalot*		
		3. *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*		
		4. *Navicula symmetrica Patrick*		
		5. *Nitzschia sp.*		
Preference		1. Moderate to good quality waters		
		2. A cosmopolitan species generally found in electrolyte rich and often heavily polluted water (including sewage effluent).		
		3. Tolerant of strong pollution, indicator of industrial organic pollution		
		4. A cosmopolitan sp. in eutrophic and electrolyte-rich water. Tolerant of strongly organically polluted water.		
		5. Generally, siltation and moderate pollution		

***Specific Pollution sensitivity Index (adapted from Eloranta & Soininen, 2002): >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)*
****The percentage of pollution tolerant valves (adapted from Kelly, 1998): <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*
*****Deformed cells: a red flag (>2%) showing potential harmful pollutants within the water column. These toxins have the potential to disturb the cell walls morphogenesis and the silica which is then laid down incorrectly in the cell wall causing changes in the cell outline or in the striae patterns of the species. Therefore, a lack to no deformed cells suggests heavy metals are not a consistent issue at the site.*

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 21.

Table 21: Reference Conditions at UO_EWR01_I (DWS, 2023)

Component	Description Of Reference Conditions
Fish	*Enteromius oraniensis, Enteromius paludinosus, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis* and *Labeo umbratus*
Macroinvertebrates	Reference taxa based on assessments of other rivers in the EcoRegion Level 2 include: 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
Riparian vegetation	Within the Grassland Biome (Mesic Highveld Grassland Bioregion). Dominated by non-woody vegetation with various grasses and herbs from surrounding Eastern Free State Clay Grassland extending into the riparian zone, which would have been dominated by *Cynodon dactylon* on the lower banks, with sedges along the river margins and emergent *Salix mucronata* trees scattered along the banks.
Hydrology	Natural flows at the EWR site were available for the period 1920 to 2004.
Geomorphology	Low gradient alluvial fine bed channel with limited lateral migration along unconfined reaches, resulting in a straight to wandering channel, with a braided pattern at very low flows. Deeper channels, pools and vegetated or bare (recently deposited) inset benches provide habitat along the margins. The banks will have a moderate gradient and will have a narrow active floodplain, set between the higher-lying terraces. The lower banks will be largely treeless.
Physico-chemical	Reference data for the site could not be obtained as the only physical-chemical data available was from 2017 to 2023. Diatom results were used to infer the reference physical-chemical condition of the system. Diatom results indicated poor water quality owing to dominant species being recorded with a preference for strong moderate to strong, including industrial organic pollution, all of which likely sourced from Ficksburg located upstream. Under reference conditions lower organic pollutant concentrations are evidently expected to be prevalent in the system.

The PES per component as derived from the various models as well as the EcoStatus are provided in

Table 22.

Table 22: PES per component for UO_EWR 01_I and EcoStatus (DWS, 2023)

Component	PES category & score	Flow/ non-flow	Explanation
Fish (FRAI)[a]	D (44.1%)	F/NF	• Alluvial bed with high mobility. • Loss of cover features within channel. • Hydrological and water quality modification due to catchment activities (high erosion rates due to loss of basal cover leading to high sediment loads, increased catchment development).
Macroinvertebrates (MIRAI) [b]	C (64.6%)	F/NF	• Water quality modification due to high sedimentation loads (upstream catchment activities, highly erodible soils and steep eroded banks). • Habitat modification – no marginal vegetation owing to eroded banks and sediment deposition. • The site is primarily alluvial with the dominant macroinvertebrate habitat being comprised of mud, and pockets of gravel.
Riparian vegetation (VEGRAI)[c]	E (22.6%)	NF	• Site is severely impacted by alien trees resulting in widespread removal of ground cover and serious bank destabilisation leading to significant erosion of banks and sediment deposition on the banks and into the channel.
Geomorphology (GAI)	D (51.0%)	NF (18% F related)	• The main driver of the poor habitat and degraded site lies with elevated sediment yields from the degrading catchment, trampling along the banks and alien vegetation changing the bank stability and shape.
Hydrology (HAI)	C (72.5%)	F	• Reduced low flows due to water abstractions for irrigation and domestic use. • Reduced freshets because of numerous small dams on tributaries (SA side).
Physical-chemical Diatoms [d]	D	NF	• Due to the lack of sufficient monitoring data, diatoms were used to infer the present physical-chemical state of the system. • Largely driven by pollution related to untreated effluent discharge upstream in Ficksburg.
ECOSTATUS[e]	**D/E (34.4%)**		

[a]*Refer to Appendix B of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2 for the fish species inventory for all EWR sites*
[b]*Refer to Appendix C of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2 for theSASS5 datasheets for all EWR sites*
[c]*Refer to Appendix D of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2 for the riparian vegetation species inventory inventory for all EWR sites*
[d]*Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2 for the diatom results*
[e]*Refer to Appendix F of Report number RDM/WMA13/00/CON/COMP/1123 (a): Eco-categorisation Report-VOLUME 2 for the EcoStatus model results*

The trends in ecological status give an indication of whether the present state is realistic and would stay the same if the management of the catchment were to continue in the same way that gave rise to the present state. The definition of the trend is "…viewed as a directional change in the attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux", Kleynhans and Louw (2007). The ecological trends for UO_EWR01_I are presented in Table 23.

Table 23: Ecological trends for UO_EWR 01_I (includes components that were assessed)

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Stable	Given the degree of catchment-level impacts present, and assuming catchment impacts remain unchanged and no additional impacting factors are present, the ecological state of the fish assemblage is likely to remain unchanged.	2
Macroinvertebrates	Stable	Water quality modification is the primary driver influencing macroinvertebrate community health. However, further influenced by habitat modifications (sediment loads, eroded banks) and flow modification due to upstream impoundments and changes in flow regimes in the catchment from catchment-scale farming/agricultural activities. Assuming these catchment impacts remain unchanged the macroinvertebrate community health is therefore unlikely to deteriorate over time because of the proposed abstraction. Subject to EWR flows being met.	2
Riparian vegetation	Stable	It is unlikely that the vegetation will degrade more than its current highly degraded state unless added pressures developed adjacent to the river as well as from upstream.	3
Hydrology	Stable	No recent changes to upstream water use or infrastructure developments	3

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Geomorphology	Stable	The drivers have been altered several decades ago, so the reach has adapted to the new equilibrium. Further degradation will take place as the water resources are further developed.	3
Physico-chemical	Stable	The physical-chemical state of the system was changed from natural with the introduction of developments upstream, which have been around for a long time. The impacts of the Ficksburg WWTW have also been reported as a problem in 2011, suggesting that issue has been existing since before then.	3
ECOSTATUS	Stable		

** 0 – no confidence to 5 – high confidence*

The overall EcoStatus for this EWR site was categorised as an E (Table 24), with the system in a seriously modified condition and the resilience of the system is often under severe stress (Table 24). The degradation of the catchment is elevating suspended sediment loads, sedimentation of the channel and a reduction of habitat diversity as coarser habitats are covered by fine sediment. At the site, disturbance along the channel and margins (notably alien infestations and bank erosion) degrade the habitat associated with inset benches and banks. This is ultimately having a knock-on effect on the biota (fish and macroinvertebrates) of the system owing to altered system dynamics in the form of catchment-scale impacts. These result in a lack of diverse substrate/biotopes within the reach. Furthermore, the presence of impoundments within the system that act as a migratory barrier for fish species moving upstream from the Orange River system during seasonal migrations.

Alien trees in the riparian zone present a serious problem for the Caledon River, which will require significant investment of capital and resources to effectively manage the situation. Solid waste and failing sewer systems present a growing problem for the water quality of the system.

It is suggested that a REC of a D (largely modified) can be achieved, should the proposed mitigation measures/ recommendations (eradication of alien vegetation on banks and re-establishing natural vegetation for stabilising the banks) be assessed and applied.

Table 24: Overall EcoStatus assessment for UO_EWR01_I (Middle Caledon)(DWS, 2023)

River	Middle Caledon
EWR Site Code	UO_EWR01_I
Driver Component	PES
Hydrology (HAI)	C
Geomorphology (GAI)	D
Response Components	PES

Diatoms	D
Fish (FRAI)	D
Macroinvertebrates (MIRAI)	C
Riparian Vegetation (VEGRAI)	E
EcoStatus	E
Ecological Importance (EI)	Moderate
Ecological Sensitivity (ES)	Moderate
Recommended Ecological Category (REC)	D

The EWR for the Middle Caledon River was determined for a REC of a D and the HFSR approach was used to determine the EWRs. The indicator species for macroinvertebrate taxa and fish species selected for the Middle Caledon were Caenidae and *Labeobarbus aeneus* (large semi-rheophilic) due to the lack of true rheophilic species.

Macroinvertebrates: The Middle Caledon 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 was available. Habitat diversity for macroinvertebrates is thus very poor in this river system, with only sand and mud as a biotope available for macroinvertebrates, although a pocket of gravel along the left bank was available. Consequently, the indicator macroinvertebrate selected for this reach is Caenidae. This family have a primary preference for gravel, sand and mud, and typically occur at depths of 10 – 30 cm. They have a wide range of preferences for velocities from 0.1 m/s to 0.6 m/s. Consequently, the macroinvertebrate habitat availability assessed as critical habitat will be the VSFS, SFS).

Fish: The reach is expected to provide very limited cover for fish, 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 life history stages. However, critical habitat required 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 Caledon River upstream of 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, a large semi-rheophilic (*Labeobarbus aeneus*) were selected to act as a flow-dependent indicator. The reach does not have any critical habitat (i.e., coarse substrate in different Very Deep (VD) classes) for early-life stages (spawning, egg development & larval nursery area), thus are likely to be used as a conduit for upstream movement during periods of high flow. Primary focus in this respect was given to the faster flowing velocity-depth classes, notably fast-intermediate and fast-deep classes.

The optimum baseflows based on the 95th percentile for the wet and dry season were determined from the reference baseflows with July (0.827 m^3/s) and February (2.474 m^3/s) representing the dry and wet season.

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 25 and illustrated in Figure 14.

It is important to note that the flow driver will be based on fish, as the selected macroinvertebrate indicator was limited by poor habitat availability, and Caenidae is not considered a sensitive macroinvertebrate.

Table 25: Stress-flow relationships

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0			12.34	Fast-intermediate class present in highest abundance, with fast-deep class dominant. Slow-deep class also present and likely associated with undercut banks, providing cover
1				
2			9.048	Significant reduction in fast-intermediate class, but some slow-deep still present (likely adjacent to banks with bank-undercut providing some cover). Fast-deep class dominant and still providing a pathway for upstream movement.
3				
4			3.331	Wetted perimeter starts to drastically reduce, thus limiting undercut banks to only one side of the river. At this point, flow starts to get confined into the lower portion of the channel, thus reducing the extent of habitat available to fish
5				
6				
7			0.291	Loss of all critical habitat, and further reduction of contact with bank. Flow now confined to central portion of channel with no cover features available. All life stages of semi-rheophilics at significant risk and likely not viable.

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
8				
9				
10	0	Average depth is 0 cm, with no critical habitat, pooled in-stream. Only specialists will persist.	0	No flow with some isolated pools of limited depth, thus no fish species expected

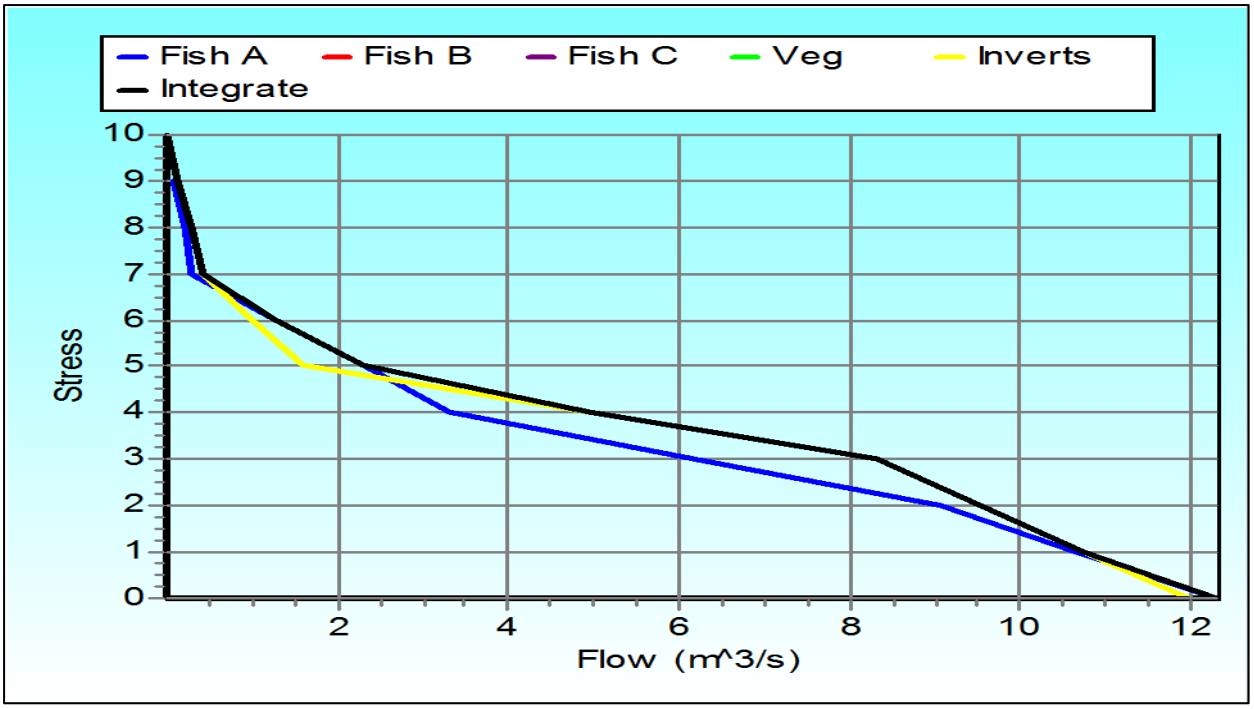


Figure 14: Final integrated stress curve for the Middle Caledon EWR site (UO_EWR01_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (February) and the final adjusted EWRs are shown in Figure 15. The adjustments made to the DRM results are:

- Increase drought flows from 3.52% to 3.77%
- Increase July maintenance low flows from 0.497 m^3/s to 1.304 m^3/s
- Increase February maintenance low flows from 1.591m^3/s to 4.171 m^3/s

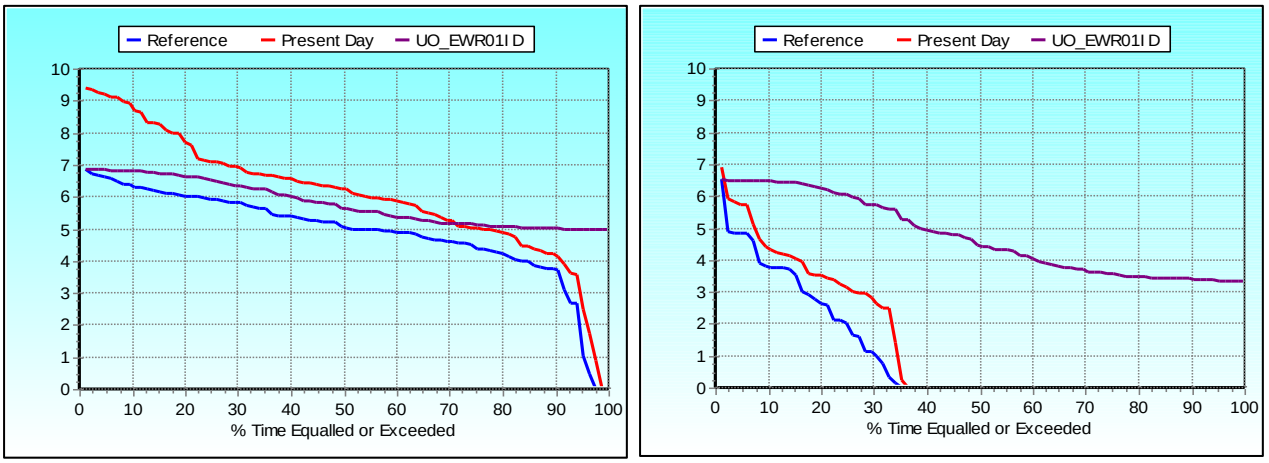


Figure 15: Final stress duration curves – dry season (July) and wet season (February) for UO_EWR01_I

The flood requirements for the Middle Caledon EWR site were specified by the specialists and include small freshets to provide cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching), as well as larger floods for clearing of the river channel. No large floods for riparian vegetation were specified due to the already heavily infested riparian zone by alien species and severe erosion/bank collapse and high flows will only degrade this further. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 26.

Table 26: Flood requirements for the Middle Caledon at the EWR site (UO_EWR01_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorph-ology	FINAL
Class 1 (0-20 m^3/s)	m^3/s				20	20
	# days				4	4
	Months				Nov, Dec, Jan, Mar	Oct-Jan, Mar, Apr
	Type				Average	Average
Class 2 (30-40 m^3/s)	m^3/s	35				35
	# days	5				5
	Months	Nov, Dec, Jan, Feb				Nov-Mar
	Type	Average				Average
Class 3	m^3/s	60				60

(60 m^3/s)	# days	3				3
	Months	Jan, Feb				Jan, Feb
	Type	Peak				Peak

** The 1:2, 1:5 and 1:10 year floods were not modelled but important to include in any water resource developments*

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 27**Error! Reference source not found.**.

Table 27: Middle Caledon - Summary of the EWR results (flows in million m^3 /annum) for UO_EWR01_I

Quaternary Catchment	**D22D**
Site name	UO_EWR01_I
River	Middle Caledon
EWR Site Co-ordinates	-28.9092102; 27.784924
Recommended Ecological Category	D
nMAR at EWR site	674.0
Total EWR	156.076 (23.16 %MAR)
Maintenance Low flows	79.548 (11.80 %MAR)
Drought Low flows	25.394 (3.77 %MAR)
Maintenance High flows	76.529 (11.35 %MAR)
Overall confidence	Moderate

4.3. IUA 3: Caledon River

4.3.1. UO_EWR 04_I : Lower Caledon

The selected EWR site located just downstream of the N6 road bridge between Rouxville and Smithfiled (Figure 16), was assessed on the 11th of July 2022 and 31st of May 2023 as part of the high confidence Reserve determination (DWS, 2023) on an Intermediate level.

River	Lower Caledon	**Altitude (m.a.s.l.)**	1 277
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,**	C
Geomorphological zone	F (0.001; Lowland)	**EI**	High
		ES	High
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

The water transfer from the Caledon River to the Knellpoort Dam and the Welbedacht Dam are approximately 100km upstream. The surrounding land use is extensive sheep farming with localised irrigation of lucerne from the Caledon River. High silt loads in this river are causing significant problems for local farmers with “fines” (silt, clay and sand) clogging the soil pores and preventing water penetration.

The site is located along an unconfined low gradient reach. The channel is relatively straight, incised into the surrounding landscape with narrow flood features (Figure 17). The banks are steep and lined with alien invasive trees and annuals. Salix and Populus trees dot the riverbanks from the waterline to ~10 m from the water. The river at this site is ~50-70m wide and defined by a couple of strong basaltic intrusions diagonally across the river defining a narrow (~5m wide) resistant bedrock shelf and providing the key geomorphic structure to this reach of the river. Coarse material (boulder and cobble sized) has been introduced for the bridge construction. This has created a series of concrete shelves under the bridge and boulder and cobble shoots, runs and riffles directly downstream of the bridge. At the reach scale the system is dominated by the finer alluvial sands and silts from active upstream erosional processes. These sediments are regularly and extensively deposited onto the riverbanks and under lower flows defines a fine sediment dominated bed and braided main channel.

Biotopes that were available for macroinvertebrates for both surveys were SIC and GSM. Limited SOOC and no marginal vegetation was present owing to undercut banks and vegetation die back and erosion. Flow-depth velocity classes available for the fish included FD, SD, SS and FS.

The marginal riparian zones are bare with emergent *Salix mucronata* trees (including some that are dead). This pattern extends into the lower portion of the lower zone. Beneath the bridge there is a broad area of exposed rocks and sand with very little vegetation cover. There is an abrupt increase in vegetation cover higher up the non-marginal zone which exists as a mosaic of woody and non-woody vegetation. A number of IAPs were recorded (i.e., 16 species), namely *Cyperus eragrostis*, *Bidens pilosa*, *Gleditsia triacanthos*, *Persicaria lapathifolia*, *Populus nigra*, *Salix babylonica* and *Tagetes minuta.* Only 11 indigenous plant species were recorded. Impactcs at the site include:

- Agriculture
- Abstraction and irrigation
- Cattle grazing and trampling
- Local water pump just upstream of the bridge
- Artificial habitats (as a result of construction material for the bridge which remain)
- Bank erosion, and
- Riparian alien invasives.

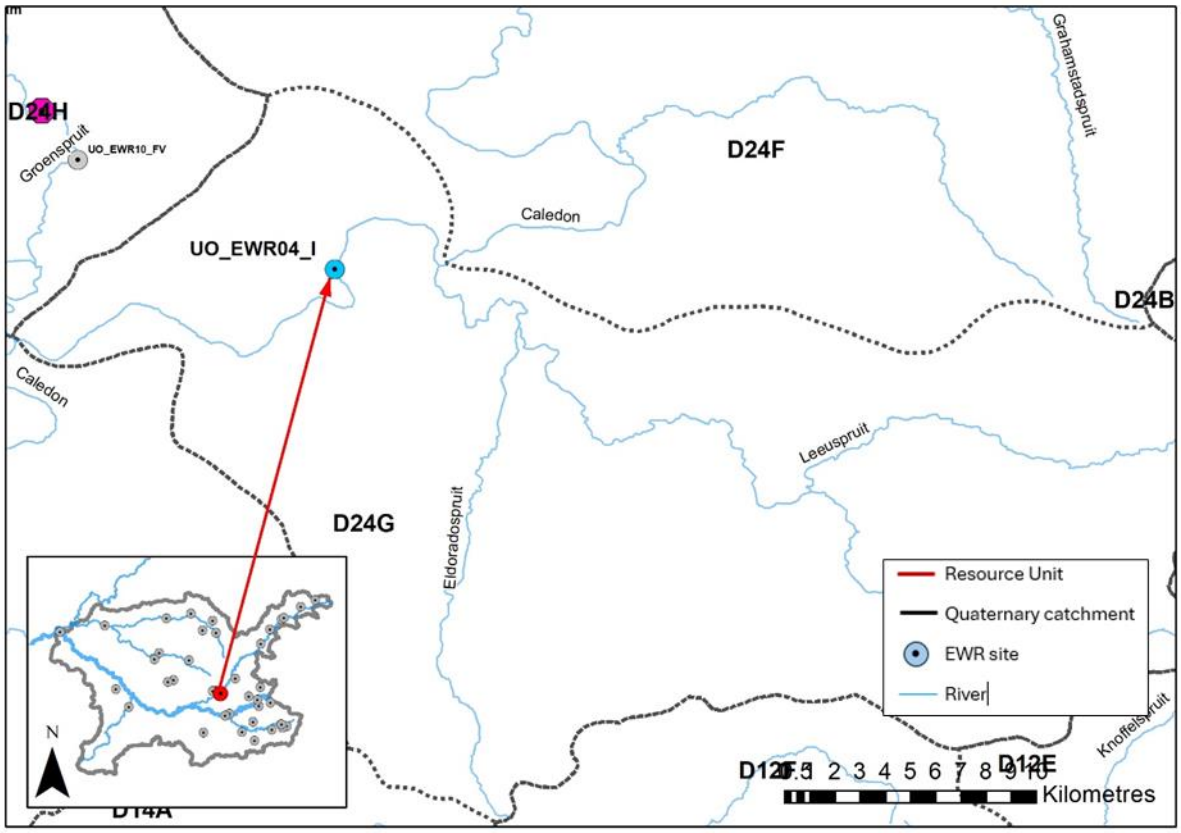


Figure 16: Location of site UO_EWR04_I (Lower Caledon) in relation to the study area

Figure 17: UO_EWR 04_I Site photographs (July 2022 - Left and May 2023 - Right

Summary results UO_EWR04_I for (DWS, 2023)

WATER QUALITY AND FLOW (In situ)		
Parameter	**Survey 1 (July 2022)**	**Survey 2 (May 2023) at EWR site**
pH	8.7	8.4
Electrical Conductivity (mS/m)	25.9	21.74
Total Dissolved Solids (mg/l)	200	200
Dissolved Oxygen (mg/l)	10.1	9.2
Dissolved Oxygen (%)	87.9	83.5
Clarity (cm)	27	11.5
Temperature (°C)	9.2	10.8
Salinity (ppt)	0.18	0.14
Discharge (m^3/s)	14.190	38.451

Diatoms:									
No. species		**SPI****		**Categorisation (quality)**		**%PTV*****		**%Deformed cells******	
07/22	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**
23	16	7.9	6.4	D (Poor)	D (Poor)	67.2	91.4	2.25	1.5

Dominant Species	**July 2022**	*Eolimna subminµScula (Manguin) Moser, Lange-Bertalot & Metzeltin*
	May 2023	*1. Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*
		2. Fistulifera saprophila (Lange-Bertalot & Bonik) Lange-Bertalot
Preference	**July 2022**	Tolerant of strong pollution and an indicator of industrial organic pollution
	May 2023	1. Tolerant of strong pollution, indicator of industrial organic pollution
		2. Some of the most pollution tolerant diatoms - indicate organic pollution (sewage) or are associated with organic detritus.

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 28.

Table 28: Reference Conditions for sire UO_EWR04_I

Component	**Description Of Reference Conditions**
Fish	*Austroglanis sclateri, Enteromius oraniensis, Enteromius paludinosus, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis* and *Labeo umbratus*

Component	Description Of Reference Conditions
Macroinvertebrates	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.
Riparian vegetation	The site is primarily defined by Upper Gariep Alluvial Vegetation, which is within the Dry Highveld Grassland Bioregion (of the Grassland Biome). The surrounding terrestrial vegetation comprises Xhariep Karroid Grassland. The river margins would have supported reedbeds and flooded grasslands on exposed alluvium, transitioning up the banks into the grassland dominated terrestrial environment.
Hydrology	Natural flows at the EWR site available for the period 1920 to 2004.
Geomorphology	Low gradient alluvial fine bed channel with straight to wandering channel, possibly braided at very low flows. Alternating sand bars and possibly small gravel bars, mid-channel bars, with a deeper low flow channel, pools and vegetated and bare (recently deposited) inset benches that provide habitat along the margins. The banks will be of moderate gradient and will have a narrow active floodplain, set between the higher-lying terraces. The lower banks will be largely treeless.
Physico-chemical	Reference data for the site could not be obtained. Diatom results were used to infer the reference Physical-chemical state of the site. Diatom results indicated that the site is heavily contaminated with organic pollution, resulting from elevated nutrient concentrations at the site, JBS 2 (2015) diatom results also suggested elevated chloride concentrations. Lower nutrient concentrations are expected to be prevalent at the site under reference conditions. The recent diatom samples from May 2023 were dominated by species being the most pollution tolerant diatoms – indicative of organic pollution (sewage) and associated with organic detritus.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 29.

Table 29: PES per component for UO_EWR 04_I and EcoStatus

Component	PES category & score	Flow/ non-flow	Explanation
Fish (FRAI)	D (46.3%)	F/NF	• Hydrological and water quality modification due to presence of Welbedacht Dam catchment activities (high erosion rates due to loss of basal cover

Component	PES category & score	Flow/ non-flow	Explanation
			leading to high sediment loads, increased catchment development) • Presence of migratory barriers downstream (Gariep Dam, Van Der Kloof Dam) and upstream (Welbedacht Dam) • Access limitations owing to high velocity conditions
Macroinvertebrates (MIRAI)	D (46.0%)	F/NF	• Bank erosion thus hampering marginal vegetation biotope • Some siltation on the SIC and SOOC biotope (high sediment loads transported downstream) • Access limitations owing to high velocity conditions
Riparian vegetation (VEGRAI)	D (50.9%)	F/NF	• Notable loss of vegetation-cover along lower banks and margins due to recent floods/high flows following a period of limited floods prior to 2021, which has been exacerbated by encroachment of aliens and terrestrial species • High number of alien spp. – woody (mostly *Salix babylonica*) and non-woody • Removal of vegetation during construction of the bridge and erosion from stormwater runoff from the road
Geomorphology (GAI)	C (62)	23% flow related	• Low density of smaller farm dams and weirs along the tributaries that trap coarser bedload Welbedacht Dam reduces longitudinal transport of suspended and bed material, partly offsetting the high sediment input from the catchment. Some storage of flood waters in smaller dams, possibly offset by increased runoff from overgrazed and gullied hillslopes, largely from Lesotho • Widespread overgrazing and soil erosion in the upper catchment (largely from Lesotho and communal land) elevating fine sediment loads. Dams and weirs along tributaries and mainstem traps suspended and coarser bed sediment • Trampling and alien trees along banks and floodplain. Bank and bench erosion along both banks, resulting in a featureless bed with steep banks
Hydrology (HAI)	C (75.9%)	F	• Localised abstraction for irrigation • Releases from Welbedacht Dam

Component	PES category & score	Flow/ non-flow	Explanation
			• Transfer of water from Caledon River upstream of Welbedacht Dam to off-channel Dam (Knellpoort) for water use in Bloemfontein area • Impacts mainly on low and moderate/ baseflows.
Physico-chemical/ Diatoms	D	NF	• Due to the lack of data to perform the PAI, the present physical-chemical state at the site was estimated using diatom results • Diatom data indicated heavy organic pollution at the site, resulting from elevated nutrient concentrations • Elevated suspended solids, resulting in low clarity. Also mentioned as an emerging issue in the JBS3 survey (site OSAEH 26_08) • Diatom results from May 2023 indicated further high sodium chloride salinity and especially irrigation return flow (*Pseudostaurosiropsis geocollegarum*)
ECOSTATUS	D (48.5%)		

Refer to Appendix A in Report number RDM/WMA13/00/CON/COMP/1123 for the Habitat Integrity assessment scores for the riparian and instream zone, and Appendix C for the fish and aquatic macroinvertebrate inventories.

The overall EcoStatus for this EWR site was categorised as a D, with the system being largely modified (Table 30: Overall EcoStatus for UO_EWR04_I). The degradation of the catchment is elevated suspended sediment loads, leading to sedimentation of the channel and a reduction of habitat diversity as coarser habitats are covered or clogged by fine sediment. At the site, disturbance along the margins is high, with concomitant degradation of the habitat associated with inset benches and banks. The integrity of the biota is compromised owing to altered system dynamics in the form of catchment-scale impacts. Hydrological and water quality modification due to presence of Welbedacht Dam and catchment activities (i.e., high erosion rates due to loss of basal cover leading to high sediment loads, intensive cultivation, increased catchment development) and the presence of migratory barriers for fish downstream (Gariep Dam, Van Der Kloof Dam) and upstream (Welbedacht Dam).

Riparian vegetation has been directly impacted following construction of the bridge, including localised stormwater runoff and erosion, and has experienced a moderate infestation of alien invasive plants, together with encroachment of woody shrubs. Recent flooding has removed most non-woody vegetation, and even some trees/shrubs, which were established along the margins and lower banks.

It is suggested that a REC of a C/D (close to moderately modified) can be achieved, should the proposed mitigation measures/recommendations (improved water quality and riparian vegetation) be assessed and applied.

Table 30: Overall EcoStatus for UO_EWR04_I, Lower Caledon

River	Lower Caledon
EWR Site Code	UO_EWR04_R
Driver Component	PES
HAI	C
GAI	C
Response Components	PES
Diatoms	D
Fish (FRAI)	D
Macroinvertebrates (MIRAI)	D
VEGRAI	D
EcoStatus	D
Ecological Importance (EI)	Moderate
Ecological Sensitivity (ES)	Moderate
Recommended Ecological Category (REC)	C/D

The EWR for the Lower Caledon River was determined for a REC of a C/D and the HFSR approach was used to determine the EWRs. This river reach is wide and homogenous and composed largely of sand and silt. Both banks are sandy, steep and highly erodible and thus no marginal vegetation is present. The indicator species for macroinvertebrates and fish selected for the Lower Caledon were Hydropsychidae and BAEN (large semi-rheophilics) due to the lack of true rheophilic species.

Macroinvertebrates: At this EWR site, there is artificial substrate in the form of SIC which functions as a biotope for the macroinvertebrates. This artificial habitat is not natural, as this material was brought in for the purpose of a foundation for the existing bridge constructed many years ago. Although, this is not representative of the reach, this artificial habitat is functioning as critical habitat for flow dependent macroinvertebrates. The indicator taxon selected for this site is Hydropsychidae, being a flow dependent taxon. They have a high preference for fast currents of >0.6 m/s, although optimal speeds are approximately 0.4 m/s, along cobble substrate. The minimum depth requirements for Hydropsychidae are 10cm, and maximum depths are about 30cm. Thus, the macroinvertebrate habitat availability assessed as critical habitat will be the FCS and VFCS. Many macroinvertebrate species are sensitive to deterioration in water quality, however there are species that are more tolerant. It is important to note that the water quality tolerance depends on the species of the Hydropschidae present. Some species are tolerant, while others are sensitive to water quality.

Fish: At this EWR site, artificial substrate is available as a habitat for fish species because of the bridge, with suitable habitat available to function 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-sectional area, 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.

The optimum baseflows based on the 95th percentile for the wet and dry season were determined from the reference baseflows with July (1.859 m^3/s) and February (3.306 m^3/s) representing the dry and wet season.

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 31 and the final integrated stress curve is shown in Figure 18: Final integrated stress curve for the Lower Caledon EWR site (UO_EWR04_I).

Table 31: Selected stress values, flows and rationale for the Lower Caledon, UO_EWR 04_I

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	14.924	The FCS and VFCS habitats are plentiful and in excess and very high quality (17% and 41% respectively) with an average flow velocity of 0.7 m/s. The average depth is 46 cm, which is around the target flow for this indicator group - Hydropsychidae.	13.88	Flow considered adequate, with 83% of all habitats within the cross-section being fast and representing elements from all fast velocity-depth classes, with discharge representing the highest percentage of fast-intermediate class.
1			11.924	Increase in fast-shallow class, activating suitable spawning habitat
2			8.913	Fast-shallow class on the margins of the wetted perimeter at its greatest extent, providing spawning habitat and suitable habitat for egg and embryo development.
3	7.777	Critical habitat remains relatively healthy, although the VFCS habitat has reduced (29%). The	7.777	Critical spawning habitat present but starts to drop off with respect to extent.

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		average depth is 37cm and average flow of 0.5 m/s, still within the preference range of the Hydropsychidae family.		
4				
5	3.183	Average depth of 30cm and average velocity of 0.37 m/s along the cross-section, with the critical habitat (VFCS) drastically reduced to just 11%, although FCS habitat slightly increased to 28%. Thus, this habitat is becoming limiting for the indicator taxon at this flow rate.	2.213	Loss of fast-deep class for adult fish with a concomitant increase in fast-intermediate class. Spawning habitat (fast-shallow class) greatly reduced and limited.
6				
7	0.591	Very little critical habitat (FCS - 8% and VFCS - 1%). Most flow-sensitive taxa will disappear. Slow current speeds of 0.15 m/s, not suitable for the indicator species.	0.142	Loss of all critical habitat and fast flow classes. Water depth presents a challenge to larger specimens of fish, with only juvenile cohorts likely to be present and associated with substrate as a means of cover.
8				
9				
10	0	No flow and an average depth of 0.2cm. Macroinvertebrates diapause phase triggered.	0	Loss of all flow components - no movement between reaches.

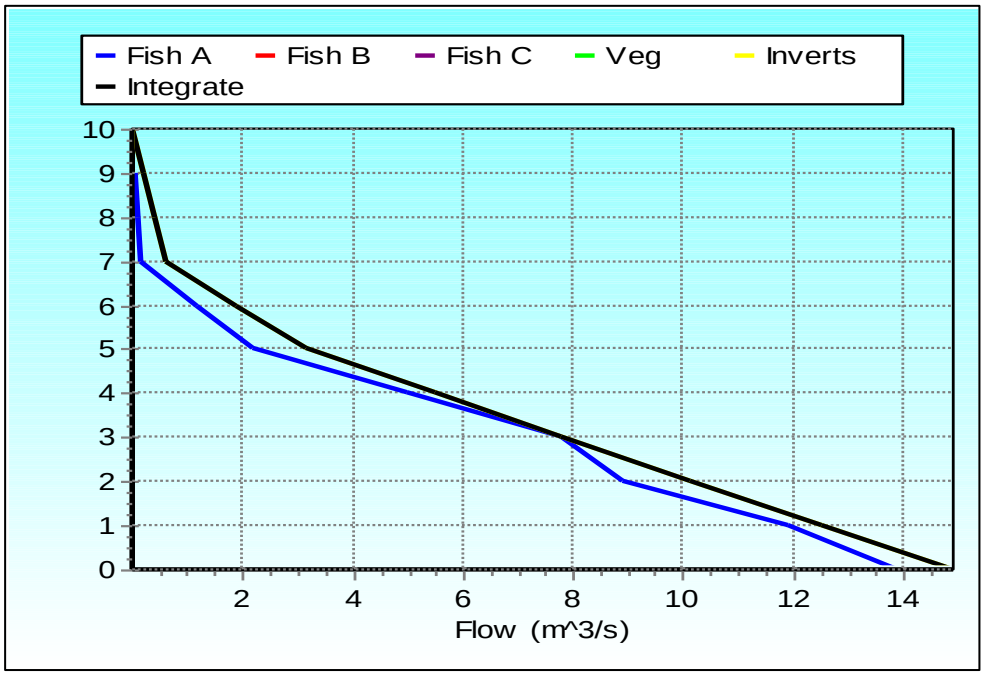


Figure 18: Final integrated stress curve for the Lower Caledon EWR site (UO_EWR04_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (February) and the final adjusted EWRs are shown in Figure 19. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality.

- Increase July maintenance low flows from 1.636 m^3/s to 3.393 m^3/s, and
- Increase February maintenance low flows from 5.310m^3/s to 11.015 m^3/s.

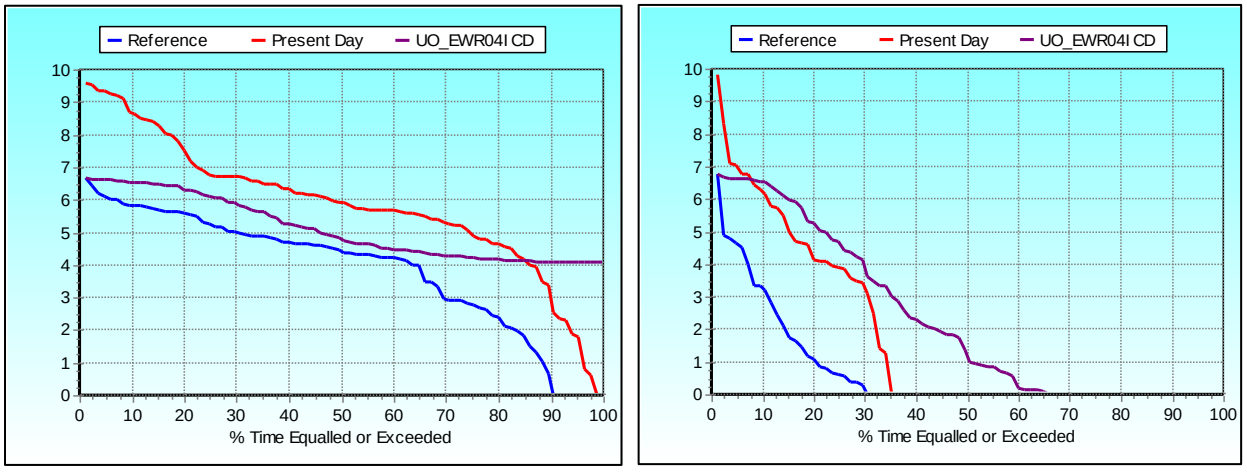


Figure 19: Final stress duration curves – dry season (July) and wet season (February)

The flood requirements for the Lower Caledon EWR site were specified by the specialist team and include small freshets to provide specific cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching). Larger floods were specified for clearing of the river channel, especially the clearing of fine silts due to extensive sediment built-up. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 32.

Table 32: Flood requirements for the Lower Caledon at the EWR site (UO_EWR04_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	FINAL
Class 1 (0-40 m^3/s)	m^3/s				38	40
	# days				5	5
	Months				Nov, Dec, Mar	Oct-Dec, Mar, Apr
	Type				Average	Average
Class 2 (60-90 m^3/s)	m^3/s	65	87	75		65
	# days	5	5	5		5
	Months	Nov, Dec, Jan, Feb	Nov, Dec, Mar, Apr	Nov, Dec, Jan		Nov, Dec, Jan, Mar
	Type	Average	Average	Average		Average
Class 3 (100-120 m^3/s)	m^3/s	110	112			110
	# days	4	5			4
	Months	Jan, Feb	Jan, Feb			Jan, Feb, Mar
	Type	Average	Average			Average
Class 4 (160 m^3/s)	m^3/s				159	160
	# days				5	7
	Months				Jan, Feb	Feb
	Type				Peak	Peak

* The 1:2, 1:5 and 1:10 year floods not modelled but important to include in any water resource developments

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 33.

Table 33: Lower Caledon - Summary of the EWR results (flows in million m^3 per annum) for UO_EWR04_I

Quaternary Catchment	D24G
Site name	UO_EWR04_I
River	Lower Caledon
EWR Site Co-ordinates	-30.280115; 26. 653060
Recommended Ecological Category	C/D
nMAR at EWR site	1 353.6
Total EWR	398.387 (29.43 %MAR)
Maintenance Low flows	203.857 (15.06 %MAR)
Drought Low flows	36.860 (2.72 %MAR)
Maintenance High flows	194.530 (14.37 %MAR)
Overall confidence	Moderate to high

4.4. IUA 4: Kraai River

4.4.1. UO_EWR 08_I: Lower Kraai River

The selected EWR site, the ORASECOM JBS3 site (26_11) and the DWS REMP site D1KRAA-ALIWA (Figure 20), was assessed on the 7th of July 2022 and 30th of May 2023 as part of the high confidence Reserve determination (DWS, 2023) on an Intermediate level.

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**	C
Geomorphological zone	E (0.001; Lower foothills)	**EI**	High
		ES	High
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

The reach has a partly confined valley setting, straight to wandering channel form and pool-riffle sequences. The channel is incised with narrow flood features. 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 (BHN) support.

This river is a free flowing river, approximately 30 m wide and has a range of biotopes. There is a solid igneous bedrock base with riffles and runs below the causeway. Much filamentous algae coverage over the SIC biotopes. Most of the river in the area has deeper, slow flowing pools. The river comprises various sections of riffles and pools downstream of the bridge, providing a range of habitats. All biotopes for the macroinvertebrates are present, SIC, SOOC, GSM, although vegetation is limiting owing to undercut banks and vegetation die back/erosion. For fish, there are FD, SD, SS and FS habitats. During both the July and May 2022 survey, the baseflows were higher than expected for the time of year because of the high rainfall during the latter part of summer.

Figure 21 illustrates the site during July 2022 and May 2023. The left bank is dominated by non-woody vegetation, with several, large Popular trees (*Populus canescens*) growing along the lower banks upstream of the weir. The site is spilt by the weir/ causeway, which results in marginal zone being inundated. Downstream of the weir is a broad, flat bench of mostly bare/exposed alluvium with patches of raised alluvial mounds covered with *Cynodon dactylon* and a narrow strip of dense *Cyperus marginatus* growing along the marginal zone. The outer edge of the riparian is marked

by a steep bank leading up into the terrestrial zone. The right bank has dense wooded vegetation comprising a mix of indigenous (e.g., *Celtis africana*, *Diospyros lyciodides, Lycium sp.*, *Salix mucronata* and *Searsia pyroides*) and IAPs (e.g., *Populus canescens* and *Salix babylonica*) which are sheltered from high velocities during flood events. There is a steep bank between the lower and upper zones. The riparian vegetation is mainly affected by vegetation removal due to roads, 4x4 tracks, footpaths, cultivation (right banks), as well as shading by IAPs. There is also serious erosion leading from the terrestrial areas into the riparian areas, especially on the left bank, as well as bank collapse and scour erosion.

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 approximately 3 m above the water level indicating large volumes passing through during flood events. Site impacts include:

- Agriculture
- Cattle activity
- Irrigation, and
- Causeway/ weir

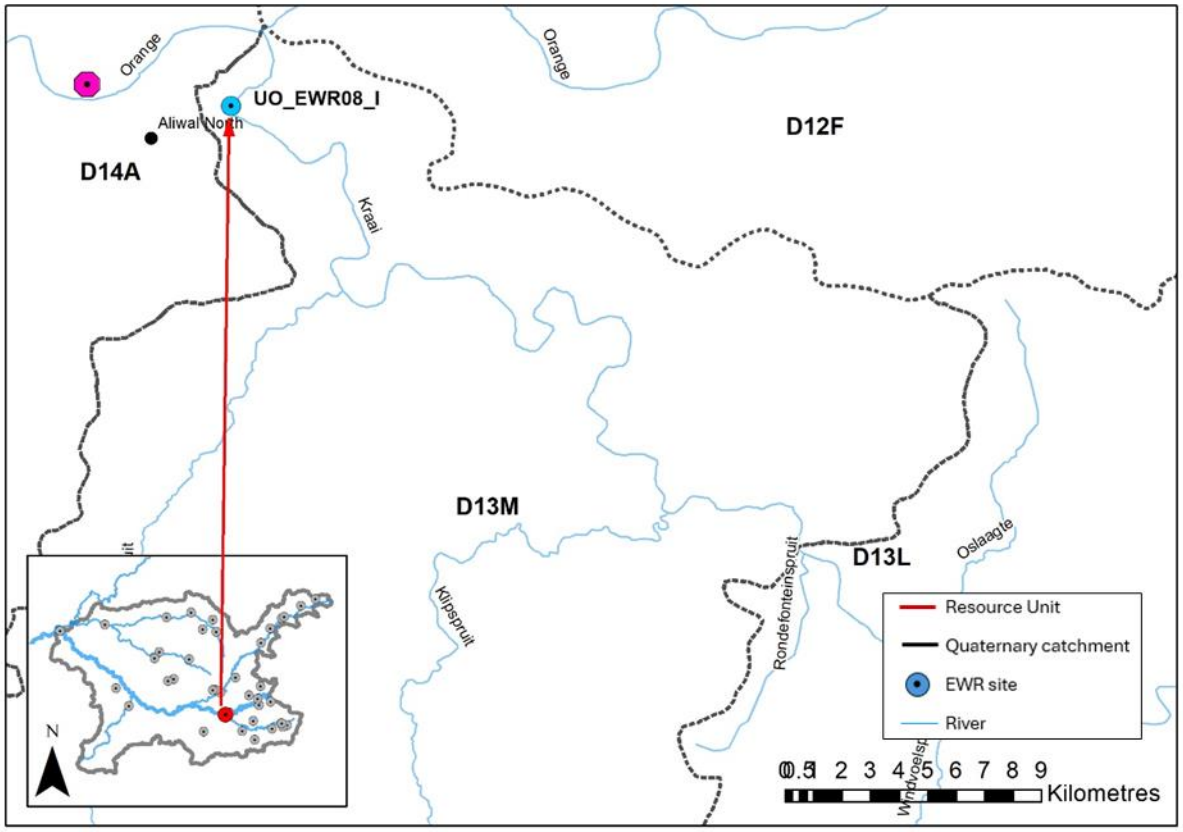


Figure 20: Location of site UO_EWR08_I (Lower Kraai) in relation to the study area

Figure 21: UO_EWR 08_I Site photographs: July 2022 (Left) and May 2023 (Right)

Summary results UO_EWR08_I (DWS, 2023)

WATER QUALITY AND FLOW (In situ)		
Parameter	**Survey 1 (July 2022)**	**Survey 2 (May 2023)**
pH	8.6	8.3
Electrical Conductivity (mS/m)	21.8	13.94
Total Dissolved Solids (mg/l)	200	100
Dissolved Oxygen (mg/l)	10.1	8.9
Dissolved Oxygen % (%)	87.7	82.1
Clarity (cm)	68	12
Temperature (°C)	9.1	11.7
Salinity (ppt)	0.15	0.09
Discharge (m^3/s)	17.300	19.030

Diatoms:									
No. species		**SPI****		**Categorisation (quality)**		**%PTV*****		**%Deformed cells******	
07/22	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**
34	31	13.8	9.8	C (Mod)	C (Mod)	7.8	62.2	0	1.75

Dominant Species	**July 2022**	*Gomphonema pumilum*
	May 2023	*Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*
Preference	**July 2022**	Strongly polluted water and high electrolytes as well as some siltation.
	May 2023	Tolerant of strong pollution, indicator of industrial organic pollution

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 34.

Table 34: Reference Conditions for site UO_EWR08_I

Component	Description Of Reference Conditions
Fish	*Austroglanis sclateri, Enteromius oraniensis, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis* and *Labeo umbratus*
Macroinvertebrates	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.

Component	Description Of Reference Conditions
Riparian vegetation	The site is primarily defined by Upper Gariep Alluvial Vegetation forming a mosaic of well-defined riparian thickets (in positions that are more sheltered from floods) and flooded grasslands/herblands. Riparian thickets would typically be dominated by trees and shrubs (i.e., *Vachellia karroo*, *Celtis africana*, *Diospyros lycioides*, *Lycium hirsutum*, *Salix mucronata* subsp. *mucronata*, *Searsia pyroides*). The river margins would have supported grasses, reeds and sedges growing on exposed alluvium. The surrounding terrestrial vegetation transitions from Dry Highveld Grassland (of the Grassland Biome) into Upper Karoo (of Nama-Karoo Biome) and comprises a mosaic of Aliwal North Dry Grassland and Besemkaree Koppies Shrubland.
Geomorphology	The reference condition for the reach is likely to be a lower gradient mixed bed alluvial channel with sand, gravel and cobble dominating the bed with localised bedrock lining the bed. The reach type would mainly be pool-riffle or pool-rapid with sand and gravel bars forming in pools. Inset benches and flood benches should form in relation to freshets and floods. A narrow floodplain can be present where the valley floor is wider.
Hydrology	Natural flows at the EWR site available for the period 1920 to 2004.
Physico-chemical	Historical Physical-chemical data for the site could not be obtained. The diatom results were used to infer the reference Physical-chemical state of the site. The diatom results indicated strongly polluted with evidence of elevated electrolyte concentrations. Lower electrolyte concentrations are expected to be prevalent in the system, under reference conditions.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 35.

Table 35: PES per component for UO_EWR 08_I and EcoStatus

Component	PES category & score	Flow/ non-flow	EXPLANATION
Fish (FRAI)	C (73.7%)	F/NF	• Water quality modifications • Flow modifications • Migration barrier • Non-native fish species
Macroinvertebrates (MIRAI)	C (65.4%)	F/NF	• Habitat modification (algae smothering SIC, upstream inundation from weir) • Water quality (high nutrient loading from agricultural return flows – resulting in the high levels of algae) • Flow modification (owing to the agricultural return flows and in other cases extensive irrigation for adjacent pivots resulting in reduced baseflows)
Riparian vegetation (VEGRAI)	D/E (40.6%)	NF/F	• Site is heavily impacted by alien trees, especially along the right bank, resulting in shading out of understorey. • Non-woody vegetation has been severely scoured due to recent floods, especially along marginal and lower zones. The flood bench on the left bank is accessed for sand mining.

Component	PES category & score	Flow/ non-flow	EXPLANATION
Geomorphology (GAI)	C (75)	17% F related	• Low density of smaller farm dams along tributaries and weirs along the mainstem that trap coarser bedload. Gullies and small areas with low vegetation cover increase water and sediment routing. • Widespread grazing and some soil erosion elevate fine sediment loads. Low water bridges and weirs along tributaries and mainstem trap coarser bed sediment. • Localised erosion along left bank due to the weir. Grazing along banks and bars. New inset benches forming along right bank.
Hydrology (HAI)	B (87.9%)	F	• Extensive irrigation in some of the tributaries and along main stem resulting in reduced baseflows.
Physico-chemical (Diatoms)	C	NF	• The present Physical-chemical state of the system was inferred from the diatom results. • Diatom results indicated that the current Physical-chemical state of the site is characterised by elevated electrolyte concentrations and pollutants.
ECOSTATUS	C (64.3%)		

Refer to Appendix A from Report number RDM/WMA13/00/CON/COMP/1123 for the Habitat Integrity assessment scores for the riparian and instream zone, and Appendix C for the fish and aquatic macroinvertebrate inventories

The overall EcoStatus for this EWR site was categorised as a C, thus the system is in a moderately modified condition, with loss and change of natural habitat and biota having occurred in terms of frequencies of occurrence and abundances (Table 36). The degradation of the catchment is elevating suspended sediment loads leading to higher turbidity during higher flows and silt deposits over coarser habitats. At the site, disturbance along the margins is moderate leading to some degradation of the habitat associated with inset benches and banks. To a large degree, all fish expected to be present within the reach were still present, albeit at a marginally reduced frequency of occurrence, with flow modifications, water quality modification, instream barriers and cover elements acting as drivers to the moderately modified ecological state obtained.

The aquatic macroinvertebrate community is still stable and indicative of moderately modified conditions (category C). Although several sensitive macroinvertebrates were recorded with a preference for both good water quality and fast to very fast flow conditions, most of the community responded to water quality modifications. The marginal vegetation was found to be in a severely modified state due to extensive scour erosion and removal of marginal vegetation, which extended up into the lower zone. The habitat structure associated with the marginal and lower zones upstream of the weir have been altered from the weir, and the right bank is compromised by alien plants. The overall condition of the riparian zone is close to largely modified (Ecological Category D/E).

It is suggested that a REC and AEC of a B/C (close to largely natural) can be achieved, should the proposed mitigation measures/recommendations (eradication of alien vegetation and re-establishment of indigenous vegetation and localised erosion control) be assessed and applied (Table 36**Error! Reference source not found.**).

Table 36: Overall EcoStatus for UO_EWR08_I

River	Lower Kraai
EWR Site Code	UO_EWR08_R
Driver Component	PES
HAI	B
GAI	C
Response Components	PES
Diatoms	C
Fish (FRAI)	C
Macroinvertebrates (MIRAI)	C
Riparian Vegetation VEGRAI	D/E
EcoStatus	C
Ecological Importance (EI)	High
Ecological Sensitivity (ES)	High
Recommended Ecological Category (REC and AEC)	B/C

The EWR for the Lower Kraai River was determined for a REC of a B/C and the HFSR approach was used to determine the EWRs. The indicator species for macroinvertebrates and fish selected for the Lower Kraai were Perlidae and *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* (large semi-rheophilics) due to the lack of true rheophilic species.

Macroinvertebrates: Biotope availability within the Lower Kraai for macroinvertebrates included SIC, SOOC, bedrock, as well as GSM. The marginal vegetation was limited to zero owing to eroded and bare banks. Perlidae have often been recorded at this site, even during the previous Joint Basin Surveys (JBS2) and JBS3, and during the DWS River Eco-Status Monitoring Programme (REMP) monitoring. Therefore, Perlidae have been identified to be the indicator taxon for this reach, as they are a flow dependent taxon. They prefer cobbles and bedrock with a preference for high velocities of >0.6 m/s, although appear optimally at flows between 0.3 and 0.6 m/s. If flows are below this target, Perlidae will be absent from the macroinvertebrate community. Thus, the macroinvertebrate habitat availability assessed as critical habitat will be the FCS. They are further very sensitive to any water quality change.

Fish: the reach associated with the site is important for the purpose of 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 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 (LSR) *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* which require fast intermediate (FI) (Juveniles) and slow deep (SD), fast deep (FD), FI (Adults) habitat. Some fast shallow (FS) (spawning and egg development) and SD (larvae) habitat required to cater for opportunistic spawning events.

Next, the optimum baseflows based on the 95th percentile for the wet and dry season were determined from the reference baseflows with July (1.751 m^3/s) and March (1.300 m^3/s) representing the dry and wet season.

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 37 and the final integrated stress curve is shown in Figure 22.

Table 37: Selected stress values, flows and rationale for the Lower Kraai EWR site

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	11.018	The critical habitat for Perlidae is high quality with 31% FCS available at an average depth of 0.52 m and maximum depth of 0.84 m. The average and maximum velocities are 0.45 and 1.27m^3/s respectively. Thus exceeds 0.6 m/s which is the target flow speed for the indicator group - Perlidae.	8.086	Max depth of 0.75 m and an average of 0.44 m with a wetted perimeter of 46.3 m. FD elements dominant (45%) with SD also present (16%). Some elements of spawning habitat available (5%) with some elements of FI available (8%)
1				
2				
3	5.023	TheFCS critical habitat lowers to 30%30%, with an average and maximum velocity of 0.34m/s and 1.03m/s respectively. Bedrock on the left bank will remain exposed, although this is not a suitable habitat for this indicator taxon. Marginal vegetation not available at these flows. Wetted perimeter slightly reduced (43.7% of the cross section).	5.244	Max depth 0.64 m with average depth of 0.35 m with a wetted perimeter of 44 m. SD class decreases below 10%; FI class has increased marginally (8%) due to loss of FD class (now at 33%); FS at 5% and reducing further

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
4				
5	2.821	Reduced critical habitat and reduced critical quality i.e., 25% available FCS habitat. However, the average and maximum velocity is 0.28 m/s and 0.89m/s – the average velocity being not suitable for the indicator taxon with a preference for 0.6 m/s or more (would need to rely on the maximum velocity). Wetted perimeter 36.6% of the cross section.	2.821	Max depth of 0.51 m with an average depth of 0.27 m with a wetted perimeter of 36.6m. Loss of SD habitat, so larval stages and some habitat for juvenile and adult stages will be affected. Spawning habitat (FS) still expected to be present (9%). FI (12%) and FD (17%) classes still available, although reduced. SS dominant class
6				
7				
8	0.119	Very little critical habitat available (FCS - 10%). Average velocity being 0.17m/s and maximum velocity being 0.55m/s. Thus habitats only very low quality. Despite FCS available at 10%, the average flow is too low for this indicator species thus very stressed conditions.		
9			0.032	Loss of all fast habitat types, with maximum depth of 0.1 m and average depth of 0.05 m and a wetted perimeter of 4.7 m, thus no cover provided for fish species and all species likely to be absent entirely.
10	0	No critical habitat (0% for both FCS and VFCS) and only hyporheic refugia.	0	No flow present

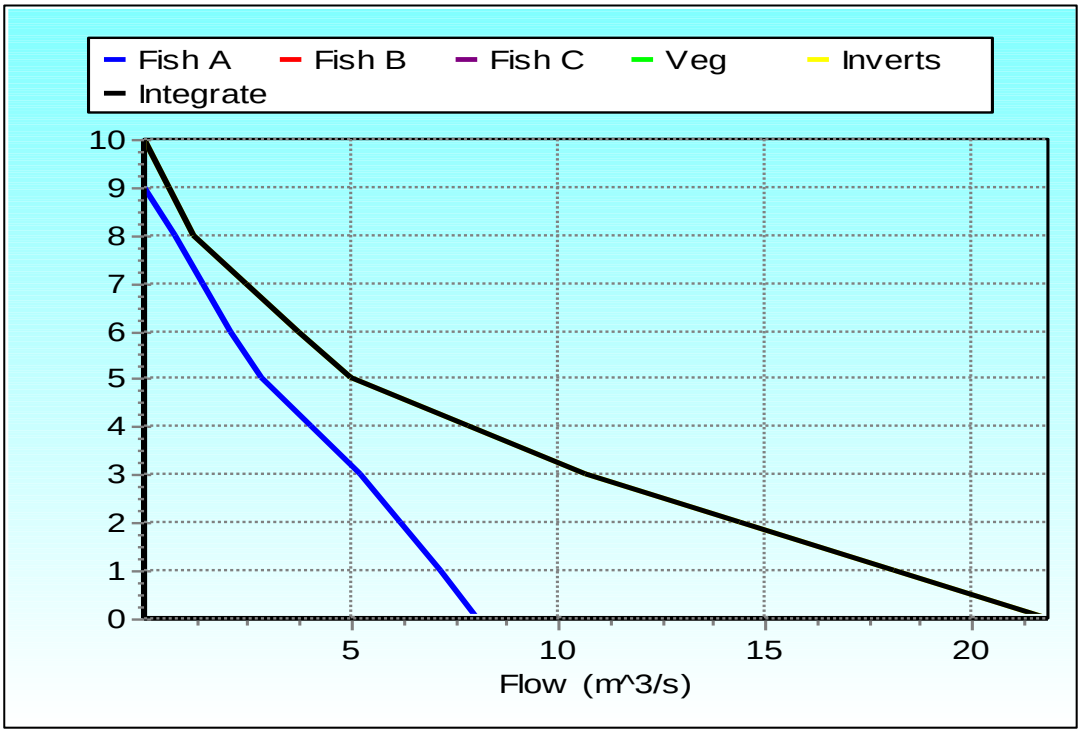


Figure 22: Final integrated stress curve for the Lower Kraai EWR site (UO_EWR08_I)

The information from the stress curves in Figure 22 was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (March) and the final adjusted EWRs are shown in Figure 23. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality.

- Increase drought flows for all months to 1.300 m^3/s
- Increase July maintenance low flows from 2.575 m^3/s to 5.289 m^3/s, and
- Increase March maintenance low flows from 4.501 m^3/s to 9.243 m^3/s

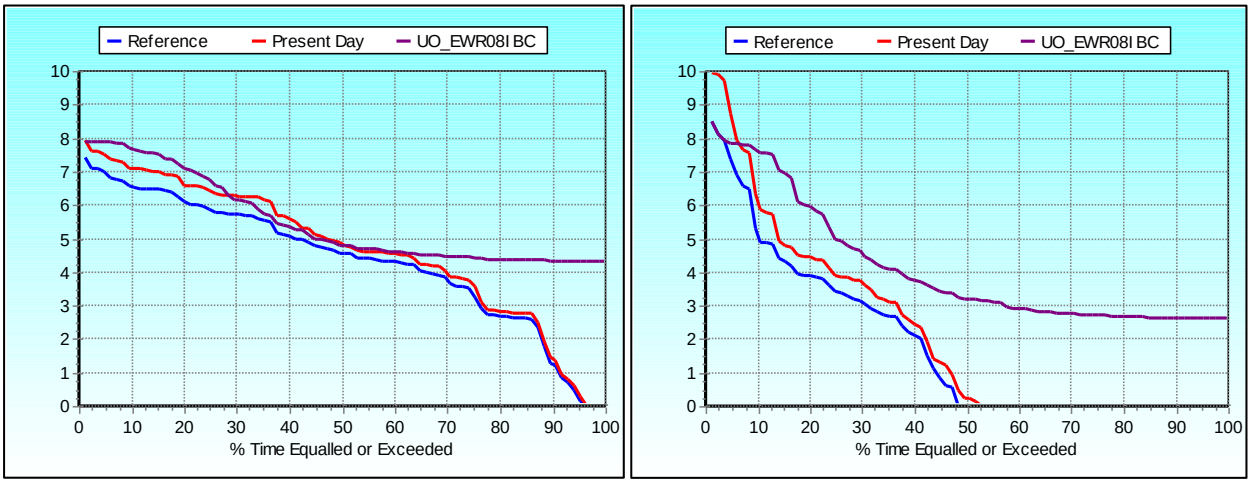


Figure 23: Final stress duration curves – dry season (July) and wet season (February) at UO_EWR 08_I

The flood requirements for the Lower Kraai EWR site were specified by the specialists and include small freshets to provide specific cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching). The larger floods were specified with the aim of clearing of the river channel, to inundate the inset benches along the left bank, mobilise instream gravel deposits to flush out fines and to rework deposited sand and to scour the stones biotope located on the left side of the channel, to remove the filamentous algae smothering that biotope for the benefit of the flow and habitat dependent macroinvertebrates. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 38.

Table 38: Flood requirements for the Lower Kraai at the EWR site (UO_EWR08_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	Final
Class 1 (20-30 m^3/s)	m^3/s	30		20 - 50	29	30
	# days	3		4	4	4
	Months	Nov, Dec, Jan		Nov, Dec, Jan	Dec, Jan, Feb March	Oct, Nov, Dec, Jan, Apr
	Type	Average		Average		Average
Class 2 (50-75 m^3/s)	m^3/s		57		Average	75
	# days		4			4
	Months		Dec, Jan, Feb March			Jan, Feb, Apr
	Type		Average			Average

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	Final
Class 3 (75-100 m^3/s)	m^3/s		76	100		100
	# days		4	6		4
	Months		Apr, May	Jan, Feb, Mar		Feb
	Type		Peak	Average		Average
Class 4 (360 m^3/s)	m^3/s				360	250
	# days				7	5
	Months				Feb, March	Mar
	Type				Peak	Peak

** The 1:2, 1:5 and 1:10 year floods not modelled but important to include in any water resource developments*

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 39.

Table 39: Lower Kraai - Summary of the EWR results (flows in million m^3 per annum)

Quaternary Catchment	D13M
Site name	UO_EWR08_I
River	Lower Kraai
EWR Site Co-ordinates	-30.69007; 26.74157
Recommended Ecological Category	B/C
nMAR at EWR site	719.0
Total EWR	334.513 (46.52 %MAR)
Maintenance Low flows	200.869 (27.94 %MAR)
Drought Low flows	40.997 (5.70 %MAR)
Maintenance High flows	133.644 (18.59 %MAR)
Overall confidence	Moderate to high

4.5. IUA 5: Upper Orange River

4.5.1. UO_EWR03_I : Upper Orange

The site is located ~8 km upstream from the confluence of the Kraai River (Figure 24). The selected site is located along a partly confined valley setting with terraces and narrow flood benches along both banks with an incised channel. The site was assessed on an intermediate level on the 7th of July 2022 and the 30th of May 2023 as part of the high confidence Reserve determination (DWS, 2023).

River	Upper Orange	**Altitude (m.a.s.l.)**	1 302
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,**	C
Geomorphological zone	F (0.001; Lowland)	**EI**	High
		ES	High
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

Figure 25 shows site photographs during the surveys in July 2022 and May 2023. The river is ~120m wide and homogenous sand bed channel with limited habitat diversity and exposed sand bars along the right bank. The surrounding area is mostly agriculture with small-scale croplands and grazing areas. Intense in-stream sand mining both downstream and upstream of the site. The macrochannel is sandy and the steep fine sand and silt banks prove to be highly erodible. Both banks show recent erosion along the lower margins, removing inset benches. Thickets of heavy infestation of alien *Salix sp*. and *Populus* sp. on both sides of the riverbanks. However, it is likely these trees are aiding in stabilising the macro channel banks to limit lateral migration. The water is turbid, and the riverbed is dominated by a featureless sand bed.

Biotopes available for macroinvertebrates was only sand and mud, there was no gravel or any stones biotope. Marginal vegetation comprised fallen down tree debris. Banks are undercut and eroded, owing to previous floods with limited inset bench development or marginal vegetation establishment. For fish there was FD and SS habitats.

The incised Orange River Channel has steep banks with a relatively narrow band of riparian vegetation, which is infested by alien Popular (*Populus candescens*), particularly of the right bank, as well as Weeping Willow (*Salix babylonica*), Tall Fleabane (*Erigeron sumatrensis*), Tall Khaki Weed (*Tagetes minuta*) and Blackjack (*Bidens pilosa*). The marginal zone is inundated by high baseflows, and the lower banks are devoid of vegetation with bare, exposed soils beneath a largely woody canopy. The upper banks also include some indigenous thicket dominated by Wild

Olive (*Olea europeae africana*), Common Currant (*Searsia pyroides*), Star Apple (*Diospyros lycioides*) and River Honey-thorn (*Lycium hirsutum).* Site impacts include:

- Upstream intense sand mining
- Future influence: proposed dam upstream
- Small-scale croplands
- Cattle grazing and trampling, and
- Reduced flows (all components) due to dams in Lesotho and abstractions for irrigation.

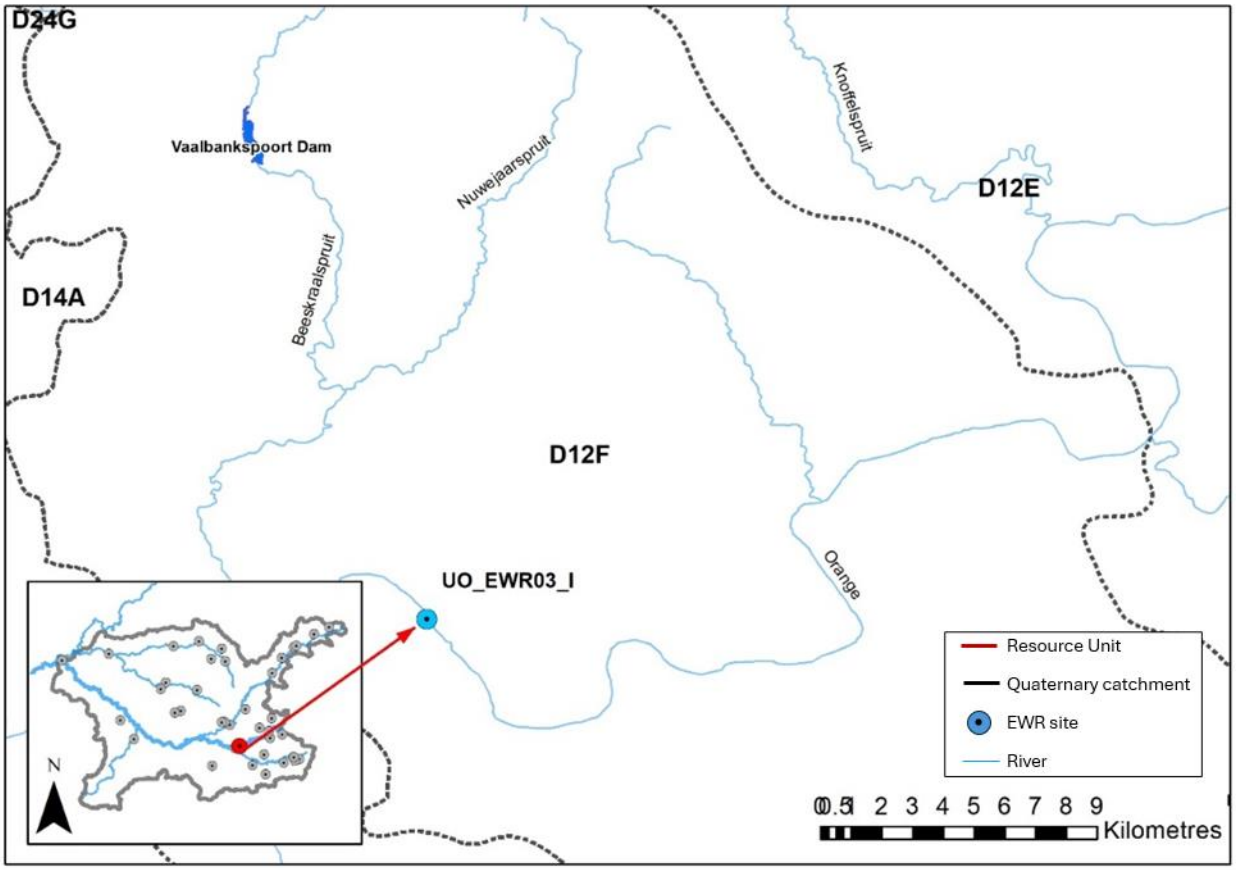


Figure 24: UO_EWR03_I site locality

Figure 25: UO_EWR03_I Site photographs during the surveys in July 2022 (Left) and May 2023 (Right)

Summary results for UO_EWR03_I (DWS, 2023)

WATER QUALITY AND FLOW (In situ)		
Parameter	**Survey 1 (July 2022)**	**Survey 2 (May 2023) at EWR site**
pH	8.8	8.3
Electrical Conductivity (mS/cm)	15.5	13.9
Total Dissolved Solids (mg/l)	150	120
Dissolved Oxygen (mg/l)	10.7	8.9
Dissolved Oxygen % (%)	93	82
Clarity (cm)	27	12
Temperature (°C)	9.0	11.7
Salinity (ppt)	0.11	0.09
Discharge (m^3/s)	41	82

Diatoms:									
No. species		**SPI****		**Categorisation (quality)**		**%PTV*****		**%Deformed cells******	
07/22	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**
16	30	9.2	10,9	C (Mod)	C (Mod)	83.1	36.5	0.5	0

Dominant Species	**July 2022**	1. *Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*
		2. *Mayamaea atomus var. permitis (Hustedt) Lange-Bertalot*
	May 2023	*Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*
Preference	**July 2022**	1. Tolerant of strong pollution and an indicator of industrial organic pollution
		2. Very pollution tolerant - organic pollution
	May 2023	Tolerant of strong pollution, indicator of industrial organic pollution

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 40.

Table 40: Reference Conditions for UO_EWR03_I

Component	Description of Reference Conditions
Fish	*Austroglanis sclateri, Enteromius oraniensis, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis* and *Labeo umbratus*
Macroinvertebrates	Turbellaria, Oligochaeta, Hirudinea, Atyidae, Perlidae, Baetidae 2spp, Caenidae, Leptophlebiidae, Trichorythidae, Coenagrionidae, Aeshnidae,

Component	Description of Reference Conditions
	Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Hydrometridae, Naucoridae, Hydropsychidae 2spp, Dytiscidae, Elmidae, Gyrinidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Empididae, Muscidae, Simuliidae, Tabanidae.
Riparian vegetation	The site is primarily defined by Upper Gariep Alluvial Vegetation comprising well-defined riparian thickets along the edge of the broad and flat alluvial terrace of the Orange River. Riparian thickets would be dominated trees and shrubs: *Vachellia karroo*, *Celtis africana*, *Diospyros lycioides*, *Lycium hirsutum*, *Olea europaea* subsp. *africana*, *Salix mucronata* subsp. *mucronata*, *Searsia pyroides* and *Ziziphus mucronata*. The river margins would have supported reedbeds and flooded grasslands on exposed alluvium. The surrounding terrestrial vegetation transitions from Dry Highveld Grassland (of the Grassland Biome) into Upper Karoo (of Nama-Karoo Biome) and comprises a mosaic of Aliwal North Dry Grassland and Besemkaree Koppies Shrubland.
Hydrology	Natural flows at the EWR site available for the period 1920 to 2004.
Geomorphology	Low gradient alluvial fine bed channel with limited lateral migration along unconfined reaches, resulting in a straight to wandering channel, with a braided pattern at very low flows. Deeper channels, pools and vegetated or bare (recently deposited) inset benches provide habitat along the margins. The bank will have a moderate gradient and will have a narrow active floodplain, set between the higher lying terraces. The lower banks will be largely treeless.
Physico-chemical	Reference Physical-chemical data for the site could not be obtained. 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, especially the Sterkspruit WWTW.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 41.

Table 41: : PES per component for UO_EWR03_I and EcoStatus (DWS, 2023)

Component	PES category & score	Flow/ non-flow	Explanation
Fish (FRAI)	D (54.0%)	F/NF	• Alluvial bed with high mobility • Limited cover features within channel • Hydrological and water quality modification due to catchment activities (high erosion rates due to loss of basal cover, increased catchment) and upstream impoundments within Lesotho
Macroinvertebrates (MIRAI)	C/D (60.6%)	NF	• Large, deep homogenous system with limited to no aquatic biotopes (dominated by mud owing to alluvial bed) • Bank erosion and cattle trampling and grazing – hampering marginal vegetation aquatic biotope • Considerable fine sediment loads through the system (water quality)

Component	PES category & score	Flow/ non-flow	Explanation
Riparian vegetation (VEGRAI)	D (57.3%)	NF	Site is heavily impacted by alien trees, notable *Populus canescens*, resulting in widespread removal of non-woody cover and bank destabilisation, especially along marginal and lower zones.
Geomorphology (GAI)	C (61.0%)	19% F related	• Low density of smaller farm dams and weirs along the tributaries that trap coarser bedload. Katse and Mohale Dams reduce longitudinal transport of suspended and bed material from parts of the upper catchment, partly offsetting the high sediment input from the lower parts of the catchment. Some storage of flood waters in smaller dams, possibly offset by increased runoff from overgrazed and gullied hillslopes, largely in Lesotho. • Widespread overgrazing and soil erosion in the catchment (largely Lesotho and communal land) elevating fine sediment loads. Dams and weirs along tributaries and mainstem traps suspended and coarser bed sediment, partly offsetting the increases in sediment load. • Trampling and alien trees along banks and floodplain. Bank and bench erosion along both banks, resulting in a featureless marginal zone with steep banks. High sediment load results in plain bed with low habitat diversity and high silt content.
Hydrology (HAI)	D (55.7%)	F	• Direct abstractions from Orange River upstream of site for mainly irrigation purposes. • Dams in Lesotho impacting on all the flow components.
Physico-chemical (Diatoms)	C	NF	• Present Physical-chemical state of the system was estimated from the diatom results, due to the lack of Physical-chemical data for the PAI. • Diatom results indicated that the site experiences heavy organic pollution. • Elevated nutrient concentrations are expected to be prevalent at the site as a result of the Sterkspruit discharging untreated sewage upstream. • Other contaminants and toxins are also expected to be present at the site given the untreated effluent discharged upstream.
ECOSTATUS	D (57.7%)		

[a]*Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 for the Habitat Integrity assessment scores for the riparian and instream zone, and Appendix C for the fish and aquatic macroinvertebrate inventories*

The trends in ecological status give an idea on whether the present state is realistic and would stay the same if the management of the catchment were to continue in the same way that gave rise to the present state. The definition of the trend is "…viewed as a directional change in the

attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux", Kleynhans and Louw (2007). The ecological trends for UO_EWR03_I are presented in Table 42.

Table 42: Ecological trends UO_EWR03_I (includes components that were assessed)

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Stable/Decline	• Proposed Polihali Dam in Lesotho and possible dam upstream of EWR site to further change the flow regime • Further catchment degradation and sediment input expected	3
Macroinvertebrates	Stable	• Habitat availability remains naturally poor along this reach, thus no improvement to biotopes to improve the integrity or diversity of the macroinvertebrate community • 89% of the reference ASPT	3
Riparian vegetation	Stable	• It is unlikely that the vegetation will degrade more than its current highly degraded state unless added pressures developed adjacent to the river as well as from upstream through significant flow alterations.	3
Hydrology	Decline	• Proposed Polihali Dam in Lesotho and possible dam upstream of EWR site to further change the flow regime	2
Geomorphology	Decline	• Ongoing catchment degradation and trees stabilising banks	3
Physico-chemical	Stable/Decline	• Sedimentation loading • Upstream sand mining compromising the water column	3
ECOSTATUS	Decline		

** 0 – no confidence to 5 – high confidence*

The overall EcoStatus for this EWR site was categorised as a D, with the system being largely modified. The degradation of the catchment is due to elevated suspended sediment loads, sedimentation of the channel and a reduction of habitat diversity as coarser habitats are covered by fine sediment and reduced flows. At the site, disturbance along the margins degrades the habitat associated with inset benches and banks. This is ultimately having a knock-on effect on the biota (fish and macroinvertebrates) of the system, owing to altered system dynamics in the form of catchment-scale impacts.

The development of several large impoundments within the upper reaches of the catchment (Lesotho) has resulted in altered hydrology as well as the lack of diverse substrate within the

reach. The presence of impoundments and weirs below the reach that act as a migratory barrier, particularly for fish species moving upstream from the Orange River system during seasonal migrations.

The presence of Gariep Dam also offers an artificially elevated source population for several fish species moving upstream, including alien fish species. Alien trees present a major problem for riparian vegetation along the Orange River resulting in loss of function provided by native species, in particular protection and stabilisation of banks from floods and consequently erosion.

It is suggested that a REC of a D (close to largely modified) can be achieved, should the proposed mitigation measures/recommendations (eradication of riparian alien vegetation, stabilising the banks and re-establishing indigenous riparian vegetation) be assessed and applied (Table 43).

Table 43: Overall assessment for UO_EWR03_I - Upper Orange

River	Upper Orange
EWR Site Code	UO_EWR03_I
Driver Component	PES
Hydrology (HAI)	D
Geomorphology (GAI)	C
Response Components	PES
Diatoms	C
Fish (FRAI)	D
Macroinvertebrates (MIRAI)	C/D
Riparian Vegetation (VEGRAI)	D
EcoStatus	D
Ecological Importance (EI)	Moderate
Ecological Sensitivity (ES)	Moderate
Recommended Ecological Category (REC)	D

The EWR for the Upper Orange River was determined for a REC of a D and the HFSR approach was used to determine the EWRs. The indicator taxa for macroinvertebrates and fish selected for the Upper Orange were Caenidae and *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* (large semi-rheophilics) due to the lack of true rheophilic species.

Macroinvertebrates: The Upper Orange is a wide homogenous alluvial river composed largely of sand and mud with very limited habitat diversity and exposed sand bars along the banks. There is limited to no marginal vegetation for macroinvertebrates to colonise along this reach. The indicator macroinvertebrate selected for this reach is Caenidae. They have a primary preference

for gravel, sand and mud, and typically occur mostly at depths of 10 – 30 cm. They further have a wide range of preferences for velocities from 0.1 m/s to 0.6 m/s. Consequently, the macroinvertebrate habitat availability assessed as critical habitat will be the VSFS, SFS.

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. 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-rheophilics (BAEN & BKIM) were selected to function as flow-dependent indicators. The reach does not have any critical habitat (i.e., substrate within differing VD 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, although some consideration was given to possible slow-deep class to sustain adult of juvenile fish species.

The optimum baseflows based on the 95th percentile for the wet and dry season were determined from the reference baseflows with July (5.908 m^3/s) and February (23.031 m^3/s) representing the dry and wet season.

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 44 and the final integrated stress curve is shown in Figure 26**Error! Reference source not found.**.

It is important to note that the flow driver will be based on fish, as the selected macroinvertebrate indicator was limited by poor habitat availability, and Caenidae is not considered a sensitive macroinvertebrate.

Table 44: Selected stress values, flows and rationale for the Upper Orange EWR site

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	81.293	The average and maximum depth of 93cm and 136cm respectively. The average and maximum velocity of 0.6 m/s and 1.44m/s respectively are suitable conditions for the indicator taxon Caenidae. The critical habitats	81.293	Abundance of FD (79%) with SD (21%) also present with maximum depth of 1.51 m and an average depth of 1.07 m to accommodate movement of LSR species through reach along edges of channel

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		are VSFS and SFS which provides 6% and 13% at this discharge across the cross-section.		
1				
2				
3	41	The average velocity of 0.49 m/s is still suitable for the indicator species, as well as critical habitat with 7% and 16% of VSFS and SFS respectively available.	41.918	Reduction of wetted extent, thus cover elements provided by banks. Water column still able to provide cover (water depth 1.1 m maximum with average depth of 0.58 m)
4				
5			8.763	Maximum Depth 0.5m with average depth 0.42 m, thus water column likely to offer some protection but with adults likely to be at high risk. Loss of SD habitat, with FI only at 4%. SS habitat dominant
6				
7				
8			1.14	No critical habitat (SD, FI or FD) remaining with a dominance of SS (86%) and likely no cover for any fish movement within the reach
9				
10	0	No critical habitat (0%), exposed sand bars across the channel.	0	No flow with some isolated pools possible with no cover present (no substrate or water column), thus no fish species expected

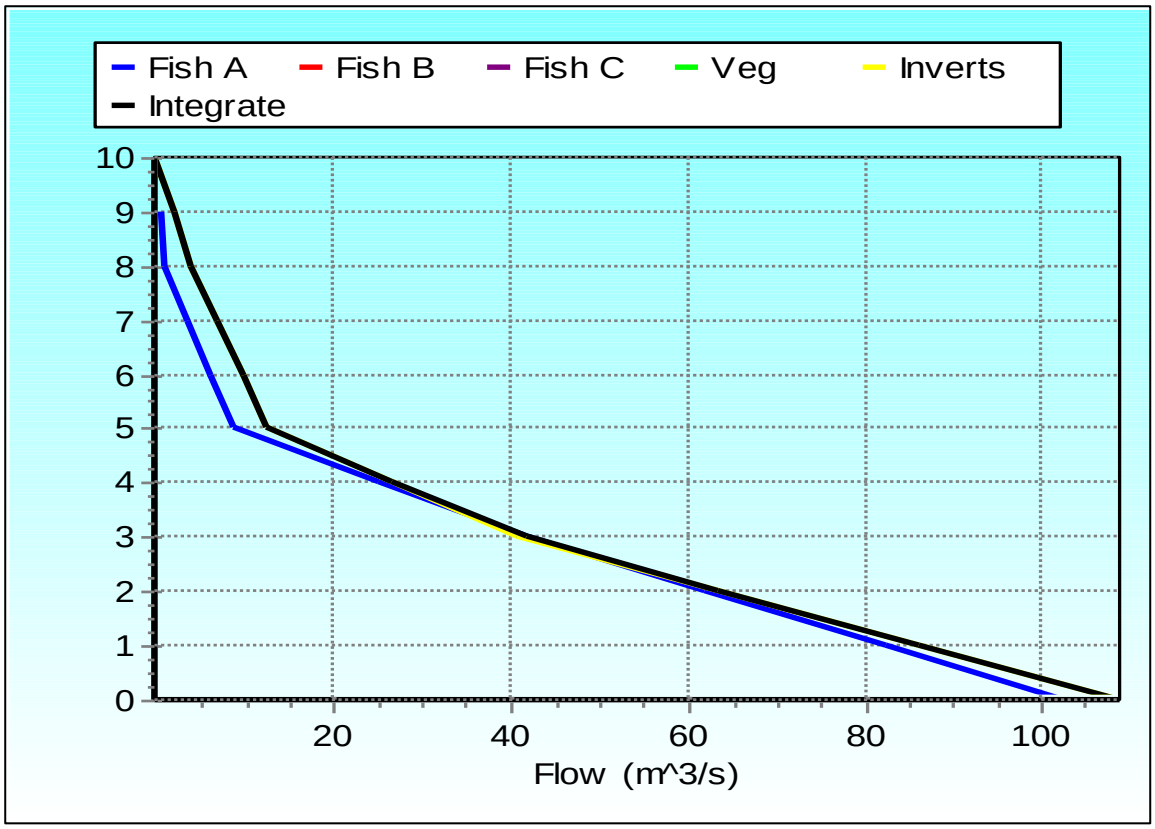


Figure 26: Final integrated stress curve for the Upper Orange EWR site (UO_EWR03_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (February) and the final adjusted EWRs are shown in Figure 27. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality. Increase drought flows for all the months as follows:

- April – July = 5 m^3/s
- August – October = 3 m^3/s
- February, March = 12 m^3/s
- November, December = 8 m^3/s, January = 10 m^3/s
- Increase July maintenance low flows from 4.999 m^3/s to 11.006 m^3/s
- Increase February maintenance low flows from 12.293m^3/s to 27.067 m^3/s

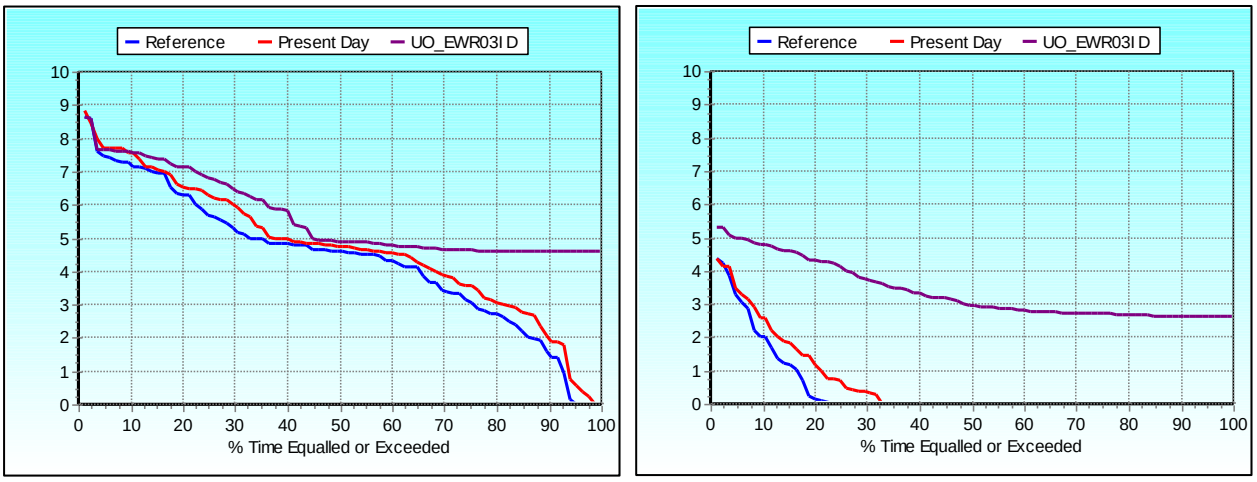


Figure 27: Final stress duration curves – Left: dry season (July) and Right: wet season (February) at UO_EWR03_I

The flood requirements for the Upper Orange EWR site were specified and driven primarily by geomorphology and riparian vegetation. The large flood's primary function is to clear the river channel and mobilise substrate (gravel) downstream and aim to activate the riparian vegetation marginal zone. The smaller freshets were set to provide specific fish cues for movement and spawning purposes. No freshets were specified for macroinvertebrates due to a lack of available macroinvertebrate biotopes (site primarily only comprising a muddy substrate). The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 45: Flood requirements for the Upper Orange at the EWR site (UO_EWR03_I).

Table 45: Flood requirements for the Upper Orange at the EWR site (UO_EWR03_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorph-ology	Final
Class 1 (200-300 m^3/s)	m^3/s	200		200 - 300	220	200
	# days	Nov, Dec, Jan, Feb		Average	Average	5
	Months	5		5	4	Oct-Dec, Mar, Apr
	Type	Average		Nov to Mar	Nov, Jan, Feb, March	Average
Class 2 (400 m^3/s)	m^3/s	400				400
	# days	3				3
	Months	Jan, Feb				Jan, Mar

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorph-ology	Final
	Type	Average				Average
Class 3 (800 m^3/s)	m^3/s			800	800	800
	# days			6 to 8 days	6	6
	Months			Jan, Feb	Feb	Feb
	Type			Peak	Peak	Peak

* The 1:2, 1:5 and 1:10 year floods not modelled but important to include in any water resource developments

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 46.

Table 46: Upper Orange - Summary of the EWR results (flows in million m^3 per annum)

Quaternary Catchment	D12F
Site name	UO_EWR03_I
River	Upper Orange
EWR Site Co-ordinates	-30.652889; 26.823049
Recommended Ecological Category	D
nMAR at EWR site	4 259.5
Total EWR	1067.450 (25.06 %MAR)
Maintenance Low flows	554.061 (13.01 %MAR)
Drought Low flows	206.669 (4.85 %MAR)
Maintenance High flows	513.389 (12.05 %MAR)
Overall confidence	Moderate

4.6. IUA 6: Gariep Dam

4.6.1. UO_FMP Site between Gariep and Vanderkloof dams to support the Flow Management Plan (FMP)

During the ORASECOM, JBS3 study, site 38 (OSAEH 26_15: -30.503784; 25.240033) was located just upstream of the site selected for this study to conduct a hydraulic survey (ORASECOM, 2023). Diatoms and a physico-chemical water quality sample was also retrieved.

Results from the study ORASECOM, 2023, calculated a EcoStatus of a D. Refer to Table 48 which illustrates the categories per component that will apply for this study.

Table 47: Overall assessment for the site between Gariep and Vanderkloof Dams

River	Orange River (between the 2 dams)
Response Components	PES
Diatoms	C
Fish (FRAI)	C/D
Macroinvertebrates (MIRAI)	C
Riparian Vegetation (VEGRAI)	D
EcoStatus	D
Ecological Importance (EI)	High
Ecological Sensitivity (ES)	High
Recommended Ecological Category (REC)	D

The main impacts along this sacrificial reach include:

- Flow variability - releases from upstream Gariep Dam for hydro power generation (hydropeaking twice a day, releases during low flow months to support Vanderkloof Dam)
- Reduced large floods
- Increased flows and sediment due to seasonal runoff
- Structure changes due to consistent baseflows
- Loss of seasonality
- Loss of habitat due to regular disturbance from Gariep Dam releases
- Loss of natural cues for biota; and
- Presence of Gariep Dam upstream of site acting as a movement barrier for fish.

As per the Upper Orange Reserve determination study, a conceptual Flow Management Plan (FMP) was established and an action plan provided. The action plan for flow-related management of the Upper Orange River catchment (specifically relating to the Vanderkloof and Gariep dams) was delineated into four stages:

- Immediate (current, emergency interventions should any be identified)
- Short-term (actions over the next 0 – 5 years)

- Medium-term (action between 5 – 20 years from now), and
- Long-term (actions 20 years from now and beyond).

Figure 30 illustrates the proposed immediate-, short-, medium- and long-term action plans.

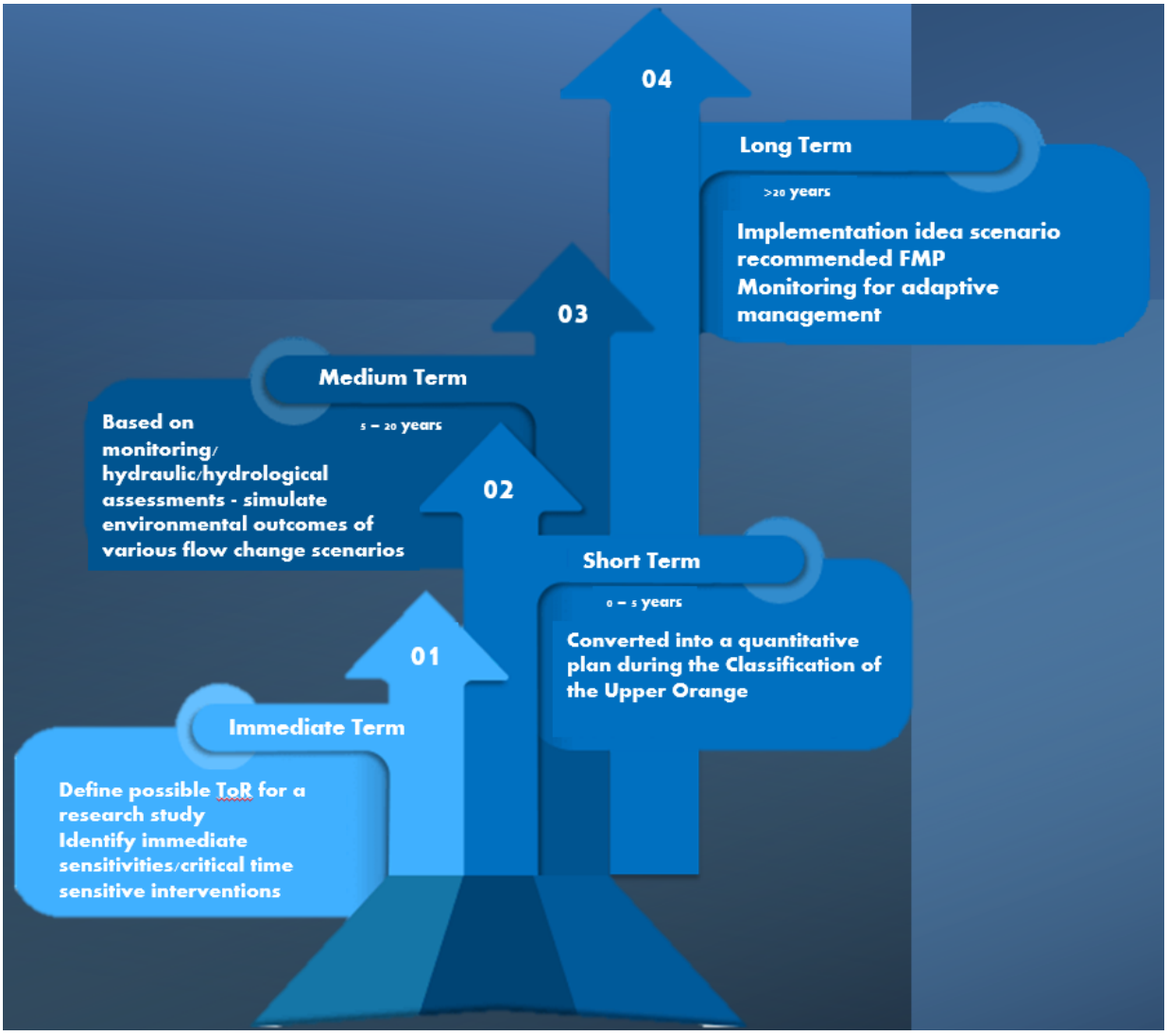


Figure 28: Proposed immediate-, short-, medium- and long-term action plans (adopted from DWS, 2023)

This study addressed a segment of the short-term plan by conducting a hydraulic survey (the first along this sacrificial reach) in October 2024 at a site between the Gariep and Vanderkloof Dams (co-ordinates: -30.50367; 25.200574).

The cross-sectional views of the site between Gariep to Vanderkloof dams, stage discharge relationships developed from the modelling and the detailed output tables are shown in Figure 29 and Figure 30.

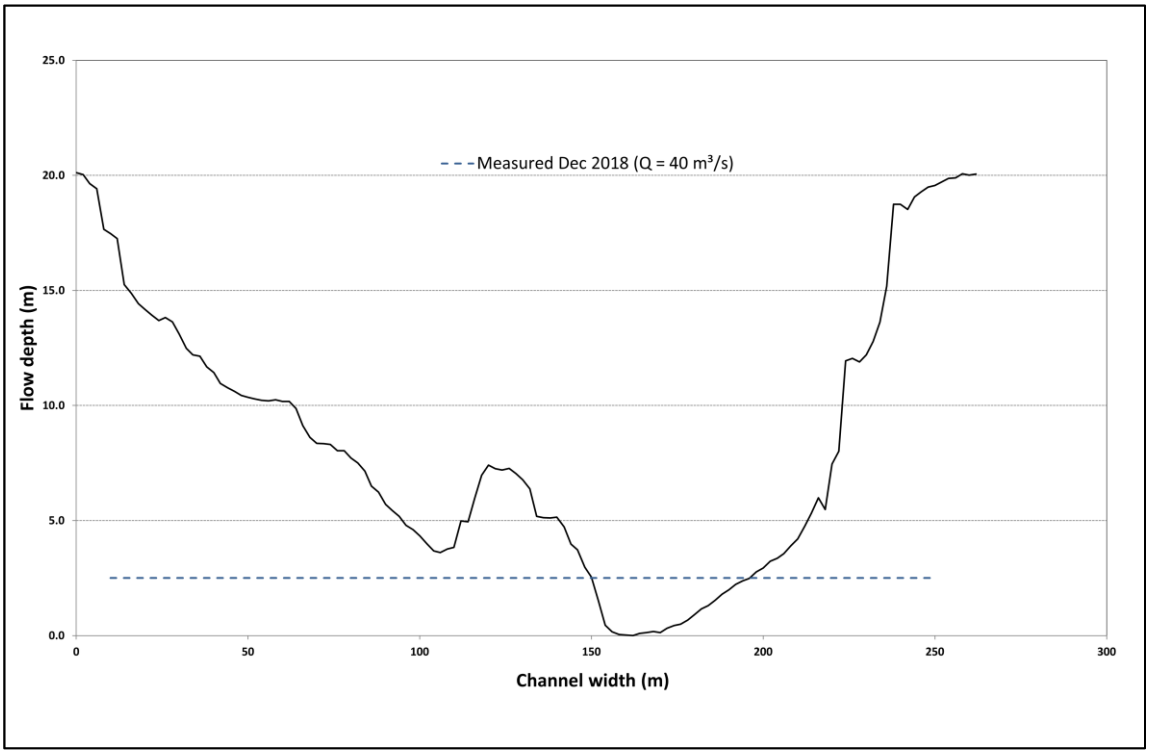


Figure 29: Cross-sectional view of the Gariep to Vanderkloof EWR site (UO_FMP)

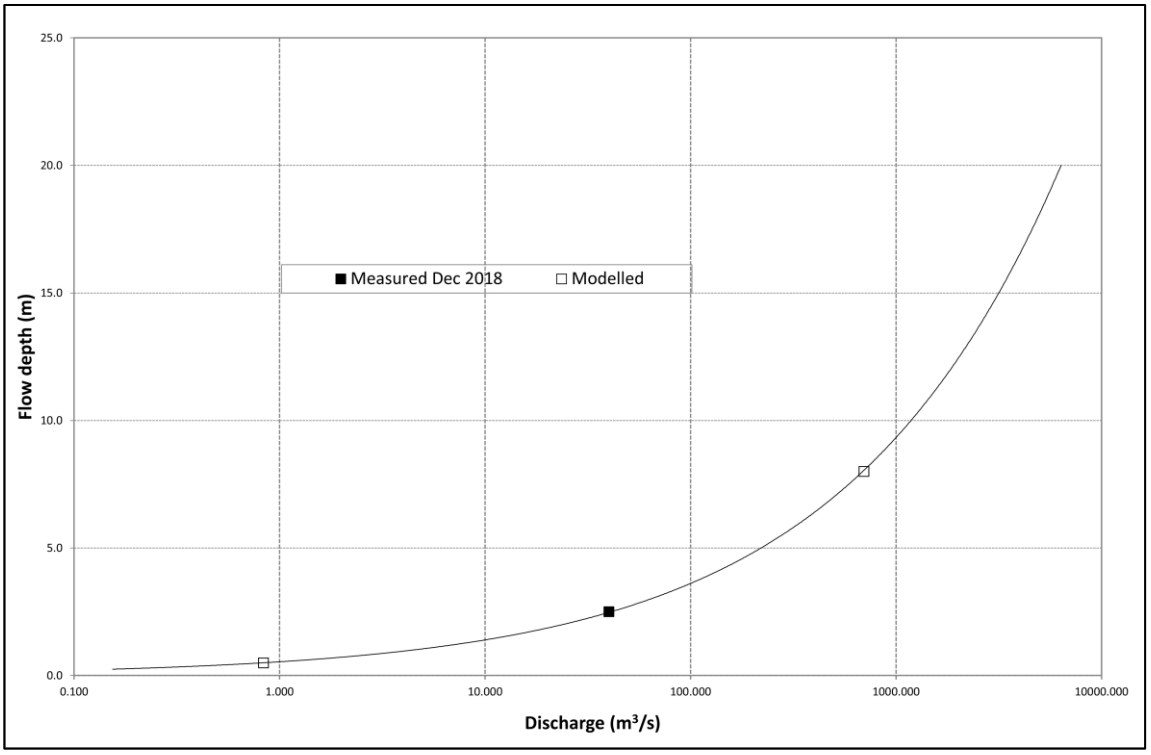


Figure 30 Relationship between flow depth and discharge at Gariep to Vanderkloof EWR site (UO_FMP)

Due to the highly variable flows at this site from hydropower and other releases from Gariep Dam, no formal EWR was determined. However, to provide some information for the FMP, the following should be considered and implemented in the short term:

i. A minimum flow of 40 m^3/s for any given month as this flow will still provide adequate habitats for the biota;

ii. Additional to the daily releases, the following freshets are also important:

- November to January – 270 m^3/s over 6 days
- February – 350 m^3/s over 3 days

iii. Releases from Gariep Dam to supplement Vanderkloof Dam in late winter to early spring should coincide with the seasonal rainfall pattern, thus a later start to the release to match the late spring natural cues for fish and cleaning of habitats.

4.7. IUA 7: Seekoei River

4.7.1. UO_EWR05_I

The selected 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 (Figure 31). The site was assessed on an intermediate level on the 7th of July 2022 and the 30th of May 2023 as part of the high confidence Reserve determination (DWS, 2023).

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,**	D
Geomorphological zone	E (0.002; Lower Foothills)	**EI**	Moderate
		ES	Moderate
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

Figure 32 shows photographs of the during the surveys in July 2022 and May 2023. The reach is relatively unconfined with the river incised into the valley floor. Flood features are narrow, and the river pattern is straight to sinuous with bedrock, boulder, cobble and gravel and finer habitats available at the site. The site continues to have high baseflows following the floods. Various upstream dams and weirs along the river reach, with a gauging weir located just upstream of the site, resulting in inundation upstream, as well as sediment accretion resulting in various instream islands of *Phragmites* sp., as well as along both banks. Downstream of the weir, the site is dominated primarily by metamorphic sandstone with igneous intrusions forming the bedrock layer along this reach, along with small pockets GSM. The bedrock was blanketed by algae and silt. Furthermore, both instream and marginal vegetation was present for sampling macroinvertebrates. Flow-depth velocity classes available for the fish included FD, SD, SS and FS.

The riparian zone is spread across a flattened valley bottom with the macro-channel extending up to 200m. The weir upstream of the EWR site has inundated sections of marginal habitat and portions of the lower zone, and resulted in an increase in reeds (*Phragmites australis*). Downstream of the weir are several areas of flat, bedrock, and the marginal zone dominated by reeds and sedges. The lower zone of the right bank is relatively steep with low thicket comprising *Searsia pyroides*, *Lycium hirsuta*, *Heteromorpha arborescens* and *Vachellia karroo*, which flattens out into a broader upper zone with scattered tall shrubs interspersed by grasses, herbs and low

shrubs. The left bank has a similar vegetation pattern, but is more sparse with more exposed alluvium. Site impact sinclude:

- Dams and weirs
- Irrigation
- Game and livestock farming
- Localised cultivation on terraces
- Bridge

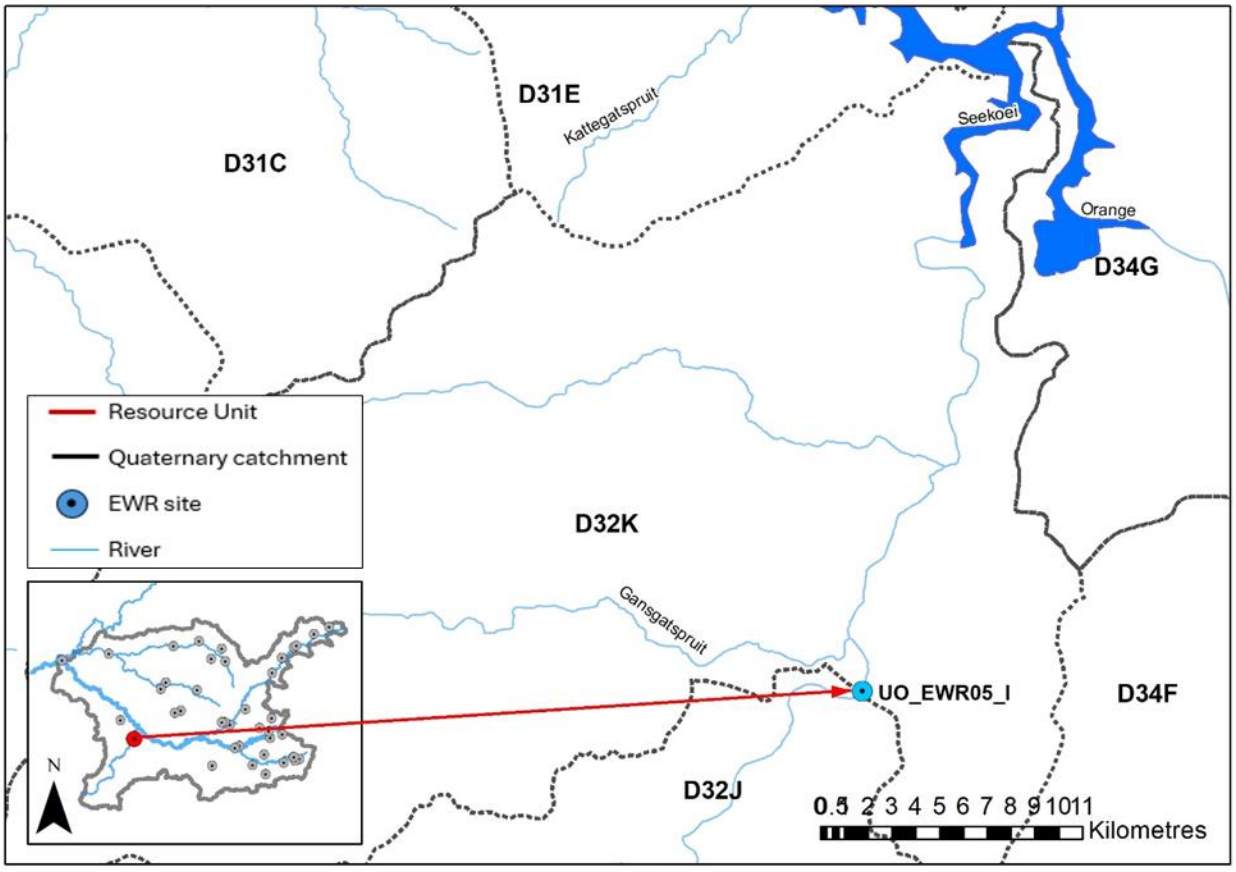


Figure 31: UO_EWR05_I site locality

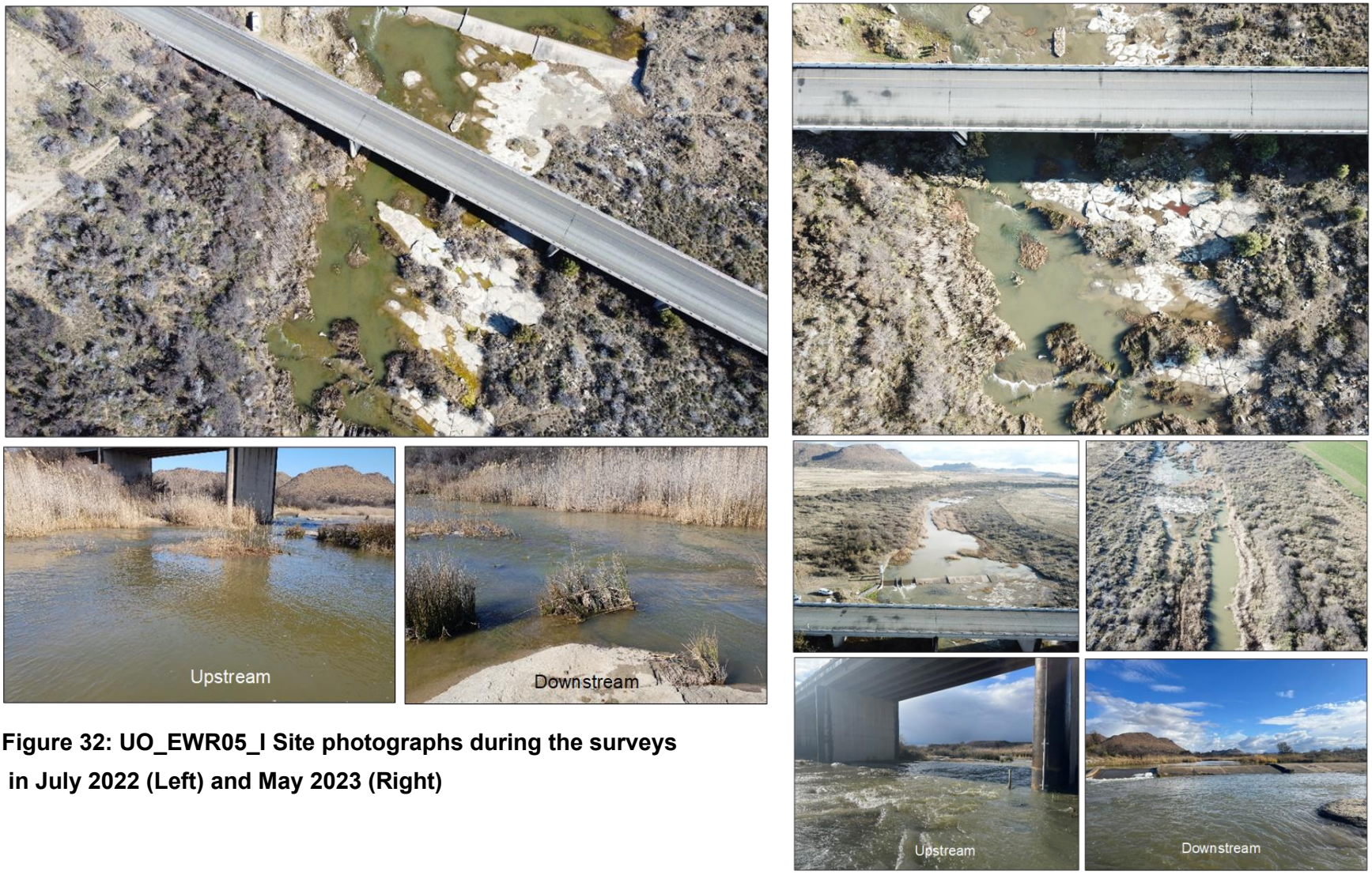


Figure 32: UO_EWR05_I Site photographs during the surveys in July 2022 (Left) and May 2023 (Right)

Summary results for UO_EWR05_I (DWS, 2023)

WATER QUALITY AND FLOW (In situ)		
Parameter	**Survey 1 (July 2022)**	**Survey 2 (May 2023)**
pH	8.8	8.5
Electrical Conductivity (mS/m)	69.5	58.0
Total Dissolved Solids (mg/l)	600	500
Dissolved Oxygen (mg/l)	11.1	10.0
Dissolved Oxygen % (%)	99.2	91.2
Clarity (cm)	30	25
Temperature (°C)	9.8	11
Salinity (ppt)	0.49	0.39
Discharge (m^3/s)	1.155	1.671

Diatoms:									
No. species		**SPI****		**Categorisation (quality)**		**%PTV*****		**%Deformed cells******	
07/22	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**
44	40	12.4	10.3	C (Mod)	C (Mod)	11.2	14.6	0.25	0.75

Dominant Species	**July 2022**	*1. Cocconeis pediculus Ehrenberg*
		2. Nitzschia dissipata (Kützing) Grunow
	May 2023	*1. Cocconeis pediculus Ehrenberg*
		2. Nitzschia frustulum (Kützing) Grunow
		3. Pseudostaurosiropsis geocollegarum (Witkowski & Lange-Bertalot) Morales
		4. Staurosirella pinnata (Ehrenberg) Williams & Round
Preference	**July 2022**	1. Epiphytic species in waters of moderate to high electrolyte content, including brackish conditions.
		2. A cosmopolitan species found in waters of moderate to high electrolyte content, not present in waters of low electrolyte content. Highly mobile - siltation
	May 2023	1. A cosmopolitan epiphytic species occurring in waters of a moderate to high electrolyte content, including brackish conditions
		2. High conductivity, heavy agriculture, very tolerant of pollution
		3. Indicators of high sodium chloride salinity and especially irrigation return flow
		4. Often occurs attached to sand grains, Found in clean waters (mild pollution and only slight organic pollution), with moderate to high electrolyte content. pH>7

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 48.

Table 48: Reference Conditions for UO_EWR05_I

Component	Description Of Reference Conditions		
Fish	*Enteromius oraniensis, Labeobarbus aeneus, Clarias gariepinus, Labeo capensis* and *Labeo umbratus*		
Macroinvertebrates	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.		
Riparian vegetation	The site is nested within the Nama Karoo Biome and forms part of the Upper Karoo Bioregion with two associated terrestrial vegetation types, namely Eastern Upper Karoo and Besemkaree Koppies Shrubland. As a result, the riparian zone should support largely sparse vegetation with grasses and low shrubs typical of the surrounding vegetation types with a higher presence of taller shrubs and trees.		
Hydrology	Natural flows at the EWR site available for the period 1920 to 2004.		
Geomorphology	The reference condition for the reach is likely be a lower gradient mixed bed alluvial channel with sand and gravel dominating the bed with localised bedrock forming the bed. The reach type would mainly be pool-riffle or pool-rapid with sand bars forming in pools. A narrow floodplain can be present where the valley floor is wider.		
Physico-chemical	Reference Physical-chemical conditions for the site were determined using DWS data (site D3H015Q01, 1981 to 1989, n =245)		
	Physical Variables	pH:	The reference data reflected a 5th percentile of 7.1 pH units and a 95th percentile of 9 pH units which fell outside the DWA (2008) benchmark for Natural (0) rating. The Natural (0) for the site was therefore re-adjusted, such that the Natural (00 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. This especially given the lack of anthropogenic impacts in this area.
		Temperature:	No historical temperature records are available for the site. DWA (2008) benchmark tables were used for a low confidence, qualitative assessment of temperature reference condition
		Clarity:	There are no clarity/turbidity records available for reference condition assessment. Reference condition was taken as that qualitatively described in the DWA (2008) benchmark tables.

Component	Description Of Reference Conditions		
		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
	Nutrients	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 PO_4 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 re-benchmarked such that ≤ 0.03 mg/l.
	Toxins	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.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 49.

Table 49: : PES per component for UO_EWR05_I and EcoStatus (DWS, 2023)

Component	PES category & score	Flow/ Non-flow	Explanation
Fish (FRAI)	C (77.4%)	F/NF	• Longitudinal fragmentation due to high number of weirs • Flow modification • Non-native fish species
Macroinvertebrates (MIRAI)	C (67.2%)	F/NF	• Biotopes were dominated by bedrock (not an ideal biotope for macroinvertebrates) • Just downstream of a weir, resulting in some flow modifications, while upstream of weir there was inundation and too deep to access • High siltation loads covering the bedrock and SOOC biotopes
Riparian vegetation (VEGRAI)	B/C (77.7%)	NF	• Localised impacts from the weir and bridge have resulted in direct removal and some changes to the riparian vegetation. • Nutrient return flows from cultivation stimulate establishment of reeds in the channel and along the lower banks.
Geomorphology (GAI)	C (78)	15% F related	• Low density of smaller farm dams along tributaries and weirs along the mainstem that trap coarser bedload. Gullies and Badlands increase water and sediment routing.

Component	PES category & score	Flow/ Non-flow	Explanation
			• Widespread grazing and soil erosion elevate fine sediment loads. Dams and weirs along tributaries and mainstem trap coarser bed sediment. • Grazing along banks, but low erosion evident as bank gradient is low, very rocky and well vegetated.
Hydrology (HAI)	B/C (80.2%)	F	Seasonal to ephemeral system with small dams for irrigation purposes, although limited irrigation in the catchment.
Physico-chemical (Diatoms)	C	NF	• Diatom results were used to infer the present Physical-chemical state of the system. • Diatoms indicated elevated electrolyte concentrations. • High conductivities have been recorded at this site as far back as early 1980s, because of high erosion and amounts of weathered geological material making its way into the river.
ECOSTATUS	C (74.6%)		

Refer to Appendix A from Report number RDM/WMA13/00/CON/COMP/1123 A for the Habitat Integrity assessment scores for the riparian and instream zone, and Appendix C for the fish and aquatic macroinvertebrate inventories

The trends in ecological status give an idea on whether the present state is realistic and would stay the same if the management of the catchment were to continue in the same way that gave rise to the present state. The definition of the trend is "…viewed as a directional change in the attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux", Kleynhans and Louw (2007). The ecological trends for UO_EWR05_I are presented in Table 50.

Table 50: Ecological trends for UO_EWR05_I (includes components that were assessed)

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Stable	• No recent water resource developments or increase in impacting feature expected	3
Macroinvertebrates	Stable	• No recent water resource developments or increase in impacting feature expected	3
Riparian vegetation	Stable	• There has not been any significant change in riparian vegetation since the construction of the weir and bridge.	3
Hydrology	Stable	• No recent water resource developments	3
Geomorphology	Stable	• Ongoing pressures with no immediate change in drivers or site impact	3
Physico-chemical	Stable	• High conductivities are characteristic of this system. No recent developments that	3

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
		could alter the physical-chemical nature of the system.	
ECOSTATUS	Stable		

** 0 – no confidence to 5 – high confidence*

The overall EcoStatus for this EWR site was categorised as a C, thus the system is in a moderately modified condition, with loss and change of natural habitat and biota have occurred in terms of frequencies of occurrence and abundances. The degradation of the catchment is elevating suspended sediment loads, but the multitude of weirs is trapping most of the sediment. At the site, disturbance along the margins is low, but still shows degradation of the habitat associated with inset benches and banks. All the expected fish species were noted to be present within the assessed reach, as were non-native fish species. However, the fragmentation of the system because of various weirs is likely to be impacting the species present, with decreased recruitment from limited access to suitable spawning areas within the reaches between the weirs.

The macroinvertebrate community, although not diverse, owing to the dominant biotope being bedrock, which is not a preferred habitat, mostly responded to water quality modifications. The riparian vegetation is in a relatively good condition with impacts mainly attributed to the weir and bridge through vegetation removal and the site has a fairly low infestation of alien plants. The overall condition of the riparian zone was moderately modified (Ecological Category C).

Overall, it is suggested that the REC be maintained as the PES category C (Table 51). This can be achieved should the proposed mitigation measures/ recommendations be assessed and applied.

Table 51: Overall assessment for UO_EWR05_I – Seekoei River

River	Seekoei
EWR Site Code	UO_EWR05_I
Driver Component	PES
Hydrology (HAI)	B/C
Geomorphology (GAI)	C
Response Components	PES
Diatoms	C
Fish (FRAI)	C
Macroinvertebrates (MIRAI)	C
Riparian Vegetation (VEGRAI)	B/C
EcoStatus	C

River	Seekoei
Ecological Importance (EI)	Moderate
Ecological Sensitivity (ES)	Moderate
Recommended Ecological Category (REC)	C

The EWR for the Seekoei River was determined for a REC of a C. The EWR was determined using mainly freshets and floods as specified by the ecologists due to the almost ephemeral nature of the system. Thus, limited baseflows were specified. The main impact on the system is the numerous weirs along the various reaches (non-flow), thus preventing the movement of fish.

Together with the site photographs and rating relationships (flow depth versus discharge) from the hydraulic model, water levels proposed for freshets and floods were assessed in terms of the habitat and biotic requirements.

The site-specific flow requirements were based mainly on the requirements to inundate the inset and flood benches, entrain cobbles and scour pools to mobilise fine gravels and remove fine sediments from coarse habitats. No floods were specified for fish as the movement is hampered by the numerous weirs in the system. The freshets and floods as required are presented in Table 52 and the final EWR for the Seekoei River at the EWR site is summarised in Table 53.

Table 52: Flood requirements for the Seekoei at the EWR site (UO_EWR05_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	FINAL
Class 1 (0-40 m^3/s)	m^3/s			5 to 10		5
	# days			7		2
	Months			Jan, Feb, Mar		Oct-Jan, Apr, May
	Type			Average		Average
Class 2 (60-90 m^3/s)	m^3/s		14		15	10
	# days		3		3	2
	Months		Apr, May		Nov, Jan, Mar	Feb
	Type		Average		Average	Average
Class 3	m^3/s		17	35		20
	# days		3	3		2

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	FINAL
(100-120 m^3/s)	Months		Nov, Jan, Mar	Feb, Mar		Mar
	Type		Average	Average		Peak

Table 53: Seekoei River - Summary of the EWR results (flows in million m^3 per annum)

Quaternary Catchment	D32J
Site name	UO_EWR05_I
River	Seekoei
EWR Site Co-ordinates	-30.533901; 24.962537
Recommended Ecological Category	C
nMAR at EWR site	24.28
Total EWR	8.301 (34.19 %MAR)
Maintenance Low flows	1.043 (4.30 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	7.258 (29.89 %MAR)
Overall confidence	Moderate to high

4.8. IUA 8: Vanderkloof Dam

4.8.1. UO_EWR10_I: Lower Orange

The selected 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 (Figure 33). The site was assessed on an intermediate level on the 3rd of June 2023 as part of the high confidence Reserve determination (DWS, 2023). On the 3rd of October 2024 the site was surveyed again, however the river was very high due to releases from Vanderkloof Dam for downstream users.

This site included a 2-D hydraulic survey, with the aim to provide ecologists with enhanced contextual data, enabling more informed decisions in quantifying the EWR for this site. See Chapter 3.2 for further detail regarding the 2D hydraulic approach, outputs and benefits.

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,**	C
Geomorphological zone	F (0.001; Lowlands)	**EI**	High
		ES	Moderate
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

Figure 34 shows site photographs during the surveys in June 2023 and October 2024. The site is defined by an incised macro-channel approximately 160m wide. The channel has a straight to sinuous planform with pool-riffle and poolrapid reach types. The riffles have cobble and gravel sediment, with bedrock and boulders forming the rapids. The pools are longer than the riffles and have sand bars and lateral bars in places. Islands form on bedrock with sedimentary coverings. The banks are steep due to the incised nature of the river and composed of fine silt and sand.

The primary land-use is irrigated agriculture/cultivation, principally centre pivots and peacan nut orchards. Water is 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. Vanderkloof Dam is located approximately 175km upstream, with Gariep Dam positioned further upstream (approximately 55km upstream of Vanderkloof Dam).

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 have since become covered by sediments that have been deposited at the site during recent floods. The active channel is now more confined to the mainstem, with the exception of two side channels

along the left bank, that provides some riffle habitat comprising boulder and some cobble substrate. Fine sediments, gravel and sand were confined. The aquatic macroinvertebrate biotopes included SIC, SOOC and GSM. Owing to various recent flood events in this system, all marginal vegetation has been removed, although evidence of pockets of reeds beginning to establish. The different flow-depth-velocity classes present for fish included FS, SD (dominance), SS and some FD.

The riparian zone associated with the EWR site is characterized by short, steep banks that flattens out into the surrounding savanna (left bank) and agricultural lands (right bank). The marginal zone is made up of bare sand/alluvium with some exposed bedrock and occasional overhanging trees on the left bank. The lower portion of the lower zone is also sandy with scattered dead trees and shrubs, becoming more vegetated further up the banks with patches of *Cynodon dactylon* and riparian thickets of *Vachellia karroo*, *Diospyros lycioides, Lycium hirsutum* and *Ziziphus mucronata*. The lower zone of the right bank is wider than the left bank and has a raised sand bar with a band of bare sand, leading into a grassy strip of *Cynodon dactylon*, then low thicket (mostly dead *Lycium* shrubs, with some *Salix mucronata* and *Ziziphus mucronata*). Beyond the sand bar the bank drops into a depression, which becomes a side channel activated during high flows. From here the bank rises steeply into the densely wooded upper zone, with mature Buffalo Thorn (*Ziziphus mucronata*) and Sweet Thorn (*Vachellia karroo*) trees. The riparian vegetation is primarily impacted by altered flows caused from Vanderkloof and Gariep Dams upstream, which affect the natural disturbance regime resulting in changes to riparian vegetation structure and composition. The site impacts include:

- Agriculture
- Cattle activity
- Extensive irrigation, and
- Changed flow regime due to releases from upstream dams for water use in the lower Orange River and estuarine requirements.

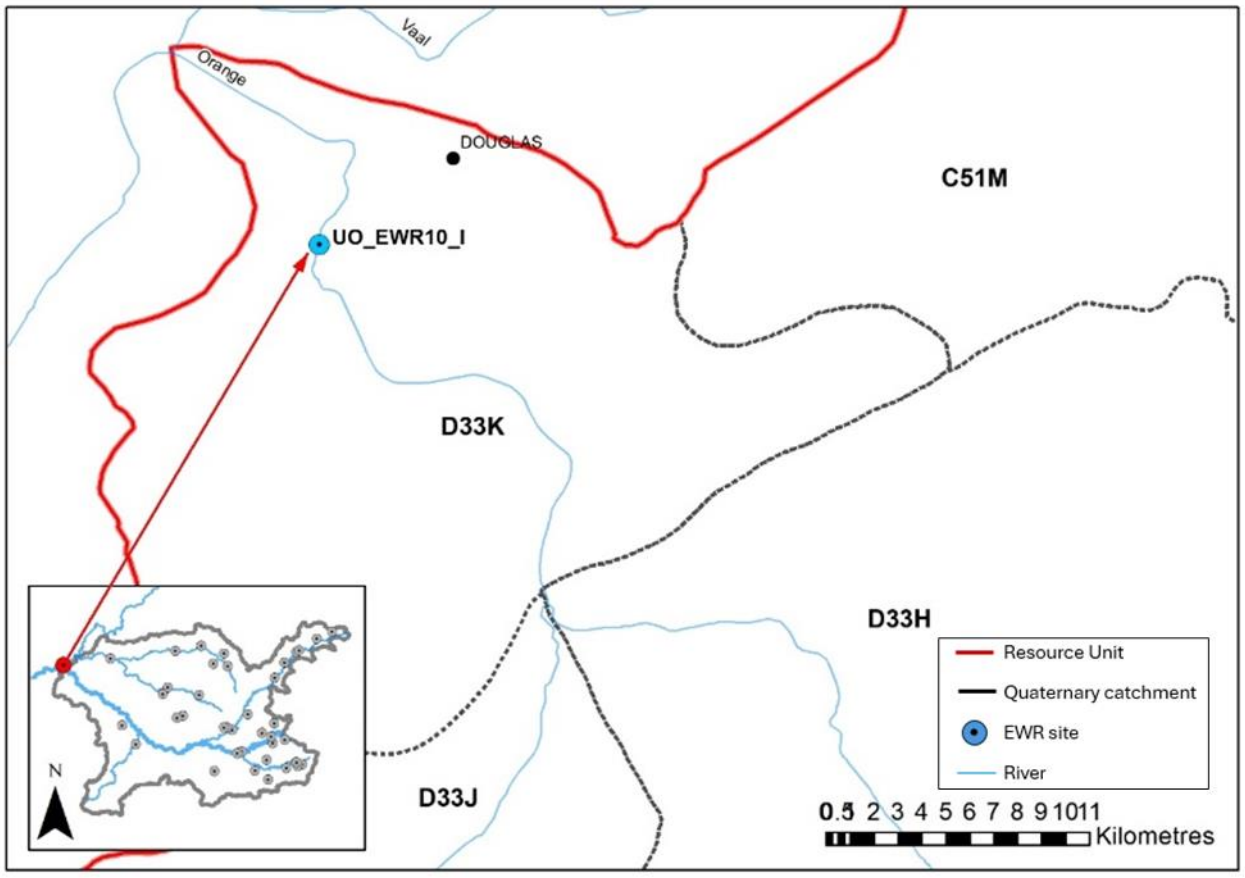


Figure 33: UO_EWR10_I site locality

Figure 34: UO_EWR10_I site photographs during the surveys in June 2023 (Left) and October 2024 (Right)

Summary results for UO_EWR10_I (DWS, 2023)

Refer to Appendix A for the biotic results from the October 2024 survey. However, the study will continue using the EcoStatus and REC form the DWS, 2023 study. The collection of biota during the October 2024 survey, was primary for the interpretation of the 2-D hydraulics being the first time undertaken at this site for the EWR quantification process.

WATER QUALITY AND FLOW (In situ)		
Parameter	**Survey 1 (June 2023)**	**Survey 2 (October 2024)**
pH	8.17	6.56
Electrical Conductivity (mS/m)	21.8	24.9
Total Dissolved Solids (mg/l)	180	100
Dissolved Oxygen (mg/l)	9.64	5.57
Dissolved Oxygen (%)	91.9	-
Clarity (cm)	24	-
Temperature (°C)	13.2	14.7
Salinity (ppt)	0.14	-
Discharge (m^3/s)	63.71	98

Diatoms:									
No. species		**SPI****		**Categorisation (quality)**		**%PTV*****		**%Deformed cells******	
06/23	**10/24**	**06/23**	**10/24**	**06/23**	**10/24**	**06/23**	**10/24**	**06/23**	**10/24**
29	-	7.8	14	D (Poor)	B (Good)	80.3	4.5	0	-

Dominant Species	**June 2023**	*Nitzschia liebetruthii Rabenhorst*
	October 2024	*Nitzschia sp., Gomphonema sp., and Navicula sp.*
Preference	**June 2023**	Cosmopolitan species found in very electrolyte-rich to brackish water.
	October 2024	Well-oxygenated, meso-to eutrophic conditions, with low to moderate electrolyte content. These taxa are tolerant to moderately polluted conditions.

The summary data indicate the changes that can occur due to the increased levels of water releases.

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 54Table 40.

Table 54: Reference Conditions at UO_ERWR10_I

Component	Description Of Reference Conditions		
Fish	*Austroglanis sclateri, Enteromius oraniensis, Enteromius paludinosus, Enteromius trimaculatus, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis, Labeo umbratus, Pseudocrenilabrus philander* and *Tilapia sparrmanii*		
Macroinvertebrates	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		
Riparian vegetation	The site is primarily defined by Upper Gariep Alluvial Vegetation comprising well-define riparian thickets along the edge of the broad and flat active channel of the Orange River with alluvial terraces supporting flooded grasslands, reedbeds and herblands. Riparian thickets would be dominated trees and shrubs: *Verchellia karroo*, *Celtis africana*, *Diospyros lycioides*, *Lycium hirsutum*, *Salix mucronata* subsp. *mucronata*, *Searsia pyroides*. The surrounding terrestrial landscape comprises Northern Upper Karoo Vegetation, which forms part of the Upper Karoo Bioregion (of the Nama-Karoo Biome).		
Geomorphology	The reference condition for the reach is likely to be a lower gradient mixed bed alluvial channel with sand and gravel dominating the bed with localised bedrock forming the bed. The reach type would mainly be pool-riffle or pool-rapid with sand bars forming in pools. A narrow floodplain can be present where the valley floor is wider.		
Hydrology	Natural flows available for the period 1920-2004.		
Physico-chemical	Reference condition for the site was determined using the DWS RQS data for site D3H008Q01 (1967 to 1980, n =163)		
	Physical Variable	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). The DWA (2008) Natural (0) rating for pH was therefore used.
		Electrical Conductivity	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 are available for the site. DWA (2008) benchmark tables were used for a low confidence, qualitative assessment of temperature reference condition
		Clarity	There are 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)

Component	Description Of Reference Conditions		
			have been utilised to characterise the site's reference condition
	Nutrients	Total Inorganic Nitrogen (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.
		Orthophosphate (PO_4 as P)	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. The Natural PO_4 rating of the site was, therefore, re-benchmarked such that it was ≤ 0.014.
	Toxins	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.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 55.

Table 55: PES per component for UO_EWR10_I and EcoStatus (DWS, 2023)

Component	PES category & score	Flow/ non-flow	Explanation
Fish	B/C (80.1%)	F/NF	• Flow modification from upstream hydropower discharges • Non-native fish species • Water quality impairment • Migratory barriers (Marksdrift Weir)
Macroinvertebrates	D (50.4%)	F/NF	• Flow modification from upstream hydropower discharges • Habitat modification – the marginal vegetation has completely been removed due to all the floods and hydro-peaks (scouring and sediment deposition) • Water quality impairment (extensive irrigation and return flows)
Riparian vegetation (VEGRAI)	C (77.7%)	NF	Site is heavily impacted by alien trees, notably *Populus canescens*, resulting in widespread removal of non-woody cover and bank destabilisation, especially along marginal and lower zones.
Geomorphology	C/D (60%)	60% flow related	• Catchment degradation elevates suspended sediment concentrations and sedimentation on coarse habitat types. • Weirs and dams trap bedload and reduce coarse habitat extent
Hydrology (HAI)	C/D (58.2%)	F	• All flow components impacted with reduced floods, increased/ constant baseflows during summer months and reduced baseflows during winter months.
Physico-chemical (diatoms)	D	NF	• Present physical-chemical condition at the site was inferred from the diatom results, because of the

Component	PES category & score	Flow/ non-flow	Explanation
			RQIS data ending in 2018, and, therefore, not representative of current physical-chemical state of the site. • The diatom results indicated very electrolyte-rich to brackish water, because of the irrigation return flows in the system. • The return flows appear to be the major physical-chemical driving factor. Historical data also shows that salinities in the system started increasing in the mid-1990s, corresponding with the increase in irrigated agriculture/cultivation in the area.
ECOSTATUS	C (71.5%)		

Refer to Appendix A from Report number RDM/WMA13/00/CON/COMP/1123 for the Habitat Integrity assessment scores for the riparian and instream zone, and Appendix C for the fish and aquatic macroinvertebrate inventories

The trends in ecological status give an idea on whether the present state is realistic and would stay the same if the management of the catchment were to continue in the same way that gave rise to the present state. The definition of the trend is "…viewed as a directional change in the attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux", Kleynhans and Louw (2007). The ecological trends for UO_EWR10_I are presented in Table 56.

Table 56: Ecological trends for UO_EWR10_I (includes components that were assessed)

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Stable	• No new water resource impacts envisaged. • No amendments to hydropower discharges expected	3
Macroinvertebrates	Stable	• No new water resource impacts envisaged. • The system continues to be highly modified. • Prolonged flooding since end of 2021 have had an impact on the macroinvertebrate community	3
Riparian vegetation	Decline	• The riparian vegetation has become more degraded since it was last assessed in October 2021 during JBS3 but is expected to improve into the next summer season.	3

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
		• Alien weeds expected to re-establish quicker that indigenous riparian species.	
Hydrology	Stable	• No recent new water resource developments	
Geomorphology	Stable	• The reach has adapted to the changes in flow and sediment so have reached a new equilibrium state, with limited anthropogenic disturbances at the site.	3
Physico-chemical	Stable	• The reach continues to adapt to the temperature changes and sediments along this reach • Continued run-off from adjacent agricultural activities	3
ECOSTATUS	Stable		

** 0 – no confidence to 5 – high confidence*

The overall EcoStatus for this EWR site was categorised as a C, thus the system is in a moderately modified condition, with loss and change of natural habitat and biota have occurred in terms of frequencies of occurrence and abundances (Table 57). Catchment degradation has increased the suspended sediment loads, resulting in sedimentation of coarser habitats. Localised weirs and dams trap bedload further upstream, reducing the extent of coarse sediment habitats.

Trampling and vegetation changes at the reach scale are relatively minor, with recent scouring and deposition evident from the last floods. To a significant extent, all the fish species expected under reference conditions were confirmed, with several species occurring at a lower frequency of occurrence than expected. The presence of two large impoundments upstream of the reach as well as hydropower discharges are however expected to be the primary drivers of the deviation from reference.

From a macroinvertebrate perspective, the community is clearly stressed owing to flood events since the end of 2021, and hydro-peaks. The macroinvertebrates do not seem to get an opportunity to recolonise. This was observed during the May 2023 survey and the inability colonise due to the floods has resulted in a community representative of largely modified conditions: Ecological Category D. The marginal vegetation zone has degraded, mostly from flooding and scouring of banks, while the lower and upper zones remain in a more moderate state. Overall, riparian vegetation at the site is moderately modified; Ecological Category C, with flow alterations unlikely to change significantly to assist to manage vegetation condition.

It is suggested that a REC and of a C (moderately modified) can be achieved, should the proposed mitigation measures/recommendations be assessed and applied (Table 57**Error! Reference source not found.**).

Table 57: Overall assessment for UO_EWR10_I - Lower Orange

River	Lower Orange
EWR Site Code	UO_EWR10_I
Driver Component	PES
Hydrology (HAI)	C/D
Geomorphology (GAI)	C/D
Response Components	PES
Diatoms	D
Fish (FRAI)	B/C
Macroinvertebrates (MIRAI)	D
Riparian Vegetation (VEGRAI)	C
EcoStatus	C
Ecological Importance (EI)	Moderate
Ecological Sensitivity (ES)	Moderate
Recommended Ecological Category (REC)	C

The EWR for the Lower Orange River downstream of Marksdrift was determined for a REC of a C. The flow regimes at this EWR site have changed considerably (Figure 35), primarily owing to the following:

- Constant releases from upstream dams for hydropower generation
- Transfers to the lower Riet River at Marksdrift
- Irrigation along the Orange River for both the Upper and Orange River catchments; and
- The lower and less frequent spills due to the Vanderkloof and Gariep Dams upstream.

Previously, during the Upper Orange Reserve Determination Study, the HFSR approach was not used during the high confidence Reserve study to quantify the EWR at this site. The EWR was determined using the Rapid III approach and based on specialist knowledge and understanding of the biotic community recorded, along with their preferences, and comparing that to the available biotopes/habitats present at the time of the surveys. These guided the setting of the drought and baseflows for this site. Further to this, freshets and floods were also specified. These requirements were subsequently revised using the information from the 2D hydraulic surveys and modelling for this survey.

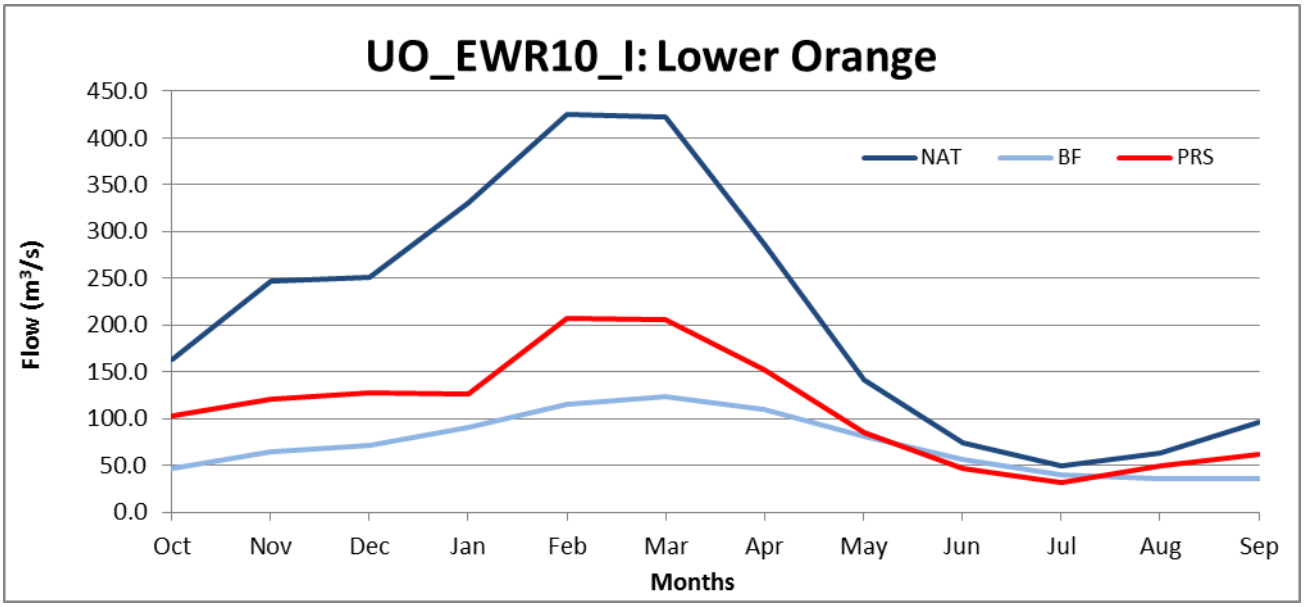


Figure 35: Hydrograph for Lower Orange EWR site indicating changed flows under present day (PRS) compared to natural (NAT and baseflows (BF)

The EWR flow data from the DRM was converted to hydraulic conditions at the EWR site (i.e., depths and flow velocities at discharges measured in m^3/s) using the results from the 2D hydraulic model. Both drought and maintenance flows were specified to ensure that the system maintain some ecological integrity. The flows for a C category were adjusted based on the velocity and habitat requirements of the flow-sensitive aquatic macroinvertebrates and to provide adequate flows and depths for fish movement. Please refer to Figure 36 to **Figure 43** which provides the 2D visual distribution of fish and macroinvertebrate habitat classes for the recommended drought and maintenance low flows specified by the ecologists. It is important to note that critical habitats for fish and macroinvertebrates includes FD, FI, FS for rheophilic fish species and FCS, VFCS, FFS and VFFS for flow dependent and sensitive taxon. When these critical habits are inundated or at least has some percentage coverage, the flows should be adequate for flow dependent fish species and microinverters.

The following changes were made to the 2023 Reserve study EWR. Figures to the habitat classes at those specific flows are also referenced:

- Increase July to October maintenance low flows to 30.0 m^3/s (Figure 36 and Figure 37)
- Increase February maintenance low flows from 51.847 m^3/s to 63.9 m^3/s (Figure 38 and Figure 39), and
- Drought flows: A minimum of 8.900 m^3/s for April to December and 25.0 m^3/s for January to March (Figure 40 to Figure 43).

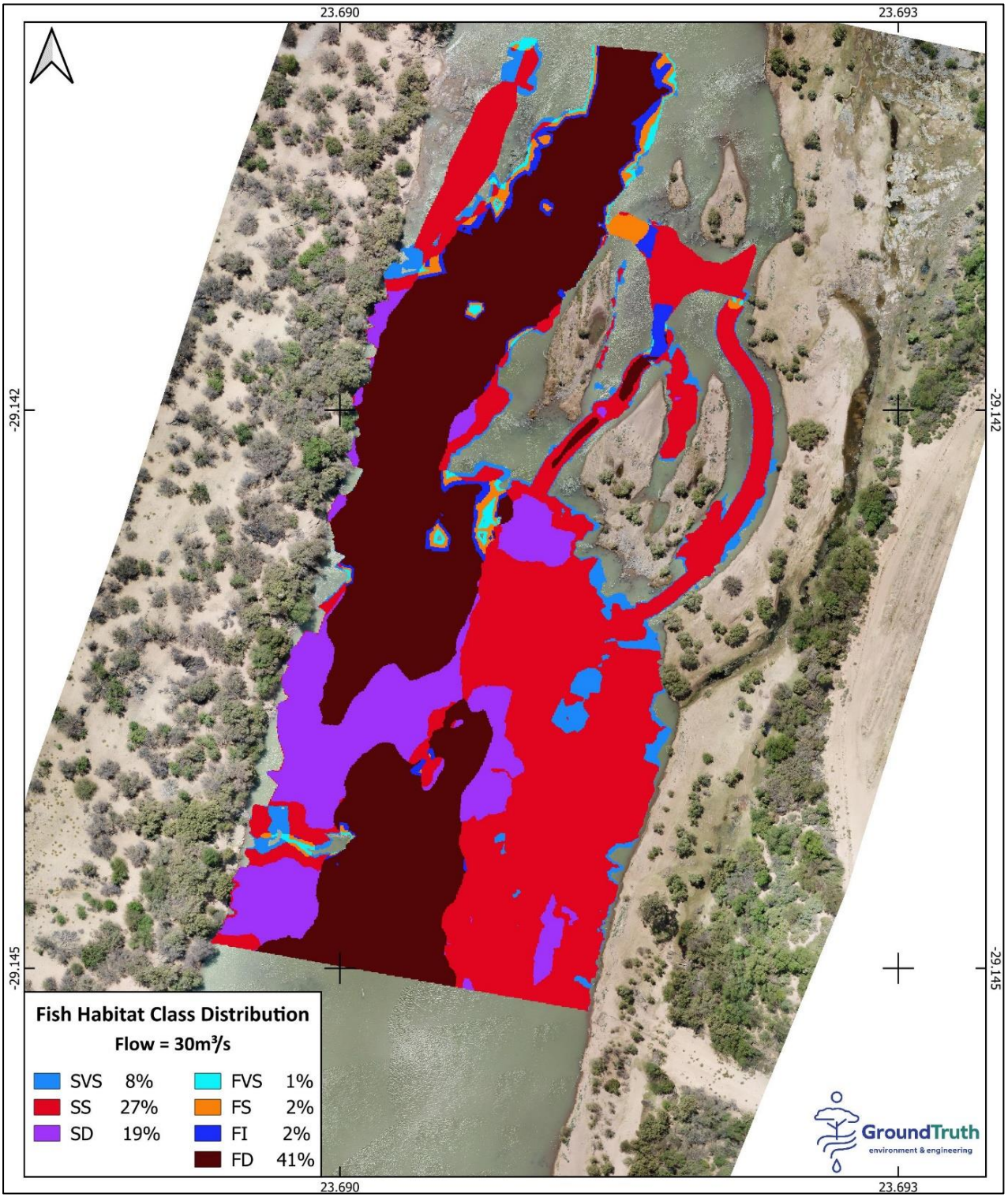


Figure 36: Visual distribution of fish habitat classes for recommended maintenance flows (30m³/s) at UO_EWR10_I

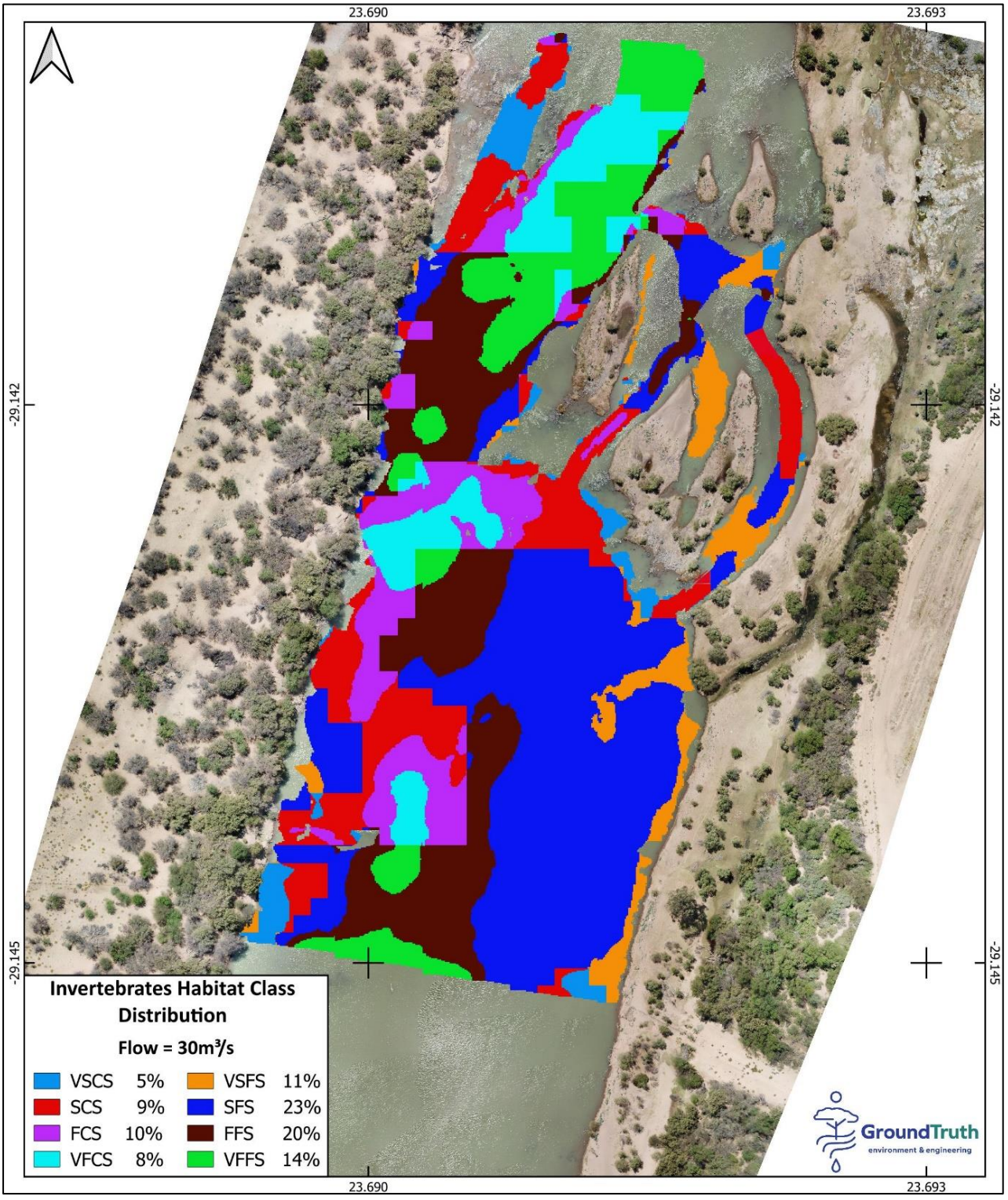


Figure 37: Visual distribution of invertebrate habitat classes for recommended maintenance flows (30m³/s) at UO_EWR10_I

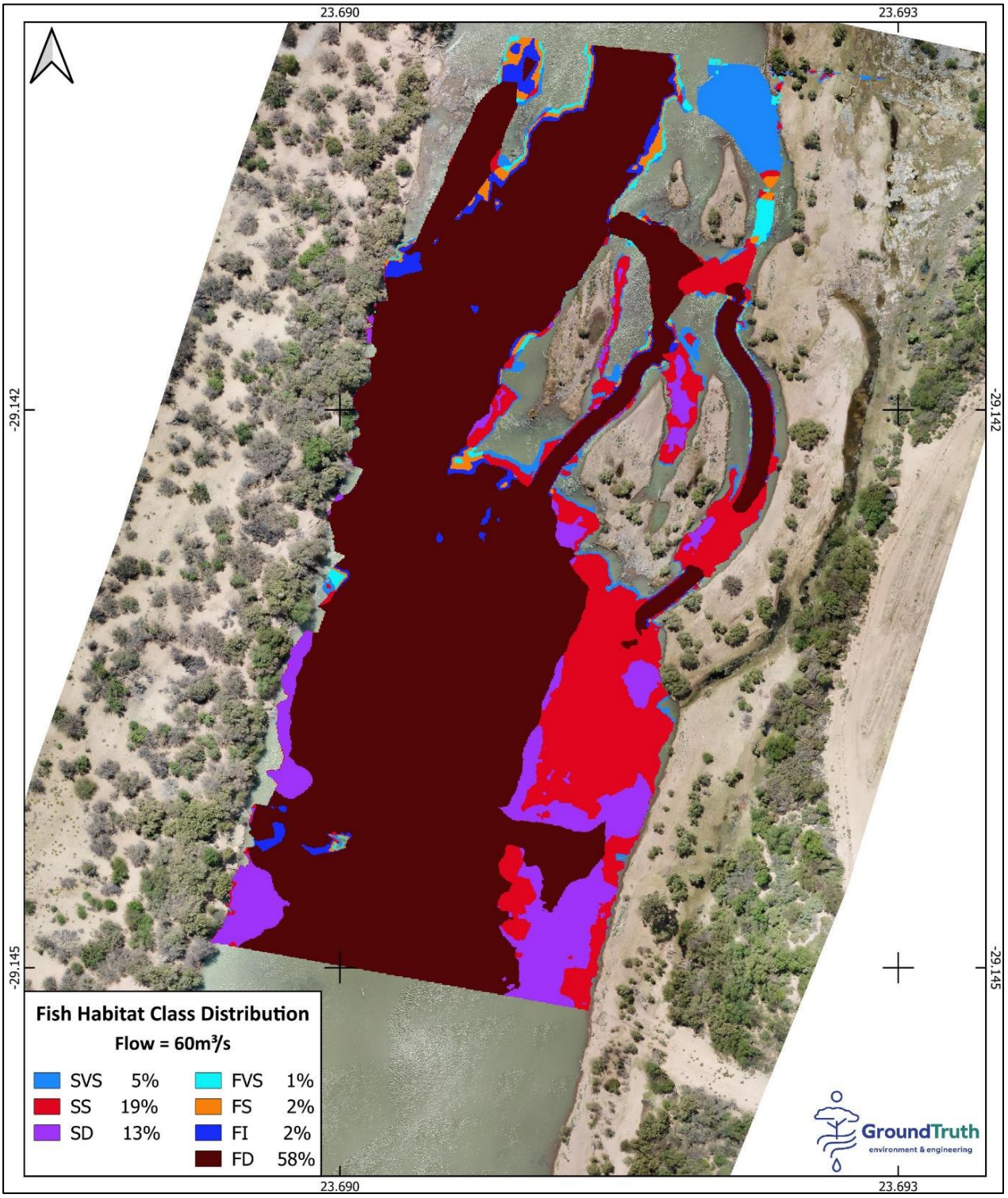


Figure 38: Visual distribution of fish habitat classes for recommended maintenance flows (60m³/s) at UO_EWR10_I

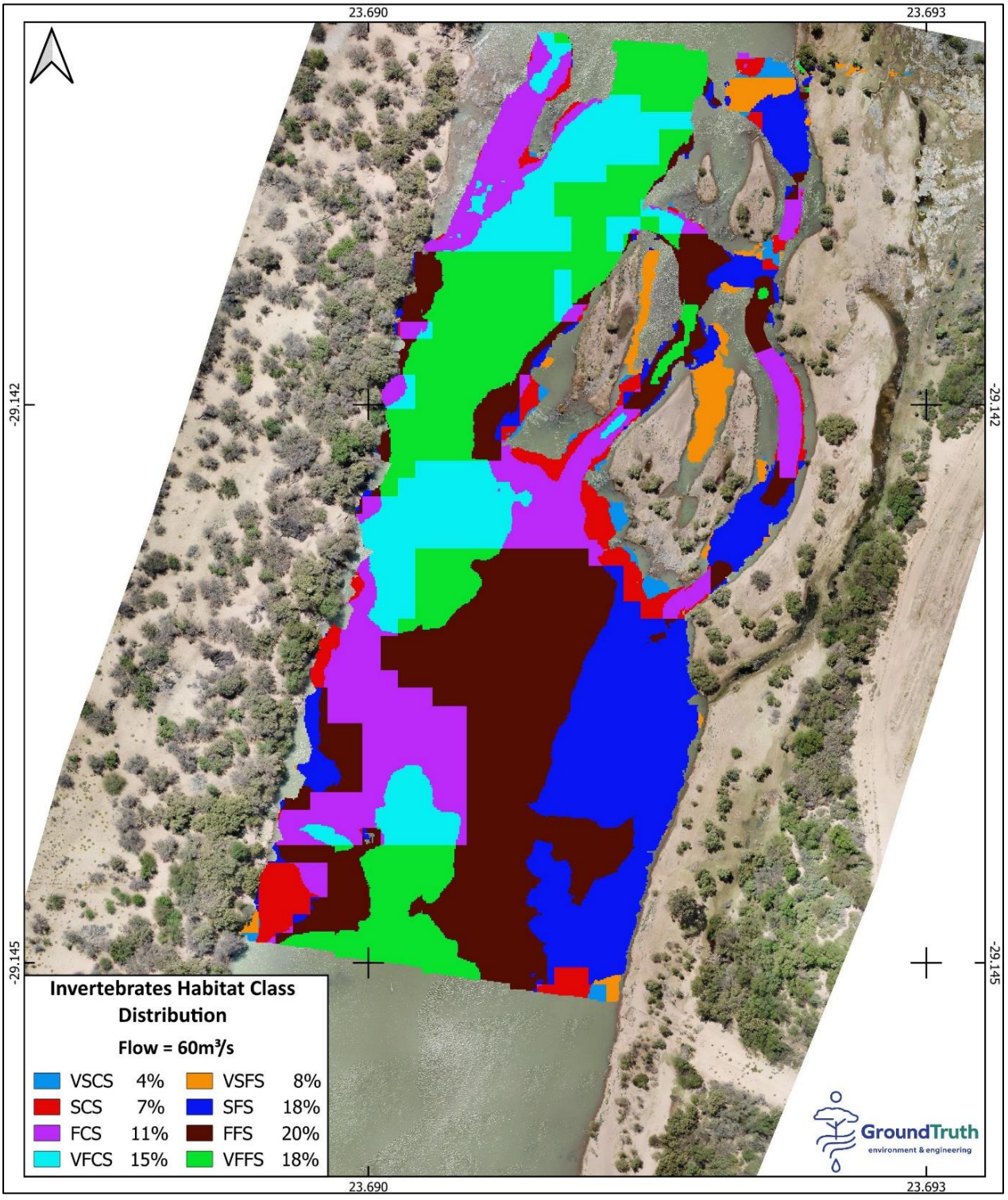


Figure 39: Visual distribution of invertebrate habitat classes for recommended maintenance flows (60m³/s) at UO_EWR10_I

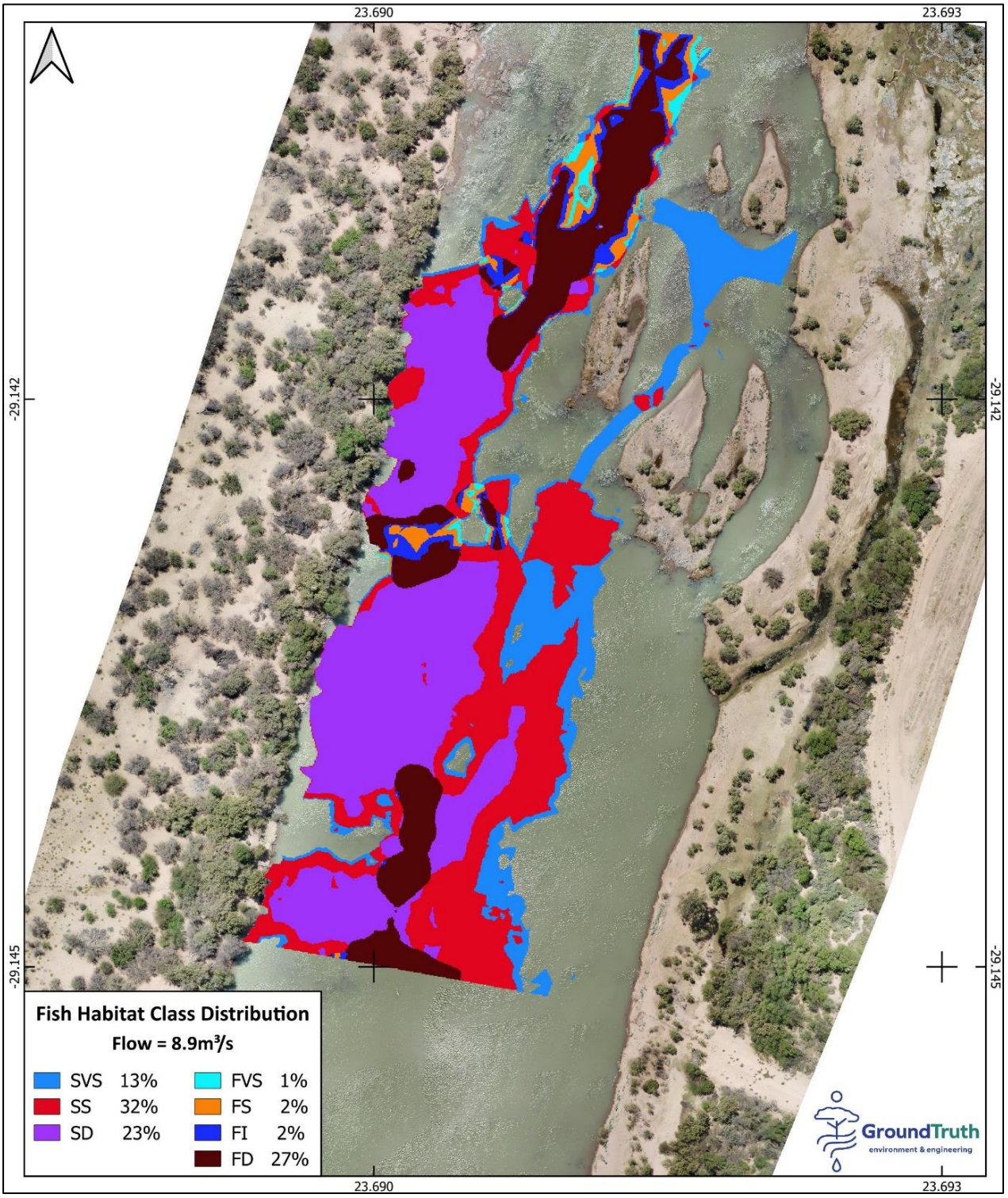


Figure 40: Visual distribution of fish habitat classes for recommended drought flows (8.9m³/s) at UO_EWR10_I

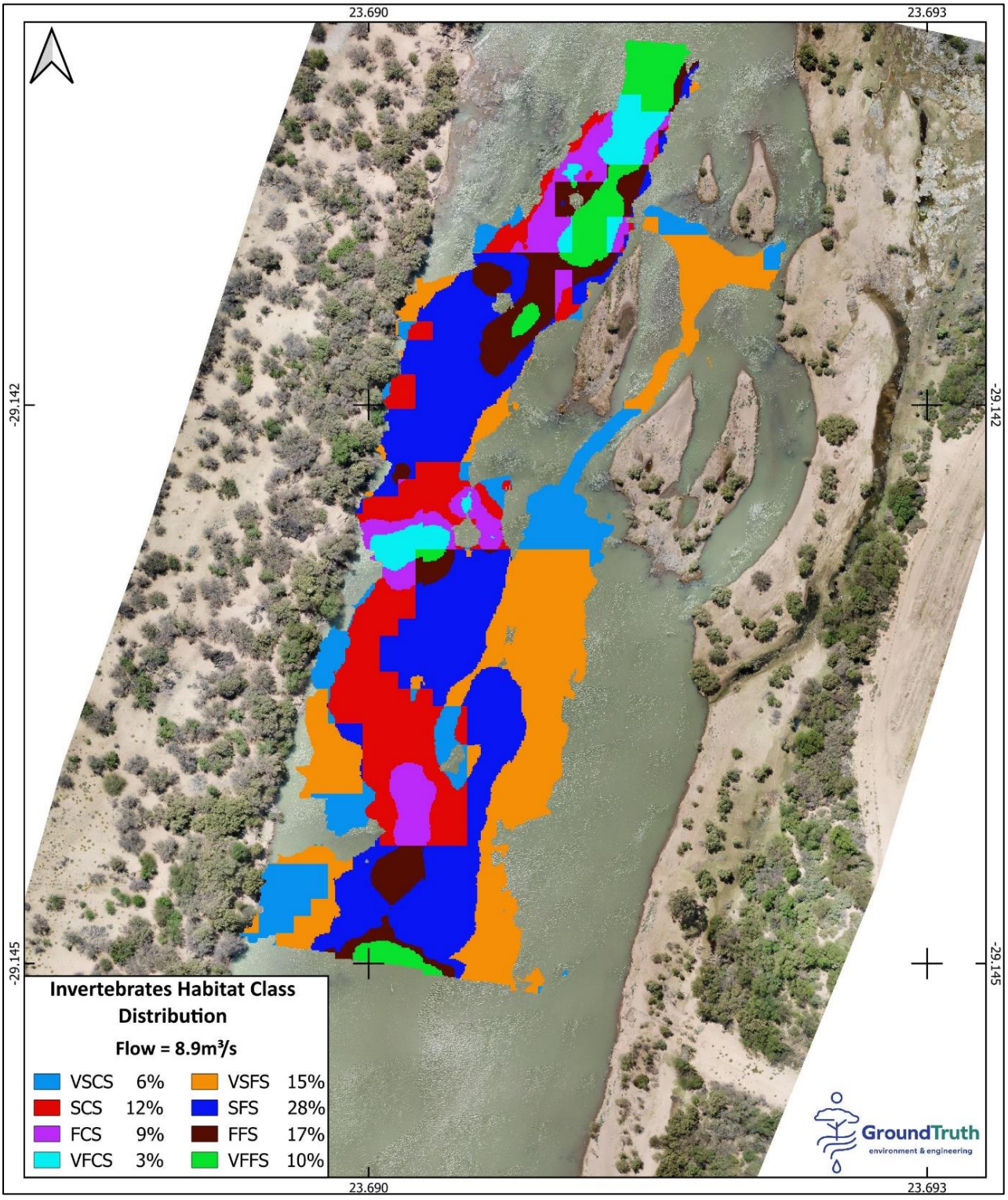


Figure 41: Visual distribution of invertebrate habitat classes for recommended drought flows (8.9m³/s) at UO_EWR10_I

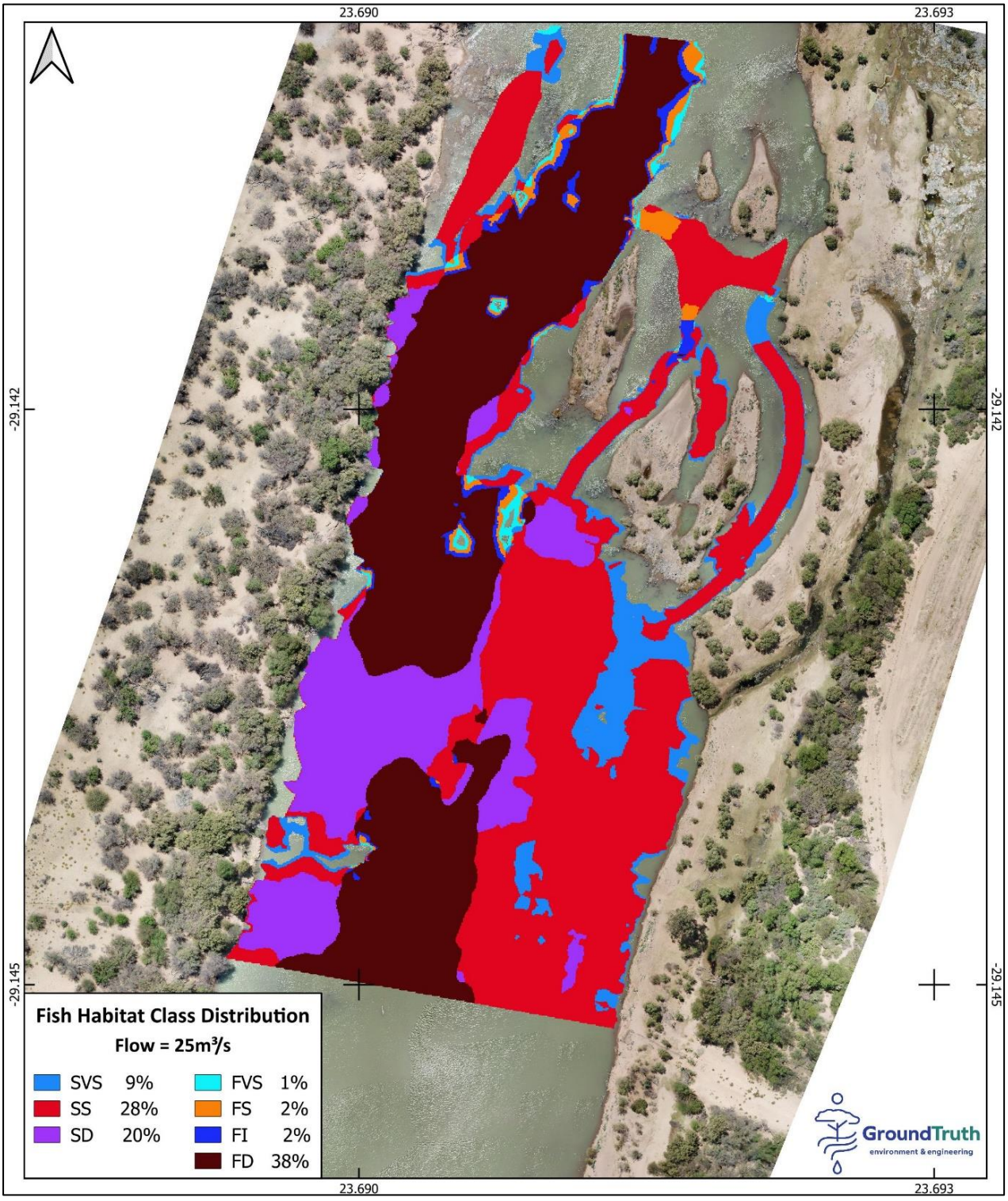


Figure 42: Visual distribution of fish habitat classes for recommended drought flows (25m³/s) at UO_EWR10_I

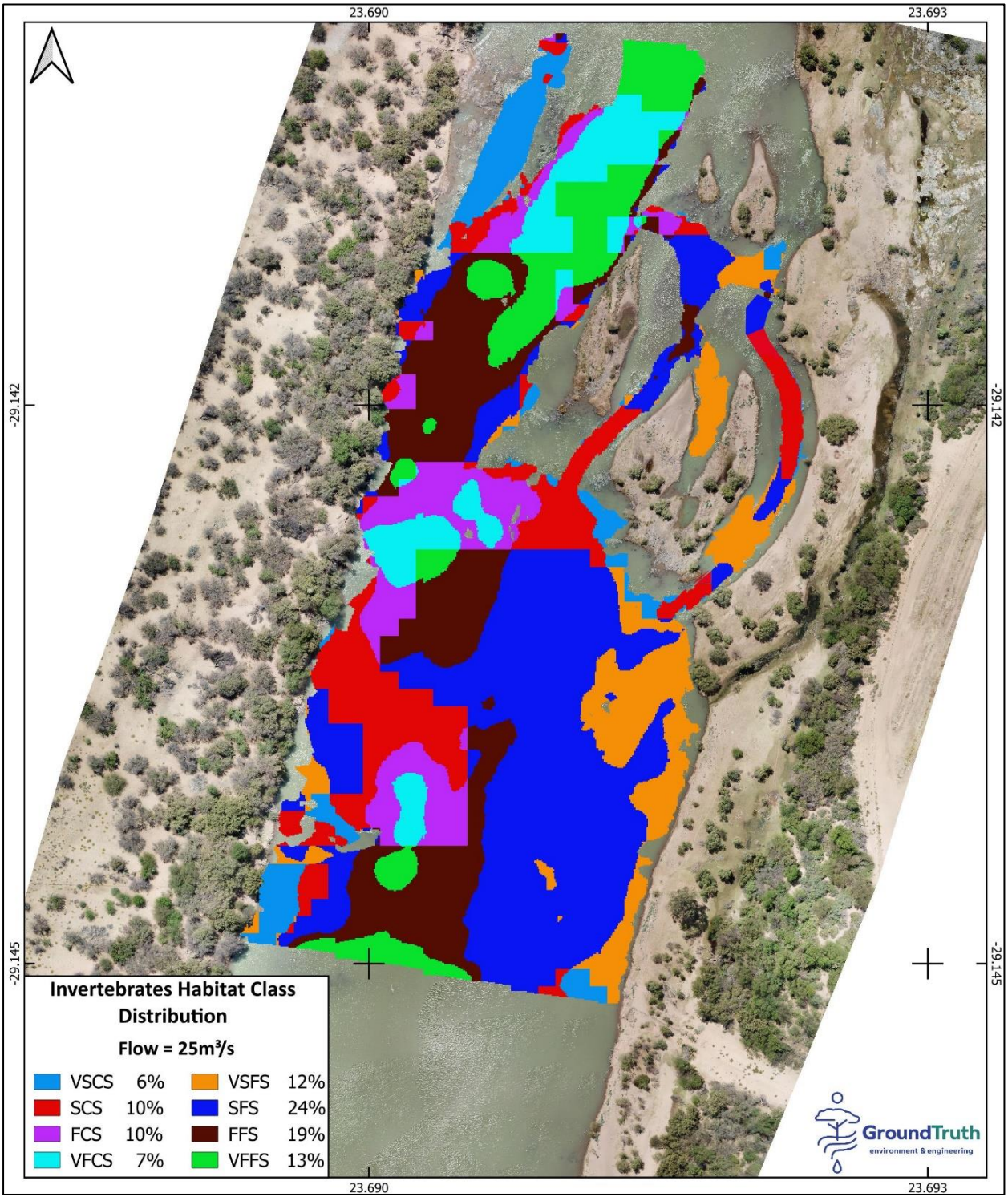


Figure 43: Visual distribution of invertebrate habitat classes for recommended drought flows (25m³/s) at UO_EWR10_I

The site-specific flow requirements for floods and freshets were based mainly on the requirements to inundate inset benches to deposit fine sediment, to mobilise fine sediment from coarse instream habitats (at velocities of 1m/s), assist with gravel movement on benches that are at approximately 2 m elevation, overtop higher flood benches and the scouring of the channel and pools and are specified in Table 58. Refer to Appendix B, Figures B-1 to B-6 for the visual distribution of the biotic habitat classes for recommended freshets and floods.

The final EWR for the Orange River at the EWR site is summarised in Table 59.

Table 58: Flood requirements for the Upper Orange at the EWR site (UO_EWR10_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	Final
Class 1 (50-70 m^3/s)	m^3/s		64			65
	# days		3			3
	Months		Nov, Dec, Jan, Mar			Oct-Jan, Apr
	Type		Average			Average
Class 2 (100-200 m^3/s)	m^3/s	155				155 (120)
	# days	3				3
	Months	Nov, Dec, Jan				Nov-Apr (May)
	Type	Average				Average
Class 3 (500-750 m^3/s)	m^3/s			500 to 750	550	550
	# days			10	7	7
	Months			Jan to Mar	Nov, Dec, Jan, Mar	Feb
	Type			Peak	Peak	Peak

** The 1:2, 1:5 and 1:10 year floods not modelled but important to include in any water resource developments*

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 59.

Table 59: Summary of the EWR results (flows in million m^3 per annum) at UO_EWR10_I

Quaternary Catchment	D33K
Site name	UO_EWR10_I
River	Lower Orange
EWR Site Co-ordinates	-29.144855; 23.691404
Recommended Ecological Category	C
MAR at EWR site	6 674.20
Total EWR	1684.770 (25.24 %MAR)
Maintenance Low flows	1341.744 (20.10 %MAR)
Drought Low flows	405.864 (6.08 %MAR)
Maintenance High flows	343.025 (5.14 %MAR)
Overall confidence	Moderate

4.9. IUA 9: Upper Modder River

4.9.1. UO_EWR07_I

The selected site is located approximately 30km east of Bloemfontein off the N8, with its confluence downstream with the Riet River near the town of Ritchie (Figure 44). The site was assessed on an intermediate level on the 14th of July 2022 and the 2nd of June 2023 as part of the high confidence Reserve determination (DWS, 2023).

River	Modder	**Altitude (m.a.s.l.)**	1 333
Latitude	-29.160017°	**Longitude**	26.572492°
Level 1 EcoRegion	Highveld	**Quaternary catchment-SQ Reach**	C52B-03819
Level 2 EcoRegion	11.03	**DWS, 2014 PES,**	D
Geomorphological zone	E (0.001; Lower Foothills)	**EI**	Moderate
		ES	**High**
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

Figure 45 shows site photographs during the surveys in July 2022 and May 2023. The reach is largely unconfined, with gently sloping hillslopes and an incised channel with narrow flood features. The site is bedrock controlled with silty banks and introduced coarser bed material. Gravel and sand bars are present downstream of the site. The site is situated approximately 13 km downstream of Rustfontein Dam. It is impeded by two (2) railway crossings and a large bridge. Furthermore, a gauging weir is located just upstream of the site. The river width varies from 3 m to 15 m in places with inundation taking place just upstream of the weir. Owing to these influences and impediments, much of the instream substrate, downstream of the weir comprises riffles with artifical loose SIC, and some SOOC. However, bedrock is the dominant substrate from the bridge and further downstream. There is relatively good GSM, but marginal vegetation, being grasses and sedges, was limited owing to undercut banks and vegetaion die back during winter (representative of the season). Sedimentation is present downstream of the weir forming a back eddie along the sandbank with algae on the rocks at the river's edge. Overaal, considerable channel and bed modification is present at this site. Both banks are heavily eroded owing to recent flooding, flow modifications and cattle trampling.

The riparian zone has been affected by altered flows as a result of Rustfontein Dam located upstream and releases from the Botshabelo WWTW, with localised impacts caused by the bridge structures associated with the N8 and the railway line, as well as the gauging wier. The right bank, upstream of the weir has a dense stand of alien Popular trees (*Populus canescens*). There has been an increase in woody vegetation, inclusive of invasive alien plants and encroachment of terrestrial species such as *Vachellia karroo* and *Searsia lancea.* Erosion along the banks is

exacerbated by runoff from the N8, as well as concentration of flows under the bridge. Various signs of impacts from cattle were also noted at the site.

Current land uses in the catchment include agricultural activities (primarily irrigated crops), urbanisation and industrial activities. The Modder River 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).

At the time of the May 2023 survey, the system was recovering/resetting from a recent flood event, which took place two days prior, measuring at approxmately 60m^3/s. This ultimately had an impact on the macroinvertebrate community and of which some of the biotopes could not be accessed, namely the SIC during this survey. Site impact sinclude:

- Upstream dams
- Weirs
- WWTW discharges
- Agriculture
- Abstrations and irrigation
- Livestock trampling, grazing
- Industrial

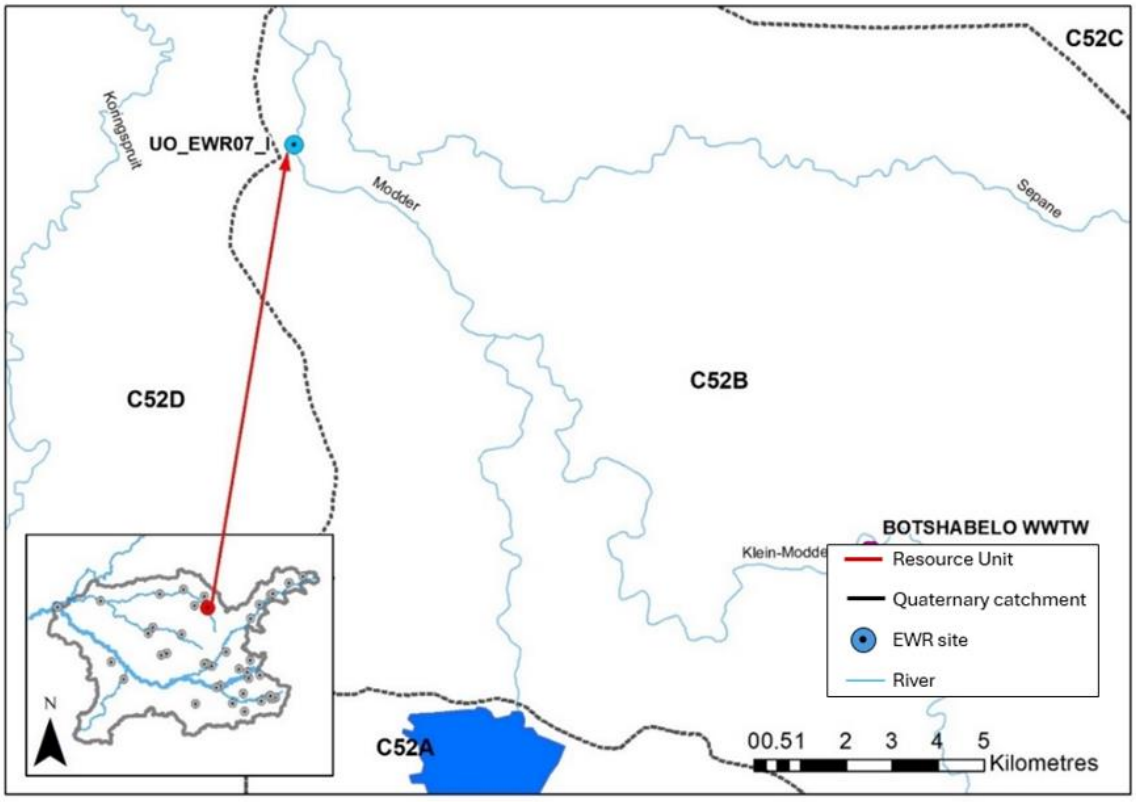


Figure 44: UO_EWR07_I site locality in C52B

Figure 45: UO_EWR07_I Site photographs during the surveys in July 2022 (Left) and May 2023 (Right)

Summary results for UO_EWR07_I (DWS, 2023)

WATER QUALITY AND FLOW (In situ)		
Parameter	**Survey 1 (July 2022)**	**Survey 2 (May 2023)**
pH	8.4	7.96
Electrical Conductivity (mS/m)	45.9	155.7
Total Dissolved Solids (mg/l)	419	1 404
Dissolved Oxygen (mg/l)	8.7	9.65
Dissolved Oxygen (%)	76.6	86.2
Clarity (cm)	52	6.5
Temperature (°C)	9.9	10.4
Salinity (ppt)	0.32	0.10
Discharge (m^3/s)	0.673	9.180

Diatoms:									
No. species		**SPI****		**Categorisation (quality)**		**%PTV*****		**%Deformed cells******	
07/22	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**	**07/22**	**05/23**
34	30	5.6	6.3	D (Poor)	D (Poor)	73.1	30	8.75*	0

Dominant Species	**July 2022**	*Eolimna subminuscula (Manguin) Moser, Lange-Bertalot & Metzeltin*
	May 2023	*1. Nitzschia frustulum (Kützing) Grunow*
		2. Gomphonema parvulum (Kützing) Kützing
		3. Navicula veneta Kützing
		4. Nitzschia palea (Kützing) W.Smith
Preference	**July 2022**	Tolerant of strong pollution, indicator of industrial organic pollution
	May 2023	1. High conductivity, heavy agriculture, very tolerant of pollution
		2. Very high load of fine sediment, diatom cells present, mostly broken
		3. Cosmopolitan, common in heavily eutrophicated, electrolyte-rich to brackish water. Very pollution tolerant, often the dominant species in industrially impacted waters.
		4. A cosmopolitan and very commonly occurring species found in eutrophic and very heavily polluted to extremely polluted waters with moderate to high electrolyte content

* *extreme deformities and cause for concern*

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 60.

Table 60: Reference Conditions for UO_EWR07_I (DWS, 2023)

Component	Description Of Reference Conditions
Fish	*Enteromius oraniensis, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis* and *Labeo umbratus*
Macroinvertebrates	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.
Riparian vegetation	The site is nested within the Grassland Biome and forms part of the Dry Highveld Grassland Bioregion. The terrestrial vegetation surrounding the site is characterised by Central Free State Grassland with the riparian component defined as Highveld Alluvial Vegetation. As a result, the riparian zone should support a largely grassland and herb land mosaic that is seasonally flooded with influences from the associated terrestrial grasslands.
Hydrology	Natural flows at the EWR site available for the period 1920 to 2004.
Geomorphology	The reference condition for the reach is likely to be a lower gradient mixed bed alluvial channel with sand and gravel dominating the bed with localised bedrock forming the bed. The reach type would mainly be pool-riffle or pool-rapid with sand bars forming in pools. A narrow floodplain can be present where the valley floor is wider.
Physico-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 Botshabelo Township upstream established in 1979. Diatoms data were used to infer the reference Physical-chemical condition 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' WWTWs upstream.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 61.

Table 61: PES per component for EWR site UO_EWR07_I and EcoStatus (DWS, 2023)

Component	PES category & score	Flow/ non-flow	Explanation
Fish (FRAI)	C (68.6%)	F/NF	• Significant water quality impairment due to raw sewage input from Botshabelo (Klein Modder) • Flow modification • Habitat modification • Migration barrier (upstream weir) • Non-native (alien) fish
Macroinvertebrates (MIRAI)	D (50.0%)	F/NF	• Loss of habitat – marginal vegetation owing to cattle trampling and overgrazing, bank erosion

Component	PES category & score	Flow/ non-flow	Explanation
			• Site is mainly dominated by bedrock (not an ideal biotope for macroinvertebrates) • High sediment loads over SIC, SOOC • Decrease water quality (highly turbid , run-off from Botshabelo - situated on the Klein-Modder River which confluences with the Modder upstream of the site) • Channel and flow modifications (weir, various bridges at the site, upstream Rustfontein dam)
Riparian vegetation (VEGRAI)	D (46.4%)	F/NF	• Notable loss of vegetation-cover due to trampling and erosion, together with an increase in woody vegetation. • River channel is largely incised through the site. • Number of aliens at the site with dense stand of *Populus alba*. • Removal of vegetation from construction of the roads, rail, bridges and weir.
Geomorphology (GAI)	D (49)	38% flow related	• A moderate density of smaller farm dams along tributaries and weirs and a large dam along the mainstem that trap coarser bedload. Gullies and areas of sheet erosion increase water and sediment routing. • 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.
Hydrology (HAI)	C/D (58.3%)	F	• Rustfontein Dam upstream impacting on all the flow components. • Discharges from Botshabelo WWTW resulting in increased flows, especially during winter months.
Physico-chemical (Diatoms)	D	NF	• The present Physical-chemical state at the site was inferred from the diatom data. • Diatom data indicated strong organic and inorganic pollution, arising from urban runoff and poorly treated wastewater from the Botshabelo township upstream.
ECOSTATUS	D (51.7%)		

Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 for the Habitat Integrity assessment scores for the riparian and instream zone, and Appendix C for the fish and aquatic macroinvertebrate inventories

The trends in ecological status give an idea on whether the present state is realistic and would stay the same if the management of the catchment were to continue in the same way that gave rise to the present state. The definition of the trend is "…viewed as a directional change in the attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away

from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux", Kleynhans and Louw (2007). The ecological trends for UO_EWR07_I are presented in Table 62.

Table 62: Ecological trends for UO_EWR07_I (includes components that were assessed)

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Decline	• Long-term decline of water quality through failing/dysfunctional sewage infrastructure	4
Macroinvertebrates	Decline	• Ongoing pressures at a catchment level • Long-term decline of water quality through failing/dysfunctional sewage infrastructure	4
Riparian vegetation	Decline	• The riparian vegetation has experienced a recent decline following floods in 2022, which is exacerbated by poor conditions at the site as well as the degraded landscape surrounding the site.	4
Hydrology	Stable	• No recent water resource developments	3
Geomorphology	Decline	• Ongoing pressures at catchment level and at the site	3.5
Physico-chemical	Decline	• Long-term decline of water quality through failing/dysfunctional sewage infrastructure	3
ECOSTATUS	Decline		

** 0 – no confidence to 5 – high confidence*

The overall EcoStatus for this EWR site was categorised as a D, with the system being largely modified (Table 63). The degradation of the catchment is elevating suspended sediment loads leading to higher turbidity and silt deposits over coarser habitats. At the site, disturbance along the margins is widespread leading to degradation of the habitat associated with inset benches and banks. The water quality is highly compromised, with the diatoms reflecting the impacts on the physical-chemical state downstream of Botshabelo and the unmaintained and dysfunctional WWTW. This is ultimately and primarily having a major impact on the biota within the system, particular with both fish and macroinvertebrates responding to very poor water quality (i.e., raw sewage input from Botshabelo and smaller upstream tributaries), could further suggest that fish kill events are likely to take place.

This reach does present the only feasible movement corridor for fish moving upstream from Mocke's Dam. The marginal and lower zones were found to be in a poor to severely modified state largely due to bank erosion, livestock grazing/trampling, stormwater runoff impacts, and altered habitat structure from the weir and bridges – overall condition of the riparian zone is poor (Ecological Category D).

It is suggested that both the REC and AEC of a C (moderately modified) can be achieved, should the proposed mitigation measures/recommendations (mainly water quality) be assessed and applied (Table 63).

Table 63: Overall assessment for UO_EWR07_I – Upper Modder River

River	Upper Modder River
EWR Site Code	UO_EWR07_I
Driver Component	PES
Hydrology (HAI)	C/D
Geomorphology (GAI)	D
Response Components	PES
Diatoms	D
Fish (FRAI)	C
Macroinvertebrates (MIRAI)	D
Riparian Vegetation (VEGRAI)	D
EcoStatus	D
Ecological Importance (EI)	Low
Ecological Sensitivity (ES)	Moderate
Recommended Ecological Category (REC)	C

The EWR for the Upper Modder River was determined for a REC of a C. It should be noted that the PES is in a D category, mainly due to water quality impacts (un-treated effluent from upstream WWTW) and to a lesser extent changes in flows. If the water quality improves the system can be managed for a C category. However, without improvements in the water quality, the system will most likely be in a D category. As the flow regime at the EWR site has changed due to constant releases from upstream WWTW (more flows than natural especially during dryer months, see graph below), the HFSR approach was not used to determine the EWR.

The EWR was determined using first principles from a habitat and biotic perspective to set the drought and baseflows based on specialist knowledge and understanding of the biotic community recorded, along with their preferences, and comparing that to the available biotopes/habitats present at the time of the surveys.

Figure 46 shows the hydrograph indicating high flows under present day (PRS) compared to natural (NAT and baseflows (BF) during dry months.**Error! Reference source not found.**

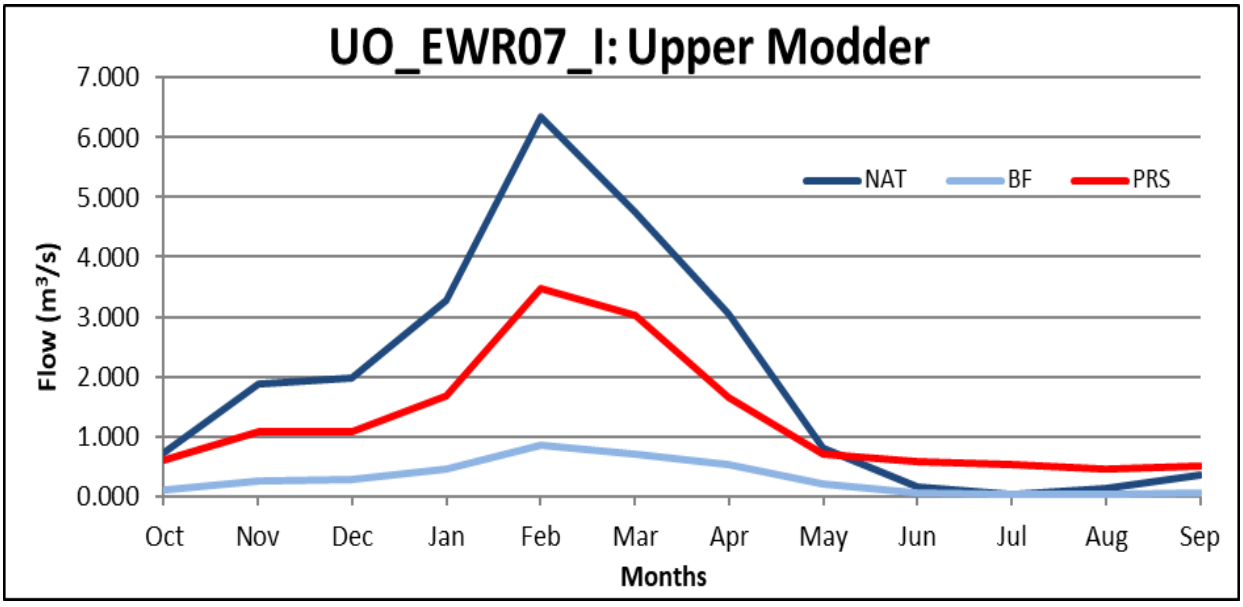


Figure 46: Hydrograph indicating high flows under present day (PRS) compared to natural (NAT and baseflows (BF) during dry months at UO_EWR07_I

The EWR flow data from the DRM was converted to hydraulic conditions at the EWR site (i.e., depths and flow velocities at discharges measured in m^3/s) using a hydraulic model. A minimum or drought flow was specified for all months to ensure that the system stays in its current perennial state and not returning to a seasonal system as pre-development. The maintenance low flows were adjusted to ensure increased velocity for those flow dependent macroinvertebrates, as well as provided additional critical habitat, namely fast course substrate and/or very fast course substrate (being the stones biotope). Furthermore, flows were increased with the aim to improve velocity depth classes and activate additional fast intermediate critical habitats, and to provide additional cover features for the fish. Further to this, freshets and floods were also specified. Thus, the maintenance flows as proposed for a C category were adjusted as follows:

- Increase July and August maintenance low flows to 0.053 m^3/s
- Increase February maintenance low flows from 0.322m^3/s to 0.848 m^3/s
- Drought flows: A minimum of 0.053 m^3/s for May, June, July, August, September and October
- Drought flows: A minimum of 0.094 m^3/s for January to April and November, December

The site-specific flow requirements were based mainly on the requirements to mobilise fine gravel on the bed and scour fine sediments from riffles. The gravel and sediments will in turn scour the instream biotopes for macroinvertebrates (namely the stones biotope) to remove filamentous algae accumulation. Furthermore, mobilising the medium gravels as specified in Table 64 and the final EWR for the Upper Modder River at the EWR site is summarised in Table 65.

Table 64: Flood requirements for the Upper Modder at the EWR site (UO_EWR07_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	Final
Class 1 (0-5 m^3/s)	m3/s	4			2.2	4
	# days	3			3	3
	Months	Nov, Dec, Jan			Nov, Dec, Jan, Mar	Nov, Dec, Jan, Mar, Apr
	Type	Average			Average	Average
Class 2 (10-20 m^3/s)	m3/s		16	10 to 20		16
	# days		3	3		3
	Months		Nov, Dec, Jan, Mar	Jan, Feb, Mar		Jan, Mar
	Type		Average	Average		Average
Class 3 (45 m^3/s)	m3/s		45		45	30
	# days		3		3	3
	Months		Apr, May		Feb	Feb
	Type		Peak		Peak	Peak

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 65: Upper Orange - Summary of the EWR results (flows in million m3 per annum).

Table 65: Upper Orange - Summary of the EWR results (flows in million m^3 per annum)

Quaternary Catchment	C52B
Site name	UO_EWR07_I
River	Upper Modder River
EWR Site Co-ordinates	-29.160017; 26.572492
Recommended Ecological Category	C
nMAR at EWR site	61
Total EWR	21.909 (35.94 %MAR)

Quaternary Catchment	**C52B**
Maintenance Low flows	9.156 (15.02 %MAR)
Drought Low flows	2.313 (3.79 %MAR)
Maintenance High flows	12.753 (20.92 %MAR)
Overall confidence	Moderate

4.10. IUA 10: Modder-Riet

4.10.1. UO_EWR06_I

The selected 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 River (Figure 47). The site was assessed on an intermediate level on the 13th of July 2022 and the 1st of June 2023 as part of the high confidence Reserve determination (DWS, 2023).

River	Upper Riet	**Altitude (m.a.s.l.)**	1 278
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,**	C
Geomorphological zone	E (0.001; Lower Foothills)	**EI**	High
		ES	Moderate
Components sampled: Fish, aquatic macroinvertebrates, riparian vegetation, *in situ* water quality, diatoms, cross-section, re-measurements of slope and water levels, discharge, geomorphology			

Figure 48 shows site photographs during the surveys in July 2022 and May 2023. The reach is largely unconfined, with the macro channel incised into the gently sloping hillslopes. The river has a straight to sinuous macro channel pattern, with a braided low flow channel pattern. Bedrock, boulder, gravel and silt sediment types at the site. Upstream of this site is the DWS REMP site and previous JBS3 site 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 channel is approximately 40m wide and braided downstream of the bridge 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 and fish. The substrate at the site is dominated by gravel and cobbles, as well as a section of bedrock along the left side of the channel. The increased flows have allowed aquatic grass to establish in the deep runs. 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.

The riparian zone is characterised by a fairly steep left bank with denser vegetation and a wider, flatter, more open right bank with areas of exposed bedrock and alluvium. The marginal zone is narrow and dominated by dense clumps of *Schoenoplectus* interspersed by the occasional woody shrub/tree (e.g., *Salix mucronata*), which leads into a grassy strip of tall/robust *Miscanthus*

capensis defining the lower edge of the non-marginal, with a broader band of *Cynodon dactylon* and other grasses above extending across the upper zone into the terrestrial areas. The upper, left bank has numerous patches of low, dense thicket comprising *Lycium* and *Asparagus spp.* with several large, alien trees (*Eucalyptus* and *Populus spp.*) scattered along the middle to upper bank. There are a number of islands and clusters of emergent *Schoenoplectus* with *Gomphostigma virgatum*. Impacts to the riparian zone are low to moderate and tend to be localised around the road crossing. Impacts at the site include:

- Rural development
- Cattle/game farming
- Cultivation, and
- Irrigation

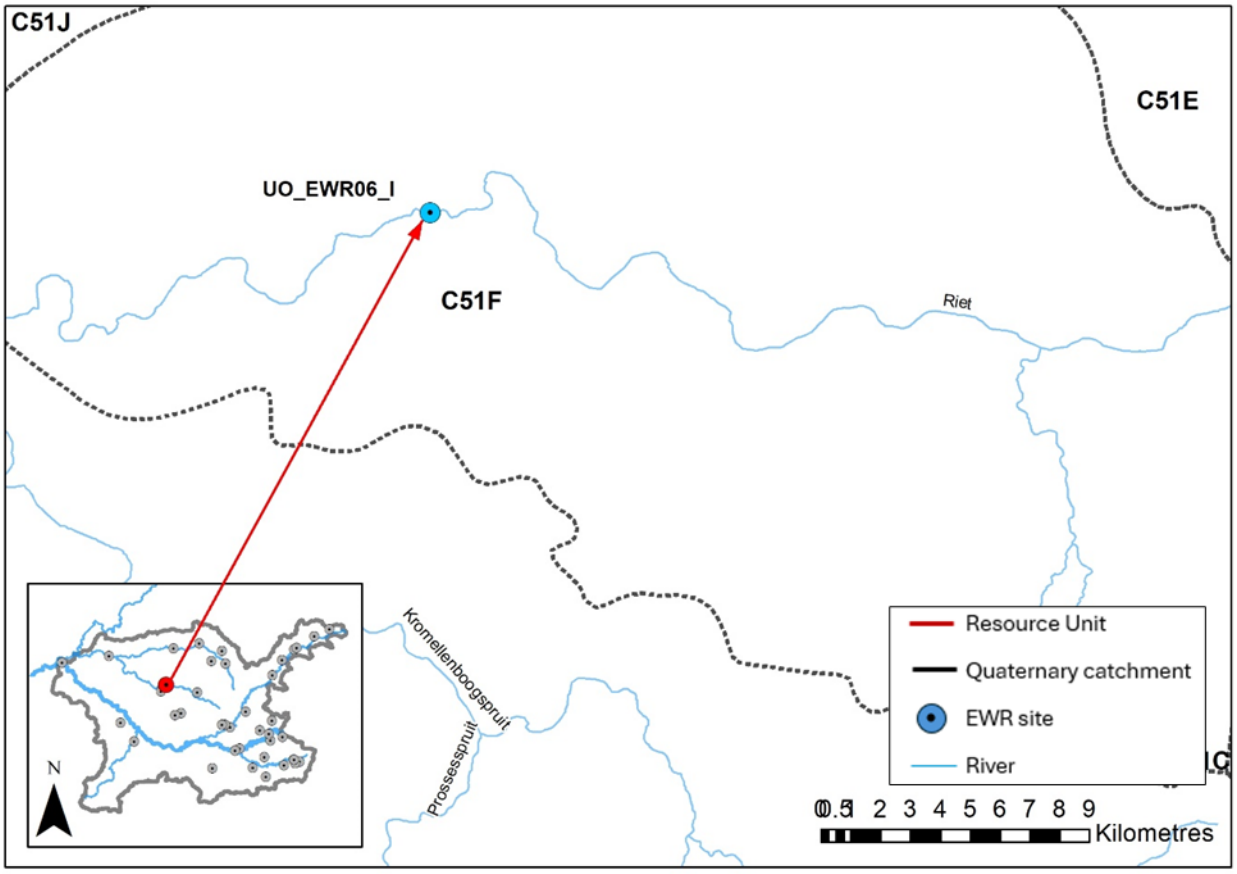


Figure 47: UO_EWR06_I site locality

Figure 48: UO_EWR06_I Site photographs during the surveys in July 2022 (Left) and May 2023 (Right)

Summary results for UO_EWR06_I (DWS, 2023)

WATER QUALITY AND FLOW (In situ)		
Parameter	**Survey 1 (July 2022)**	**Survey 2 (June 2023)**
pH	8.8	8.34
Electrical Conductivity (mS/m)	48.6	55.7
Total Dissolved Solids (mg/l)	450	500
Dissolved Oxygen (mg/l)	9.9	8.98
Dissolved Oxygen (%)	97.4	81.3
Clarity (cm)	22	13
Temperature (°C)	9.5	11.0
Salinity (ppt)	0.34	0.37
Discharge (m^3/s)	4.22	12.41

Diatoms:									
No. species		**SPI****		**Categorisation (quality)**		**%PTV*****		**%Deformed cells******	
07/22	**06/23**	**07/22**	**06/23**	**07/22**	**06/23**	**07/22**	**06/23**	**07/22**	**06/23**
31	20	19.3	6.2	C (Mod)	D (Poor)	16.6	94	1	0.5

Dominant Species	**July 2022**	1. *Cyclostephanos invisitatus (Hohn & Hellerman) Theriot, Stoermer & Hakans*
		2. *Fragilaria biceps (Kützing) Lange-Bertalot*
	May 2023	*Nitzschia frustulum (Kützing) Grunow*
Preference	**July 2022**	1. Species is of wide-spread occurrence and is common in the summer. Often found in plankton nutrient-rich waters
		2. Cosmopolitan taxon. Often found in mesotrophic to eutrophic waters.
	May 2023	High conductivity, heavy agriculture, very tolerant of pollution

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 66.

Table 66: Reference Conditions for UO_EWR06_I

Component	Description Of Reference Conditions
Fish	*Enteromius oraniensis, Enteromius paludinosus, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis, Labeo umbratus, Tilapia sparrmanii* and *Pseudocrenilabrus philander*
Macroinvertebrates	Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Baetidae >2spp, Caenidae, Oligoneuridae, Trichorythidae, Coenagrionidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae,

Component	Description Of Reference Conditions
	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.
Riparian vegetation	The site is nested within the Grassland Biome and forms part of the Dry Highveld Grassland Bioregion. The terrestrial vegetation surrounding the site is characterised by Xhariep Karroid Grassland with the riparian component defined as Highveld Alluvial Vegetation. As a result, the riparian zone should support a grassland and herb-land mosaic that is seasonally flooded with influences from the associated terrestrial grasslands.
Hydrology	Natural flows at the EWR site available for the period 1920 to 2004.
Geomorphology	The reference condition for the reach is likely to be a lower gradient mixed bed alluvial channel with sand and gravel dominating the bed with localised bedrock forming the bed. The reach type would mainly be pool-riffle or pool-rapid with sand bars forming in pools. A narrow floodplain can be present where the valley floor is wider.
Physico-chemical	Historical Physical-chemical data at the site began in 2011, which did not reflect the reference conditions at the site. The reference Physical-chemical condition of the site was, therefore, inferred from the diatom data. The diatom data indicated that the site is free from organic pollution, however the system is prone to eutrophic conditions and high phosphorus concentrations. Lower nutrient conditions are expected to be prevalent under reference conditions.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 67.

Table 67: : PES per component for EWR site and EcoStatus (DWS, 2023)

Component	PES category & score	Flow/ non-flow	Explanation
Fish (FRAI)	C (68.1%)	F/NF	• Weirs acting as upstream migration barriers • Flow modifications • Sediment input into the system due to catchment activities • Presence of non-native fish species
Macroinvertebrates (MIRAI)	C (62.6%)	NF	• Water quality (irrigation from adjacent and upstream agriculture, highly turbid and sediment inputs)
Riparian vegetation (VEGRAI)	C (62.3%)	NF	• Nutrient inputs from upstream increasing vigour of sedges. • Pressure grazing and reduced fire intensity resulting in increased woody cover • Encroachment of both alien and terrestrial species.
Geomorphology (GAI)	C (73)	30% F related	• Low density of smaller farm dams along tributaries and weirs and dams along the mainstem that trap coarser bedload. Gullies and badlands increase water and sediment routing.

Component	PES category & score	Flow/ non-flow	Explanation
			• 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.
Hydrology (HAI)	C (67.9%)	F	• Mainly irrigation and Tierpoort Dam on a tributary of the Riet River resulting in reduced low flows, freshets and floods.
Physico-chemical (Diatoms)	D		• Due to the lack of historical physical-chemical data, the present physical-chemical state of the site was inferred from the diatom data. • The diatom results indicated heavily polluted waters (organic pollution) with elevated conductivities.
ECOSTATUS	C (63.7%)		

[a]*Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 for the Habitat Integrity assessment scores for the riparian and instream zone, and Appendix C for the fish and aquatic macroinvertebrate inventories*

The trends in ecological status give an idea on whether the present state is realistic and would stay the same if the management of the catchment were to continue in the same way that gave rise to the present state. The definition of the trend is "…viewed as a directional change in the attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux", Kleynhans and Louw (2007). The ecological trends for UO_EWR06_I are presented in Table 68

Table 68: Ecological trends for UO_EWR06_I (includes components that were assessed)

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Stable	• No recent water resource developments or increase in impacting feature expected	3
Macroinvertebrates	Stable	• No recent water resource developments, although turbidity levels continue to rise due to sediment supply.	3
Riparian vegetation	Stable	• There has not been any significant change in riparian vegetation since the construction of the bridge other than gradual encroachment of terrestrial and alien vegetation.	3
Hydrology	Stable	• No recent water resource developments	3
Geomorphology	Stable	• Ongoing pressures with no immediate change in drivers or site impact	3
Physico-chemical	Decline	• The diatoms have illustrated in a decline in water quality from being moderately	3

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
		modified to poorly modified (recent diatom samples taken in May 2023); and • The diatoms were indicative of the site being heavily contaminated with organic pollution.	
ECOSTATUS	Stable		

** 0 – no confidence to 5 – high confidence*

The overall EcoStatus for this EWR site was categorised as a C, thus the system is in a moderately modified condition, with loss and change of natural habitat and biota have occurred in terms of frequencies of occurrence and abundances (Table 69). The degradation of the catchment is elevating suspended sediment loads leading to higher turbidity and silt deposits over coarser habitats. At the site, disturbance along the margins is low, but still shows degradation of the habitat associated with inset benches and banks. The fish assemblage was noted to be in a moderately modified state, with Kalkfontein Dam and several weirs noted to be impacting the assemblage due to movement limitations. Additional elements impacting the fish species present included flow modifications as well as the presence of non-native species.

The macroinvertebrate community was found to be indicative of moderately modified conditions (Ecological Category C) as well, mostly responding to poor water quality. The marginal zone was found to be in a moderately good condition, while the lower zone and upper zone were more degraded – overall condition of the riparian zone was moderately modified (Ecological Category C).

Overall, it is suggested that the REC be maintained as the PES (category C)(Table 69). This can be achieved should the proposed mitigation measures/recommendations (water quality) be assessed and applied.

Table 69: Overall assessment for UO_EWR06_I – Upper Riet River

River	Upper Riet River
EWR Site Code	UO_EWR06_I
Driver Component	PES
Hydrology (HAI)	C
Geomorphology (GAI)	C
Response Components	PES
Diatoms	D
Fish (FRAI)	C
Macroinvertebrates (MIRAI)	C
Riparian Vegetation (VEGRAI)	C

River	Upper Riet River
EcoStatus	C
Ecological Importance (EI)	High
Ecological Sensitivity (ES)	Moderate
Recommended Ecological Category (REC)	C

The EWR for the Upper Riet River was determined for a REC of a C and the HFSR approach was used to determine the EWRs. It should be noted that the Upper Riet River was naturally a seasonal system. However, due to increased return flows from extensive irrigation and other discharges in the upper catchment, the system became more perennial with higher drought and baseflows (no zero flows presently) with changes to the water quality. Thus, the requirements specified for the system is based on the new established perennial characteristics of the river. The indicator taxa for macroinvertebrates and fish selected for the Upper Riet were Hydropsychidae and *Labeobarbus aeneus* (large semi-rheophilic) due to the lack of true rheophilic species.

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 is Hydropsychidae, being a flow dependent taxon. They have a high preference for fast currents of >0.6 m/s, although optimal speeds are approximately 0.4 m/s, along cobble substrate. Their greatest response to water depth is between 15 cm and 40 cm (Thirion, 2016), which forms part of their critical habitat, and which can be assessed on the HabFlo. Thus, the macroinvertebrate habitat availability assessed as critical habitat will be the FCS and VFCS. The Hydropsychidae family further tolerate a wide fluctuation in water quality.

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, and with water column and emergent vegetation providing the primary cover features. Due to the lack of true rheophilic species, large semi-rheophilic (*Labeobarbus aeneus*) were selected to function 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. Consideration was nevertheless also given to juvenile and adult life stages in determining stressor responses.

Next, the optimum baseflows based on the 90th percentile for the wet and dry season were determined from the reference baseflows with July (0.000 m^3/s) and March (0.135 m^3/s) representing the dry and wet season. The 90th percentile for the present-day flows for July and March are 0.049 m^3/s and 0.190 m^3/s for July and March.

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats, and velocities. The selected stress values and associated flows are provided in Table 70 and the final integrated stress curve is shown in Figure 49**Error! Reference source not found.**.**Error! Reference source not found.**

Table 70: Selected stress values, flows and rationale for the Upper Riet, UO_EWR06_I

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	14.373		12.389	Greatest extent of critical habitat elements, i.e., fast-shallow and fast-intermediate classes for spawning and egg and embryo development. Slow deep habitat presents to allow for larval development. Slow-shallow class also present with emergent vegetation for support of other fish species.
1			10.2777	
2				
3	9.022	Critical habitat remains relatively healthy, although the VFCS habitat has reduced (19%), but the FCS has increased (30%), thus still enough critical habitat available. The average depth is 47cm and average flow of 0.5m/s, still within the preference range of the Hydropsychidae family.	3.985	Significant loss of extent of critical spawning habitat, with slow-deep and fast-deep classes still present in moderate abundances.
4				
5	2.555	Average depth of 41 cm and average velocity of 0.23 m/s along the cross-section, with the critical habitat (VFCS) drastically reduced to just 3%, although 20% of FCS habitat still available. Thus, this habitat is becoming limiting for the indicator taxon at this flow rate.	1.901	Critical flow-dependant habitat very reduced, but with slow-deep class still present to support juveniles and larger specimens. Loss of contact with vegetated island within central portion of channel and confinement to central channel expected.
6				
7	0.796	Very little critical habitat (7% and 1% of available VFC and VFCS habitats), with very low average velocities at 0.15 m/s. The	0.385	Loss of habitat for all life stages of *Labeobarbus aeneus*

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		Hydropsychidae will disappear, along with any other flow-sensitive taxa.		
8				
9	0.002	No flow. Macroinvertebrates diapause phase triggered.	0.01	Loss of habitat for all fish species
10	0		0	

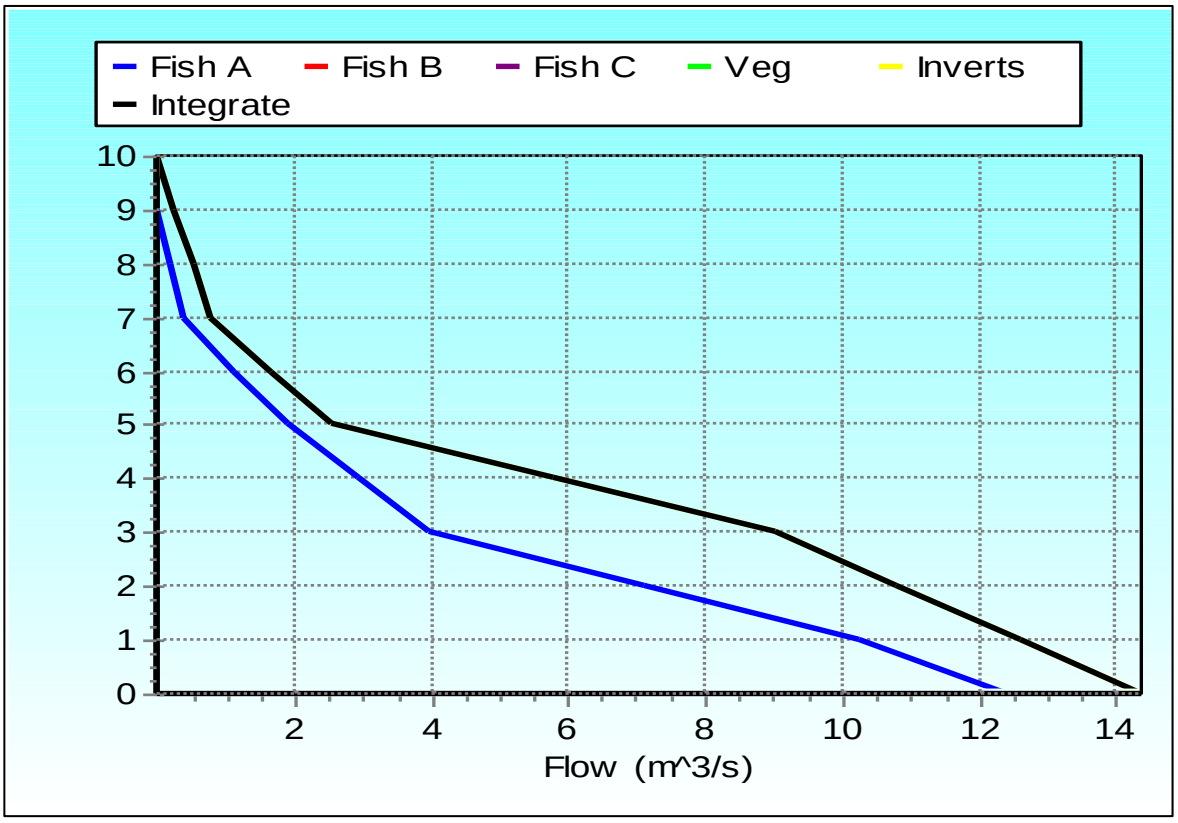


Figure 49: Final integrated stress curve for the Upper Riet River EWR site (UO_EWR06_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (March) and the final adjusted EWRs are shown in Figure 50. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality.

- Increase July maintenance low flows from 0.068 m^3/s to 0.096 m^3/s
- Increase March maintenance low flows from 0.428m^3/s to 0.743 m^3/s

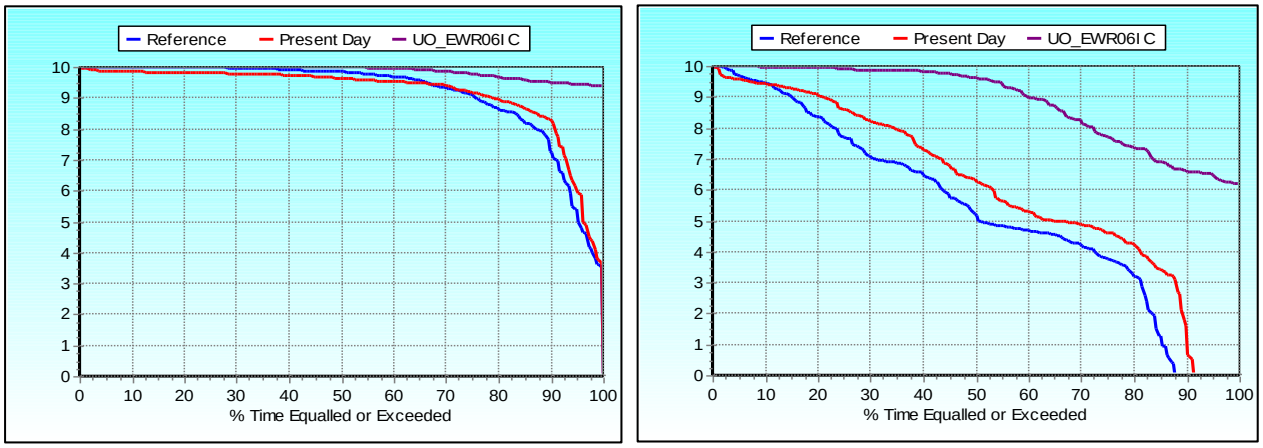


Figure 50: Final stress duration curves – Left: dry season (July) and Right: wet season (February) at UO_EWR06_I

The flood requirements for the Upper Riet EWR site were specified by the specialists and include small freshets to provide specific cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching). Larger floods specified for clearing of the river channel and mobilising the gravel substrate. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 71.

Table 71: Flood requirements for the Upper Riet at the EWR site (UO_EWR06_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	Final
Class 1 (5-15 m^3/s)	m3/s	12		5 to 10	14	15
	# days	5		5	3	5
	Months	Dec, Jan, Feb, Mar		Dec, Jan, Feb, Mar	Nov, Dec, Mar	Nov, Dec, Jan, Apr
	Type	Average		Average	Average	Average
Class 2 (20-30 m^3/s)	m3/s	20	29			25
	# days	3	3			3
	Months	Jan, Feb, Mar	Nov, Dec, Mar			Feb
	Type	Average	Average			Average
Class 3 (65 m^3/s)	m3/s		64			50
	# days		3			3
	Months		Apr, May			Mar

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geo-morphology	Final
	Type		Peak			Peak

* The 1:2, 1:5 and 1:10 year floods not modelled but important to include in any water resource developments

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 72.

Table 72: Upper Riet River - Summary of the EWR results (flows in million m^3 per annum)

Quaternary Catchment	C51F
Site name	UO_EWR06_I
River	Upper Riet
EWR Site Co-ordinates	-29.534787; 25.524496
Recommended Ecological Category	C
nMAR at EWR site	105.2
Total EWR	32.671 (31.05 %MAR)
Maintenance Low flows	8.721 (8.29 %MAR)
Drought Low flows	0.078 (0.07 %MAR)
Maintenance High flows	23.950 (22.76 %MAR)
Overall confidence	Moderate to high

4.10.2. UO_EWR09_I: Lower Riet River

The selected site is located downstream of the Modder River confluence and the small farming town of Modder Rvier (Figure 51). The assessment used Hydraulic data from Vaal comprehensive study (Vaal_EWR19) and biological data from JBS2, JBS3 ORASECOM site OSAEH 29_5 (ORASECOM, 2023a) and DWS REMP site C5RIET-DEKRA.

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,**	D
Geomorphological zone	E (0.002; Lower foothills)	**EI**	Very High

		ES	**High**
Components sampled: Hydraulic data from Vaal comprehensive study (Vaal_EWR19) and biological data from JBS2, JBS3 ORASECOM site OSAEH 29_5 (ORASECOM, 2023a) and DWS REMP site C5RIET-DEKRA			

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.

The site lies along a confined reach of the Riet system and is largely controlled by bedrock. The channel is straight to wandering with localised anastomosing sections. Sand bars are present along the pools, and inset benches and flood features are narrow with no flood plain. The bedrock forms steeper riffles and rapids interspersed by long pools. Boulders, cobble and gravel are present along the riffles and rapids, with fine sediment or bedrock dominating the pools.

Figure 52 shows the site conditions.

The river is approximately 40 to 50 meters wide with turbid waters. The stream bed is dominated by bedrock, with some GSM. The riverbanks are dominated by phragmites, potentially due to the lack of regular scouring from flood events, Salix is also present on the banks.Impacts at the site include:

- Upstream settlements
- Agriculture
- Cattle activity
- Irrigation, and
- Large dams and numerous abstraction weirs.

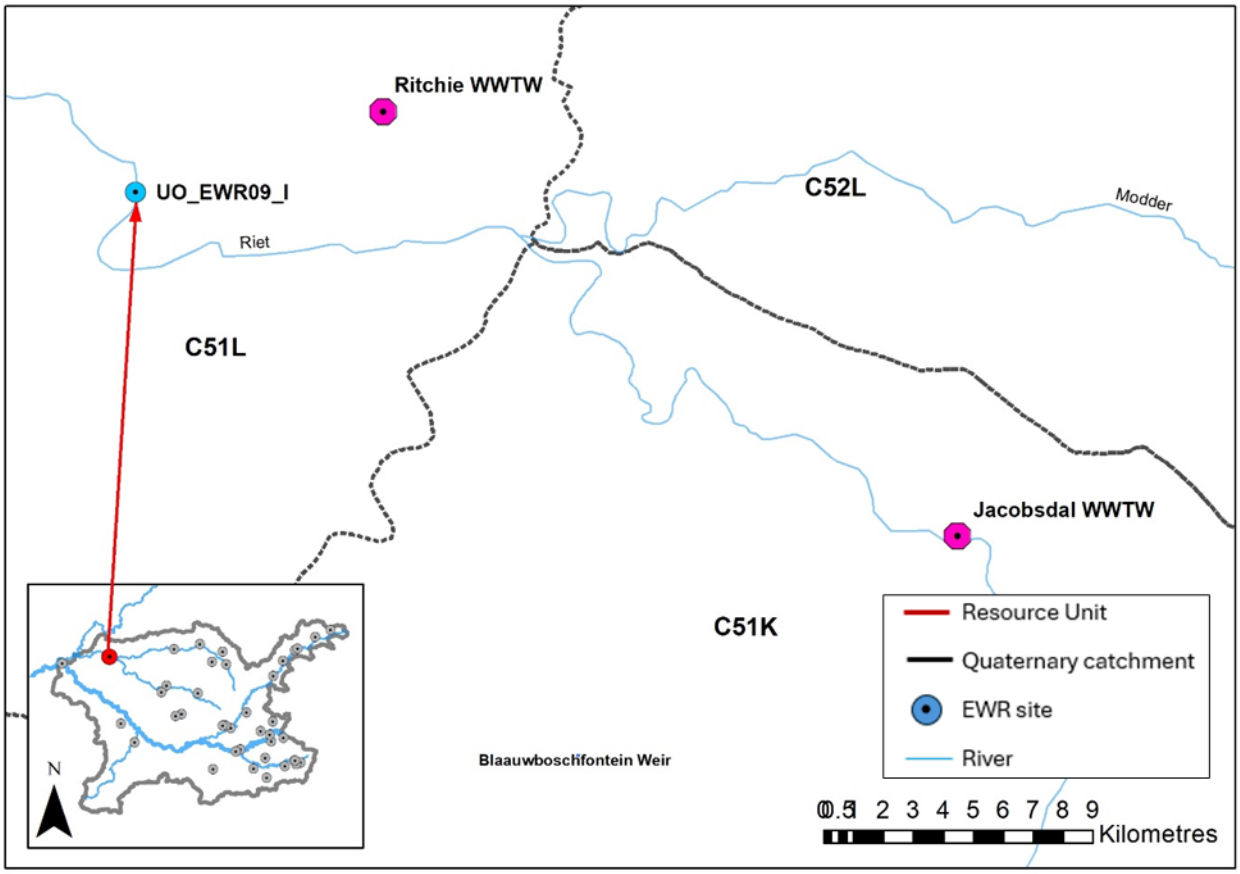


Figure 51: UO_EWR09_I site locality in C51L

Figure 52: UO_EWR09_I Site photographs of the Lower Riet EWR site

Summary results for UO_EWR09_I (DWS, 2023)

WATER QUALITY AND FLOW	
Parameter	(In situ water quality (data obtained from JBS3, October 2021, site OSAEH 29_5) (ORASECOM, 2023a)
pH	8.8
Electrical Conductivity (mS/m)	32.1
Total Dissolved Solids (mg/l)	112
Dissolved Oxygen (mg/l)	10.1
Clarity (cm)	12
Temperature (°C)	20.5

A description of the reference conditions and present ecological state for the fish, macroinvertebrates, riparian vegetation, hydrology, geomorphology and physico-chemical components are provided in Table 73.

Table 73: Reference Conditions for UO_EWR09_I

Component	Description of Reference Conditions
Fish	*Austroglanis sclateri, Enteromius oraniensis, Enteromius paludinosus, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis* and *Labeo umbratus*
Macroinvertebrates	Reference conditions used from DWS REMP (C5RIET-DEKRA): 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
Geomorphology	The reference condition for the reach is likely to be a lower gradient mixed bed alluvial channel with sand and gravel dominating the bed with localised bedrock forming the channel boundary. The reach type would mainly be pool-riffle or pool-rapid with sand bars forming in pools. Pools are likely to be longer than riffle and rapid sections. A narrow floodplain can be present where the valley floor is wider.
Hydrology	Natural flows available for the period 1920-2004.
Physico-chemical	Historical Physical-chemical data obtained for the site indicated high salt concentrations, which has been linked to irrigation return flows from the Riet River Irrigation Scheme and has been raised as an issue in the system. The reference condition was therefore determined from the diatom data. The

Component	Description of Reference Conditions
	diatom data indicated elevated electrolyte concentrations and turbidity. Lower electrolyte concentrations are expected to have been prevalent at the site under reference conditions.

The PES per component as derived from the various models as well as the EcoStatus are provided in Table 74.

Table 74: PES per component for UO_EWR09_I and EcoStatus (DWS, 2023)

Component	PES category & score	Flow/ non-flow	Explanation
Fish*	C	NF	• Decreased substrate quality and sedimentation • Increased turbidity • Decreased species diversity and abundance • Reduced baseflows
Macroinvertebrates*	C	NF	• Water quality (nutrient enrichment from upstream agriculture and town)
Riparian vegetation (VEGRAI)*	B	NF	• Vegetation removal • Water quantity (abstraction for irrigation and small impoundments upstream of the site)
Geomorphology	C (67%)	32 % flow related	• 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.
Hydrology	C (64.2%)	F	• Both freshets and flood components severely impacted by upstream dams.
Physico-chemical (Diatoms)*	C	NF	• Present Physical-chemical condition was estimated as of the RQS data ending in 2018, which did not reflect the current conditions at the site. • The diatom results indicated 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 the Riet River Irrigation Scheme.
ECOSTATUS*	C		

*Refer to Appendix A of Report number RDM/WMA13/00/CON/COMP/1123 for the Habitat Integrity assessment scores for the riparian and instream zone, and Refer to Appendix C for the fish and aquatic macroinvertebrate inventories; *Results used and interpreted from JBS3 (ORASECOM, 2023a)*

The trends in ecological status give an idea on whether the present state is realistic and would stay the same if the management of the catchment were to continue in the same way that gave rise to the present state. The definition of the trend is "…viewed as a directional change in the

attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux", Kleynhans and Louw (2007). The ecological trends for UO_EWR09_I are presented in Table 75.

Table 75: Ecological trends for UO_EWR09_I (includes components that were assessed)

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish*	Unclear	Due to the high flows at the time of the JBS3 assessment, it was difficult to determine trends with previous results. It was however likely that the trend will reflect a stable trajectory through assessing the REMP results for C5RIET-DEKRA which has been a C Category since 2018.	2
Macroinvertebrates*	Stable		2
Habitat integrity: Instream	-	-	-
Habitat integrity: Riparian	-	-	-
Hydrology	Stable	No recent water resource developments	3
Geomorphology	Stable	Drivers were altered several decades ago, so the system has formed a new equilibrium. Disturbance along the reach is minimal due to the protected area with low game densities.	3
ECOSTATUS*	Stable		

** 0 – no confidence to 5 – high confidence*

The overall EcoStatus for this EWR site was categorised as a C, thus the system being in a moderately modified condition (Table 76). There is degradation in the catchment due to grazing, changes in hillslope-channel connectivity and cropping elevating fine sediment loadings and siltation of coarser habitats. The dams and weirs along the Modder and Riet Rivers trap bedload sediment, reducing coarser habitat extent for the reach. Disturbance along the banks and channel margins are localised due to the protected area. From a biological perspective, the fish and macroinvertebrate communities represent moderately modified conditions (category C), while the riparian vegetation component continues to be largely natural with few modifications, most from a water quality perspective and vegetation removal from cattle trampling.

It is suggested that a REC of a B/C (close to largely natural most of the time) can be achieved, although the upstream dams that are used mainly for irrigation will impact this. should the proposed mitigation measures/recommendations be assessed and applied (Table 76). Not with, but we can test during trade-offs.

Table 76: Overall assessment for UO_EWR09_I – Lower Riet

River	Lower Riet
EWR Site Code	UO_EWR09_I
Driver Component	PES
Hydrology (HAI)	C
Geomorphology (GAI)	C
Response Components	PES
Diatoms	C
Fish (FRAI)	C
Macroinvertebrates (MIRAI)	C
Riparian Vegetation (VEGRAI)	B
EcoStatus	C
Ecological Importance (EI)	Very High
Ecological Sensitivity (ES)	High
Recommended Ecological Category (REC)	B/C

This EWR site was assessed on a comprehensive level during the Comprehensive Reserve study (DWA, 2010). The PES and REC were determined as a D category. The HFSR approach was used to determine the EWR, with high confidence in the results.

The JBS2 (2015) and JBS3 (2021) results at site OSAEH 29_5 determined the PES as a C category, thus an improvement in the system from the 2010 study (PES = D) with the PES a B/C and C respectively. The results from the 2021 JBS3 study, together with the EWR results from the Reserve study in 2010 were used to determine the EWR for the current assessment. As the site is located within the Mokala Nature Reserve and thus requiring attention to the conservation/ environmental needs and further which forms part of a recreational fishing area (Largemouth Yellow fish), the REC was set at a B/C.

However, it must be noted that the water quality is compromised due to WWTW releases (from upper catchment) and extensive irrigation. Thus, if not managed, the REC of a B/C will likely not be attainable, despite the JBS2 and JBS3 EcoStatus results indicating the system in a B/C to C category.

It is recommended that the 2010 EWR for a D category, together with the floods as specified during the study (Table 77) is implemented as an absolute minimum. Continuous REMP monitoring of both fish and macroinvertebrates and interpretation of the results are recommended at this site to identify any negative trend to be addressed and modified timeously.

Table 77: Flood requirements for the Upper Orange at the EWR site (UO_EWR09_I)

Floods		FINAL
Class 1	m^3/s	4
	# days	4
	Months	Nov, Dec, Jan, Feb, Mar, Apr
	Type	Average
Class 2	m^3/s	25
	Number of days	7
	Months	Nov, Dec, Jan, Feb, Mar
	Type	Average

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 78.

Table 78: Lower Riet - Summary of the EWR results (flows in million m^3 per annum)

Quaternary Catchment	C51L
Site name	UO_EWR09_I
River	Lower Riet River
EWR Site Co-ordinates	-29.026963; 24.512919
Recommended Ecological Category	D (from DWA, 2010)*
nMAR at EWR site	373.8
Total EWR	89.974 (24.07 %MAR)
Maintenance Low flows	54.274 (14.52 %MAR)
Drought Low flows	0.544 (0.15 %MAR)
Maintenance High flows	35.700 (9.55 %MAR)
Overall confidence	High

4.10.3. UO_EWR26_FV (Lower Riet)

Diatom and physico-chemical water quality samples were collected at this site during the survey conducted in October 2024, with the aim to gain further information related to water quality for this reach.

River	Lower Riet	**Altitude (m.a.s.l.)**	995
Latitude	-29.005676°	**Longitude**	23.942121°
Level 1 EcoRegion	Southern Kalahari	**Quaternary catchment-SQ Reach**	C51M-03519
Level 2 EcoRegion	29.02	**DWS, 2014 PES,**	D (from DWA 2013)
Geomorphological zone	E (0.002; Lower foothills)	**EI**	High
		ES	**High**

Water quality and diatom results

Laboratory water quality results for samples taken from the Lower Riet River are set out in Table 80 and ecological descriptors for the sites based on the diatom community are set out in Table 80.

Table 79: Water quality results for samples collected from the Lower Riet River at UO_EWR26_FV

Variables measured		Units	Results
Physico-chemical	pH	pH units	8.32
	Electrical Conductivity	mS/m	126.3
	Total Dissolved Solids	mg/l	772
	Dissolved Oxygen	mg O_2/l	9
	Total Suspended Solids	mg/l	16
	Total Alkalinity as $CaCO_3$	mg/l	212
	Sodium Absorption ratio (SAR)	ratio	3.27
Major Ions	Calcium (Ca)	mg/l	57.4
	Magnesium (Mg)	mg/l	49
	Sodium (Na)	mg/l	140
	Chloride (Cl)	mg/l	170
	Potassium (K)	mg/l	3.1
	Sulphate (SO_4)	mg/l	169.5
	Fluoride (F)	mg/l	0.15
Metals	Aluminium(Al)	mg/l	0.01
	Iron (Fe)	mg/l	0.01
	Manganese (Mn)	mg/l	0.001
Nutrients	Nitrate as N (NO_3-N)	mg/l	0.09

Variables measured		Units	Results
	Orthophosphate as (PO_4)	mg/l	0.015
	Ammonia as N (NH_3-N)	mg/l	0.13

Table 80: Ecological Classification for Water Quality: ecological descriptors based on the diatom community (Van Dam et al., 1994 and Taylor et al., 2007)

pH	Salinity	Organic Nitrogen uptake	Oxygen levels	Trophic State
Alkaline	Fresh brackish	N-Autotrophic tolerant indicating tolerance for high concentrations of organically bound nitrogen	High (.75% saturation)	Mesotrophic

The Specific Pollution Sensitivity Index (SPI) was used in this diatom assessment and is an inclusive index, taking factors such as salinity, eutrophication and organic pollution into account (CEMAGREF, 1982). This index comprises 2035 taxa (Taylor, 2004). It is recognised as the broadest species based of any index currently in use and has been adapted to include taxa endemic to and commonly found in South Africa, therefore, increasing the accuracy of diatom-based water quality assessments. This is known as the South African Diatom Index (SADI) (Harding and Taylor, 2011). The limit values and associated ecological water quality classes adapted from Eloranta & Soininen (2002) were used for interpretation of the SPI scores. The SPI index is based on a score between 0 – 20, where a score of 20 indicates no pollution and a score of zero indicates an increasing level of pollution or eutrophication.

The percentage Pollution Tolerant Valves (%PTV) is part of the UK Trophic Diatom Index (TDI) (Kelly & Whitton, 1995) and was developed for monitoring organic pollution (sewage outfall-orthophosphate-phosphorus concentrations), and not general stream quality. The %PTV has a maximum score of 100, where a score above 0 indicates no organic pollution and a score of 100 indicates definite and severe organic pollution. The presence of more than 20% PTVs shows organic impact. All calculations were computed using OMNIDIA ver. 4.2 programme (Lecointe et al., 1993).

Table 81 shows the SPI for the Lower Riet River as 9.8, indicating an ecological category B, Good quality, and a %PTV 9.8, which indicates that the site is free from organic pollution.

Table 81: Diatom index scores for the study sites indicating the ecological water quality for the October

Site	%PTV	SPI	Ecological Category (EC)	Class
Riet River	9.8	13.9	B	Good

5 VAAL CATCHMENT AREA CONTRIBUTION TO UPPER ORANGE CATCHMENT

5.1. UO_EWR27_FV (Vaal River)

Although this site is in the Vaal catchment area, the water quality data will be valuable for understanding the inflows into the Upper Orange Catchment area from the Vaal River. Thus, a diatom and physico-chemical water quality sample was collected at this site during the survey conducted in October 2024.

River	Lower Riet	**Altitude (m.a.s.l.)**	980m
Latitude	-29.051455°	**Longitude**	23.766012°
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment-SQ Reach**	C92C-03366
Level 2 EcoRegion	26.01	**DWS, 2014 PES,**	D
Geomorphological zone	E (0.002; Lower foothills)	**EI**	Moderate
		ES	High

Water quality and diatom results

Laboratory water quality results for samples taken from the Vaal River at Douglas are set out in Table 82 and ecological descriptors for the sites based on the diatom community are set out in Table 83.

Table 82: Water quality results for samples collected from the Lower Vaal River, UO_EWR27_FV

Variables measured		Units	Results
Physico-chemical	pH	pH units	8.16
	Electrical Conductivity	mS/m	86.2
	Total Dissolved Solids	mg/l	536
	Dissolved Oxygen	mg O_2/l	10
	Total Suspended Solids	mg/l	12

Variables measured		Units	Results
	Total Alkalinity as $CaCO_3$	mg/l	172
	Sodium Absorption ratio (SAR)	ratio	2.19
Major Ions	Calcium (Ca)	mg/l	48.7
	Magnesium (Mg)	mg/l	35
	Sodium (Na)	mg/l	83
	Chloride (Cl)	mg/l	99
	Potassium (K)	mg/l	4.6
	Sulphate (SO_4)	mg/l	119.5
	Fluoride (F)	mg/l	0.15
Metals	Aluminium(Al)	mg/l	0.01
	Iron (Fe)	mg/l	0.01
	Manganese (Mn)	mg/l	0.001
Nutrients	Nitrate as N (NO_3-N)	mg/l	0.18
	Orthophosphate as (PO_4)	mg/l	0.015
	Ammonia as N (NH_3-N)	mg/l	0.05

Table 83: Ecological Classification for Water Quality: ecological descriptors based on the diatom community (Van Dam et al., 1994 and Taylor et al., 2007)

pH	Salinity	Organic Nitrogen uptake	Oxygen levels	Trophic State
Circumneutral	Fresh brackish	N-Autotrophic tolerant indicating tolerance for high concentrations of organically bound nitrogen	High (.75% saturation)	Eutrophic

Table 84 shows the SPI for the Vaal River at Douglas as 12.8, indicating an ecological category C, moderate quality, and a %PTV 9, which indicates that the site is free from organic pollution.

Table 84: Diatom index scores for the study sites indicating the ecological water quality for the October

Site	%PTV	SPI	Ecological Category (EC)	Class
Vaal River	9	12.8	C	Moderate

6 CONCLUSIONS

This report relates to the quantification of ecological water requirements (EWR) and describes the approaches, methods and models used to determine the EWR for priority rivers in the Upper Orange River catchment, at selected sites. These determinations are on the various levels of detail as described in volume 3 of the RDM methodology of 1999 (DWAF, 1999). Where available and applicable, information from the recently completed Reserve study (DWS, 2023) have been used and updated with new information from field surveys undertaken In October 2024.

The Ecological Water Requirements sites (EWR) comprised the following, however these sites were assessed for their importance and prioritised in respect of the requirements for scenario analysis in the next step of the classification process:

- 10 Intermediate sites
- 6 Rapid III sites,
- 25 Field verification sites, and
- Recommendations for the Flow Management Plan for the reach between Gariep and Vanderkloof dams have also been included.

Table 85 summarises the overall EWR results per site that has been selected, including the site coordinates and PES.

It is noted that at the site related to the Flow Management Plan, because of the highly variable flows at this site from hydropower and other releases from Gariep Dam, no formal EWR was determined. However, to provide some information for the FMP, the following should be considered and implemented in the short term:

i. A minimum flow of 40 m^3/s for any given month as this flow will still provide adequate habitats for the biota;

ii. Additional to the daily releases, the following freshets are also important:
    - November to January – 270 m^3/s over 6 days
    - February – 350 m^3/s over 3 days

iii. Releases from Gariep Dam to supplement Vanderkloof Dam in late winter to early spring should coincide with the seasonal rainfall pattern, thus a later start to the release to match the late spring natural cues for fish and cleaning of habitats.

Table 85: Summary of PES, REC and EWR per site

IUA	Quaternary Catchment	Site name	River	EWR Site Co-ordinates	PES	REC	nMAR at EWR site	Total EWR	Maintenance Low flows	Drought Low flows	Maintenance High flows	Overall confidence
1	**D21D**	UO_EWR01_R	Little Caledon	-28.557796; 28.405709	C	B/C	25.9	10.154 (39.20 %MAR)	5.981 (23.09 %MAR)	1.919 (7.41 %MAR)	4.173 (16.11 %MAR)	Moderate
2	**D22D**	UO_EWR01_I	Middle Caledon	-28.9092102; 27.784924	D/E	D	674	156.076 (23.16 %MAR)	79.548 (11.80 %MAR)	25.394 (3.77 %MAR)	76.529 (11.35 %MAR)	Moderate
3	**D24G**	UO_EWR04_I	Lower Caledon	-30.280115; 26.653060	D	C/D	1 353.6	398.387 (29.43 %MAR)	203.857 (15.06 %MAR)	36.860 (2.72 %MAR)	194.530 (14.37 %MAR)	Moderate to high
4	**D13M**	UO_EWR08_I	Lower Kraai	-30.69007; 26.74157	C	B/C	719	334.513 (46.52 %MAR)	200.869 (27.94 %MAR)	40.997 (5.70 %MAR)	133.644 (18.59 %MAR)	Moderate to high
5	**D12F**	UO_EWR03_I	Upper Orange	-30.652889; 26.823049	D	D	4 259.5	1067.450 (25.06 %MAR)	554.061 (13.01 %MAR)	206.669 (4.85 %MAR)	513.389 (12.05 %MAR)	Moderate
6	D34E	FMP site*	Orange	-30.503677; 25.200574	D	-	-	-	-	-	-	-
7	**D32J**	UO_EWR05_I	Seekoei	-30.533901; 24.962537	C	C	24.28	8.301 (34.19 %MAR)	1.043 (4.30 %MAR)	0.000 (0.00 %MAR)	7.258 (29.89 %MAR)	Moderate to high
8	**D33K**	UO_EWR10_I	Lower Orange	-29.144855; 23.691404	C	C	6 674.20	1684.770 (25.24 %MAR)	1341.744 (20.10 %MAR)	405.864 (6.08 %MAR)	343.025 (5.14 %MAR)	Moderate
9	**C52B**	UO_EWR07_I	Upper Modder River	-29.160017; 26.572492	D	C	61	21.909 (35.94 %MAR)	9.156 (15.02 %MAR)	2.313 (3.79 %MAR)	12.753 (20.92 %MAR)	Moderate
10	**C51F**	UO_EWR06_I	Upper Riet	-29.534787; 25.524496	C	C	105.2	32.671 (31.05 %MAR)	8.721 (8.29 %MAR)	0.078 (0.07 %MAR)	23.950 (22.76 %MAR)	Moderate to high
	C51L	UO_EWR09_I	Lower Riet River	-29.026963; 24.512919	C	B/C	373.8	89.974 (24.07 %MAR)	54.274 (14.52 %MAR)	0.544 (0.15 %MAR)	35.700 (9.55 %MAR)	High

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APPENDIX A: Results of the assessment of UO_EWR10_I: Marksdrift in October 2024

UO_EWR10_I: MARKSDRIFT (OCTOBER 2024)

Site Evaluation			
Component	**Confidence Score***	**Advantages**	**Disadvantages**
Fish	3	• Potential habitat related to riffle/rapid	• Sedimentation • Loss of habitat for in-stream species • Loss of riparian/overhanging and instream habitat
Macro-invertebrates	5	• Pockets of Stones-in-Current (SIC), Stones-out-of-current (SOOC), although mostly boulders; and • Diversity of flow regimes.	• Wide homogenous channel. • Limited aquatic biotopes – dominated by a muddy substrate and boulders; • Limited marginal vegetation – bare banks; and • High sediment deposition.

** Confidence scores: 0 = no confidence; 5 = high confidence*

Information Availability		
Component	**Information availability***	**Description of information**

Fish	5	• FROC (Kleynhans et al., 2007);
		• Updated PESEIS study (2024);
		• Collection records;
		• JBS3 ORASECOM site OSAEH 26_3 data; and
		• The High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange (UO Reserve), Report No's.:
		  • RDM/WMA13/00/CON/COMP/1223 (a)
		  • RDM/WMA13/00/CON/COMP/1223 (b)

Macro-invertebrates	5	• River Eco-status Monitoring Programme (REMP) river database (macroinvertebrate data) – 2023 hydrological year;
		• Updated PESEIS study (2024);
		• JBS3 ORASECOM site OSAEH 26_3; and
		• UO Reserve, Report No's.:
		  • RDM/WMA13/00/CON/COMP/1223 (a)
		  • RDM/WMA13/00/CON/COMP/1223 (b)

** 0 (no information) to 5 (large amount of data available)*

Reference Conditions	
Component	**Description of reference conditions**
Fish	*Austroglanis sclateri, Enteromius oraniensis, Enteromius paludinosus, Enteromius trimaculatus, Labeobarbus aeneus, Labeobarbus kimberleyensis, Clarias gariepinus, Labeo capensis, Labeo umbratus, Pseudocrenilabrus philander* and *Tilapia sparrmanii*
Macro-invertebrates	Porifera, Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Baetidae >2spp, Caenidae, Heptageniidae, Leptophlebiidae, Prosopistomatidae,

Reference Conditions	
Component	**Description of reference conditions**
	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, Tipulidae, Ancylidae, Lymnaeidae, Physidae, Thiaridae, Corbiculidae, Sphaeridae.

PES per component for EWR site and EcoStatus			
Component	**PES category & score**	**Flow/ non-flow**	**Explanation**
Fish	E (34.5)	F/NF	• Flow modification from upstream hydropower and irrigation related discharges • Water quality impairment and sedimentation • No substantial marginal vegetation • Migratory barriers (Marksdrift Weir).
Macro-invertebrates	C (76.10)	F/NF	• Flow modification from upstream hydropower discharges; • Habitat modification – the marginal vegetation is still recovering from the large floods that took place in 2022 and 2023, along with all the hydro-peaks (scouring and sediment deposition); and • Water quality impairment (extensive irrigation and return flows).

PES and causes	
Component	**Causes** **Present/Absent**
Fish	High flows limit sampling in channels and no sampling with other gear (e.g. cast nets) possible. Strong flows limited sampling with electro shocker and hand-held nets. No species sampled, however some were observed when dashing away in the strong current.

METRIC GROUP	WEIGHT (%)
VELOCITY-DEPTH	98.04
COVER	100.00
FLOW MODIFICATION	70.31
PHYSICO-CHEMICAL	71.07
MIGRATION	61.45

	IMPACT OF INTRODUCED	**38.04**

Macro- invertebrates

All biotopes were accessible for sampling, except for marginal vegetation, which remained limited. This limitation is still attributed to the major La Niña floods that took place in 2022 and 2023, and as such, the system continues to recover. The stone biotopes were primarily dominated by boulders, with some cobbles and gravel present in the interstitial zones. A few days prior to the survey, a small freshet was recorded at gauging station D3H012. This resulted in noticeable scouring of the stone biotopes and less embeddedness compared to previous observations at this EWR site. Despite this, a total of 19 taxa were recorded, most of which exhibited a preference for low to very low water quality, cobbles, and varying hydraulic conditions. The primary drivers of the macroinvertebrate community composition were water quality (71.2%) and habitat metrics (75.3%), largely due to the limited diversity of available biotopes. The scarcity of marginal vegetation eliminated many families that prefer this habitat, such as Dytiscidae, Nepidae, Pleidae, and Hydrophilidae. Flow modification, measured at 82.3%, was not a significant driver of the community structure (**Table 1**). Overall, the collected aquatic macroinvertebrate assemblage was representative of moderately modified conditions (Ecological Category C, 76.10%). This marks a notable improvement from previous surveys conducted for the Reserve determination study, which classified the macroinvertebrate community as seriously modified (Ecological Category D). The shift is primarily due to the above-mentioned impacts of the La Niña floods in 2022 and 2023, which caused extensive scouring of banks and habitats, reducing the diversity and abundance of expected macroinvertebrate families.

Table 1: Macroinvertebrate community Ecological Category based on weights of metric groups for UO_EWR10_I (Marksdrift)

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	82.3	*0.345*	28.382	1	100
HABITAT	H	75.3	*0.310*	23.376	3	90
WATER QUALITY	WQ	71.2	*0.328*	23.3119	2	95
CONNECTIVITY & SEASONALITY	CS	60.0	*0.017*	1.03448	4	5
						290
INVERTEBRATE EC				76.1044		
INVERTEBRATE EC CATEGORY				C		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						

Ecological trends for the EWR site (include components that were assessed)			
Component	**Trend (stable, decline, improvement)**	**Reason**	**Confidence (0-5)***
Fish	Decreasing	• Loss of habitat • Very limited marginal vegetation • Varied flows will impact on physiological processes e.g. spawning cycles • Impact on fry – limited habitat (vegetation) to grow and mature.	3
Macro-invertebrates	Stable, although slight improvement since 2022/2023 (**Figure A-1**)	• No new water resource impacts envisaged. • The system continues to be modified – continues to respond to deteriorating water quality (consistently the driver) • Prolonged flooding since end of 2021 have had an impact on the macroinvertebrate community and associated habitats (recovering)	3

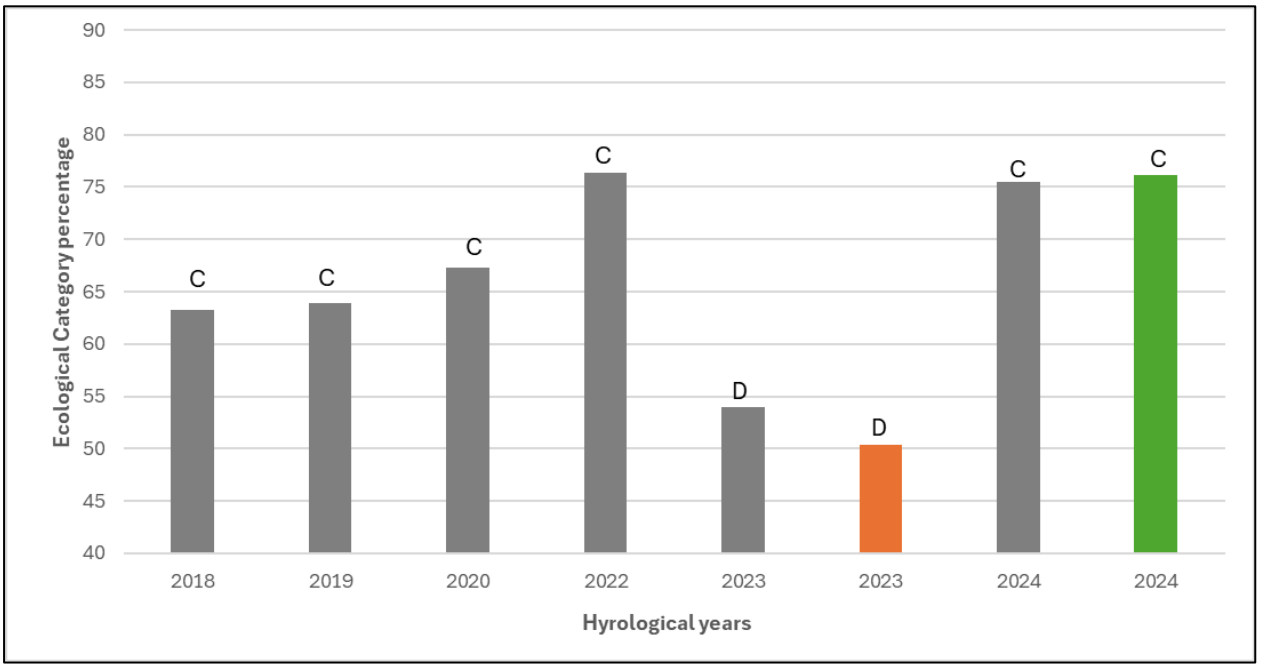

Figure A-1: Graph illustrating the Ecological Category percentage for REMP site D3ORAN-MARKS (grey), UO Reserve (orange) and this current Classification study's results (green)

APPENDIX B: 2D Visual Distribution of Biotic Habitat Classes for Recommended Freshets and Floods at UO_EWR10_I

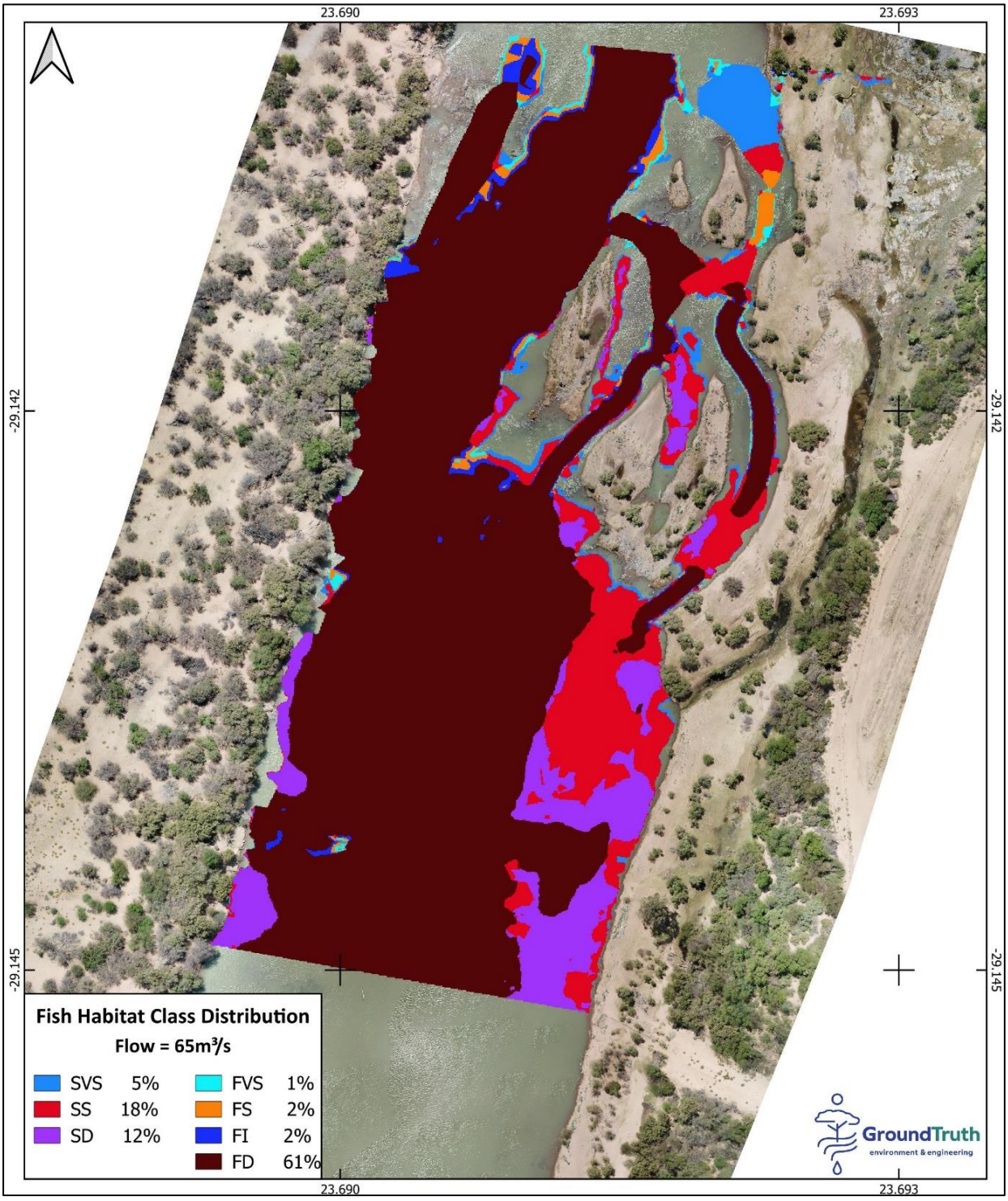

Figure B-1: Visual distribution of fish habitat classes for recommended freshets and floods (65m³/s) at UO_EWR10_I

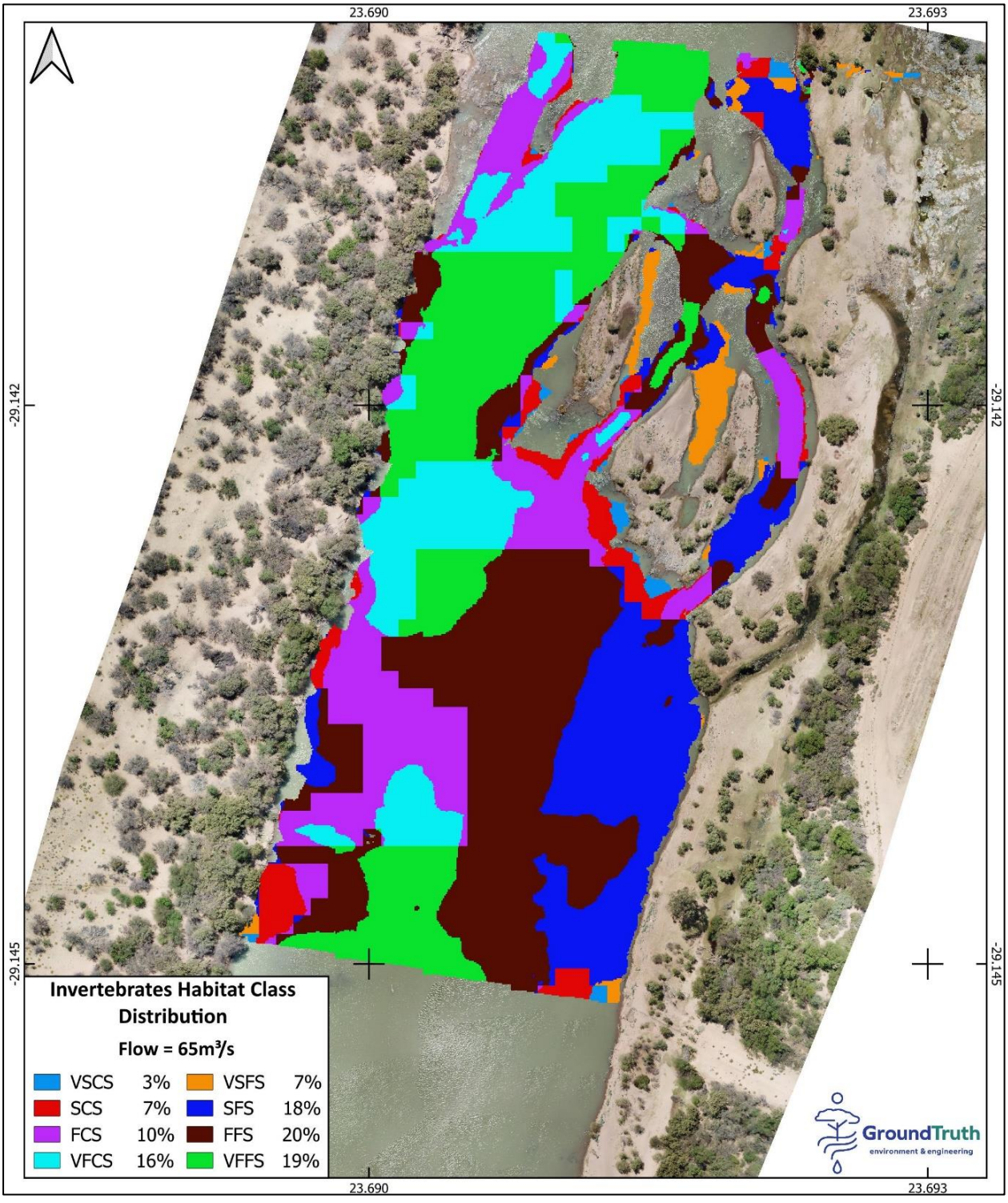

Figure B-2: Visual distribution of invertebrate habitat classes for recommended freshets and floods (65m³/s) at UO_EWR10_I

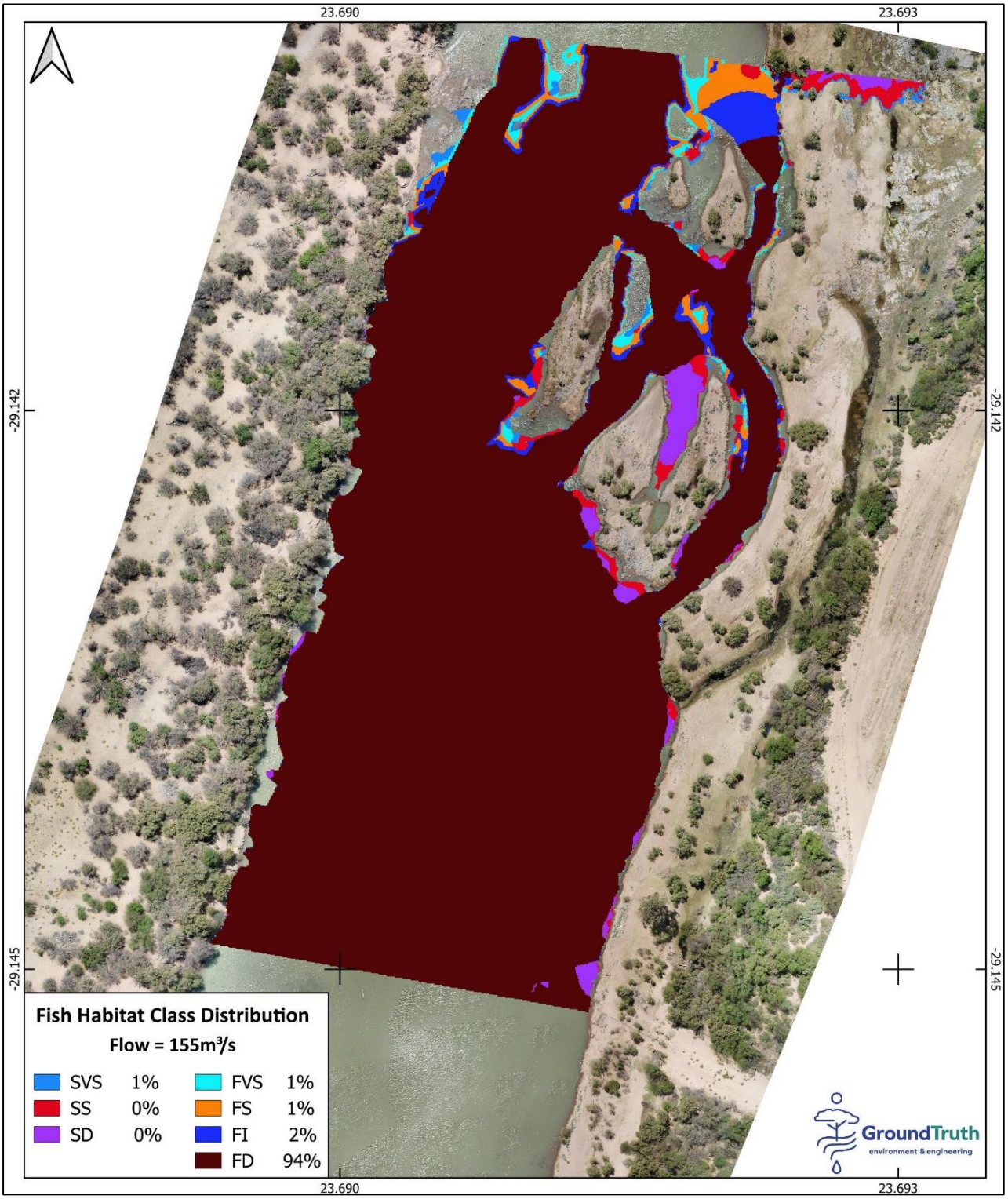

Figure B-3: Visual distribution of fish habitat classes for recommended freshets and floods (155m³/s) at UO_EWR10_I

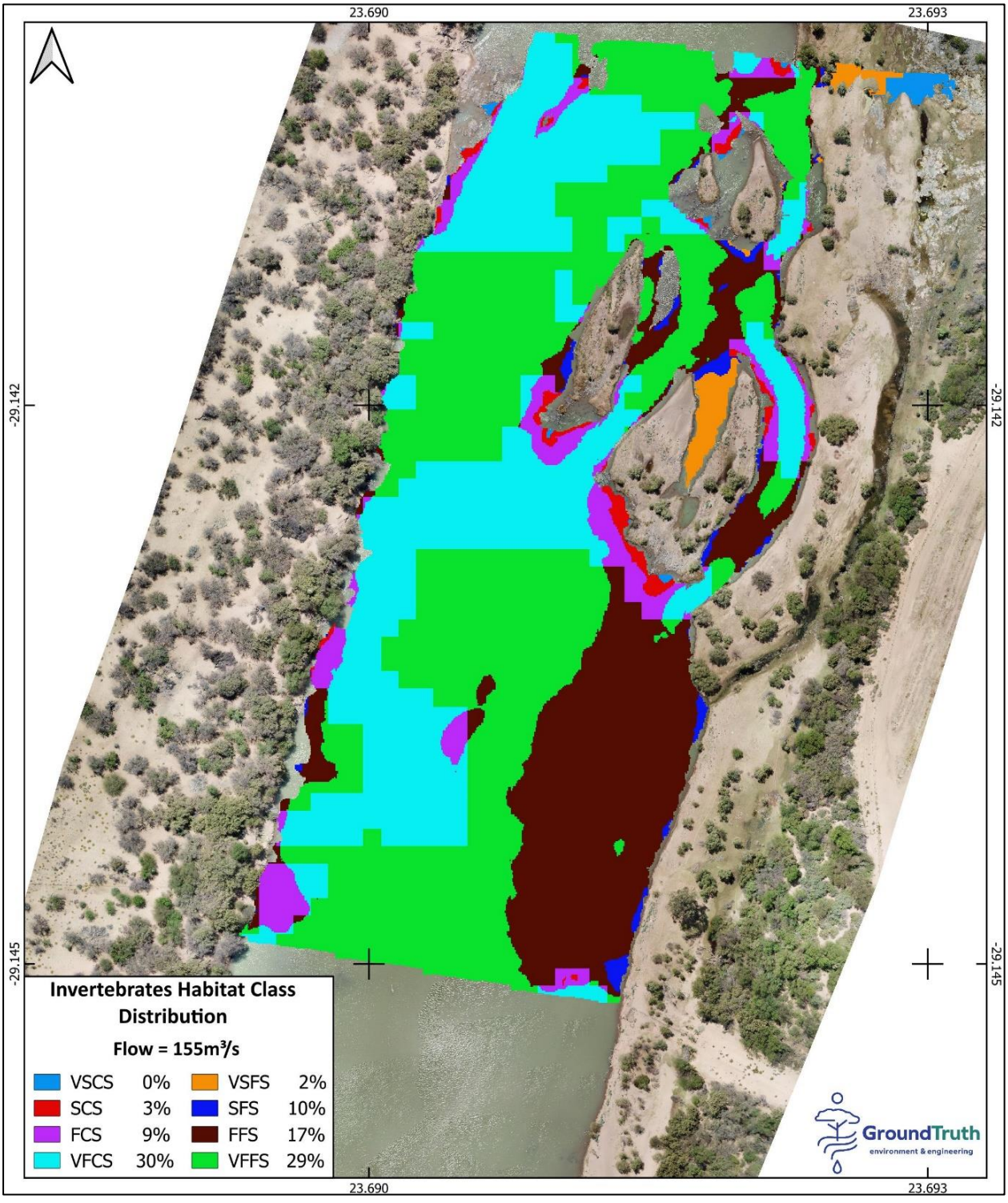

Figure B-4: Visual distribution of invertebrate habitat classes for recommended freshets and floods (155m³/s) at UO_EWR10_I

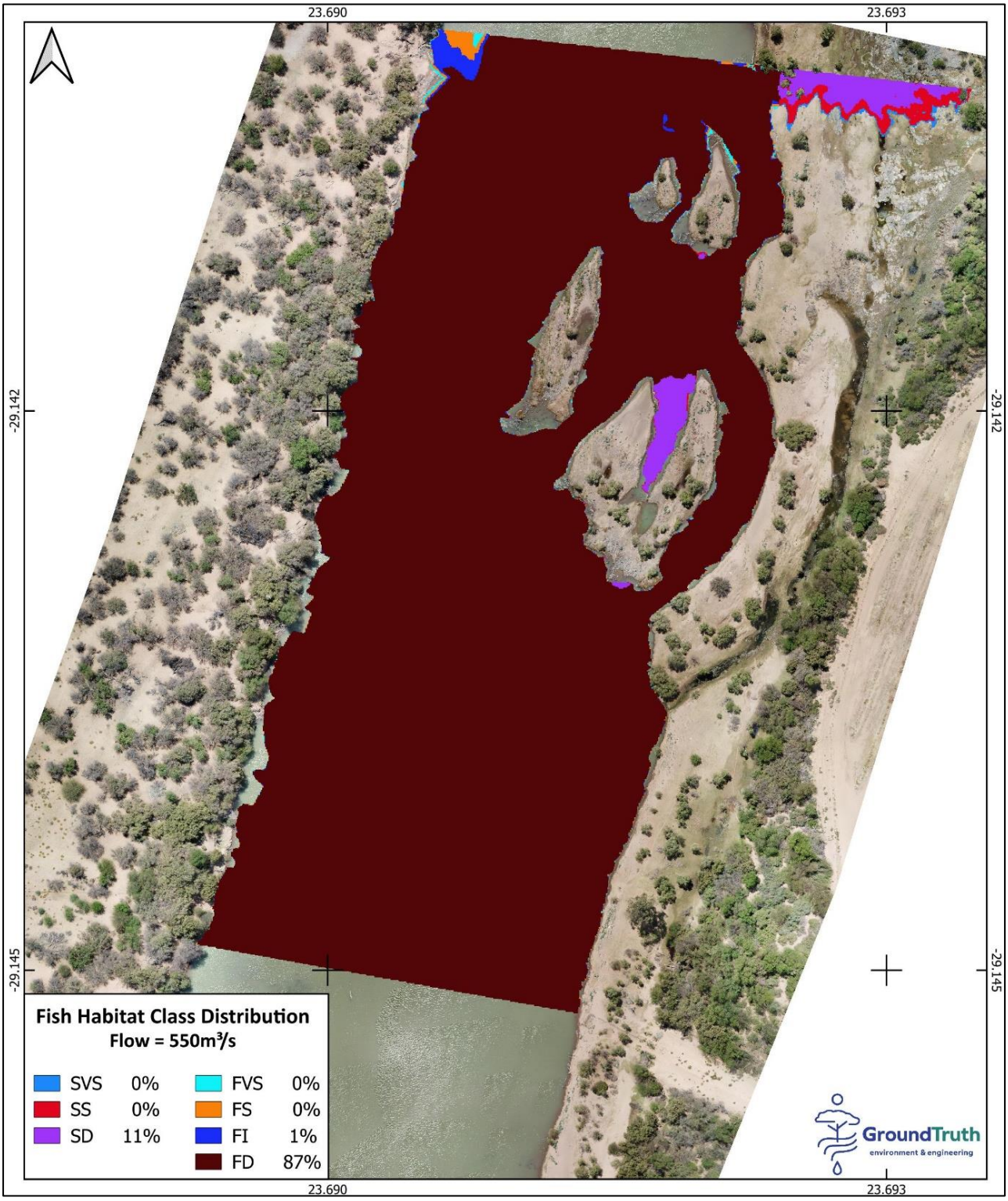

Figure B-5: Visual distribution of fish habitat classes for recommended freshets and floods (550m³/s) at UO_EWR10_I

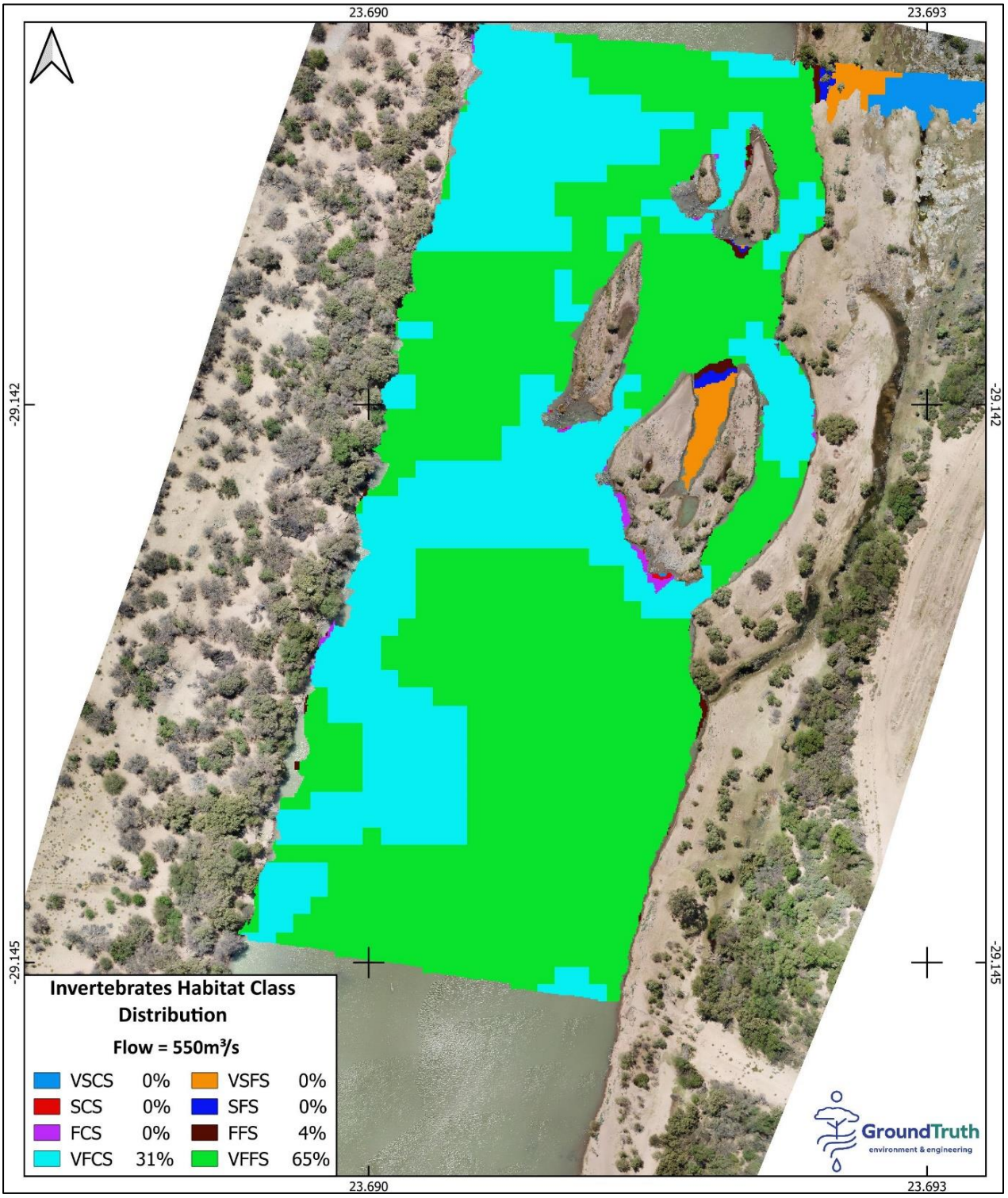

Figure B-6: Visual distribution of invertebrate habitat classes for recommended freshets and floods (550m³/s) at UO_EWR10_I

APPENDIX C: Water Quality Certificate for samples taken in October 2024

APPENDIX D: Diatom Report for samples taken in October 2024