DEPARTMENT OF WATER AND SANITATION

Chief Directorate: Water Ecosystems Management

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

ECOLOGICAL WATER REQUIREMENTS REPORT
WP 11438

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TERMINOLOGY AND ABREVIATIONS

Acronym	Description
ASPT	Average Score Per Taxon
CD: WEM	Chief Directorate: Water Ecosystems Management
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EBSA	Ecological or Biological Significant Marine Area
EC	Ecological Category
EFR	Ecological Flow Requirement
EFZ	Estuarine Functional Zone
EI	Ecological Importance
EIS	Ecological Importance and Sensitivity
ES	Ecological Sensitivity
EWR	Ecological Water Requirements
FRAI	Fish Response Assessment Index
FEPA	Freshwater Ecosystem Priority Areas
GRU	Groundwater Resource Unit
GSM	Gravel, Sand, Mud
IHAS	Integrated Habitat Assessment System (Version 7)
IUA	Integrated Unit of Analysis
MAR	Mean Annual Runoff
MIRAI	Macroinvertebrate Response Assessment Index
MPA	Marine Protected Area
NBA	National Biodiversity Assessment
NFEPA	National Freshwater Ecosystem Priority Areas
nMAR	Natural Mean Annual Runoff
NWA	National Water Act
ORASECOM	Orange River Senqu Commission
PAI	Physico-chemical Assessment Index

Acronym	Description
PES	Present Ecological Sate
QV	Quality/Sensitivity Value (aquatic macroinvertebrates)
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RDM	Resource Directed Measures
RQOs	Resource Quality Objectives
RUs	Resource Units
SASS	South African Scoring System
SIC	Stones-in-Current
SEZ	Socio-Economic Zones
SOOC	Stones-out-of-current
VEG	Vegetation
WMA	Water Management Area
WRCS	Water Resource Classification System

EXECUTIVE SUMMARY

The Chief Directorate: Water Ecosystems Management (WEM) of the Department of Water and Sanitation (DWS) is underway with a study to determine Water Resource Classes and associated Resource Quality Objectives (RQOs) in the Lower Orange River Catchment, as part of the protection framework defined in Chapter 3 of the National Water (NWA, Act No. 36 of 1998).

The main objective of the study is to coordinate the implementation of the water resources classification system (WRCS) in order to classify all significant water resources in the Lower Orange Catchment within the Vaal-Orange Water Management Area (WMA 4) and determine the associated RQOs for the prioritised units.

The Orange River is the primary river in the catchment and originates as the Senqu River in the Maluti Mountains in Lesotho, flowing 2200 km to discharge into the Atlantic Ocean on the western side of the catchment. The Lower Orange River originates at the confluence of the Upper Orange River and the Vaal River tributary, approximately 20km from Douglas. The major tributaries from the north include the Molopo, Kuruman and Nossob Rivers in Namibia, Botswana and the Northern Cape Province; and the Fish River draining the southern part of Namibia. Major tributaries to the Lower Orange River from the south draining the Karoo include the Ongers, Sak and Hartbees Rivers. The study area includes the lower D primary drainage region comprising of the secondary drainage regions D4 to D8. It comprises only the South African portion of the Lower Orange River Catchment and includes F10 to F50 tertiary catchments and quaternary catchment F60A.

The Lower Orange River discharges via the Orange River Estuary, a delta type river mouth which comprises a distributor channel system between sand banks covered with pioneer vegetation, a tidal basin and the saltmarsh on the south bank of the mouth. The Orange River Estuary lies along the town of Alexander Bay and is of national importance. The Lower Orange River catchment includes other smaller estuaries of importance which are the Buffels, Sout, Swartlintjies, Spoeg and Groen estuaries (in the F catchment). These estuaries are all classified as Arid Predominantly Closed estuaries.

Groundwater in the Lower Orange catchment occurs in a large range of aquifer systems varying from younger semi-consolidated (Cenozoic) sedimentary sequences, large spatial sequences of Karoo Supergroup (Paleozoic) and Nama Group (Namibian) sedimentary sequences that overly highly variable meta-sedimentary and metamorphic rocks towards the lower part of the Lower Orange River catchment. Aquifers within the study area include intergranular, fractured contact-zone, fractured hard rock, fractured and intergranular and karst aquifer systems. Dependance on groundwater in the catchment is high, with groundwater being the sole water source for most of tributary catchment areas.

Six wetland types have been identified in the Lower Orange Catchment. They include seeps, depressions (pans), unchanneled valley bottoms, channelled valley bottoms, floodplains and flats, which are associated with major rivers in the catchment (Orange, Hartbees, Sak, Molopo and Nossob). Wetland systems are associated with the Orange River mouth (which is a RAMSAR site).

To classify a water resource, the Water Resource Classification System (WRCS) lays out a set of procedures grouped together in seven steps that, when applied to a specific catchment, will result in the determination of a water resource class. The study is underway with Steps 3 of the process which requires the quantification of the Ecological Water Requirements (EWR) that is aimed to support the configuration of the ecologically sustainable base configuration scenario (Step 4), which serves as the key input into the scenario evaluation task (Task 5).

The Integrated Units of Analysis (IUAs) - the spatial units (sub-catchments) that define the network of significant water resources has been delineated for the Lower Orange River Catchment. A detailed status quo assessment that included a socio-economic analysis of the catchment has been undertaken to understand the current conditions. The IUAs are a combination of Socio-Economic Zones (SEZs) and watershed boundaries. The SEZs are areas defined by socio-economic characteristics such as population density, land use, economic activities, and resource dependency. The process also requires that IUAs include EWR sites, where applicable. Ten IUAs have been delineated for the Lower Orange catchment. The EWR sites serve as the key modelling points in the system presenting the ecological requirement per IUA.

The EWR is determined as part of the Reserve Determination Process and specifies the ecological flow requirement to protect the aquatic system (habitat and biota) and maintain its integrity. The EWRs of the Reserve forms a basis to the water resource classification process by ensuring that the ecological requirements of the significant water resources are accounted for in the analysis. In addition, they define the quantity component of the resource quality objectives.

As the Reserve has been determined for the Lower Orange catchment, this ‘Quantification of Ecological Water Requirements (EWR) Report’ describes the approaches, methods and models used to review and confirm the EWRs for the Orange River in the catchment (as the only perennial river) at selected sites. The applicable, information from the previous Reserve studies were utilised and updated with new information from the Rapid III field survey undertaken at two sites during September-October 2024. These determinations are on the various levels of detail as described in volume 3 of the RDM methodology of 1999 (DWAF, 1999).

Location of Ecological Water Requirements Sites

In the Lower Orange catchment, an intermediate Environmental Flow Requirements (EFR) study was undertaken for ORASECOM in 2010 and included three sites on the lower Orange River at Boegoeberg (EFR 02), Augrabies (EFR O3) and Vioolsdrift (EFR O4). A Reserve Determination study undertaken for DWS for the Lower Orange River catchment in 2016 based on the 2013 used the same sites and included an additional site on the Lower Orange at Sendelingsdrift (EFR O5). No sites were selected on the main tributaries (Sak, Hartbees, Ongers) presumably due to the arid nature of these rivers. The EWRs were only determined for the main Orange River within the study area and the Orange River Estuary.

The river EWR sites are set out in Table E1. As part of the recent high confidence Reserve study that has been finalised for the Upper Orange River catchment (2024), a site was selected at Marksdrift just upstream of the Upper Orange River and Vaal River confluence at

Douglas. This site requirement will be considered in term of the inflow into IUA 1 of the Lower Orange River, from the Upper Orange.

In terms of the estuary, the location to allocate the flow requirements must be at the head of the Orange River Estuary, which is defined at the Sir Ernest Oppenheimer Bridge, approximately 11 km from the mouth of the Orange River Estuary (latitude: -28.6240 and longitude: 16.4591).

Table E1: Ecological Water Requirements sites

EWR site code	Site description/ Location	River	Quaternary catchment	Co-ordinates	
COMPREHENSIVE EWR SITES					
LO_EWR02	Boegoeberg	Orange	D73C	-28.969493	22.17843
LO_EWR03	Augrabies	Orange	D81B	-28.510372	20.17165
LO_EWR04	Vioolsdrift	Orange	D82F	-28.7553	17.71696
LO_EWR05	Sendelingsdrift	Orange	D82J	-28.0718	16.95951
Orange River Estuary	Estuarine functional Zone delineation – upper boundary	Orange	D82L	-28.56212	16.52306

LO - Lower Orange

There are no EWR sites for the ephemeral systems/ episodic rivers in the Lower Orange catchment, as they are groundwater driven systems. From a biotic perspective, the presence of the inverts is related to the hydrological phase (*i.e.,* pool, onset of flow or flow). If the river is dry, no invertebrates are present and keeping in mind that it takes between 4 and 6 weeks for the invertebrates to re-colonise. For these systems, flow is also not always available for a solid period (*i.e.,* throughout the year), thus there is a high level of unpredictability of surface flow in these systems. The fish usually move to the lower reaches into the pools if there are still pools or stay in the main stem. It will also be unlikely that it will be possible to address vegetation as the rivers are mostly sandy. The approach will need to focus on the land use/ activities assessment - if there is an increase in land use, what it is and how it alters/ impacts the river system.

Ecological Water Requirements Quantification for Water Resource Classification

The approach followed for the quantification of the ecological water requirements in the Lower Orange River catchment as part of the water resource classification process was as follows:

(i) New Rapid III assessments (surveys in September-October 2024) at EWR02 Boegeberg and EWR 03 Augrabies, and included the following:
- Information collected during the field surveys,
- Results from the Eco-classification process (Present Ecological State (PES), Ecological Importance (EI), Ecological Sensitivity (ES) and Recommended Ecological Category (REC),
- Desktop Reserve Model (DRM) within SPATSIM for the integration of data produced from the surveys and Eco-classification to quantify the EWRs,
- Results from the hydraulic modelling (cross-sectional profile and discharge) to evaluate the DRM requirements, and

- Evaluation of the water quality at the sites.

(ii) Review of existing EWRs from the Lower Orange 2016 Reserve Study, for EWR04 Vioolsdrift and EWR05 Sendelingsdrift to assess any changes in flow within these reaches, that could have resulted in changes in the PES, using existing hydraulics and biological data. Comparisons were made between the natural MARs as used during the previous studies (ORASECOM, 2011 and DWS, 2016) with the latest natural Mean Annual Runoff (MAR) for this study.

(iii) Orange River Estuary – the existing comprehensive assessment information was adopted.

Table E2 provides a summary of the information for the EWR sites where the EWRs were quantified or re-assessed.

Table E2: Summary of the Ecological Water Requirements site assessment in the Lower Orange River Catchment

EWR site[1]	Quaternary catchment/ Sub-reach	River	Coordinates	Gauge	PES[2]	EI/ES[3]	REC[4]	Level and comments
IUA 1: Orange from Vaal confluence to Augrabies Waterfall								
LO_ EWR02	D73C-02945	Lower Orange River	-28.969493; 22.17843	D7H008	C	High	B/C	Reassessed - Rapid III survey of existing comprehensive EWR site
IUA 2: Downstream Augrabies to Pella								
LO_ EWR03	D81B-03140	Lower Orange River	-28.510372; 20.171659	D7H014	C	High	B	Reassessed - Rapid III survey of existing comprehensive EWR site
IUA 3: Pella to Vioolsdrift weir								
LO_ EWR04	D82F-03531	Lower Orange River	-28.7553; 17.71696	D8H003 D8H013	C	High	B/C	Existing comprehensive EWR – possible flow changes reassessed (desktop)
IUA 4: Downstream Vioolsdrift to Orange River Mouth								
LO_ EWR05	D82J-02886	Lower Orange River	-28.0718; 16.95951	D8H015	B/C	High	B	Existing comprehensive EWR - possible flow changes

EWR site[1]	Quaternary catchment/ Sub-reach	River	Coordinates	Gauge	PES[2]	EI/ES[3]	REC[4]	Level and comments
								reassessed (desktop)
IUA 5: Orange River Mouth								
Estuary	D82L10-03298	Orange River Estuarine functional Zone delineation	d/s boundary -28.63303; 16.562119 u/s boundary -28.56212; 16.52306	D8H015	D	Very High	C	Existing comprehensive assessment adopted. Biotic components surveyed (once off)

[1]*Ecological Water Requirement site*
[2]*Present Ecological State*
[3]*EI-ES: Ecological Importance – Ecological Sensitivity (H-H: High-High)*
[4]*Recommended Ecological Category*

Hydraulic and hydrological data and modelling

Hydraulic information was obtained during the river survey conducted in September/October 2024 at the selected Rapid III EWR sites. These included the selection and surveying of an appropriate cross-sectional profile of the river and longitudinal water slope and to measure the discharge. This data was used to develop the depth/discharge relationships for each EWR site. In addition, the hydraulics was further modelled using the HABFLO (HABitat FLOw) program to predict statistical distributions of hydraulic habitats for fish and macroinvertebrates. The results of the hydraulic modelling were used during the quantification of the EWRs.

Natural and present-day hydrology was obtained from several sources, including the data in the latest water resources yield and planning models, WR2012 hydrology, and dam operating rules studies. The flow time series obtained from these studies were used and adjusted by catchment area to obtain the flows at the EWR sites.

Eco-categorisation and EWR quantification results

The final Eco-categorisation and EWR quantification results for the EWR sites in the Lower Orange for the Recommended Ecological Category (REC) is presented in Table E3. These EWRs per site will be used in the next steps during the configuration of the ecological baseline scenario and the evaluation of ecological consequences of management scenarios, trade-offs with socio-economic considerations to determine the Water Resource Classes per IUA and for the setting of RQOs.

Table E3: Summary of the EWR quantification for the sites along the Orange River

IUA[1]	EWR site	Quat[2]	PES[3]	EI-ES[4]	REC[5]	Total EWR as %nMAR for REC[6]	nMAR ($10^6 m^3$)[7]
1	LO_EWR02_Boegoeberg	D73C	C	H-H	B/C	31.11	10 772.6
2	LO_EWR03_Augrabies	D81B	C	H-H	B/C	24.90	11 043.6

IUA[1]	EWR site	Quat[2]	PES[3]	EI-ES[4]	REC[5]	Total EWR as %nMAR for REC[6]	nMAR ($10^6 m^3$)[7]
3	LO_EWR04_Vioolsdrift	D82F	C	H-H	B/C	12.2	11 064.3
4	LO_ EWR05_Sendelingsdrift	D82J	B/C	H-H	B	14.66	11 670.2
5	Orange River Estuary	D82L	D	H	C	5 m^3/s - 6% of the time; < 2 m^3/s – 1.8% of the time	

[1]Integrated Unit of Analysis
[2]Quaternary catchment
[3]Present Ecological State
[4]EI-ES: Ecological Importance – Ecological Sensitivity (H-H: High-High)
[5]Recommended Ecological Category
[6]Total Ecological Water Requirement as a percentage of the natural Mean Annual Runoff for the Recommended Ecological Category
[7]Natural Mean Annual Runoff in Million Cubic Meters

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1 INTRODUCTION

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

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). The classification system is intended to ensure comprehensive protection of all water resources.

1.1. Study Objective

The main objective of the study is to coordinate the implementation of the Water Resource Classification System (WRCS) in order to classify all significant water resources in the Lower Orange Catchment and determine the associated Resource Quality Objectives (RQOs) for the prioritised units, within the Vaal-Orange Water Management Area (WMA 4) 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.

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 Lower Orange Catchment.

Appropriate integration with water resource planning and management processes, as well as engagement with stakeholders, are the key success factors in setting the water resource classes and RQOs.

The outcomes of the process will be a protection framework for the catchment that will guide actions, management and monitoring, to ensure a sustainable water resource system that balances use and protection in the Lower Orange River Catchment.

The Lower Orange River forms part of the Orange River System with the major contribution to flow coming from the Upper Orange. The Upper Orange Water Resource Classification Study is also underway. While the Upper and Lower Orange River catchment studies are being undertaken separately, they are occurring in parallel, with continuous liaison and integration where necessary.

1.2. Purpose of this Report

To classify a water resource, the Water Resource Classification System (WRCS) lays out a set of procedures grouped together in seven steps that, when applied to a specific catchment, will result in the determination of a water resource class (Figure 1). The study is underway with Step 3 of the process which requires the quantification of the ecological water requirements (EWR) that is aimed to support the configuration of the ecologically sustainable base configuration scenario (Step 4), which serves as the key input into the scenario evaluation task (Step 5).

The EWR of a water resource is determined as part of the Reserve Determination component of RDM and specifies the flow requirement to protect the aquatic system (habitat and biota) and maintain its integrity. The EWRs of the Reserve forms a basis to the water resource classification process by ensuring that the ecological requirements of the significant water resources are accounted for in the analysis. In addition, they define the quantity component of the RQOs.

As the Reserve has been determined for the Lower Orange catchment between 5 to 10 years ago, this quantification of Ecological Water Requirements (EWR) Report describes the approaches, methods and models used to review and confirm the EWRs for the Orange River in the catchment (as the only perennial river) at the selected sites. The applicable, information from the previous Reserve studies were utilised and updated with new information from field surveys undertaken during September-October 2024. These determinations are on the various levels of detail as described in volume 3 of the RDM methodology of 1999 (DWAF, 1999).

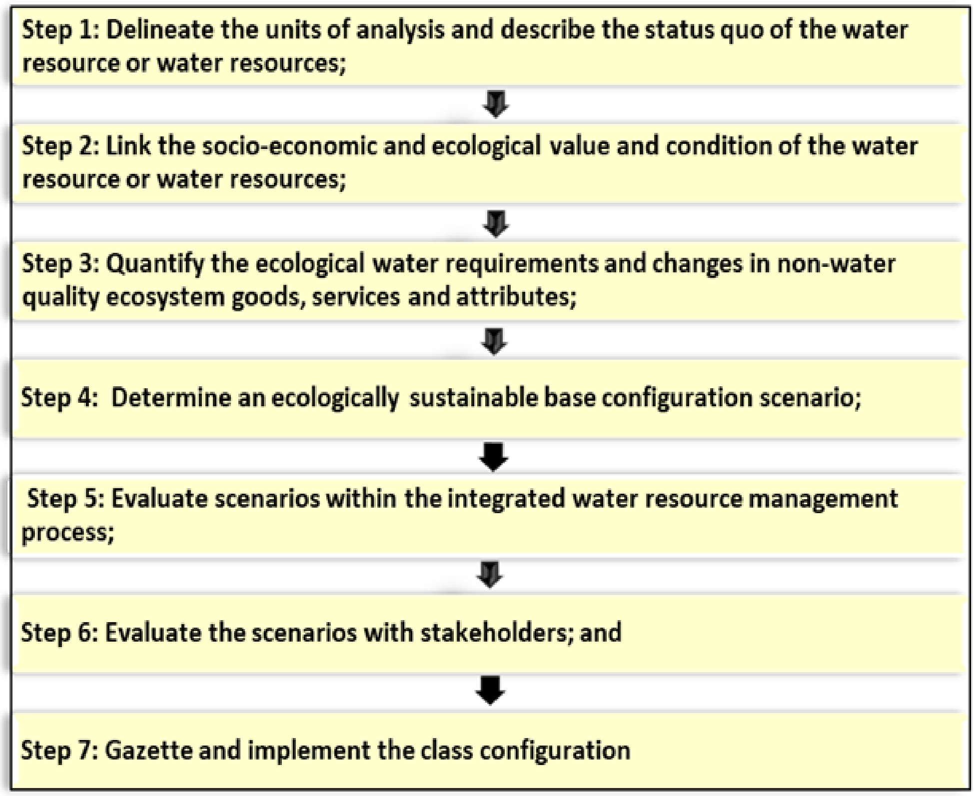


Figure 1: The Water Resource Classification 7 Step Procedure

1.3. Previous EWR Studies

Several water resource related studies were carried out in the past, which covers not only the Lower Orange catchment but the entire Integrated Vaal River System (IVRS), and the Orange and Senqu River basins. The Orange River Senqu Commission (ORASECOM) Phase III and the Orange Reconciliation Strategy studies both used the most up to date hydrology and related Water Resource Planning Model (WRPM) system setups covering the entire Orange / Senqu basin. The 2015 annual operating analysis for the IVRS, Orange and Greater Bloemfontein used the same data sets, but included more recent demand updates.

Approximately 12 full EWR studies as well as several smaller, desktop studies were undertaken over a period of about 16 years for different parts of the Orange-Senqu Basin. Previous Ecological Flow Requirement (EFRs) studies that only focused on the Lower Orange catchment, includes the following ORASECOM studies:

- GIZ IWRM Phase 2: EFR study covering the Molopo River basin by Louw and Koekemoer
- GIZ IWRM Phase 2: EFR study focussing on the Orange River (Vaal River excluded) by Louw and Koekemoer (2010) (Referred to as the 2010 EWR study)
- GEFTDA/SAP EFR Study covering the Fish River in Namibia, Orange River downstream of the Fish River confluence and the Orange River Mouth by Louw *et al* (2013) (Referred to as the 2013 EWR study)
- GIZ IWRM Phase 3: Consolidation of Environmental Flow Requirements Report focussing on the Orange Senqu basin by Rivers for Africa (ORASECOM, 2014)

The last of the four studies (ORASECOM IWRMP Phase 3 study, ORASECOM 2014), consolidated the findings especially from GEF/TDA and IWRM Phase 2 work, and included the testing for different flow scenarios based on existing and possible future infrastructure and demands.

In the Lower Orange catchment, the Intermediate EFR study was undertaken for ORASECOM in 2010 and included three sites on the Lower Orange River. A Reserve Determination study undertaken for DWS for the Lower Orange River catchment in 2016 used the same sites and included an additional site on the Lower Orange. Any other relevant information available for the study area was gathered and reviewed, over and above the mentioned studies, however the ORASECOM 2010 EWR study and DWS 2016 Reserve study provided the bulk of the available data.

2 OVERVIEW OF THE STUDY AREA AND ECOLOGICAL WATER REQUIREMENT SITES

The Orange River catchment, comprising the Upper Orange and Lower Orange catchments and forming part of the recently gazetted Vaal-Orange WMA (WMA04), is the largest catchment in the country (Figure 2). The Lower Orange includes the stretch of Orange River between the Orange-Vaal confluence and Alexander Bay. The catchment area is characterised by a harsh climate with minimal rainfall and prolonged droughts, sometimes to be terminated by severe flooding. The area is mostly arid with rainfall varying from 400mm in the east to 50 mm on the west coast. Rainfall usually occurs during late summer to autumn. The topography of the area is in general flat, including large pans or endorheic areas that do not contribute to runoff reaching the main Orange River. The average mean annual evaporation for this area is 2600 mm/a (DWS, 2016).

The geographic extent of the Lower Orange catchment area primarily overlaps with the Northern Cape Province, with smaller portions extending into the Western Cape, North West, and Free State Provinces along the southern and eastern boundaries, respectively. The Lower Orange catchment is the most downstream of covering the Orange -Vaal River Basin, with most of its water requirements being met from releases from major dams in the Upper Orange catchment. It also borders on three other water management areas. The Orange River is also the main river in this water management area.

The Orange River is the primary river in the catchment and rises as the Senqu River in the Maluti Mountains in Lesotho flowing 2200 km to discharge into the Atlantic Ocean on the western side of catchment. The Lower Orange River originates at the confluence of the Upper Orange River and the Vaal River tributary, approximately 20 km from Douglas. The major tributaries flowing into the Orange River from the north include the Molopo and Kuruman Rivers (both in the Northern Cape Province), and the Nossob River, which flows through Namibia, enters the Northern Cape, and then flows into the Orange River. Additionally, the Fish River drains the southern part of Namibia. Major tributaries to the Lower Orange River from the south draining the Karoo include the Ongers, Sak and Hartbees rivers. The study area includes the lower D primary drainage region comprising of the secondary drainage regions D4 to D8. It comprises only the South African portion of the Lower Orange River Catchment and also includes F10 to F50 tertiary catchments and quaternary catchment F60A.

The Lower Orange River flows into the Orange River Estuary, a delta-type river mouth, located near the town of Alexander Bay. The estuary is of national importance and has been designated a Ramsar Site, recognizing it as a wetland of international significance. The study area catchment includes other smaller estuaries of importance which are the Buffels, Sout, Swartlintjies, Spoeg and Groen estuaries (in the F catchment). These estuaries are all classified as arid predominantly closed estuaries.

Groundwater in the Lower Orange River catchment is found in a wide range of aquifer systems. These include younger semi-consolidated sedimentary sequences, extensive sequences of the Karoo Supergroup and Nama Group (Namibian) sedimentary formations, as well as highly variable meta-sedimentary and metamorphic rocks in the lower part of the region. Aquifers within the study area include intergranular, fractured contact-zone, fractured hard rock, fractured and intergranular and karst aquifer systems. Dependance on groundwater in the catchment is high, with groundwater being the sole water source for most of the tributary catchment areas. Among the more valued natural resources in the river basin is a transboundary Ramsar protected wetland at the mouth of the Orange River. Important nature conservation areas include the Kgalagadi Transfrontier Park, the Ai-Ais-Richtersveld Transfrontier Park, and the Augrabies Falls National Park.

The Lower Orange River is the only mainstem river making up the lower D drainage region comprising of the secondary drainage regions D4 to D8 (Figure 3). It comprises only the South African portion of the Lower Orange River Catchment that includes the tertiary catchment areas portions of C92B, C92C, portions of D41, D42, D51 to D58, D61, D62, D71 to D73 (excluding some portions D73), D81, D82 and primary catchment F with some exclusions as set out in Table 1 (and shown in Figure 3). The lower portions of quaternary catchments C92B and C92C (lower Vaal) are included in this catchment as it follows the boundary of the Orange Vaal Water User Association (supplied by the Orange River Project). Quaternary catchment F60A is also included.

There is very limited regulation capacity in the Lower Orange catchment. Although no large dams are present in the Lower Orange catchment, Boegoeberg, Neusberg and Vioolsdrift storage weirs are used for the regulation of flows into canal systems for irrigation purposes. Two small dams are located in the Orange tributaries sub-areas, used for localized irrigation and domestic use, *viz*. the Smartt Syndicate Dam on the Ongers River; and the Rooiberg Dam on the Hartbees River.

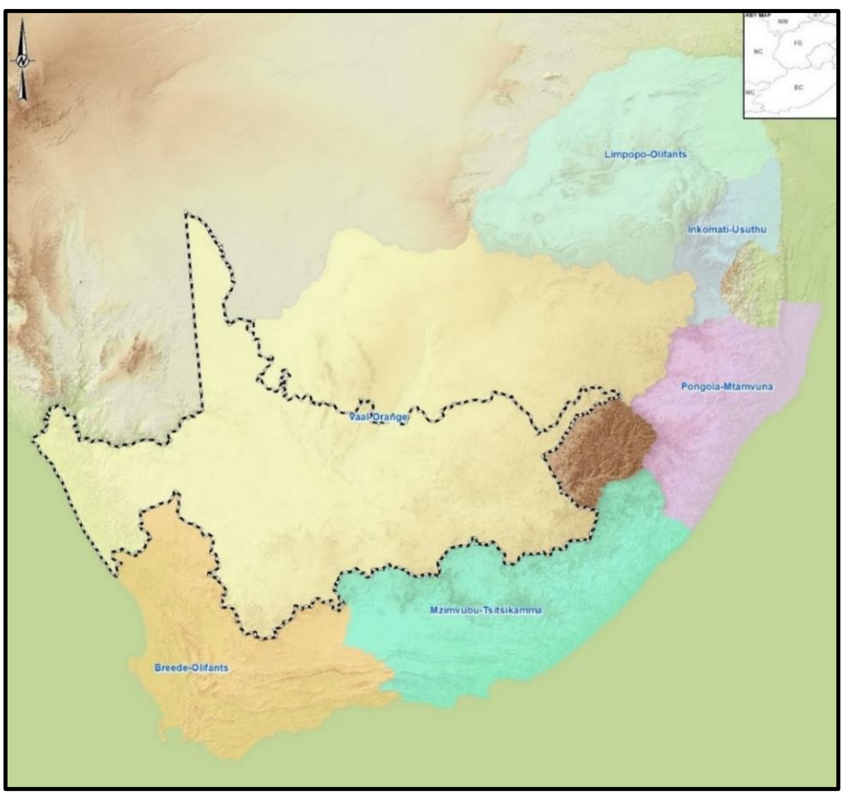


Figure 2: Orange River Catchment within Vaal- Orange WMA (WMA04) in South Africa

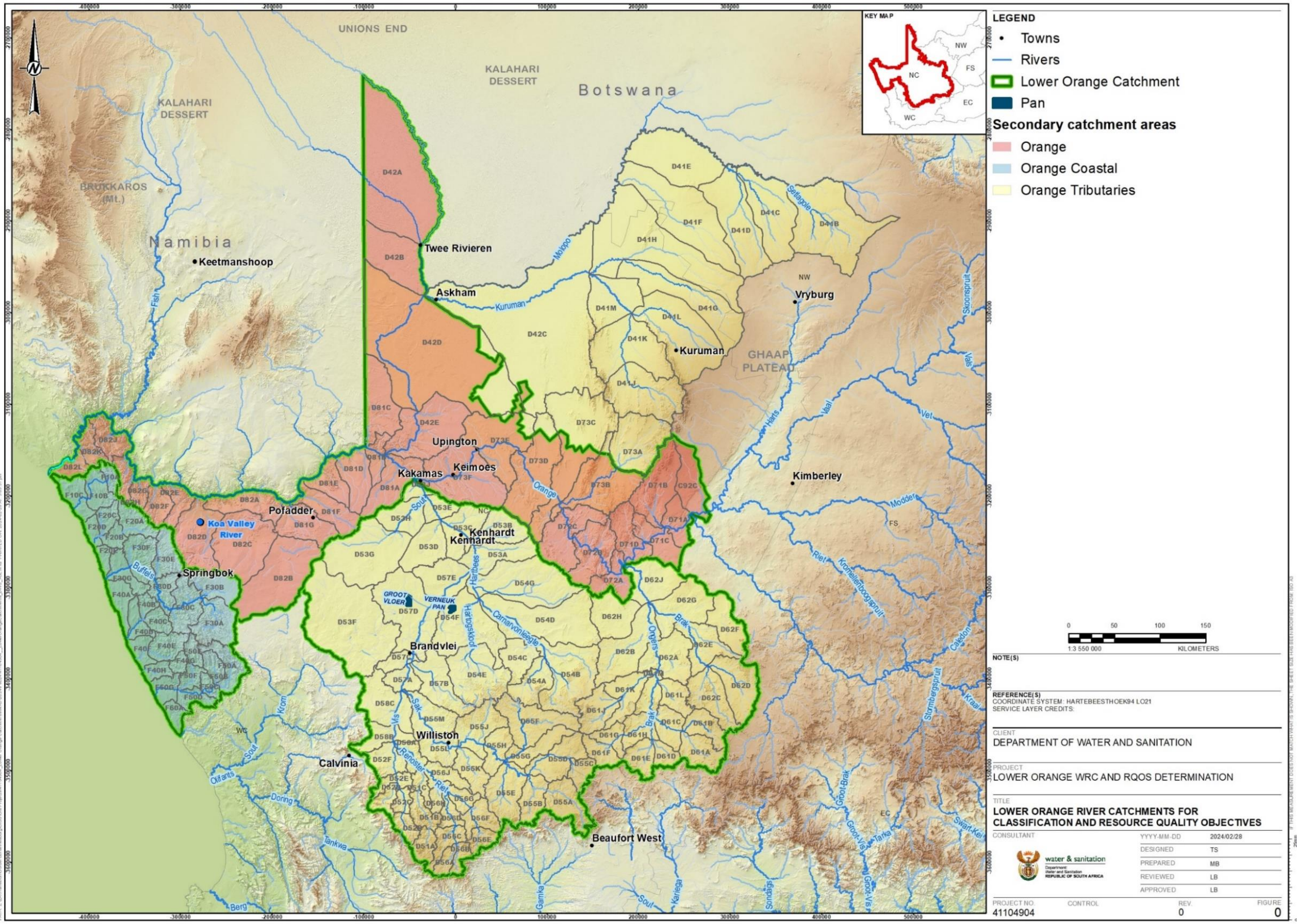


Figure 3: Lower Orange River catchment – Study Area extent and Locality (South African Portion)

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

Secondary Catchment	Tertiary Catchment	Quaternary catchments	River/s	Catchment area[1] (km^2)	
				Gross	Net
C9	C92	C92B, C92C	Vaal	3938	1324
D4	D41	D41B-M	Molopo, Kuruman	54 045	30173
	D42	D42A- D42E	Molopo, Kuruman, Nossob, Auob	33898	31872
D5	D51	D51A-D51C	Renoster, Dorps, Kariega, Boesmanfontein se laagte	2192	2192
	D52	D52A-D52F	Vis, Visrivier-oos, Visrievier-wes, Muiskraal, Kookfontein, Hottentotsfontein se Laagte	2750	2750
	D53	D53A-D53J	Hartbees, Mottels, Klein-Lat, Rugseers, Rooiput se Leegte, Rougas se Loop, Driekop se, Tuins, Graafwaters, Sandnoute, Rietfontein, Brulkolk se Holte, Soutputs, Souts se Laagte, Steenkampsvlei se Holte	23050	20527
	D54	D54A-D54G	Hartbees, Holsloot, Kalksloot, Carnarvonleegte, Boesak, Bitterpoortloop, Renosterpoort se Leegte, Bloudrif, Ysterdoringspan, Botterslaagte, Vernuekpan, Hartogskloof, Bloubosleegte, Keelafsnyleegte, Brandholteloop, Bastersput se Leegte, Lekkerleleegte, Elandsfontein	23622	15640
	D55	D55A-D55M	Sak, Brak, Sout, Klein-Sak, Rietfontein, Damfontein se, Klein-Brak, Slangfontein, Soutpoort, Reitzvilleleegte, Kareebergleegte, Alarmleegte, Stofkraalleegte, Platkuil, Gansvlei, Palmietfontein se Loop, Draaiwal se Leegte, Beeswaterleegte, Hongerkloof se Leegte, Ploegfontein se Leegte, Witleegte, Rietfonteinleegte, Tulbaghlaagte, Wielkolkslaagte	19398	19225
	D56	D56A-D56J	Riet, Portugals, Klein-Riet, Wolwe, Nuweveld, Karee, Elands, Valslaagte, Leenderts	6303	6303
	D57	D57A-D57E	Sak, Soutsloot, Swartbosleegte, Rooidam se Laagte, Soutsloot, Kettingkop se Laagte, Knapsaklaagte, Bosduiflaagte	10165	6197

Secondary Catchment	Tertiary Catchment	Quaternary catchments	River/s	Catchment area(1) (km^2)	
				Gross	Net
	D58	D58A-D58C	Vis, Renoster, Klein-Vis, Dassiesstraatlaagte	763	763
D6	D61	D61A-D61M	Ongers, Brak, Klein-Brak, Lakenrivier, Brakpoort, Pretoriuskuil se Leegte, Visgatspruit, Vis, Groen, Biesiekuilleegte, Gaafwaterspruit	13405	12426
	D62	D62A-D62J	Ongers, Brak, Sand, Elandsfontein, Renostervleispruit, Hondeblafspruit	20328	12178
D7	D71	D71A-D71D	Orange, Withoekskloof, Lanyon spruit	7390	4792
	D72	D72A-D72C	Prieska, Karabeeloop, Rooiloop, Kat, Marydale	6742	5714
	D73	D73A-D73F	Orange, Sout, Brak, Groenwaterspruit, Skeifonteinspruit, Soutloop, Eselfontein, Helbrandleegte, Kareeboom, Vaalputs, Kameel, Neusspruit	25968	11080
D8	D81	D81A-D81G	Orange, Slang, Brak, Brabees, Wegsteek se Laagte, Bak, Bul, Nous, Kaboep, Koeiamlaagte, Goob se Laagte	12809	10975
	D82	D82A-D82L	Orange, Mik, Fontein se, Nam se Laagte, Kirrie, Matjies, Koubank, Kosies, Geelfontein, Groen, Kahams, Abiekwa, Gannakouriep, Bloubos, Annis, Khubus	20212	18185
F	F10	F10A-F10C	Holgat, Gaigas, Kook	2725	1335
	F20	F20A-F20E	Kamma, Kwaganap	3137	2899
	F30	F30A-F30G	Buffels, Brak, Gasab, Papkuils, Klein-Nou, Jaagleegte, Drodab, Melk, Wolwepoort, Skaap, Doring, Stry	9756	9460
	F40	F40A-F40H	Wildeperdehoek se Brak, Swartlintjies, Spoeg, Bitter, Brand, Outeep	5346	3783
	F50	F50A - F50G	Hartbees, Groen, Swart-Doring	4869	4600
	F60	F60A	Brak	572	386

[1]WR2012 data

2.1. Ecological Water Requirement Sites

In the Lower Orange catchment, the intermediate EFR study undertaken for ORASECOM in 2010 included three sites on the lower Orange River at Boegoeberg (EFR 02), Augrabies (EFR O3) and Vioolsdrift (EFR O4). The Reserve Determination study undertaken by DWS for the Lower Orange River catchment in 2016 used the same sites and included an additional site on the Lower

Orange at Sendelingsdrift (EWR O5). No sites were selected on the main tributaries (Sak, Hartbees, Ongers) due to the arid nature of these rivers.

The EWRs were only determined for the mainstem Orange River within the study area as it is the only perennial river in the catchment - these sites are set out in Table 2. As part of the high confidence Reserve study that has been finalised for the Upper Orange River catchment, a site was selected at Marksdrift just upstream of the Upper Orange River and Vaal River confluence at Douglas as the Lower Orange River forms. The Marksdrift EWR site provides a flow modelling site of the inflows into the Lower Orange catchment.

There are no EWR sites for the ephemeral systems /episodic rivers in the Lower Orange catchment, which include the Hartbees/Sak, Brak/Ongers, Molopo, Kuruman and Coastal River Systems.

The Reserve determination in the Lower Orange was undertaken at a comprehensive level of assessment. Table 3 defines the various levels of assessment for Reserve (EWR) determination.

Table 2: Ecological Water Requirements sites

EWR site code	Site description/ Location	River	Quaternary catchment/reach	Co-ordinates	
COMPREHENSIVE EWR SITES					
UO_EWR10_I*	Marksdrift	Upper Orange	D33K	-29.14485	23.691403
EWR02	Boegoeberg	Lower Orange	D73C	-28.969493	22.17843
EWR03	Augrabies	Lower Orange	D81B	-28.510372	20.171659
EWR04	Vioolsdrif	Lower Orange	D82F	-28.7553	17.71696
EWR05	Sendelingsdrift	Lower Orange	D82J	-28.0718	16.95951
Orange River Estuary	Estuarine Functional Zone	Lower Orange	D82L10-03298	u/s boundary -28.56212; 16.52306 d/s boundary -28.63303; 16.562119	

** Part of the Upper Orange Reserve study*

Table 3: Ecological Water Requirements surveys per level of Reserve assessment

Comprehensive/ Intermediate	Rapid III	Rapid II	Rapid I	Desktop
Dry and post-wet season surveys Hydraulics Fish Macroinvertebrates Riparian vegetation Geomorphology Hydrology Water quality	Dry season survey Hydraulics Fish Macroinvertebrates Rapid Habitat Integrity Assessment Hydrology Water quality	Dry season survey Discharge only Fish Macroinvertebrates Rapid Habitat Integrity Assessment Hydrology Water quality	Dry season survey Fish Macroinvertebrates Rapid Habitat Integrity Assessment	No surveys Desktop PES/EI/ES results Hydrology

2.2. Summary of the IUAs and Associated Priority Rivers

The Integrated Units of Analysis (IUAs) - the spatial units (sub-catchments) that define the network of significant water resources have been delineated for the Lower Orange River Catchment. A detailed status quo assessment that included a socio-economic analysis of the catchment has been undertaken to understand the current conditions. The IUAs are a combination of Socio-Economic Zones (SEZs) and watershed boundaries. The SEZs are areas defined by socio-economic characteristics such as population density, land use, economic activities, and resource dependency. The process also requires that IUAs include EWR sites, where applicable. Ten IUAs have been delineated for the Lower Orange catchment. The EWR sites serve as the key modelling points in the system presenting the ecological requirement per IUA.

The ten IUAs delineated are shown in Figure 3, while Table 4 summaries the IUAs, including the associated priority rivers and the Orange River Estuary. For further detail on the IUAs, please refer to Report No. RDM/WMA14/00/CON/CLA/0224, Status Quo and delineation of Integrated Units of Analysis and Resource Units Report, September 2024. The EWR sites are shown in Figure 5.

Table 4: Summary of the IUAs within the Lower Orange Catchment Area

IUA	Description	Quaternary Catchments	EWR sites
1	Orange from Vaal confluence to Augrabies Waterfall	C92C, D71A, D71B, B71C, D71D, D72A, D72B, C72C, D73B, D73C, D73D, D73E, D73F, ~80%D81A	LO_EWR02 in D73C (Boegoeberg)
2	Downstream Augrabies to Pella	Portion of D81A, B, D81D – D81G	LO_EWR03 in D81B (Augrabies (Blouputs))
3	Pella to Vioolsdrift weir	D82A – D82F	LO_EWR04 in D82F (Vioolsdrift)
4	Downstream Vioolsdrift to Orange River Mouth	D82G, D82H, D85J, D82J, D82L (upper)	LO_EWR05 in D82L (Sendelingsdrift)
5	Orange River Estuary	Orange River Mouth – Lower reach of D82L	Orange River Estuary
6	Ongers/Brak	D61A, D61B, D61C, D61D, D61E, D61F, D61G, D61H, D61J, D61K, D61L, D61M, D62A, D62B, D62C, D62D, D62E, D62F, D62G, D62H, D62J	Groundwater driven
7	Hartbees/Sak	D52 - D58	Groundwater driven
8	Coastal Area	F10A to F60A	Groundwater and estuarine
9	Upper Molopo and Upper Kuruman	D41B, D41C, D41D, D41E, D41F, D41H, D41K, D41G, D41M, D41J and D41L	Groundwater driven
10	Lower Kuruman and Lower Molopo	D42A, D42B, D42C, D42D, D42E, D81C	Groundwater driven

2.3. Approach

The approach followed for the quantification of the ecological water requirements in the Lower Orange River catchment as part of process was as follows:

(iv) New Rapid III assessments (surveys in September-October 2024) at EWR02 Boegeberg and EWR 03 Augrabies, and included the following:
- Information collected during the field surveys,
- Results from the Eco-classification process (Present Ecological State (PES), Ecological Importance (EI), Ecological Sensitivity (ES) and Recommended Ecological Category (REC),
- Verification of the Desktop Reserve Model (DRM)/ Revised DRM within SPATSIM for the integration of data produced from the surveys and Eco-categorisation to quantify the EWRs for the Rapid III sites.
- Results from the hydraulic modelling (cross-sectional profile and discharge) to evaluate the DRM requirements, and
- Evaluation of the water quality at the sites.

(v) Review of existing EWRs from the Lower Orange 2016 Reserve Study, for EWR04 Vioolsdrift and EWR05 Sendelingsdrift to assess any changes in flow within these reaches, that could have resulted in changes in the PES, using existing hydraulics and biological data. Comparisons were made between the natural MARs as used during the previous studies (ORASECOM, 2011 and DWS, 2016) with the latest natural Mean Annual Runoff (MAR) for this study.

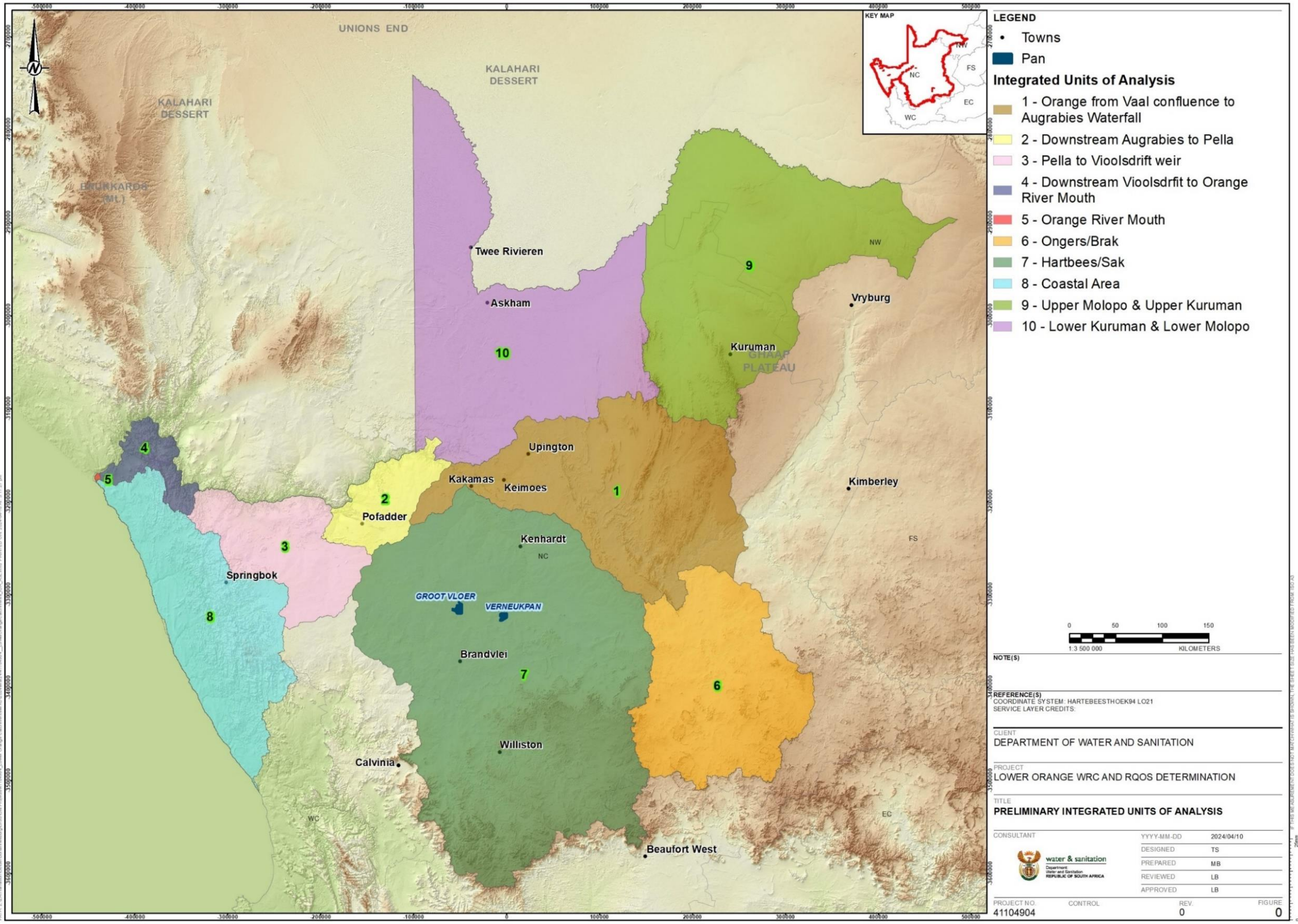
(vi) Orange River Estuary – the existing comprehensive assessment information was adopted.

Table 4 provides a summary of the information for the EWR sites where the EWRs were quantified or re-assessed.

There are no EWR sites for IUAs 6 to 10 in the Lower Orange catchment as these are the ephemeral systems /episodic rivers, that are groundwater driven. From a biotic perspective, the presence of the macroinvertebrates is related to the hydrological phase (*i.e*. pool, onset of flow or flow). If the river is dry though, no invertebrates are present and keeping in mind they take between 4 and 6 weeks to re-colonise. For these systems flow is also not available for a solid period of time (only present for a few days), thus there is a high level of unpredictability of surface flow in these systems. The fish usually move to the lower reaches into the pools if there are still pools or stay in the main stem. It is also not possible to address vegetation as the ephemeral rivers are mostly sandy.

Table 5: Summary of EWR sites in the Lower Orange River

EWR site	Quaternary catchment/ Sub-reach	River	Coordinates	Gauge	PES	EI/ES	REC	Level and comments
IUA 1: Orange from Vaal confluence to Augrabies Waterfall								
EWR02	D73C-02945	Lower Orange River	-28.969493; 22.17843	D7H008	D	High	B/C	Reassessed - Rapid III survey of existing comprehensive EWR site
IUA 2: Downstream Augrabies to Pella								
EWR03	D81B-03140	Lower Orange River	-28.510372; 20.171659	D7H014	C	High	B	Reassessed - Rapid III survey of existing comprehensive EWR site
IUA 3: Pella to Vioolsdrift weir								
EWR04	D82F- 03531	Lower Orange River	-28.7553; 17.71696	D8H003 D8H013	C	High	B/C	Existing comprehensive EWR – possible flow changes reassessed (desktop)
IUA 4: Downstream Vioolsdrift to Orange River Mouth								
EWR05	D82J-02886	Lower Orange River	-28.0718; 16.95951	D8H015	B/C	High	B	Existing comprehensive EWR - possible flow changes reassessed (desktop)
IUA 5: Orange River Mouth								
Orange River Estuary	D82L10-03298	Orange River Estuarine functional Zone delineation	d/s boundary -28.63303; 16.562119 u/s boundary -28.56212; 16.52306	D8H015	D	Very High	C	Existing comprehensive assessment adopted. Biotic components surveyed.


UNIONS END
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Vryburg
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Pofadder
Kenhardt
Springbok
GROOT VLOER
VERNEUKPAN
Brandvlei
Williston
Calvinia
Beaufort West
KEY MAP
LEGEND
Towns
Pan
Integrated Units of Analysis
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2 - Downstream Augrabies to Pella
3 - Pella to Vioolsdrift weir
4 - Downstream Vioolsdrfit to Orange River Mouth
5 - Orange River Mouth
6 - Ongers/Brak
7 - Hartbees/Sak
8 - Coastal Area
9 - Upper Molopo & Upper Kuruman
10 - Lower Kuruman & Lower Molopo
1:3 500 000
KILOMETERS
NOTE(S)
REFERENCE(S)
COORDINATE SYSTEM: HARTEBEESTHOEK94 LO21
SERVICE LAYER CREDITS:
CLIENT
DEPARTMENT OF WATER AND SANITATION
PROJECT
LOWER ORANGE WRC AND RQOS DETERMINATION
TITLE
PRELIMINARY INTEGRATED UNITS OF ANALYSIS
CONSULTANT
YYYY-MM-DD 2024/04/10
DESIGNED TS
PREPARED MB
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water & sanitation
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Figure 4: IUAs Delineated for the Lower Orange Catchment Area

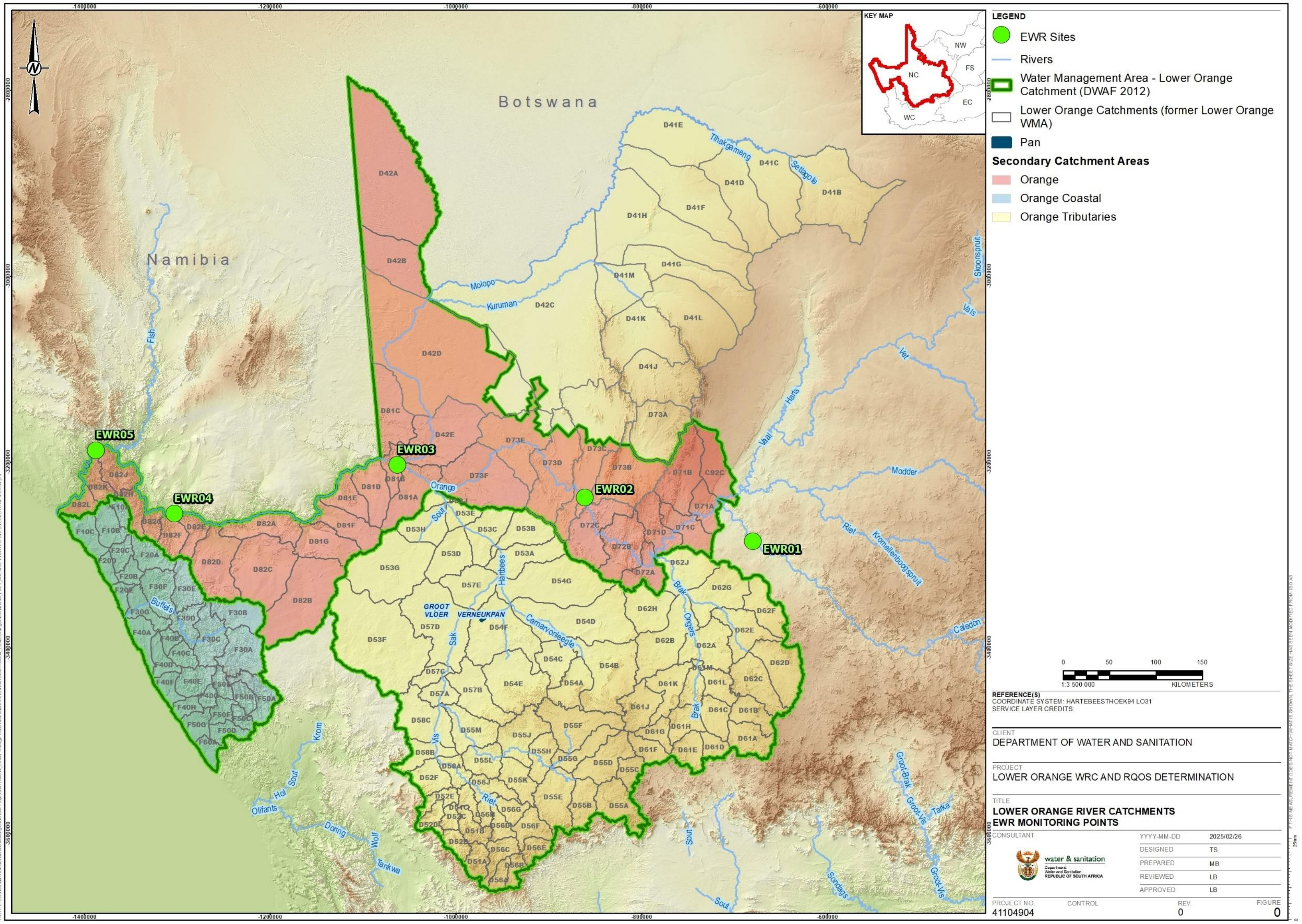

Figure 5: Lower Orange River EWR sites

3 ECO-CATEGORISATION APPROACH

3.1. Eco-Categorisation Approach

Rapid Level III surveys were conducted from 30 September to 4 October 2024, whereby LO_EWR02_Boegoeberg and LO_EWR03_Augrabies sites were surveyed. Water quality, fish, macroinvertebrates and hydraulics were conducted at these sites.

The Ecological Categorisation (Eco-Categorisation) approach is used to determine and categorise the Present Ecological State (PES) and the Recommended Ecological Category (REC) based on the health and integrity of the biophysical attributes of a river ecosystem, relative to the natural or reference condition of that system (Kleynhans and Louw 2007). It forms an integral part of the Ecological Reserve determination methods. Flows and water quality conditions cannot be recommended without information on the predicted resulting state, the Ecological Category (EC) (Kleynhans and Louw 2007). The primary objective of the eco-categorisation process is to recognise the causes and sources of the deviation of the derived PES through the various models, in relation to the reference condition of that river's biophysical attributes. The result is to ultimately gain information to derive future desirable and attainable ecological objectives for the river (Kleynhans and Louw 2007).

The various components required for the Eco-Categorisation process to determine the integrated state or PES, the EcoStatus Level 4 model (Kleynhans and Louw 2007) include the following:

- Drivers:
  - Physical-chemical variables/ diatoms;
  - Hydrology
- Biological Responses:
  - Fish;
  - Instream habitat integrity (as a surrogate to the riparian vegetation); and
  - Aquatic macroinvertebrates

Below is a detailed outline of the various components conducted during the surveys for the eco-categorisation of the various EWR sites.

3.1.1. Drivers

Water quality: *In situ* and physico-chemical water quality

A range of ancillary in-situ water quality parameters was measured at the EWR sites during the survey. The variables included pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), oxygen saturation (DO%), temperature, salinity, and clarity. All equipment was calibrated before the site surveys to ensure accurate and reliable measurements. The *in-situ* water quality data were compared to the South African Guidelines for Freshwater Ecosystems (Volume 7, DWAF, 1996). Measured parameters also included oxidation-reduction potential in addition to the core variables.

Water quality grab samples taken at the sites were tested for macro cations and anions, physical variables, metals, pesticides, organics (phenols and polyaromatic hydrocarbons) and semi-volatile organic compounds.

The results of the water quality analysis are used to identify the presence of pollutants and the physico-chemical drivers present at the sites that could impact/influence the ecological condition of the biota and associated responses.

Hydrology

The Hydrological Assessment Index (HAI) has been developed as part of the methodologies for the determination of the Ecological Water Requirements. The approach provides an indication of the changes in hydrology from reference/ natural to present day at each selected EWR site and is based on monthly long term natural and present-day flow time series. The result of HAI is used by ecologists to interpret changes in habitats using the hydraulics (depths, velocities, wetted perimeter, etc.) and to explain some changes in the response components (fish, macroinvertebrates, vegetation).

The assessment is based on the long-term changes from natural to present with 0, no change to 5, extreme change from natural in five metrics, namely:

- Low flows – changes to baseflows and can either be less or more flows than natural or the introduction of constant flows due to dam releases;
- Introduction of zero flows/ duration – Changing a perennial system (no zero flows) to a more seasonal or even ephemeral system due to no flows or the duration of the zero flow months increase in a seasonal stream;
- Seasonality – changes due to reduced flows during wet months (storing of excess runoff in dams) and releases from these dams during dry months for water use downstream. The so called “swopping of seasons”;
- Moderate events – changes to moderate floods/ freshets due to delayed spilling of dams after dry season (dam need to fill with first rains), thus delaying the early season cleaning of the rivers from algae and sediment build-up (flushing event); and
- Even hydrology (floods) – reduction in the peaks of flood events or less frequent spilling due to large dams capturing most of the catchment runoff, resulting in the loss of important ecosystems.

Ecologists rank these metrics according to the impact that changes will have on the available habitats, thus affecting the overall habitats.

3.1.2. Responses

Benthic diatoms (surrogate for water quality)

Sampling of diatoms was done according to the prescribed protocols in Taylor *et al*. (2005). Typically, this entailed collecting five smallish rocks at each sample site from random positions across the river where there was flow of water. The top surface of all the rocks that were exposed to the water column were then scraped using a toothbrush, which removed diatoms attached to the rock surface into a container with a small volume (<100 ml) of river water. Once the rocks had been adequately scraped, the water in the container that has the five subsamples was then transferred to a small sample bottle. A small amount of 95% ethanol (~10% of the sample bottle volume) was then added to the bottle to preserve the diatom sample. Sample bottles were then labelled and submitted to the Northwest University for preparation and analysis. The results from the laboratory were then interpreted according to the Specific Pollution sensitivity Index (SPI) to determine river "health status" (CEMAGREF, 1982). Other useful diatom indices used to further infer water quality conditions were the Percentage of pollution Tolerant Valves (% PTV), which was the proportion of diatoms in the sample that are tolerant to pollution, and the percentage of deformed cells, which was the proportion of diatoms in the sample which were deformed because of toxicants in the water.

For this study, both diatoms, historic and the once-off sampling analysis data were used for the Physico-chemical Driver Assessment Index (PAI). The desktop assessment revealed some gaps in data available for reference and recent conditions at the EWR sites or the Sub-Quaternary (SQ) reach within which the sites are located. Several data sources were used to collate information of the current and historical physical-chemical state of the assessed river systems and associate catchments. The DWS Resource Quality Information Services (RQIS) website was the obvious first choice used to obtain data from the country wide DWS monitoring network. This was supported by monitoring data obtained from the regional monitoring programme of the Upington DWS office (2019 - 2023). Most of the data obtained from the RQIS and regional programme did not show reference/baseline conditions as most of it was collected after major impacts had been introduced in the catchments. Additionally, the lack of consistent monitoring left years' worth of gaps in data. (Appendix D for DWS water quality site information and RQIS data obtained during desktop assessment). Other data sources were also sought for information including local conservation bodies, literature and experts who have done work in the area.

The diatom results and water quality analysis (historic and once-off sample) obtained from the river survey was used to infer the reference condition and the current status of the river systems in question. The use of diatoms in the monitoring of water quality is well documented. In the study, the diatoms were used to infer the reference and current physical-chemical status of the system for the following reasons:

- **Long environmental memory** – analyses of diatom fossil records allow for the reconstruction of the history of water quality in an area. This is useful in assessing the changes in water over time and possibly infer the reference/ natural state of the system in question;
- **Diverse species composition** – diatom communities exhibit extensive species diversity. Each species has unique preferences and tolerances to specific physico-chemical property changes. By quantifying diatom communities, it is possible to identify which physico-chemical properties have deviated from natural and are driving the physical-chemical status currently observed in the system in question;

- **Indicators of nutrient enrichment** – nutrient enrichment is one of the leading contributors to impaired water quality in the catchment. This is largely due to the mismanaged wastewater treatment works, which discharge poorly and, in some cases, untreated wastewater into watercourses. Certain diatom species are known to be good indicators of eutrophic water bodies and identifying river systems with elevated nutrient concentration and prone to algal blooms;
- **Sensitivity to pollutants** – diatoms are also good indicators of inorganic pollution. This is especially important in identifying heavy metal pollution in river system; and
- **Rapid assessment and monitoring** – diatom sampling and analyses are relatively easy, quick and cost effective. This allows for an effective and holistic assessment of water quality.

The diatom and the historic and once-off water quality dataset to assess reference and current physico-chemical state, diatoms proved to be adequate from which information on the physical-chemical status of the systems could be drawn. Satellite imagery, geographic information system (GIS) and Green Drop Report data were used to assess the change and identify the catchment drivers of the physical-chemical state of the systems in question. Combined these sets of data provided a picture of the natural state of each EWR site and how the current state has deviated from reference conditions.

Ichthyofauna

Fish samples were collected using different techniques, including electrofishing, cast netting as well as from visual observations at all Rapid III and EWR sites. Fish sampling techniques were deployed in a variety of depth and flow classes to sample each habitat to show fish species preferences for each. Electrofishing is regarded as the most effective single method for sampling fish communities in wade-able streams (Plafkin *et al*. 1989). Fish were identified in the field, photographed, and released at the point of capture. Fish species were identified using the guide Freshwater Fishes of Southern Africa (Skelton, 2001).

The FRAI method developed by Kleynhans (2007) for application in South Africa was used to assess the response of the reference fish assemblage to changing environmental conditions based on the observations made during the two river surveys. Fish species are categorised in the FRAI model according to an intolerance rating that take trophic preferences and specialisation into account, as well as all the flow, habitat, and water quality requirements. The ratings are then formulated into a relative FRAI index value, which is grouped into one of six descriptive fish assemblage integrity index classes.

The expected and observed Frequency of Occurrence (FROC) of fish species were compiled using the reference frequency of occurrence for fish species in South Africa (Kleynhans *et al*. 2007). Data from the 2014 Present Ecological State (PES) - Ecological Importance and Ecological Sensitivity (EIS) dataset (DWS, 2014), along with the currently updated PES, 2024, was also consulted with the derivation of FROC. These FROC values were used to interrogate the FRAI model to evaluate changes from reference conditions. FRAI is a rule-based model developed by DWA (Kleynhans, 2007) that assesses environmental intolerances and preferences of the reference fish assemblage, as well as the response of the constituent species of the assemblage to particular groups of environmental determinants or drivers. These intolerance and preference attributes are categorised into metric groups with constituent metrics that relates to the environmental requirements and preferences of individual species.

Assessment of the response of the species metrics to changing environmental conditions occur either through direct measurement (surveys) or are inferred from changing environmental conditions (habitat). Evaluation of the derived response of species metrics to habitat changes are based on knowledge of species ecological requirements. Usually, the FRAI is based on a combination of fish sample data and available habitat for fish. Changes in environmental conditions are related to fish stress and form the basis of ecological response interpretation and to determine the Present Ecological Category of the fish assemblage.

Index of Habitat Integrity

This index was conducted at the two Rapid III EWR sites, as prescribed in Kleynhans *et al*. (2008). The Index of Habitat Integrity (IHI) assessed indicators of instream and riparian habitat modification. Furthermore, it essentially considers the deviations of habitat from natural conditions with reference to intensity and extent of human-induced impacts that have affected habitat integrity within river catchments. The assessments were achieved through determining the condition of each site by incorporating biological responses to driver changes (e.g., hydrological, geomorphological, physico-chemical, etc.) as well as through an integration of driver state or condition. The instream criteria assessed included water abstraction, flow modification, bed and channel modification, physico-chemical, inundation, alien macrophytes, introduced aquatic fauna and rubbish dumping. The riparian integrity took cognisance in vegetation removal, alien vegetation, bank erosion, channel modification, water abstraction, inundation, flow modification and physico-chemical conditions. The riparian score from this index was consequently used as a surrogate to the VEGRAI score for Rapid III sites when running the EcoStatus Level 4 model.

Aquatic Macroinvertebrates

Aquatic macroinvertebrate sampling was done using the South African Scoring System (SASS) version 5 protocol, as developed and refined by Dickens & Graham (2002). This index measures aquatic macroinvertebrate presence data at a family taxon level. Each taxon is allocated a sensitivity value between 1 and 15 according to its perceived sensitivity to water quality changes (with 1 being the least sensitive and 15 the most sensitive). Results are expressed as index scores: the SASS Score and the Average Score per Taxon (ASPT). This SASS5 technique has been accredited to ISO 17025 standards and forms part of one of the DWS river eco-categorisation models for EcoStatus determination. The SASS5 sampling was undertaken by an accredited SASS5 practitioner at all Rapid 3 and Intermediate EWR sites during both river surveys. The prescribed DWS MIRAI (Thirion, 2008, Thirion 2016) uses SASS5 and pre-determined reference condition data to determine the macroinvertebrate Ecological Condition of a site. The model considers three main drivers influencing macroinvertebrate community composition, namely: i) flow, ii) habitat and iii) water quality. These drivers create the instream habitats that affect instream biotic communities. Therefore, the Ecological Category generated by the MIRAI reflects the influence of each driver on the site and the macroinvertebrate community.

Additional aquatic macroinvertebrate data was gathered from the regional DWS office from Upington, overseen by Dr Christa Thirion. The regional officials conduct routine SASS5 biomonitoring at REMP sites D8ORN-BLOUP and D7ORANG-GROBL within the Lower Orange catchment area. These sites were aligned to these studies selected EWR sites. This enabled the specialist to supplement the macroinvertebrate database, and which was added to the MIRAI model, supporting both reference conditions and/or macroinvertebrate data recorded for the last hydrological year.

3.1.3. Ecological Categories

Varying procedures are followed for each component to assign an Ecological Category (EC) ranging from A to F (where A represents a natural state and F a critically modified state) (Figure 6). It must be noted that the ecological category scale represents a continuum whereby the boundaries between categories, along the continuum, are descriptive, notional and arbitrarily defined points. Subsequently, there may be circumstances where there could be ambiguity as to which category a particular entity belongs to. This situation falls within the concept of a fuzzy boundary, where a particular entity may potentially have membership of both classes (Robertson *et al*. 2004). This is therefore referred to as boundary categories and assigned a B/C, C/D category etc (Figure 6).

Figure 6: Illustration of the distribution of ecological categories on a continuum

3.1.4. EcoStatus and Recommended Ecological Categories

Ecological evaluation against the expected reference conditions, followed by integration of the categories of each component, provides a description of the Ecological Status or EcoStatus of a river. Consequently, the EcoStatus is defined as the integration of the river's features (instream and riparian zones) which influences its ability to support appropriate biota (Kleynhans and Louw 2007). This ability relates directly to the capacity of the system to provide a variety of ecosystem services.

The trends in the PES are then evaluated. A 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 hanged 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. Generally, such an assessment can be approached from a driver perspective. This means that there can be a positive or negative trend response from the biota if the drivers (specifically geomorphology and water quality) are still in a directional state of change (+ or -).

It must be noted that cognisance was taken when comparing the PES, 2014 and the EcoStatus results. The PES, 2014 was based on various components, while the EcoStatus run for this study was only based on fish, macroinvertebrates and the riparian habitat integrity. The reason for deviation is thus provided.

Furthermore, the evaluation/comparison of the following 9 ecological importance and 8 ecological sensitivity (EIS) components were evaluated for each EWR site using the PES/EIS (2014) study (although the EIS was done per sub-quaternary reach), along with in-field results from the surveys:

(i) Ecological Importance
  - Fish representativity and rarity
  - Macroinvertebrate representativity and rarity
  - Riparian-wetland-instream: vertebrates
  - Riparian-wetland-instream: natural vegetation
  - Habitat diversity
  - Habitat size
  - Habitat integrity
  - Riparian-wetland habitat integrity
  - Instream and riparian migration

(ii) Ecological Sensitivity
  - Physical-chemical sensitivity:
  - Fish and macroinvertebrates
  - Fish: no flow
  - Macroinvertebrates: velocity
  - Riparian-wetland-instream – vertebrates: flow or water level changes
  - Riparian-wetland – vegetation:
  - water level changes
  - Stream size (flow/water level changes)

This updated information was then used when assessing the REC for the EWR sites. The approach followed by DWS's Chief Directorate: Water Ecosystems Management (WEM) is that, if the EI or ES is high or very high, the ecological aim should be to improve the condition of the river. However, the causes related to a particular PES should also be considered to determine if improvement is realistic and attainable. This relates to whether the problems in the catchment can be addressed and mitigated. If the EI or ES evaluated was moderate or low, the ecological aim should be to maintain the river in its PES. Within the Ecological Reserve context, Ecological Categories A to D can be recommended as future states (the REC) depending on the EIS and PES. For ecological categories E and F - the PES is regarded as ecologically unsustainable, and remediation is required.

3.1.5. Eco-categorisation Workshop

An Eco-Categorisation specialist workshop was held on 4 November 2024, to determine the EcoStatus of the two Rapid III surveys for the Boegoeberg and Augrabies EWR sites in the Lower Orange River. The process included the following:

- Description of site localities within the catchment;
- Type of historical and existing information availability for each EWR site;
- Characterisation and evaluation of each site in terms of both the drivers and responses identified (*i.e.,* habitat availability, aquatic biota and water quality) and associated advantages and disadvantages of each component;
- Reference conditions for the aquatic biota;
- Description of both sites and upstream impacts;
- Completion of the EcoStatus 4 model resulting in an overall PES category and score coupled with an explanation for each component;
- A comparison using the previous PES results from preceding Reserve studies was undertaken to compare the final selected PES identified during this study from the EcoStatus Model 4 and reasons for the potential deviations;
- Assessment of the PES ecological trends from 2014 for each component (aquatic biota and riparian and instream habitat integrity);
- Evaluation/ comparison of the EIS; and
- Discussions and finalisation of the REC.

4 APPROACH TO THE QUANTIFICATION OF THE ECOLOGICAL WATER REQUIRMENTS

The methodology for the hydraulics modelling and hydrology analysis conducted as part of the Rapid Level III surveys at the LO_EWR02_Boegoeberg and LO_EWR03_Augrabies sites is presented in this section. In addition, the available DWS water quality site information and RQIS data obtained during desktop assessment is included in Appendix D.

4.1. Hydraulics: Data collection and modelling

During the site visits, the following activities were undertaken:

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

The hydraulic data collected during the site visit is listed in Table 6.

Table 6: Hydraulic data measured for the Lower Orange catchment EWR sites

EWR site	Survey date	Discharge Q (m^3/s)*	Maximum flow depth (m)
LO_EWR02_Boegoeberg	02 October 2024	56.4	1.56
LO_EWR03_Augrabies	30 September 2024	50.9	1.84

**Q-Discharge in cubic meters per second*

Modelling was carried out 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 7.

Table 7: Hydraulic data used to extend observed rating data at the EWR sites

EWR site	Discharge Q (m^3/s)[1]	Maximum flow depth (m)	Manning's n resistance, *n*[2]	Surface slope, S (m/m)[3]	Average Velocity, V (m^3/s)[4]
LO_EWR02_ Boegoeberg	56.4	1.56	0.2483	0.025	0.508
LO_EWR03_ Augrabies	50.9	1.84	0.5281	0.008	0.177

[1]Q-Discharge in cubic meters per second
[2]Manning's n resistance (unitless coefficient) refers to the degree of roughness and obstruction of flow (i.e. Rock bedded streams would have a higher degree of roughness therefore a higher Manning's n value versus a sandy stream would be smoother therefore reducing the Manning's n value)
[3]Surface slope S (m/m) refers to the slope of the water surface in the channel. Slope is calculated as the difference in elevation (m) between two points in the channel, divided by the longitudinal distance (m) between them. The Manning's equation requires the slope to be represented in m/m (not percentage or ratio).
[4]Average velocity in cubic meters per second

The depth/discharge relationship (Hirschowitz PM, Birkhead AL and CS James) was determined using the following equation:

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

Y is the maximum depth, Q is the discharge (m^3/s) and a, b and c coefficients. The coefficients used in equation (1) are shown in Table 8.

Table 8: Regression coefficients in equation (1)

EWR site	River	Regression coefficients		
		a	b	c
LO_EWR02_ Boegoeberg	Lower Orange	0.4599	3028	0
LO_EWR03_ Augrabies	Lower Orange	0.437	3663	0

The cross-sectional views of the LO_EWR02_Boegeberg and LO_EWR03_Augrabies EWR sites and stage-discharge relationships developed from the modelling, as well as the aerial view of the sites are illustrated in Figure 7 to Figure 12.

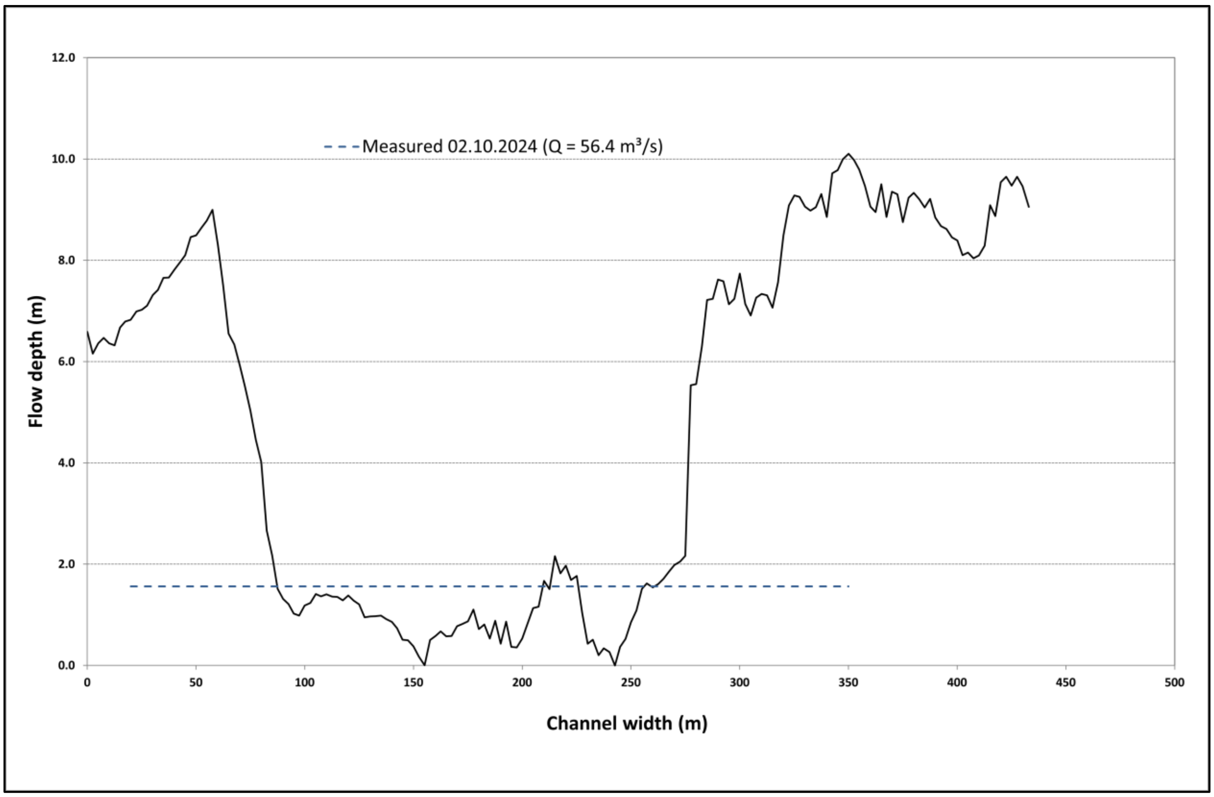

Figure 7: Cross-sectional view of the LO_EWR02_Boegoeberg EWR site

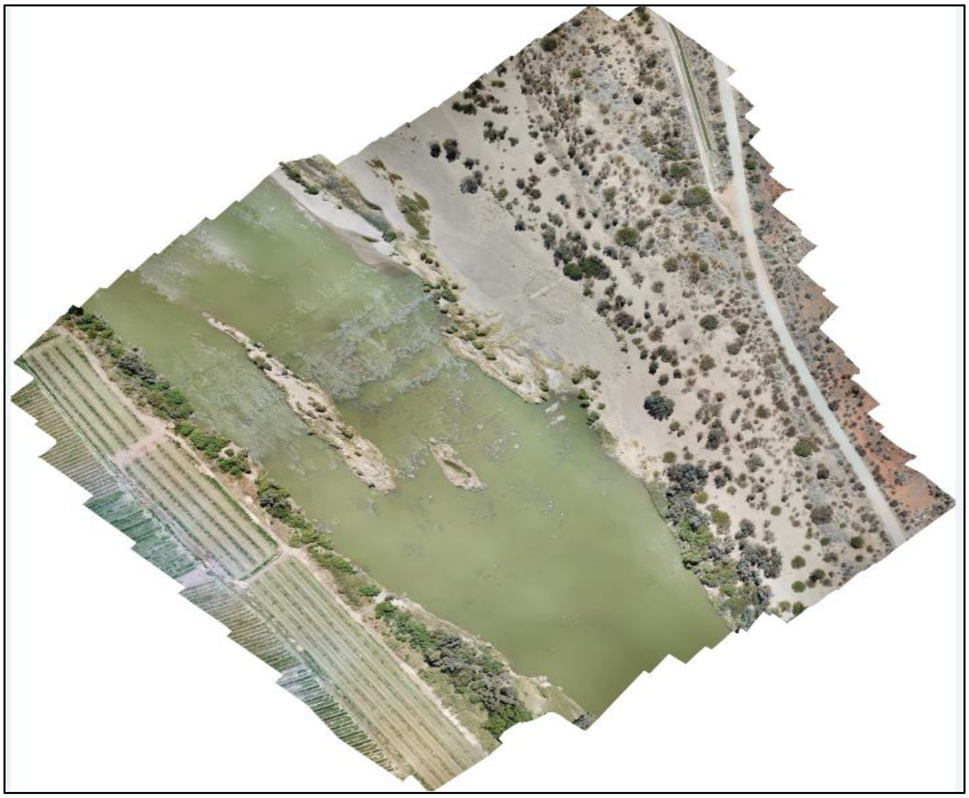

Figure 8: Aerial view of LO_EWR02_ Boegoeberg EWR site (02/10/2024)

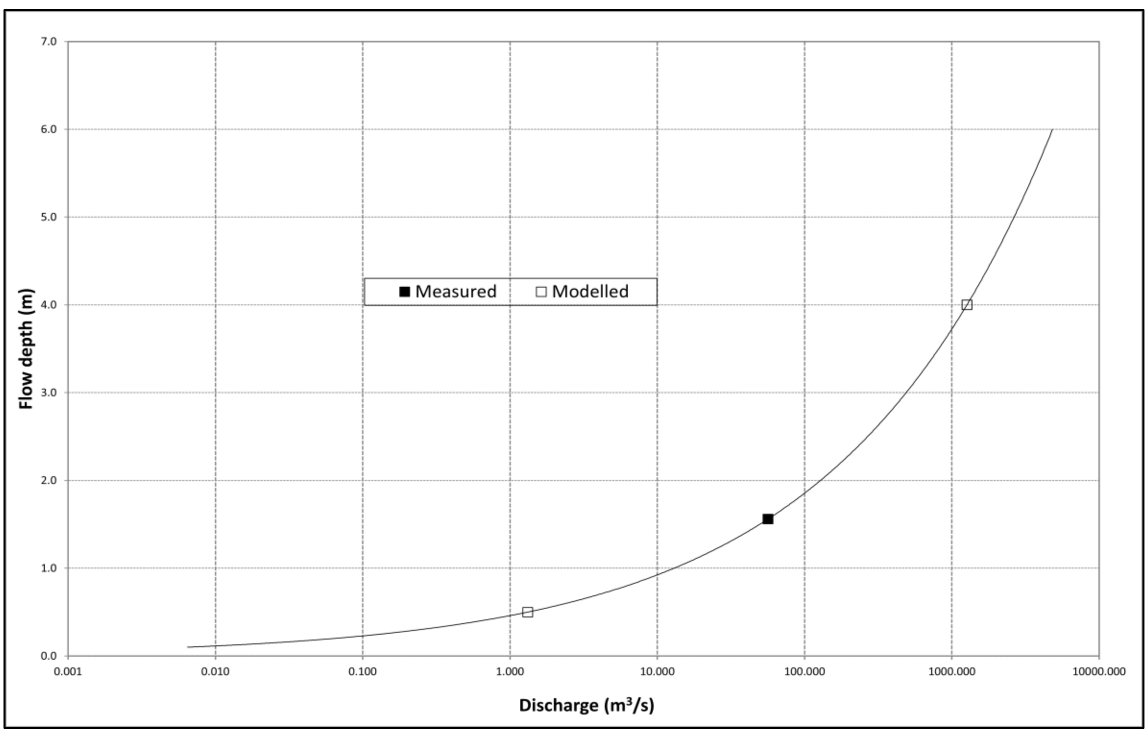

Figure 9: Relationship between flow depth and discharge at LO_EWR02_Boegoeberg EWR site

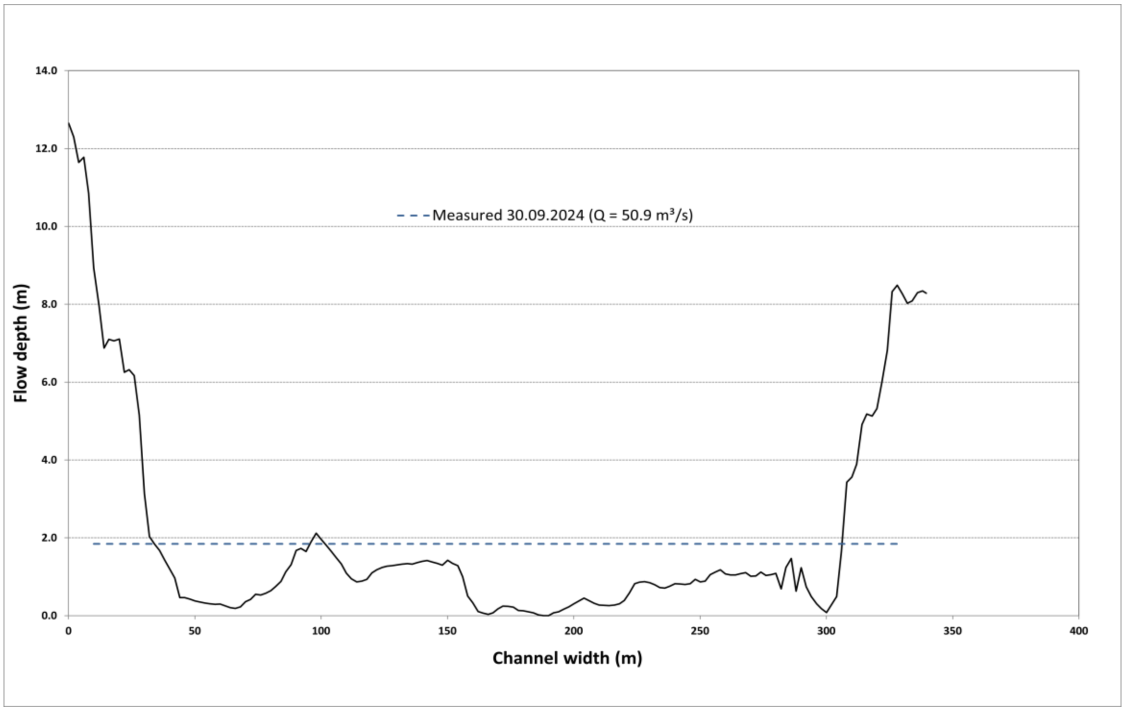

Figure 10: Cross-sectional view of the LO_EWR03_Augrabies EWR site

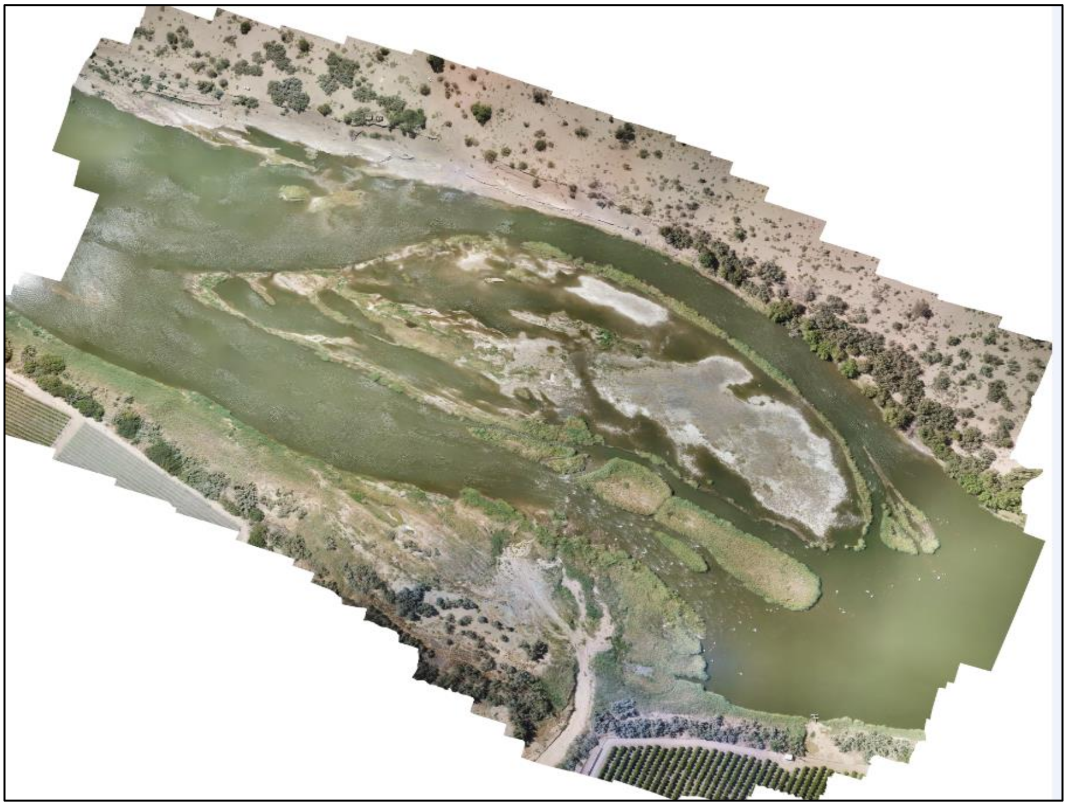

Figure 11: Aerial view of LO_EWR03_Augrabies EWR site (30/09/2024)

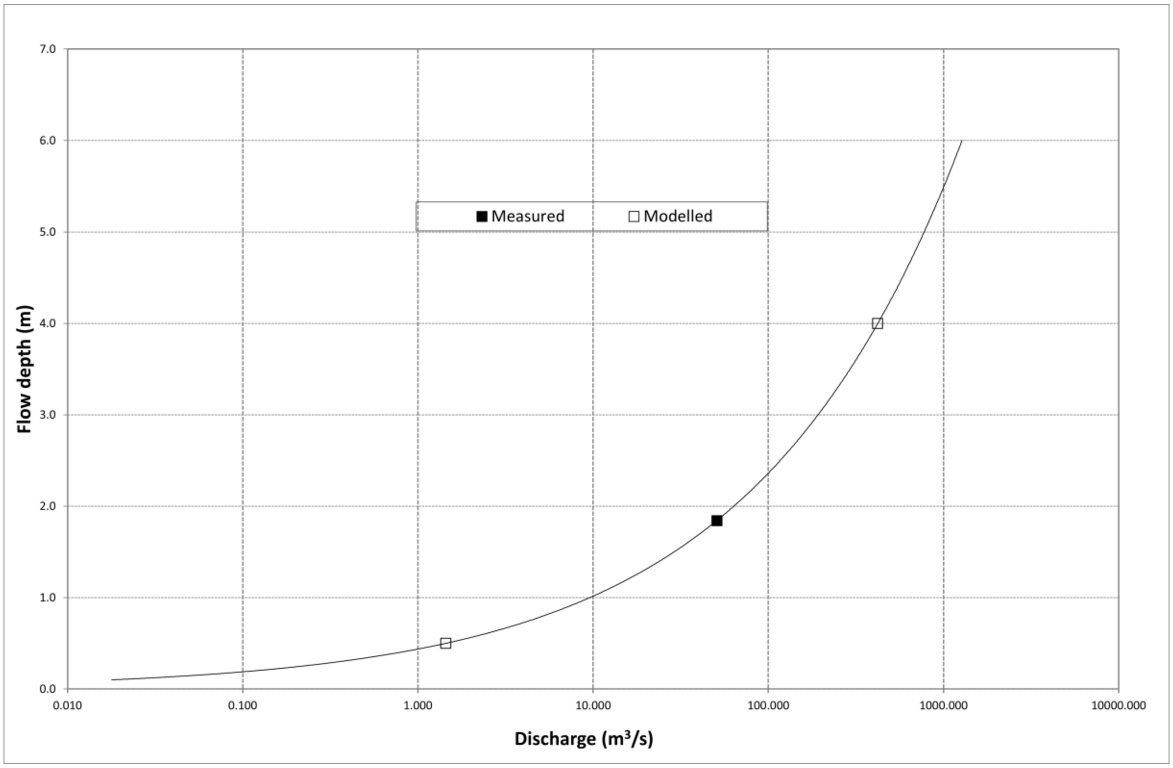

Figure 12: Relationship between flow depth and discharge at LO_EWR03_Augrabies EWR site

The confidence rating in the hydraulic modelling results for the EWR sites ranges from 0=none to 5=high and is indicated in Table 9.

Table 9: Confidence in the hydraulic modelled results at EWR sites on the Lower Orange River

EWR site	Limits of measured discharge range (m^3/s)	Confidence rating for discharge (Q) range		Comments
	Q measured	Q < Q measured	Q > Q measured	
LO_EWR02_ Boegoeberg	56.4	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.
LO_EWR03_ Augrabies	50.9	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.

4.2. Hydrological data

The natural hydrology for the study area was sourced from several previous and current studies. These include data from:

- Latest Water Resources Yield and Planning models for the upper and lower Orange River as well as the inclusion of specific flow time series from the Vaal and Modder/ Riet rivers. This included the revised model that was used for the recently completed comprehensive Reserve determination study for the Upper Orange River and Modder/ Riet catchments.
- The inflows from the contributing rivers from Lesotho and Namibia have also been included to calculate the total flows at the EWR sites and the Orange River Estuary; and
- WR2012 data was used for the drier, ephemeral rivers (Ongers/ Brak, Hartbees/Sak, Molopo and Kuruman).

The natural flow time series obtained from these studies and models were used and adjusted by catchment area and evaporative losses to obtain the natural flows at the selected EWR sites. Thus, during the generation of the natural hydrology for Rapid III level Reserve determination assessment, the position of the EWR sites was determined in relation to the natural hydrology timeseries' representative catchment areas. The natural hydrology timeseries was then scaled by area to approximate the natural flows at the sites. Care was taken to ensure that existing infrastructure in the model network were considered in determining the area scaling to be consistent with the current configuration and to ensure that Present Day flows generated were representative.

Where available, observed daily data from gauging weirs were used during the setting of floods and freshets at the Boegeberg and Augrabies EWR sites.

Table 10 provides the natural MAR (nMAR) for the EWR sites.

Table 10: Natural MAR per EWR site in the Lower Orange Catchment.

IUA	EWR site	River	Latitude	Longitude	Quat*	nMAR ($10^6 m^3$)
1	LO_EWR02	Orange @ Boegoeberg	-28.969493	22.17843	D73C	10 772.6
2	LO_EWR03	Orange @ Augrabies	-28.510372	20.171659	D81B	11 043.6
3	LO_EWR04	Orange @ Vioolsdrift	-28.7553	17.71696	D82F	11 064.3
4	LO_EWR05	Orange @ Sendelingsdrift	-28.0718	16.95951	D82J	11 670.2

** Quaternary catchment*
nMAR – natural MAR

4.3. Water quality data

Water quality data for the Orange River sites were sourced from DWS Upington Office, the RQIS Water Management System (WMS), a once off grab sample and *in situ* sampling undertaken during the Rapid III surveys. This information was used to assess the water quality characteristics at the EWR sites to determine the physico-chemical assessment index for the eco- categorisation. Appendix D includes the analysis results of the DWS historic monitoring undertaken at water quality sites in the vicinity of the EWR sites (either upstream or downstream) (2019 - 2023) and once off grab sample taken at EWR02 and EWR03 during the Rapid III survey. Field measurements taken at the survey are also presented. This information was used for the physico-chemical assessment as an input to eco-categorisation. Most of data obtained from the RQIS did not show reference/baseline conditions as most of it was collected after major impacts had been introduced in the catchments.

5 RESULTS OF THE QUANTIFICATION OF THE ECOLOGICAL WATER REQUIREMENTS

The results of the quantification of the EWRs for the sites along the Lower Orange River are presented in this section. This includes the Rapid III re-surveying of two existing EWR sites (EWR02 and EWR03) and the re-assessment of the EWRs the remaining two sites (EWR04 and EWR 05) using existing hydraulics and biological data. An EWR quantification specialist workshop was held on 4 and 5 November 2024, to determine the EWRs for the two Rapid III EWR sites. The quantification of the EWRs used the following approaches to calculate the requirements for the REC at the EWR sites:

i. LO_EWR02 and LO_EWR03: Verification of the Desktop Reserve Model (DRM) (SPATSIM, version 2.12) for the Rapid III surveys. 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

ii. LO_EWR04 and LO_EWR05: Comparisons between the natural MARs as used during the previous studies (ORASECOM, 2010 and DWS, 2016) with the latest natural MARs for this study. If there was a small percentage change between the natural MARs (<10%) at the EWR sites, the requirements as determined previously were accepted. For larger percentage differences, the new natural MAR was used, and the requirements recalculated using the information as provided during the previous studies. The percentage difference at both the EWR site was less than 10% and thus the EWR results from the previous studies were accepted.

Additionally, for the rapid III surveys at the sites, freshets and annual floods were specified taking the release capacities of dams/ weirs into consideration. The freshets/ floods specified by the ecologists were evaluated using information from a nearby gauge (if available) with daily data to determine whether they are realistic. Without daily data from a nearby gauge, the results of the hydraulic modelling and cross-section of the river were used to guide the ecologists. Comparisons were also made with the freshets and floods that were specified as part of the previous studies (ORASECOM, 2010 and DWS, 2016) as these also included riparian vegetation requirements.

These EWR results for the recommended ecological categories were then used to produce the final EWR 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.

The final total EWR results (summary tables, rule tables and long-term requirements) per EWR site will be provided to DWS electronically.

5.1. LO EWR02_BOEGEBERG ON ORANGE RIVER

5.1.1. Site Details

Site LO_EWR02 (Boegoeberg) is located along the Orange River mainstem approximately 650 meters downstream of the Orange River and Soutloop Tributary of the Orange River. The tributary is predominantly non-perennial. There is extensive agricultural activity (Sandpunt boerdery) on the left side of the riverbank. The average channel width during the survey was measured at 190 meters. The surveyed site is spatially located about 8.8 km downstream of site D7H008Q01 (Boegoeberg Reserve/Zeekoebaart) and 11 km downstream of Boegoeberg Dam. There is water released via canals for downstream users just downstream of the site while the primary flow regulation occurs from the Upper Orange River via Vanderkloof Dam. The site details are described in Table 11, with the location illustrated in Figure 13 and the site photographs depicted in Figure 14.

Table 11: Site Details LO_EWR02_Boegeberg

Sample Date	2 October 2024	**Reserve Level Assessment**	Rapid III
Site Name	LO_EWR02_Boegoeberg	**IUA**	LO_IUA1
River	Orange River	**IUA description**	Orange from Vaal confluence to Augrabies Waterfall. Orange River is the mainstem river with no major tributaries.
Altitude (m.a.s.l.)	1001 m	**Prioritised RU**	RU 1.2
Latitude	-28.969493°	**Longitude**	22.178430°
Level 1 EcoRegion	26. Nama Karoo	**Quaternary catchment**	D73C
Level 2 EcoRegion	26.05	**SQ Reach**	D73C-02945
Geomorphological zone	F (Lowlands)	**PES, 2014**	D
Ecological Importance	High	**Ecological Sensitivity**	High

Site impacts include:

- Flow modification from operation of the upstream Vaal and upper Orange, releases from Vanderkloof Dam for downstream water use and operation of Boegoeberg Weir approximately 10 km upstream of the EWR site
- Return flows (water quality)
- Off-take for canals (Boegoeberg Weir)
- Agriculture and irrigation
- Agriculture encroachment into riparian zone
- Alien invasive plants within riparian zone.

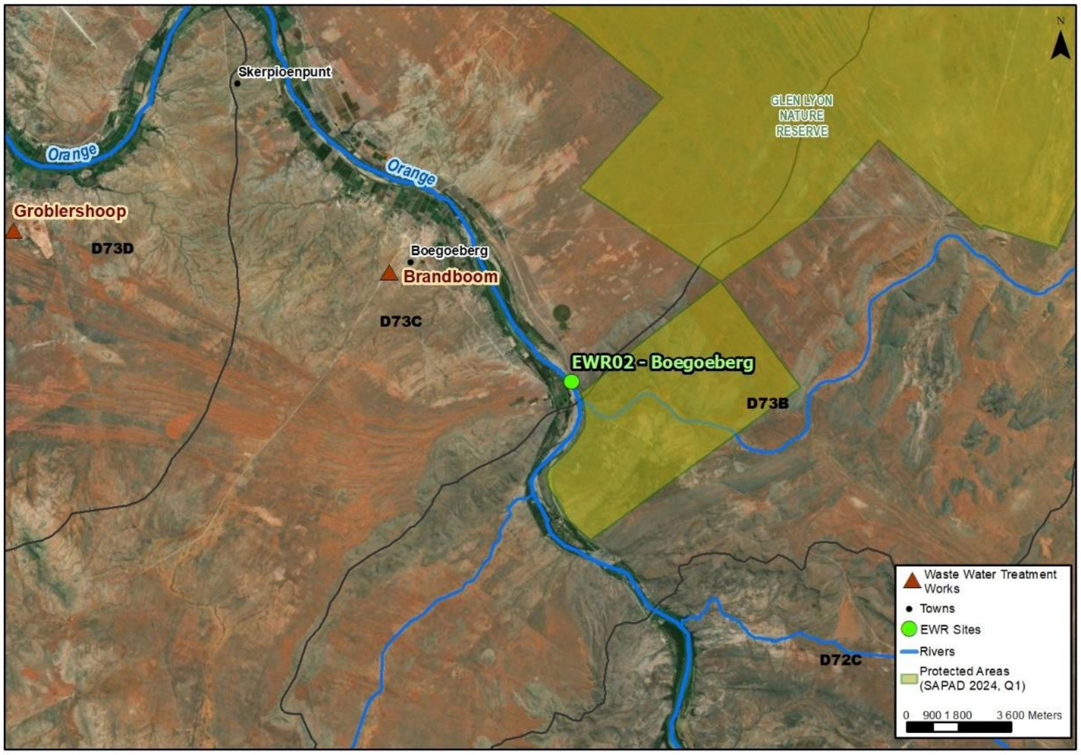

Figure 13: Location of site LO_EWR02_Boegoeberg in relation to the study area

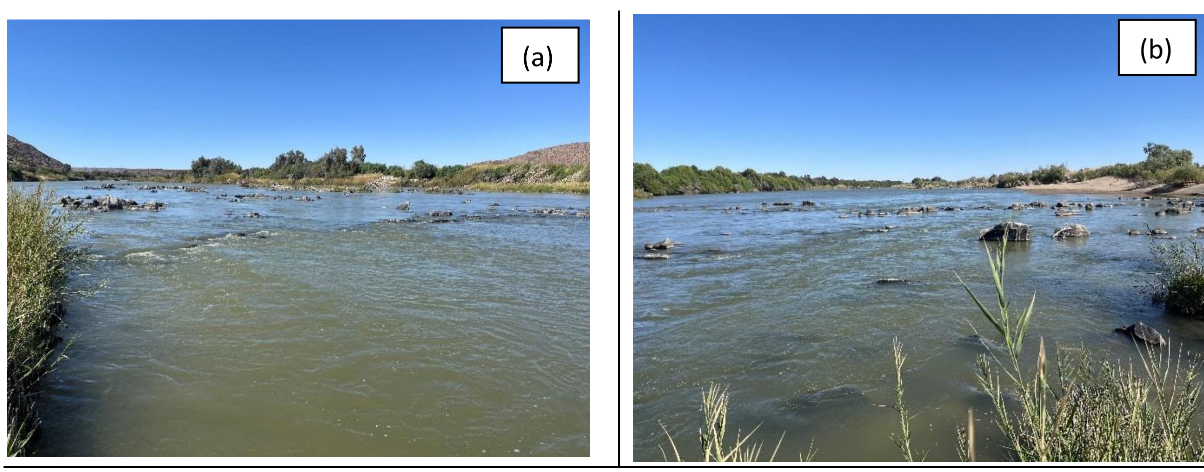

Figure 14: Site photographs of site LO_EWR02_Boegoeberg. (a) downstream and (b) upstream of the EWR site

5.1.2. Eco-Categorisation Results

The information, assessment and results of the eco-categorisation for LO_EWR02_ Boegeberg site are presented in Table 12 to Table 20.

Table 12: Site Evaluation LO_EWR02 Boegeberg

Component	Confidence Score*	Advantages	Disadvantages
Hydraulics	2	• Straight channel form	• -
Fish	3	• Varied flow – releases for irrigation etc. • Diverse habitat available under low flow conditions	• Regulated flow, can influence fish during sudden increases in velocity and depth (physiological adaption periods = low activity) • In high flows, limited habitat to sample. • High nutrients and sediments. • Limited marginal vegetation – related to sudden flow changes, no time for vegetation to establish.
Macro-invertebrates	3	• Good habitat availability • Diversity of flow regimes	• The stones biotope dominated by boulders; • Limited marginal vegetation – bare banks. • High sediment deposition • Downstream of Boegoeberg, water released via canals for downstream users; • Flow regulation from Vanderkloof Dam, likely resulting in a reduction of seasonal variation and a proliferation of the *Simuliidae* population

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

Table 13: Information Availability LO_EWR02 Boegeberg

COMPONENT	INFORMATION AVAILABILITY*					DESCRIPTION OF INFORMATION
	0	1	2	3	4	
Hydraulics		■				• Single observation
Fish				■		• River Eco-status Monitoring Programme (REMP) – limited updated data
Macroinvertebrates					■	• River Eco-status Monitoring Programme (REMP) river database (macroinvertebrate data) – 2023 hydrological year • Updated PESEIS study (2024)
Hydrology				■		• Monthly hydrology available for natural and present day • Daily data from upstream weir D7H008 and spills from Boegoeberg Weir (D7R001) for period 1932-2024
Water quality			■			• Data retrieval from single survey (October 2024) • *In situ* water quality • Physical-chemical water quality • Diatom sample • Green Drop Report Northern Cape, 2022

COMPONENT	INFORMATION AVAILABILITY*					DESCRIPTION OF INFORMATION
	0	1	2	3	4	
			■			• Historic physical-chemical water quality (2019 - 2023) DWS Regional monitoring site at Groblershoop

** 0 (no information) to 4 (large amount of data available)*

Table 14: Site Evaluation LO_EWR02 Boegeberg

COMPONENT	DESCRIPTION OF REFERENCE CONDITIONS
Fish	*Engraulicypris gariepinus* (open water and backwaters – breeds early summer), *Enteromius oraniensis* (pools and impoundments – breeds summer, eggs in vegetation), *Enteromius paludinosus* (slow well vegetated waters – eggs in vegetation), *Enteromius trimaculatus* (prefer vegetation, migrate upstream to breed in summer), *Labeo capensis* (running water, graze on rocks and plants – breed in summer on shallow rapids), *Labeo umbratus* (prefers standing or slow moving water, feed on soft sediment and detritus – breed in summer and spawn on grass inundated grass beds), *Labeobarbus aeneus* (deep pools or flowing water with sandy or rocky substrate – 5+ km home ranges, sensitive to weather events – breeds spring/summer after substantial freshets, spawn of suitable gravel beds), *Labeobarbus kimberleyensis* (adults in flowing water below rapids, home range up to 12 km, breed mid- to late summer over well oxygenated gravel beds), *Pseudocrenilabrus philander* (variety of habitats, prefer vegetated zones – breed early spring to late summer in constructed nest (male)), *Tilapia sparrmanii* (wide habitat, but prefer standing water with rooted vegetation – males make a shallow nest), *Austroglanis sclateri* (Benthic species in riffles – unknown breeding biology), *Clarias gariepinus* (wide habitat – breeds after good rains on grass banks).
Macro-invertebrates	Porifera, Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Hydracarina, Perlidae, Baetidae >2spp, Caenidae, Heptageniidae, Leptophlebiidae, Prosopistomatidae, Trichorythidae, Chlorocyphidae, Coenagrionidae, Protoneuridae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Naucoridae, Nepidae, Notonectidae, Pleidae, Veliidae, Ecnomidae, Hydropsychidae >2spp, Polycentropodidae, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Muscidae, Simuliidae, Tabanidae, Tipulidae, Ancylidae, Lymnaeidae, Planorbinae, Thiaridae, Corbiculidae, Sphaeridae, Unionidae.
Hydrology	Natural flows at the EWR site were available for the period 1920 to 2004.
Water quality	Reference data (pre-development) for the site could not be obtained. Physical chemical data was available from 2019 - 2023 (DWS Regional monitoring site at Groblershoop). Diatom results were also used to infer the reference Physical-chemical state of the site. Results of the diatom analysis and diatom communities present, indicate that good conditions with low (<20%) levels of organic pollution. According to the spatial diatom analysis, the sites reflected high oxygen saturation levels and low nutrient levels. The regular flow releases down the river system does provide dilution capacity and flushing of the system.

Table 15: PES per component for LO_EWR02 Boegeberg and EcoStatus

COMPONENT	PES category & score	Flow (F)/ Non-flow (NF)	EXPLANATION
Fish (FRAI)[1]	D (52.5)	F/NF	• Poor water quality – silt and nutrient loads, limit sight for predators • Varied flows, seasonality modified – impact on spawning and growth cycles • Poor marginal vegetation for smaller species and fry. • Poor water quality influence food sources *i.e.,* the macroinvertebrates.
Macroinvertebrates (MIRAI) [2]	C (70.25%)	F/NF	• Flow modification from upstream hydropower discharges from Vanderkloof Dam; • Flow modification from Boegoeberg, whereby water is released via canals for downstream users; • Good habitat diversity, although boulder dominated amongst the stones biotope; and • Water quality impairment (extensive irrigation and return flows, pesticides – Simullidae control programme).
Habitat Integrity: Instream[3]	D (46%)	F/NF	• Primary driver/s: • Water abstraction • Flow modification • Bed modification
Habitat Integrity: Riparian[3]	C (65%)	NF	• Primary driver/s: • Exotic vegetation
Physico-chemical[4]	C/D (61.5%)	NF	• Moderate salinity impacts from upstream irrigation • Some presence of nutrients driven by non-compliant WWTWs upstream in the Upper Orange and Lower Vaal (e.g., Hope Town)
Diatoms[5]	B	NF	• Well-oxygenated, meso-to eutrophic conditions • Low levels of organic nutrients present. • Good condition with %PTV of 6, and SPI of 13.3
ECOSTATUS (PES)[g]	**C (62.9%)**	**Primary drivers: fish component and instream habitat integrity**	

[1]*Refer to Appendix A for the fish inventory and FRAI Models*
[2]*Refer to Appendix B for the SASS5 data and MIRIA Models*
[3]*Refer to Appendix C for the IHI results*
[4]*Refer to Appendix D for the* Physical-chemical *results*
[5]*Refer to Appendix E for the* Diatom *results*

Table 16: Component PES and related causes LO_EWR02 Boegeberg

<table>
<tr><th></th><th>Causes
Present/Absent</th></tr>
<tr><td>Fish[1]</td><td>
During the survey, high flows limited access for effective sampling with the electro shocker. It was not possible to use other methods for sampling e.g., cast nets due to the high flow velocities.
The result was a low diversity and number of fish collected.
Changes in flow velocities – releases prior to the site visit resulted in fish taking refuge from increased flows – low activity in the changing environment. Lack of marginal and instream vegetation is a concern as many of the smaller species utilise it as general habitat, nursey areas or spawning habitat. The sediment loads limit habitat for spawning (Labeobarbus spp. and Austroglanis sclateri) and visual limit for predators (L. kimberleyensis). Sediment loads abrasive on fish gills and small fish.
Physiological impacts (e.g., breeding and stress), lack of habitat (i.e., sedimentation and limited instream and marginal vegetation) related to the flow modifications and physio-chemical declines in water quality will have an impact on most species (especially the fry).
The low diversity resulted in a poor PES score (52.5 %) and a class “D”.
<table>
<tr><th>METRIC GROUP</th><th>WEIGHT (%)</th></tr>
<tr><td>VELOCITY-DEPTH</td><td>98.04</td></tr>
<tr><td>COVER</td><td>100.00</td></tr>
<tr><td>FLOW MODIFICATION</td><td>70.31</td></tr>
<tr><td>PHYSICO-CHEMICAL</td><td>71.07</td></tr>
<tr><td>MIGRATION</td><td>61.45</td></tr>
<tr><td>IMPACT OF INTRODUCED</td><td>38.04</td></tr>
</table>
</td></tr>
<tr><td>Macroinvertebrates[2]</td><td>
A total of 15 SASS5 taxa was observed at the site, with a SASS5 Score of 90, and the ASPT value of 6.0.
A variety of macroinvertebrate biotopes were accessible, with the exception of marginal vegetation, which was limited. The stone biotopes were primarily dominated by boulders, with some cobbles and gravel present in the interstitial zones.
Of the 15 macroinvertebrate families recorded, most showed a preference for low water quality, cobbles, and varying hydraulic conditions. The primary drivers of community composition were water quality (63.3%) and habitat metrics (69.8%), due to the dominance of boulders and the scarcity of marginal vegetation. This, however, reflects the natural characteristics of the system. Flow modification, measured at 77.6%, was not the main driver, but the site's location downstream of Boegoeberg, where water is released via canals for downstream users, along with flow regulation from Vanderkloof Dam, likely reduces seasonal variation. This has contributed to a proliferation of Simuliidae (species: Simulium chutteri), often present in high abundance. As a result, farmers along the reach undertake annual or bi-annual pesticide spraying to control Simuliidae populations. Overall, two key points of interest emerged. The high abundance of Hirudinea at the site during the survey. This family prefers moderate flows, cobbles, GSM, and very low water quality. Secondly, the population of Simuliidae, which, as stated above, was expected to be abundant, was in fact limited. This may be due to recent spraying as part of the Simuliidae control programme.
Overall, the collected aquatic macroinvertebrate assemblage was representative of moderately modified conditions (Ecological Category C, 70.25%) (refer to Table 17), aligning with the results from the previous hydrological year's (2023) REMP findings (site located just downstream of this studies EWR site).
</td></tr>
</table>

	Causes Present/Absent
Hydrology	Refer to Figure **15** which illustrates the differences in the the flow curve for Natural (NAT), Baseflows (BF) and the Present Day flows (PRS).

[1]*Refer to Appendix A for the fish inventory and FRAI Models*
[2]*Refer to Appendix B for the SASS5 data and MIRAI Models*

Table 17: Macroinvertebrate community Ecological Category based on weights of metric groups for LO_EWR02_Boegoeberg

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	77.6	0.316	24.4976	2	90
HABITAT	H	69.8	0.316	22.0559	2	90
WATER QUALITY	WQ	63.3	0.351	22.2089	1	100
CONNECTIVITY & SEASONALITY	CS	85.0	0.018	1.49123	3	5
						285
INVERTEBRATE EC				70.2537		
INVERTEBRATE EC CATEGORY				C		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						

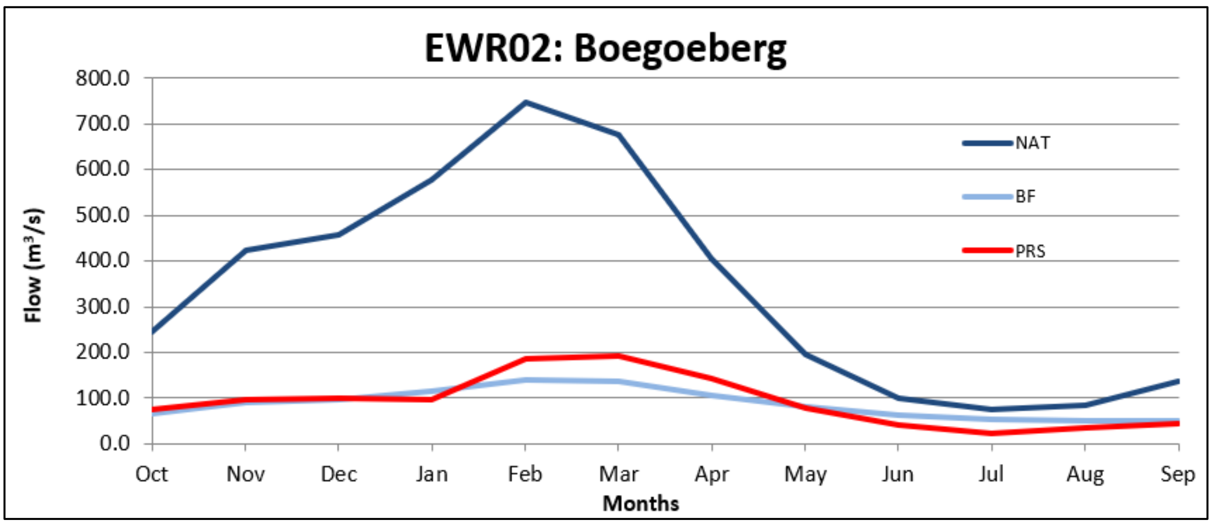

Figure 15: Flow curve for LO_EWR02 (Boegoeberg)

Table 18: Ecological trends for LO_EWR02 Boegeberg

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Declining	• Decline in water quality • Fishing with nets reported throughout many systems will have a negative impact • Loss of marginal vegetation – habitat for smaller spp. • Loss of spawning habitat – substrate in-channel due to siltation and marginal vegetation and grassy flooded banks.	3
Macroinvertebrates	Stable to declining (Figure 16)	• Deterioration of water quality • Annual proliferation of *Simuliidae* populations in response to poor water quality and seasonal flow variations. • Main riffle/run supports good flow throughout the year and as such, habitat is there to support sensitive taxa.	3
Physico-chemical	Declining trend	• Increasing salinity from upstream irrigation (intensive irrigation activity from Douglas, Prieska area and Boegoeberg). High salts from the Vaal catchment are also becoming a concern. • Nutrients impacts are noted due increased loads from deteriorating (non-compliant) WWTWs in towns in the Vaal, Upper Orange (before confluence (e.g., Hope Town) • Increase in toxics specifically aluminium is becoming a concern (historic data 2022 – 2023 at DWS Regional monitoring site at Groblershoop). • The reach does adapt to the impacts probably due to the constant flow releases.	4
ECOSTATUS (PES)	**Stable**		

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

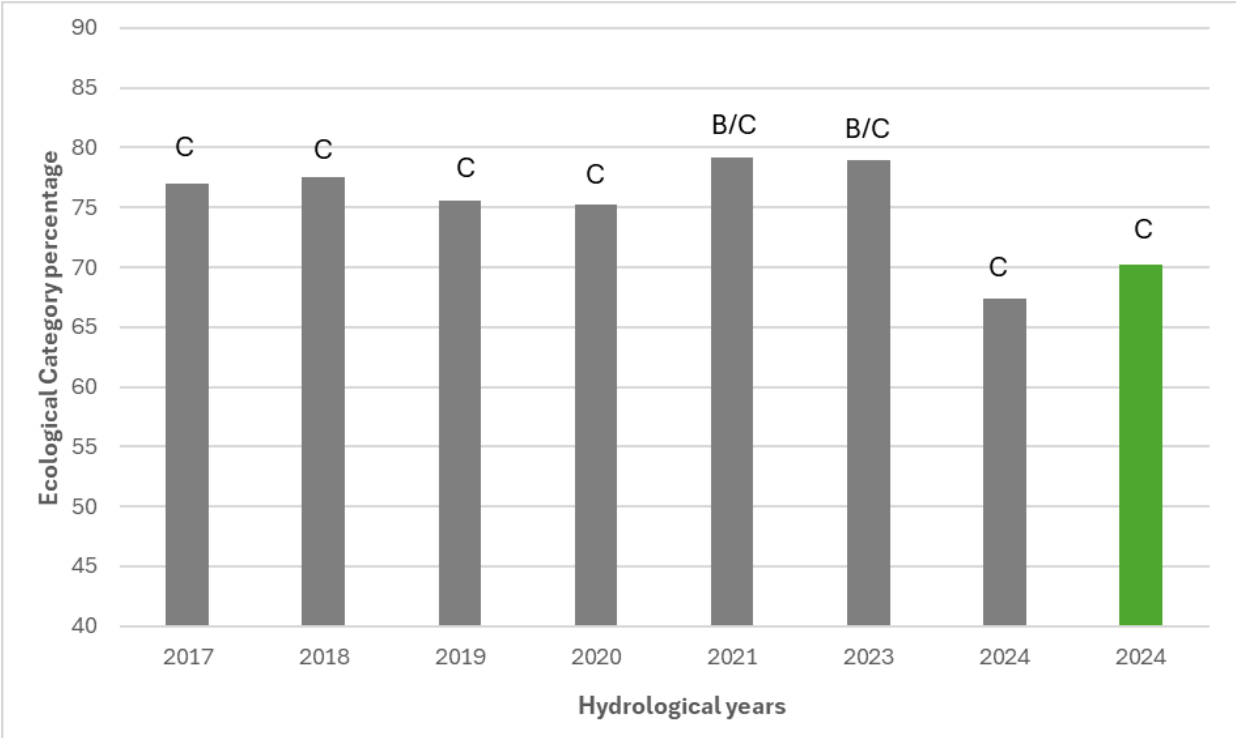

Figure 16: Graph illustrating the Ecological Category percentage for REMP site D7ORAN-GROBL (grey) and this current Classification study's results (green) (no data for 2022).

The overall change and reason for deviation from reference conditions are as follows:

- Loss of frequency of large floods (owing to upstream dams);
- Increased agricultural return flows (water quality impairment);
- Increase in the blackfly (*Simulium chutteri*) population owing to flow fluctuations;
- Higher low flows than natural in the dry season, drought and dry periods (providing incorrect ques for fish for movement and spawning);
- Decreased low flows at other times;
- Annual release of sediment; and
- Presence of alien fish species and barrier effects of dams.

The revised Ecological Importance and Ecological Sensitivity will remain High, High as per WRP Consulting Engineers in association with Golder Associates, DMM, PIK, RAMBOLL and WCE - Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan Study, 2010. Please refer to Table 19 for the PES and REC results for this EWR site and whether the results are as per flow or non-flow related impacts.

Table 19: EcoStatus PES and REC results for LO_EWR02_Boegoeberg

Eco status PES	REC	
C	B/C	• *F: L*ower baseflows during the dry season, combined with a greater seasonal range, are expected to enhance habitat diversity, which should boost biodiversity and help reduce outbreaks of the pest blackfly *Simulium chutteri*. Other taxa will likely establish under a more natural flow regime, including providing the correct cues for fish species to respond to in terms of movement and spawning habits. • *NF: W*ater quality issues may keep the category in Category C.

Important to note that various recommendations/interventions have been summarised, with the aim to improve the EcoStatus (PES) and achieve the REC. These have been split between:

1. *Flow (F) interventions: whereby to what extend can the impacts/influences be mitigated i.e. implementing operating rules for instream dams to release the EWR, or at least a baseflow to aid in improved flows; and*
2. *Non-Flow (NF) interventions, being those that could potentially be rehabilitated and/or restored (i.e., Wastewater Treatment Works (WWTW)).*

This applies throughout the report for the REC.

5.1.3. Overall Assessment

The overall EcoStatus for this EWR site is classified as Category C, indicating a moderately modified condition with loss and alteration of natural habitat and biota, evident in changes to frequency and abundance (Table 20). Catchment degradation is influenced by elevated nutrient loads from return flows and flow modifications caused by upstream hydropower operations at Vanderkloof Dam, leading to seasonal disruptions that affect spawning and growth cycles of fish. Poor marginal vegetation further contributed to this category, by limiting habitat availability for smaller fish species, fry, and macroinvertebrates that rely on this biotope.

It is suggested that a REC of a B/C (close to largely natural) can be achieved, should the proposed mitigation measures/ recommendations be assessed and applied (Table 20).

Table 20: Overall EcoStatus assessment for LO_EWR02_Boegoeberg

River	**Orange**
EWR Site Code	**LO_EWR02_Boegoeberg**
Driver component	**PES**
Water quality (physico-chemical)	C
IHI (instream)	D
IHI (riparian)	C
Response component	**PES**
Diatoms	**B**
FRAI	D
MIRAI	C
EcoStatus	**C**
EI	High

ES	High
REC	**B/C**

5.1.4. Recommendations

- Ensure the upstream movement of fish species is not impacted in any way through the development or disturbance of instream connective integrity. Where any new activities are proposed, appropriate fishways should be implemented;
- Any future land use activities within the upstream catchment should be managed to prevent degradation of the ecological health of the system and deterioration of the water quality (buffer zones should be implemented for future proposed developments);
- Alien weed infestation eradication implementation programme;
- Catchment management (cattle grazing and trampling);
- Strive towards undertaking the blackfly control spray programme to be carried out three weeks before the first scheduled freshet, as outlined in the EWR (see section 5.1.5). The freshet aims to scour the stones biotope of dead blackfly larvae, reset the biotopes, and dilute the water column to support the establishment and colonisation of other macroinvertebrates; and
- Any future land use activities within upstream catchment should be managed to prevent degradation of the ecological health of the system and deterioration of the water quality (buffer zones to be implemented for future proposed developments).

5.1.5. EWR Quantification Results for EWR02

The EWR for the Orange River at Boegoeberg 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 February and July. July is the month with the lowest average flow (*i.e.,* base-flow) and February is the month with the highest average flow conditions (according to the natural flows). October was also examined as the surveys were undertaken during October to provide a visual baseline for the ecologists when considering the various flow requirements.

Together with the site photographs and flow rating (discharge tables) (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 2 October 2024 was 56.4 m^3/s and was used as reference to adjust the recommended EWRs (Figure 17). It should be noted that the baseflows were higher than expected during the survey as a result of the releases from upstream for water users downstream in the catchment.

The consensus reached by the aquatic ecologists was that the recommended flows for both drought and maintenance low flows did not provide adequate velocities and availability of instream habitats for the macroinvertebrates. The maintenance low flows were adjusted in order 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). However, consideration was also given to the annual *Simuliidae* outbreaks in this region. For specific months (e.g., July), flow adjustments were evaluated to expose the stone biotope, aiming to reduce the outbreak in coordination with the *Simuliidae* spraying programme (see Section 6.1 for further details).

In terms of the fish component, 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 community. The available biotic critical habitat at these recommended flows is provided in Table 21. Those habitats highlighted in grey are critical habitats for rheophilic fish species and fast to very fast flow dependent macroinvertebrates (*i.e.*, sensitive taxa to flow). Therefore, the recommended flows (drought and maintenance) were adjusted as follows and which are illustrated on the cross-section in Figure 17.

(i) Maintenance low flows:
- October - Adjusted from 37.0 m^3/s to 56.1 m^3/s
- February - Adjusted from 93.8 m^3/s to 142.7 m^3/s

(ii) Drought flows:
- A minimum of 15.0 m^3/s for April to October, 22.0 m^3/s for November to January and 33.0 m^3/s for February and March.

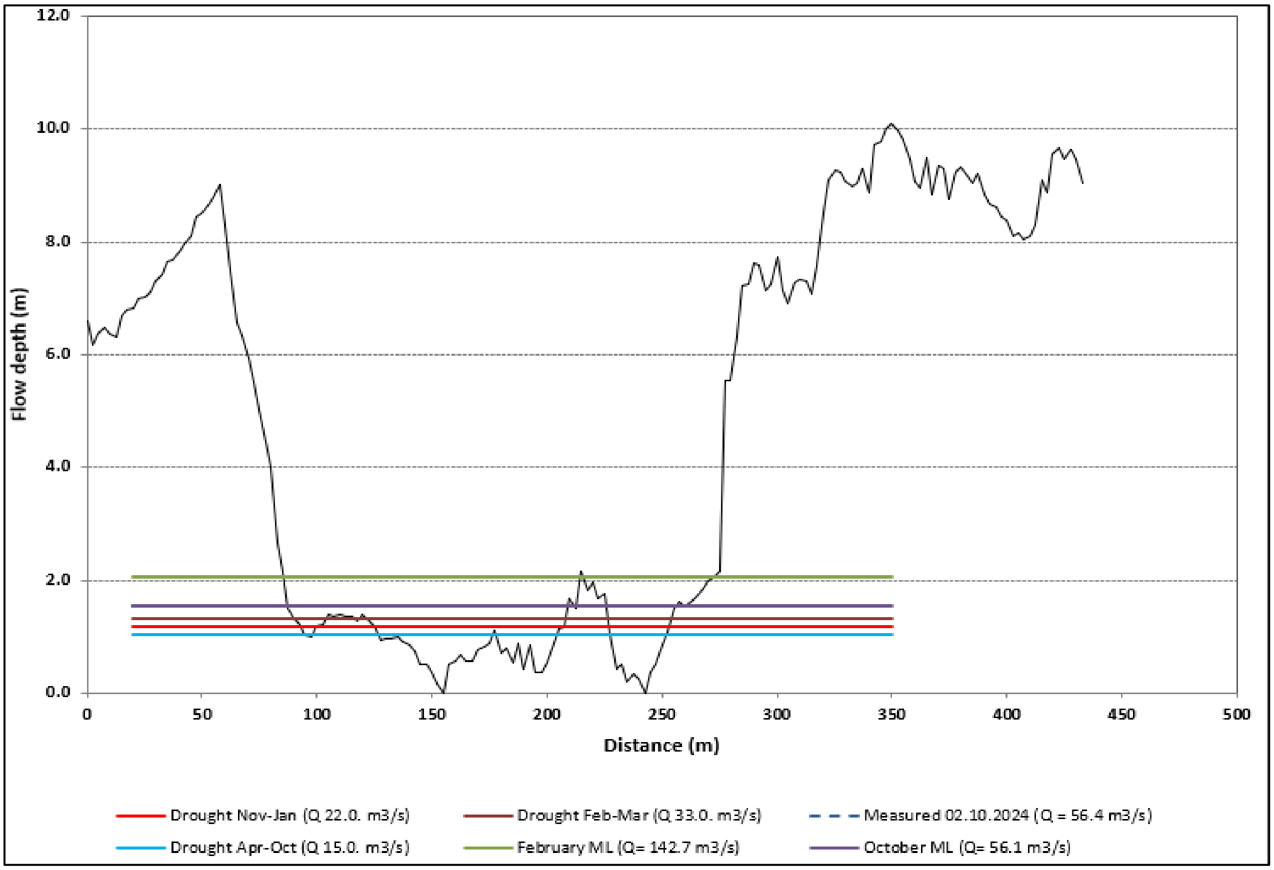

Figure 17: Water levels on cross-section of EWR site LO_EWR02_Boegoeberg

Table 21: Percentage available of the critical habitats for fish and macroinvertebrates at the recommended maintenance low flows

Fish habitats*	% availability	Macroinvertebrates habitats*	% availability
Maintenance low flows (October - 56.1 m³/s)			
SvS[1]	1	VSCS[2]	8
SS	9	SCS	14
SD	21	FCS	23
FVS	3	VFCS	25
FS	7	VSFS	3
FI	5	SFS	6
FD	54	FFS	10
		VFFS	11
		VEG	0
Maintenance low flows (February - 142.7 m³/s)			
SvS	1	VSCS	2
SS	3	SCS	5

Fish habitats*	% availability	Macroinvertebrates habitats*	% availability
SD	16	FCS	9
FVS	2	VFCS	21
FS	2	VSFS	4
FI	2	SFS	8
FD	73	FFS	15
		VFFS	36
		VEG	0

**Those habitats which are critical are highlighted in grey*
[1]Fish habitats: SvS: slow very shallow; SS: slow shallow; SD: slow deep; FVS: fast very shallow; FS: fast shallow; FI: fast intermediate; FD: fast deep
[2]Macroinvertebrate habitats: VSCS: very slow course substrate; SCS: slow course substrate; FCS: fast course substrate; VFCS: very fast course substrate; VSFS: very slow fine substrate; SFS: slow fine substrate; FFS: fast fine substrate; VFFS: very fast fine substrate; VEG: vegetation

From a macroinvertebrate perspective, the outbreaks that occur from the blackfly along this reach (and beyond) was taken cognizance of when considering quantifying the EWR. The critical periods for controlling population sizes of *Simuliidae* are generally July to August (winter months) when most of the population is present in the larval or pupal phase (O'Keeffe and de Moor, 1988). Thus, reduced flows, and lower water levels, during these months is critical to expose the substrate to dry out blackfly larvae and pupae in these months (de Moor, 1982b, 1997; O'Keeffe and de Moor, 1988). This may potentially avoid the typical spring outbreaks of blackfly's during the end of winter/ spring seasonal period (*i.e.,* September). Furthermore, ensuring those freshets or floods come through during the months of October/ November to March/ April so to scour the substrate and re-set the systems are applied.

The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 22. The final EWR for the Lower Orange River at the EWR site LO_EWR02 is summarised in Table 23.

Table 22: Lower Orange at LO_EWR02 - Freshets and flood requirements for implementation

Months	Freshets			Floods		
	Q (m³/s)[1]	# events	days	Q (m³/s)[1]	# events	days
October	130	1	2			
November	180	3	6			
December	180	2	6			
January	180	2	6			
February	180	2	6	410	1	8
March	300	2	6			
April	180	1	6			

Q – discharge in cubic meters per second

Table 23: Lower Orange EWR02 - Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D73D	
Site number	LO_EWR02	
River	Lower Orange @ Boegoeberg	
	Current study	**ORASECOM, 2011**
Recommended Ecological Category	B/C	C
Natural MAR at EWR site	10 772.6	10 573.7
Total EWR	3351.544 (31.11 %MAR)	15.2%
Maintenance Low flows	2673.139 (24.81 %MAR)	11.6%
Drought Low flows	620.438 (5.76 %MAR)	4.4%
Maintenance High flows	678.404 (6.30 %MAR)	5.4%
Overall confidence	Moderate	

5.2. LO_EWR03_AUGRABIES – ORANGE RIVER

5.2.1. Site Details

Site LO_EWR03 (Augrabies) is located along the Orange River mainstem approximately 4.3 km downstream of the Orange River and the Molopo River confluence. A few non-perennial tributaries confluence with the Orange River near this site along the left banks, with the notable one being the Bul River located about 1.4 km just upstream of the site and about 500 meters downstream of Benede Oranje Bridge. Extensive agricultural cultivation is limited to the left side of the riverbank due to steep right bank slopes and mountainous geology. The average channel width during the survey was measured at 70 meters where water quality and biota sampling was conducted. The hydraulics assessment was conducted about 500 meters upstream from the sampling site with the channel width averaging 200 meters. The surveyed site located about 8.8 km downstream of site D8H014 (Blouputs weir) and 24 km downstream of Augrabies Falls. The site details are described in Table 24 with the site location illustrated in

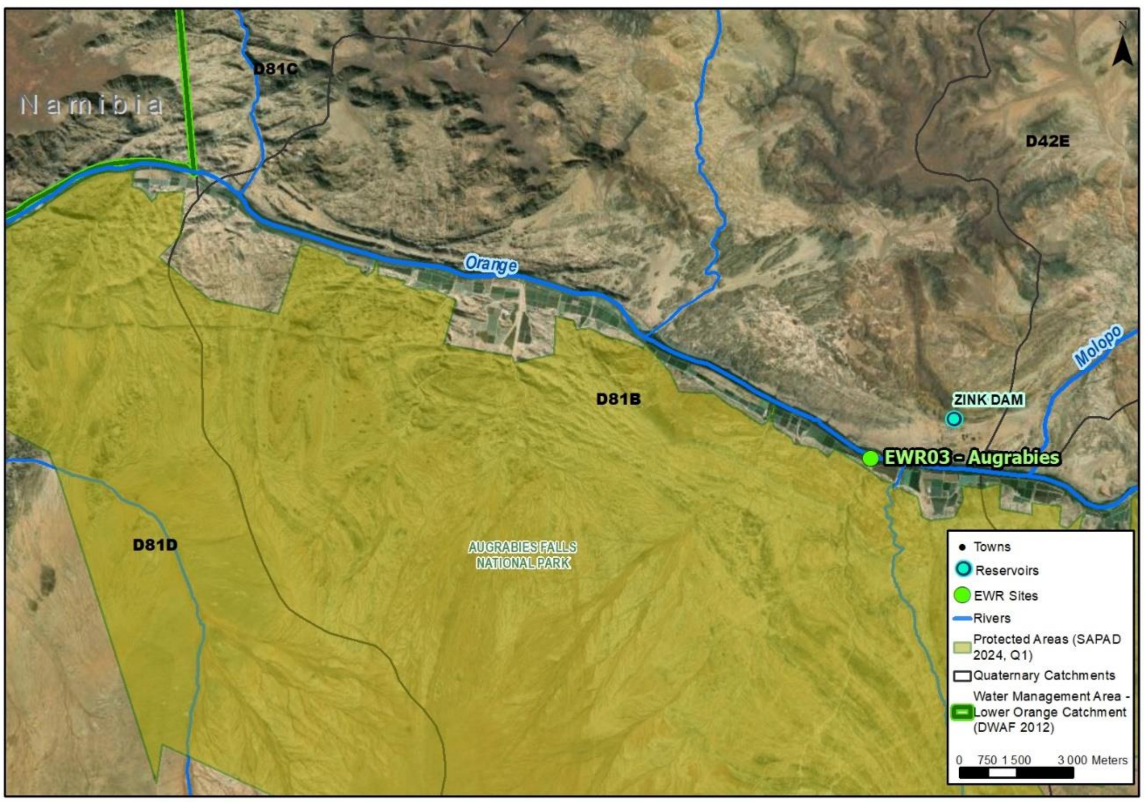

Figure **18** and site photographs depicted in Figure 19.

Table 24: Site Details LO_EWR03 Augrabies

Sample Date	30 September 2024	**Reserve Level Assessment**	Rapid III
Site Name	LO_EWR03_Augrabies	**IUA**	LO_IUA2

River	Orange River	**IUA description**	Downstream Augrabies to Pella. Orange River mainstem with a number of ephemeral tributaries.
Altitude (m.a.s.l.)	436 m	**Prioritised RU**	RU 2.2
Latitude	-28.510372°	**Longitude**	20.171659°
Level 1 EcoRegion	28. Orange River Gorge	**Quaternary catchment**	D81B
Level 2 EcoRegion	28.01	**SQ Reach**	D81B-03140
Geomorphological zone	F (Lowlands)	**PES, 2014**	C
Ecological Importance	Moderate	**Ecological Sensitivity**	High

Site impacts include:

- Flow modification
- Return flows (water quality)
- Agriculture and irrigation
- Agriculture encroachment into riparian zone

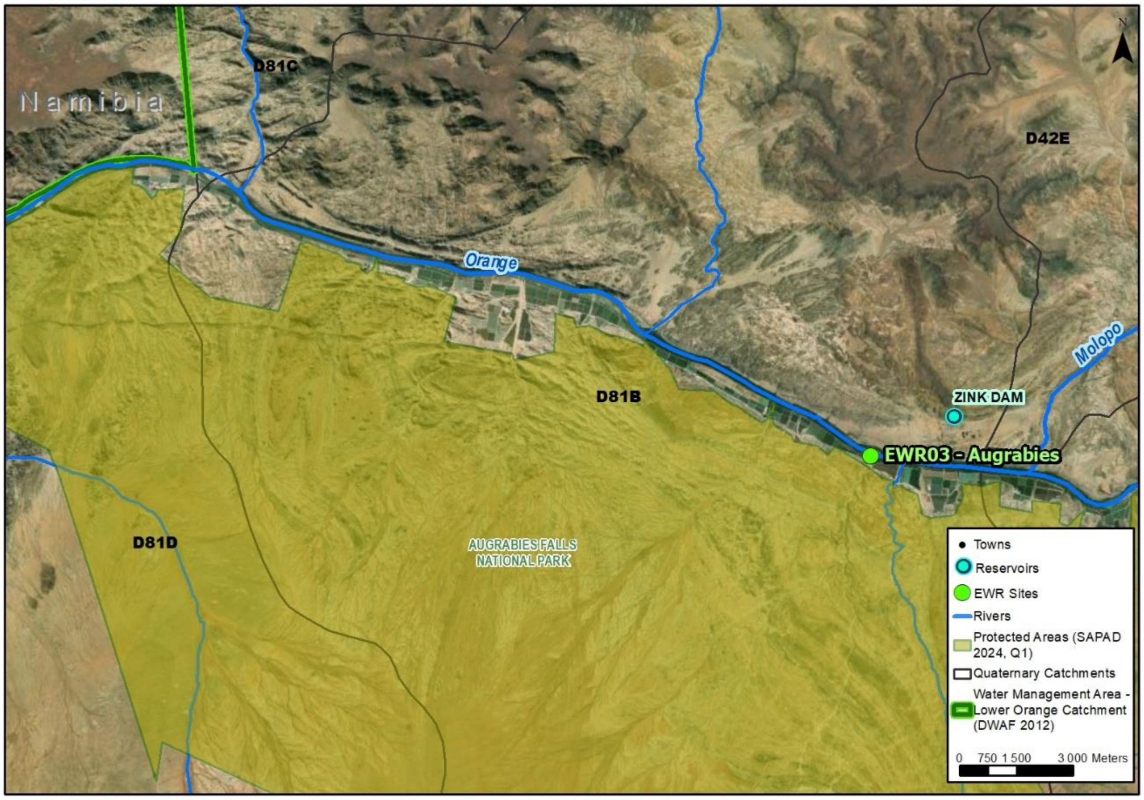

Figure 18: Location of site LO_EWR03_Augrabies in relation to the study area

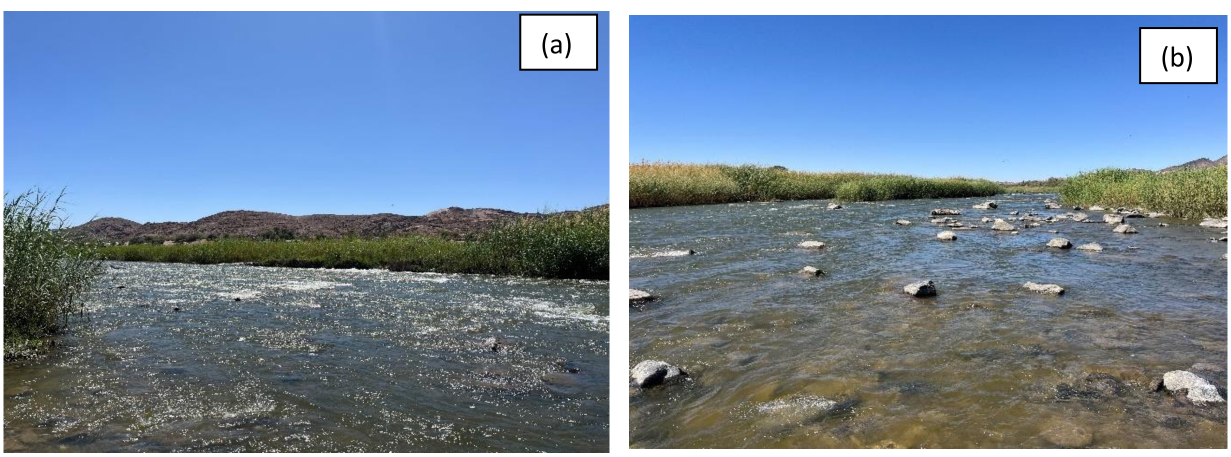

Figure 19: Site photographs of site LO_EWR03_Augrabies (a) downstream and (b) upstream of the EWR site

5.2.2. Eco-Categorisation Results

The information, assessment and results of the eco-categorisation for the LO_EWR03_ Augrabies site are presented in Table 25 to Table 33.

Table 25: Site Evaluation LO_EWR03 Augrabies

Component	Confidence Score*	Advantages	Disadvantages
Hydraulics	2	• Straight channel form	• Slightly downstream from braided islands
Fish	3	• Good habitat under low flow conditions • Regulated flows – but gives good diversity of regimes	• Rapid changes in flow velocities can have a negative impact on the fish. • Poor marginal vegetation – this was owing to the floods that took place early 2023 which removed virtually all the vegetation, to which has not yet recovered to date. Pre-flood, there was extensive reeds along the marginal zone. • Poor water quality can impact on sensitive species. • High silt loads – limit predators to hunt.
Macro-invertebrates	3	• Good habitat availability • Diversity of flow regimes	• Marginal vegetation dominated by hard woody *Phragmites australis*, limited deciduous plant species/shrubs (as per reasoning stated above regarding the floods) • High sediment deposition • Some irrigation water mostly released in canals; • Unfortunately, Augrabies Falls does not act as a barrier to changes in river flow caused by releases from the upstream Vanderkloof Dam. This stretch of the river still responds to flow regulation, seasonal variations, and an increase in the Simuliidae population due to Vanderkloof Dam and the associated activities.

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

Table 26: Information Availability LO_EWR03 Augrabies

COMPONENT	INFORMATION AVAILABILITY*					DESCRIPTION OF INFORMATION
	0	1	2	3	4	
Hydraulics		■				• Single observation
Fish				■		• River Eco-status Monitoring Programme (REMP) – limited updated data • Updated PESEIS study (2024); and • JBS3 ORASECOM site OSAEH 28_02.
Macroinvertebrates					■	• River Eco-status Monitoring Programme (REMP) river database (macroinvertebrate data) – 2023 hydrological year (data collected since 2017); • Updated PESEIS study (2024); and • JBS3 ORASECOM site OSAEH 28_02.
Hydrology				■		• Monthly hydrology available for natural and present day

COMPONENT	INFORMATION AVAILABILITY*					DESCRIPTION OF INFORMATION
	0	1	2	3	4	
				■		• Daily data from upstream weir D8H014 (2014-2024) from downstream weir D8H004 (1971-2024)
Water quality			■			• Data retrieval from single survey (September 2024) • *In situ* water quality • Physical-chemical water quality • Diatom sample • Green Drop Report Northern Cape, 2022 • Historic physical-chemical water quality (2019 - 2023) DWS Regional monitoring site at Blouputs

** 0 (no information) to 4 (large amount of data available)*

Table 27: Reference Conditions - LO_EWR03 Augrabies

COMPONENT	DESCRIPTION OF REFERENCE CONDITIONS
Fish	*Namaquacypris hospes* (open water over sand and gravel – spawn September to March) *Engraulicypris gariepinus* (open water and backwaters – breeds early summer), *Enteromius oraniensis* (pools and impoundments – breeds summer, eggs in vegetation), *Enteromius paludinosus* (slow well vegetated waters – eggs in vegetation), *Enteromius trimaculatus* (prefer vegetation, migrate upstream to breed in summer), *Labeo capensis* (running water, graze on rocks and plants – breed in summer on shallow rapids), *Labeo umbratus* (prefers standing or slow moving water, feed on soft sediment and detritus – breed in summer and spawn on grass inundated grass beds), *Labeobarbus aeneus* (deep pools or flowing water with sandy or rocky substrate – 5+ km home ranges, sensitive to weather events – breeds spring/summer after substantial freshets, spawn of suitable gravel beds), *Labeobarbus kimberleyensis* (adults in flowing water below rapids, home range up to 12 km, breed mid- to late summer over well oxygenated gravel beds), *Pseudocrenilabrus philander* (variety of habitats, prefer vegetated zones – breed early spring to late summer in constructed nest (male)), *Tilapia sparrmanii* (wide habitat, but prefer standing water with rooted vegetation – males make a shallow nest), *Austroglanis sclateri* (Benthic species in riffles – unknown breeding biology), *Clarias gariepinus* (wide habitat – breeds after good rains on grass banks).
Macro-invertebrates	Porifera, Turbellaria, Oligochaeta, Hirudinea, Potamonautidae, Atyidae, Perlidae, Baetidae >2spp, Caenidae, Heptageniidae, Leptophlebiidae, Trichorythidae, Chlorocyphidae, Chlorolestidae, Coenagrionidae, Platycnemidae, Aeshnidae, Corduliidae, Gomphidae, Libellulidae, Belostomatidae, Corixidae, Gerridae, Hydrometridae, Naucoridae, Nepidae, Notonectidae, Pleidae, Veliidae, Ecnomidae, Hydropsychidae >2spp, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Helodidae, Hydraenidae, Hydrophilidae, Ceratopogonidae, Chironomidae, Culicidae, Empididae, Muscidae, Simuliidae, Tabanidae, Tipulidae, Ancylidae, Lymnaeidae, Physidae, Planorbinae, Thiaridae, Corbiculidae, Sphaeridae, Unionidae.
Hydrology	Monthly natural flows available for period 1920 to 2004.

COMPONENT	DESCRIPTION OF REFERENCE CONDITIONS
Water quality	Reference data (pre-development) for the site could not be obtained. Physical chemical data was available from 2019 – 2023 (DWS Regional monitoring site at Blouputs). Diatom results were also used to infer the reference Physical-chemical state of the site. Results of the diatom analysis and diatom communities present, indicate that good conditions with low (<20%) levels of organic pollution. According to the spatial diatom analysis, the sites reflected high oxygen saturation levels and low nutrient levels. The regular flow releases down the river system does provide dilution capacity and flushing of the system.

Table 28: PES per Component for LO_EWR03 Augrabies and Ecostatus

COMPONENT	PES category & score	Flow (F)/ Non-flow (NF)	EXPLANATION
Fish (FRAI)[1]	D (49.9)	F/NF	• Changes in flows regime • Off takes and abstraction • Habitat diversity good, but fluctuations limit the establishment of overhanging vegetation. • Limited food resources (macroinvertebrates and instream vegetation) as result of the poor water quality.
Macroinvertebrates (MIRAI)[2]	C (68.9%)	F/NF	• Flow modification from upstream hydropower discharges from Vanderkloof Dam; • Offtake weirs upstream; • Good habitat diversity, although boulder dominated amongst the stones biotope; and • Water quality impairment (extensive irrigation and return flows, pesticides – *Simullidae* control programme).
Habitat Integrity: Instream[3]	D (51%)	F/NF	• Primary driver/s: • Water abstraction • Flow modification
Habitat Integrity: Riparian[3]	B/C (89%)	NF	• Primary driver/s: • Physico-chemical • Flow modification
Physico-chemical[4]	D (57.9%)	NF	• Increased in salinity concentration (TDS and macro ions) • Toxics are a concern • Elevated nutrients
Diatoms[5]	B	NF	• Well-oxygenated, meso-to eutrophic conditions • Low levels of organic nutrients present. • Good condition with %PTV of 4.2, and SPI of 13.3
ECOSTATUS (PES)[g]	**C (66.6%)**	**Primary drivers: fish component and instream habitat integrity**	

[1]*Refer to Appendix A for the fish inventory and FRAI Models*
[2]*Refer to Appendix B for the SASS5 data and MIRIA Models*
[3]*Refer to Appendix C for the IHI results*
[4]*Refer to Appendix D for the Physical-chemical results*
[5]*Refer to Appendix E for the Diatom results*

Table 29: Component PES and related causes for LO_EWR03 Augrabies

<table>
<tr><th></th><th>Causes
Present/Absent</th></tr>
<tr><td>Fish[1]</td><td>During the survey, high flows limited access for effective sampling with the electro shocker. It was not possible to use other methods for sampling e.g., cast nets due to the high flow velocities.

The result was a low diversity and number of fish collected.
Changes in flow velocities – releases prior to the site visit resulted in fish taking refuge from increased flows – low activity in the changing environment.

Changes in flows, depth classes and water quality increase physiological stress on biota.

<table>
<tr><th>METRIC GROUP</th><th>WEIGHT (%)</th></tr>
<tr><td>VELOCITY-DEPTH</td><td>97.72</td></tr>
<tr><td>COVER</td><td>100.00</td></tr>
<tr><td>FLOW MODIFICATION</td><td>70.05</td></tr>
<tr><td>PHYSICO-CHEMICAL</td><td>69.68</td></tr>
<tr><td>MIGRATION</td><td>61.09</td></tr>
<tr><td>IMPACT OF INTRODUCED</td><td>37.82</td></tr>
</table>
</td></tr>
<tr><td>Macroinvertebrates[2]</td><td>A total of 20 SASS5 taxa was observed at the site, with a SASS5 Score of 109, and the ASPT value of 5.5.

A wide diversity and abundance of habitats was sampled during the 2024 survey. However, marginal vegetation biotopes were limited, as the banks were dominated by woody Phragmites. This was reflected in the collection of only four out of an expected 15 families that typically colonise vegetation — Atyidae, Hydroptilidae, Hydrophilidae, and the exotic Physidae. The aquatic macroinvertebrate assemblage represented moderately modified conditions (Ecological Category C, 68.91%), influenced by some water quality impairment (64.9%) and subtle changes in available habitat (70.6%).

Although flow modification wasn't a primary driver of the macroinvertebrate family composition, the upstream releases from hydropower facilities remained a concern. These releases, regulated daily and varying by season, were observed during the survey. The MIRAI scores from the REMP and JBS3 (2021) were generally consistent with those from this survey, despite the absence of previously recorded taxa such as Tricorythidae and Ecnomidae. However, Perlidae were observed in this survey (although in low abundances and visually recorded), a taxon not often recorded. In fact, according to the DWS REMP data, Perlidae have only been recorded on three occasions out of 23 data sets since May 2017. Overall, these taxa tend to prefer moderately to fast-flowing water and cobbles, which may explain their absence in some earlier surveys due to accessibility constraints and high flows.

Two key points of interest emerged. The high abundance of Hirudinea at the site during the survey. This family prefers moderate flows, cobbles, GSM, and very low water quality. Secondly, the population of Simuliidae (species: Simulium chutteri), which was expected to be abundant, was in fact limited. This may be due to recent spraying as part of the Simuliidae control programme.</td></tr>
</table>

	Causes Present/Absent
Hydrology	Refer to **Error! Reference source not found.** which illustrates the differences in the the flow c urve for Natural (NAT), Baseflows (BF) and the Present Day flows (PRS).

[1]*Refer to Appendix A for the fish inventory and FRAI Models*
[2]*Refer to Appendix B for the SASS5 data and MIRAI Models*

Table 30: Macroinvertebrate community Ecological Category based on weights of metric groups for LO_EWR03 (Augrabies)

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	71.8	0.339	24.3451	1	100
HABITAT	H	70.6	0.305	21.5528	2	90
WATER QUALITY	WQ	64.9	0.339	21.9945	1	100
CONNECTIVITY & SEASONALITY	CS	60.0	0.017	1.01695	3	5
						295
INVERTEBRATE EC				68.9093		
INVERTEBRATE EC CATEGORY				C		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						

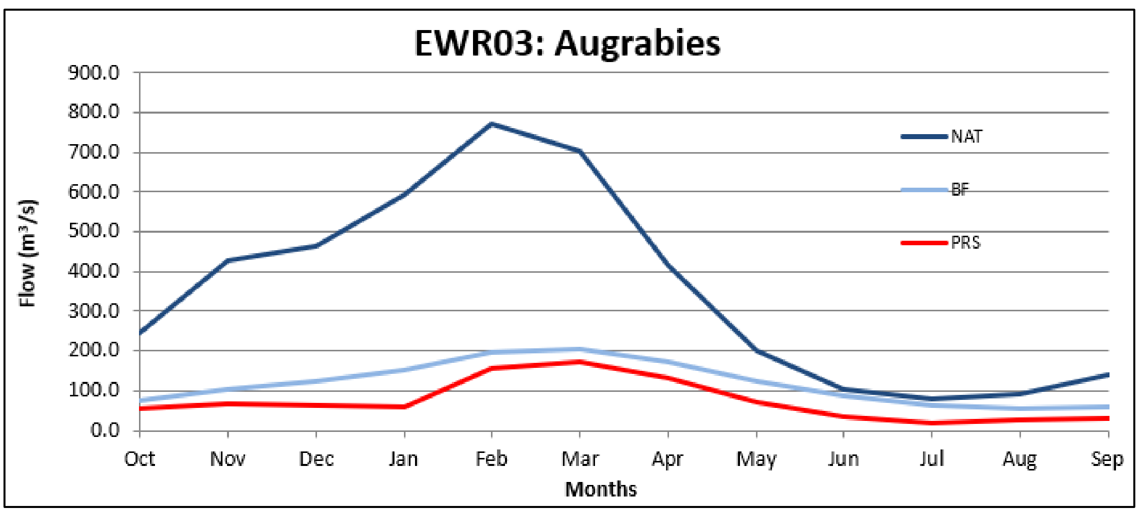

Figure 20: Flow curve for LO_EWR03 (Augrabies)

Table 31: Ecological Trends for LO_EWR03 Augrabies

Component	Trend (stable, decline, improvement)	Reason	Confidence (0-5)*
Fish	Declining	• Decline in water quality • Fishing with nets reported throughout many systems will have a negative impact • Loss of marginal vegetation – habitat for smaller spp. • Poor water quality impact on food resources *i.e.,* instream vegetation and macroinvertebrates.	3
Macroinvertebrates	Stable (Figure 21)	• Deterioration of water quality • Annual proliferation of *Simuliidae* populations in response to poor water quality and seasonal flow variations. • Main riffle/run supports good flow throughout the year and as such, habitat is there to support sensitive taxa.	3
Physico-chemical	Declining	• Salinity increases compared to upstream are observed • Continued run-off from adjacent agricultural activities • Elevated toxics is a concerning aspect.	4
ECOSTATUS (PES)	Stable		

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

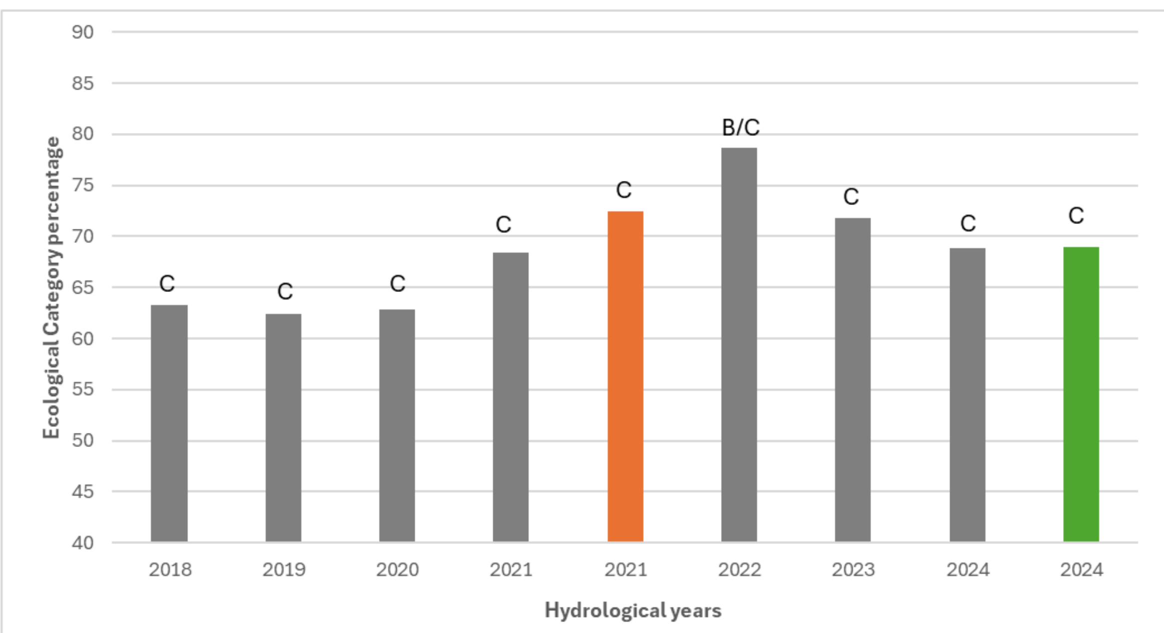

Figure 21: Graph illustrating the Ecological Category percentage for REMP site D8ORAN-BLOUP (grey), JBS3 (orange) and this current Classification study's results (green)

Overall, the change and reason for deviation from reference conditions are as follows:

- Loss of frequency of large floods (owing to upstream dams);
- Increased agricultural return flows (water quality impairment);
- Increase in the blackfly (*Simulium chutteri*) population owing to flow fluctuations.
- Higher low flows than natural in the dry season, drought and dry periods (providing incorrect ques for fish for movement and spawning);
- Decreased low flows at other times; and
- Annual release of sediment.

The revised Ecological Importance and Ecological Sensitivity went from Moderate, High to High, High respectively, as per WRP Consulting Engineers in association with Golder Associates, DMM, PIK, RAMBOLL and WCE - Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan Study, 2010. Please refer to Table 32 for the PES and REC results for this EWR site and whether the results are as per flow or non-flow related impacts.

Table 32: EcoStatus PES and REC results for LO_EWR03_Augrabies

Eco Status (PES)	REC	
C	B/C	• *F*: Lower baseflows during the dry season, combined with a greater seasonal range, are expected to enhance habitat diversity, which should boost biodiversity and help reduce outbreaks of the pest blackfly *Simulium chutteri*. Other taxa will likely establish under a more natural flow regime, including providing the correct ques for fish species to respond to in terms of movement and spawning habits. • *NF*: Water quality issues may keep the category in Category C.

Important to note that various recommendations/interventions have been summarised, with the aim to improve the EcoStatus (PES) and achieve the REC. These have been split between:

1. *Flow (F) interventions: whereby to what extend can the impacts/influences be mitigated i.e implementing operating rules for instream dams to release the EWR, or at least a baseflow to aid in improved flows; and*
2. *Non-Flow (NF) interventions, being those that could potentially be rehabilitated and/or restored (i.e., Wastewater Treatment Works (WWTW)).*

This applies throughout the report for the REC.

5.2.3. OVERALL ASSESSMENT

The overall EcoStatus for this EWR site is classified as Category C, indicating a moderately modified condition with loss and alteration of natural habitat and biota, evident in changes to frequency and abundance (Table 33). Catchment degradation is influenced by elevated nutrient loads from return flows and flow modifications, leading to seasonal disruptions that affect spawning and growth cycles of fish.

It is suggested that a REC of a B/C (close to largely natural) can be achieved, should the proposed mitigation measures/ recommendations be assessed and applied (Table 33).

Table 33: Overall EcoStatus assessment for LO_EWR03_Augrabies

River	**Orange**
EWR Site Code	**LO_EWR03_Augrabies**
Driver component	**PES**
Water quality (physico-chemical)	D
IHI (instream)	D
IHI (riparian)	**B/C**
Response component	**PES**
Diatoms	**B**
FRAI	D
MIRAI	C
Ecostatus	**C**
EI	High
ES	High
REC	**B/C**

5.2.4. Recommendations

- Ensure the upstream movement of fish species is not impacted in any way through the development or disturbance of instream connectivity integrity. Where any new activities are proposed, appropriate fishways are to be implemented.
- Any future land use activities within upstream catchment should be managed to prevent degradation of the ecological health of the system and deterioration of the water quality (buffer zones to be implemented for future proposed developments);
- Catchment management (cattle grazing and trampling);
- Strive towards undertaking the blackfly control spray programme to be carried out three weeks before the first scheduled freshet, as outlined in the EWR (see chapter below). The freshet aims to scour the stones biotope of dead blackfly larvae, reset the biotopes, and dilute the water column to support the establishment and colonisation of other macroinvertebrates; and
- Any future land use activities within upstream catchment should be managed to prevent degradation of the ecological health of the system and deterioration of the water quality (buffer zones to be implemented for future proposed developments).

5.2.5. EWR Quantification Results

The EWR for the Orange River at Augrabies (downstream Blouputs) was 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 February and July. July is the month with the lowest average flow (*i.e.,* base-flow) and February is the month with the highest average flow conditions (according to the natural flows). September/ October was also examined as the surveys were undertaken during October to provide a visual baseline for the ecologists when considering the various flow requirements.

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 30 September 2024 was 50.9 m^3/s and was used as reference to adjust the recommended EWRs (Figure 22). It should be noted that the baseflows were higher than expected during the survey as a result of the releases from upstream for water users lower down in the catchment.

The consensus reached by the aquatic ecologists was that the recommended flows for both drought and maintenance low flows did not provide adequate velocities and availability of instream habitats for the macroinvertebrates. The maintenance low flows were adjusted in order 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) for those flow dependent and sensitive macroinvertebrates expected to be present. However, consideration was also given to the annual *Simuliidae* outbreaks in this region. For specific months (e.g., July), flow adjustments were evaluated to expose the stone biotope, aiming to reduce the outbreak in coordination with the *Simuliidae* spraying programme (see Chapter 6.1 for further details).

In terms of the fish component, 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 community. The available biotic critical habitat at these recommended flows is provided in Table 34. Those habitats highlighted in grey are critical habitats for rheophilic fish species and fast to very fast flow dependent macroinvertebrates (*i.e.,* sensitive taxa to flow). Therefore, the recommended flows (drought and maintenance) were adjusted as follows and which are illustrated on the cross-section in Figure 22.

(i) Maintenance low flows:

- October - Adjusted from 37.5 m^3/s to 43.0 m^3/s
- February - Adjusted from 96.2 m^3/s to 110.0 m^3/s

(ii) Drought flows:

- A minimum of 13.0 m^3/s for July to October and 20.0 m^3/s for November to January.

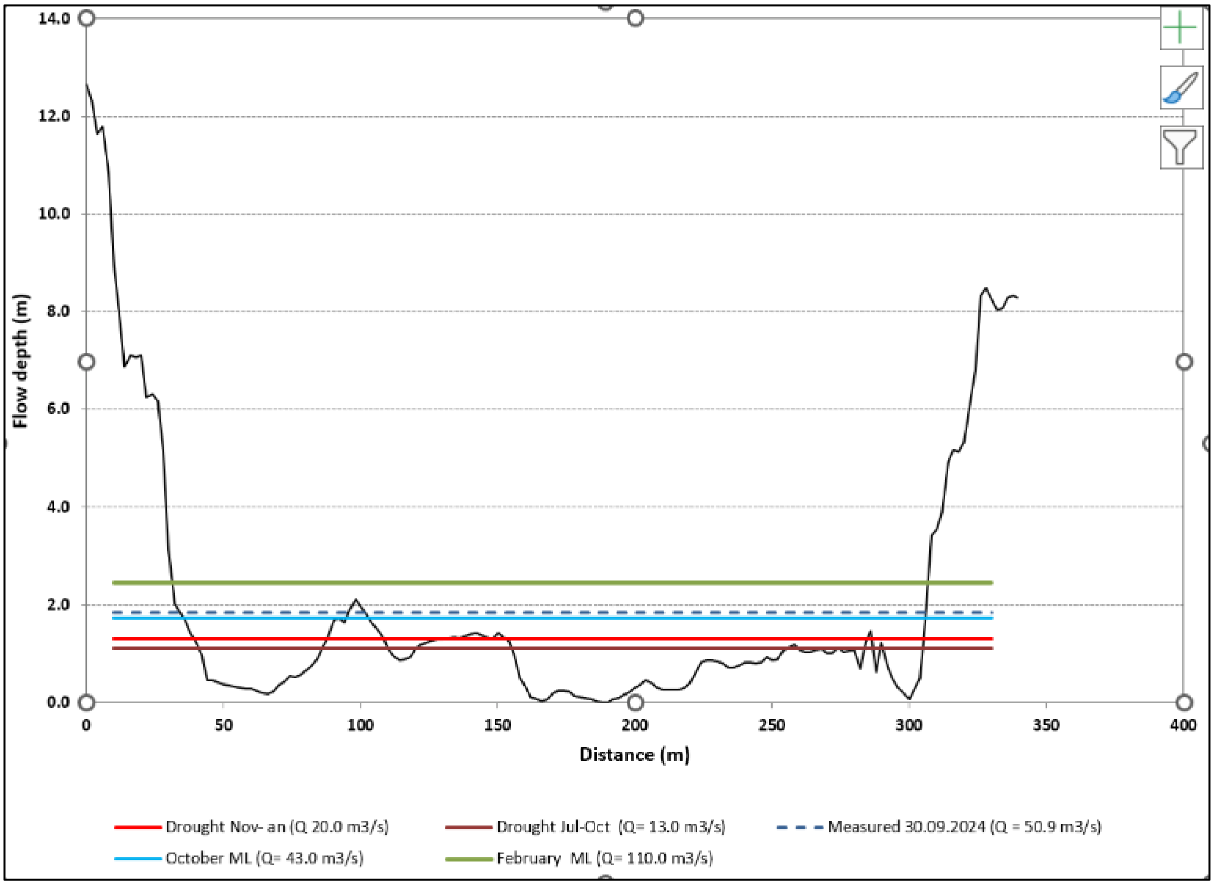

Figure 22: Water levels on cross-section of EWR site LO_EWR03_Augrabies

Table 34: Percentage available of the critical habitats for fish and macroinvertebrates at the recommended maintenance low flows

Fish habitats*	% availability	Macroinvertebrates habitats*	% availability
Maintenance low flows (October – 43.0 m³/s)			
SvS[1]	2	VSCS[2]	20
SS	15	SCS	21
SD	67	FCS	7
FVS	0	VFCS	1
FS	0	VSFS	20
FI	0	SFS	21
FD	15	FFS	7
		VFFS	1
		VEG	3
Maintenance low flows (February – 110.0 m³/s)			
SvS	0	VSCS	12

Fish habitats*	% availability	Macroinvertebrates habitats*	% availability
SS	2	SCS	15
SD	66	FCS	10
FVS	0	VFCS	3
FS	0	VSFS	17
FI	0	SFS	21
FD	32	FFS	14
		VFFS	
		VEG	

**Those habitats which are critical are highlighted in grey*
[1]Fish habitats: SvS: slow very shallow; SS: slow shallow; SD: slow deep; FVS: fast very shallow; FS: fast shallow; FI: fast intermediate; FD: fast deep
[2]Macroinvertebrate habitats: VSCS: very slow course substrate; SCS: slow course substrate; FCS: fast course substrate; VFCS: very fast course substrate; VSFS: very slow fine substrate; SFS: slow fine substrate; FFS: fast fine substrate; VFFS: very fast fine substrate; VEG: vegetation

The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 35, the final EWR for the Lower Orange River at LO_EWR03 is summarised in Table 36.

Table 35: Lower Orange at LO_EWR03 - Freshets and flood requirements for implementation

Months	Freshets			Floods		
	m^3/s	# events	days	m^3/s	# events	days
October	100	1	2			
November	150	3	6			
December	150	2	6			
January	150	2	6			
February	150	2	6	420	1	8
March	255	2	6			
April	150	1	6			

Table 36: Lower Orange EWR03 - Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D81B	
Site number	LO_EWR03	
River	Lower Orange @ Augrabies (Blouputs)	
	Current study	**ORASECOM, 2011**

Quaternary Catchment	**D81B**	
Recommended Ecological Category	B/C	B
nMAR at EWR site	11 043.6	10 513.1
Total EWR	2749.598 (24.90 %MAR)	19.2%
Maintenance Low flows	2161.119 (19.57 %MAR)	17.7%
Drought Low flows	590.219 (5.34 %MAR)	3.4%
Maintenance High flows	588.479 (5.33 %MAR)	4.7%
Overall confidence	Moderate	

5.3. LO_EWR04_VIOOLSDRIFT – ORANGE RIVER

This EWR site was not surveyed for this study owing to existing information from the study "Determination of Ecological Water Requirements for Surface Water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA (2016)".

Comparisons between the natural MAR as used during the previous study (DWS, 2016) with the latest natural MARs for this study were made. If there was a small percentage change between the natural MARs (<10%) at the EWR sites, the requirements as determined previously were accepted. For larger percentage differences, the new natural MAR was used, and the requirements recalculated using the information as provided during the previous studies.

5.3.1. Site Details

Site EWR04 (Vioolsdrift) is located along the Orange River mainstem approximately 10 km upstream of Vioolsdrift boarder post bridge to Namibia along the N7 national road. A number of non-perennial tributaries confluence with the Orange River near this site along the left banks, with the notable ones being the Koubank River located about 8.7 km just downstream of the site. The site is located downstream of the confluence with the Namibian Haib River about 20 km upstream. Apart from the agricultural cultivation being located approximately 60 km further upstream, there are no notable anthropological activities on the South African side of the riverbank. Although not surveyed, the average channel width at this site is approximately 210 meters (DWS, 2016). The site is located 1.5 km downstream of site D8H003 (Vioolsdrift weir). A 12 km canal system exists which diverts river water from the weir to agricultural farms at Vioolsdrift. The site details are described in Table 37 with the site location illustrated in Figure 23 and a site photograph obtained from the DWS Upington Regional Office is depicted in Figure 24.

Table 37: Site Details _LO_EWR04 Vioolsdrift

Site Name	LO_EWR04_Vioolsdrift	**IUA**	LO_IUA3
River	Orange River	**IUA description**	Pella to Vioolsdrift weir. Orange River. Tributaries are all ephemeral systems.
Altitude (m.a.s.l.)	167 m	**Prioritised RU**	RU 3.1
Latitude	-28.7553	**Longitude**	17.71696
Level 1 EcoRegion	28. Orange River Gorge	**Quaternary catchment**	D82F
Level 2 EcoRegion	28.01	**SQ Reach**	D82F-03531
Geomorphological zone	F (Lowlands)	**PES, 2014**	C
Ecological Importance	High	**Ecological Sensitivity**	High

Site impacts include:

- Flow modification

- Return flows (water quality)
- Agriculture and irrigation
- Agriculture encroachment into riparian zone.

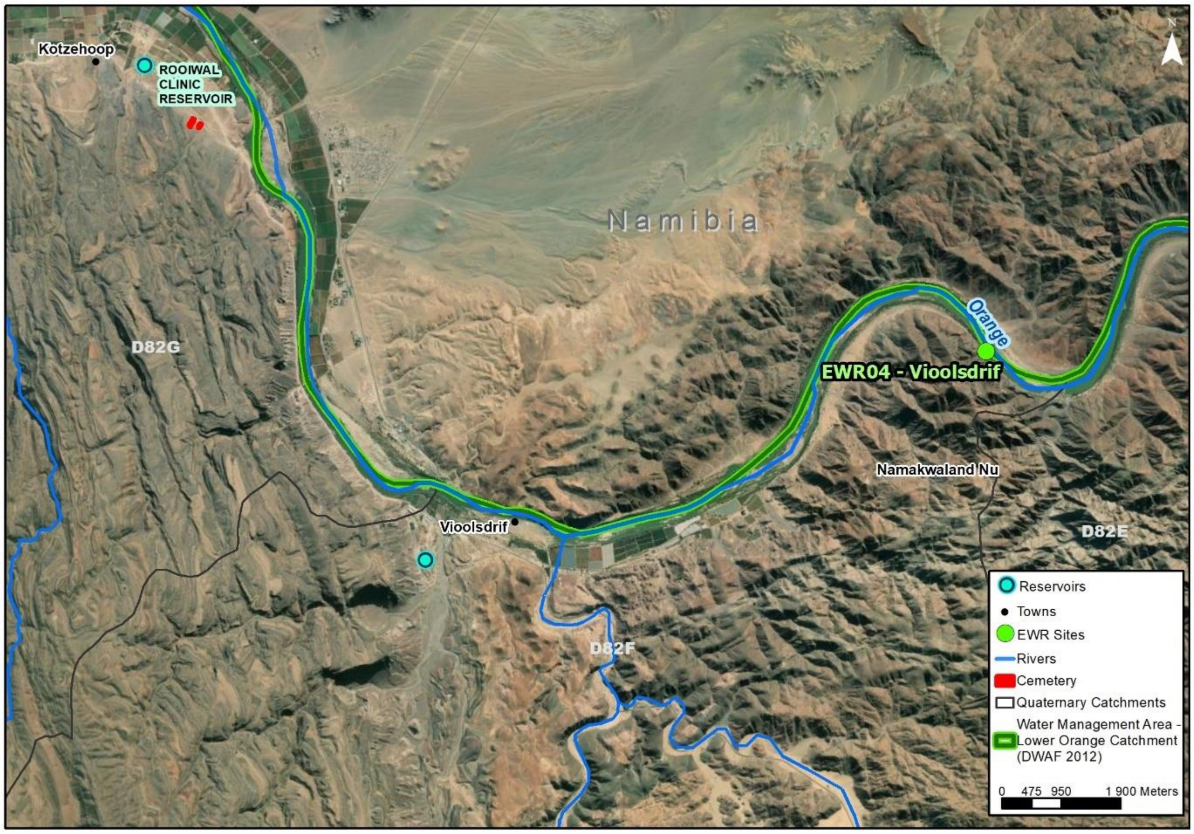

Figure 23: Location of site LO_EWR04_Vioolsdrift in the study area

Figure 24: Site photograph (2024) obtained from the DWS Upington Regional Office

5.3.2. Eco-Categorisation Results

The eco-categorisation results are illustrated in Table 38 for this EWR site. Only vegetation and riverine fauna exhibited a negative trend. During the 2016 survey, the EWR site showed significant physical disturbance, including vegetation removal, grazing, and trampling. These factors had already influenced, and were likely to continue influencing, the dominance of pioneer species, particularly exotic riparian species such as *Prosopis glandulosa* and other perennial and annual species. The left bank was heavily infested with invasive weeds, while the right bank experienced extreme overutilisation. As a result, the alteration of the riparian structure caused by the influx of exotic riparian species had a detrimental impact on the riverine fauna assemblage.

5.3.3. Overall Assessment

Table 38: Overall EcoStatus assessment for LO_EWR04_Vioolsdrift

River	**Orange**
EWR Site Code	**LO_EWR04_Vioolsdrift**
Driver component	**PES**
Hydrology	D
Water quality	C/D
Geomorphology	C
IHI (instream)	D
IHI (riparian)	D
Response component	**PES**
FRAI	C
MIRAI	C
Instream	C
Riparian vegetation	C
Riverine Fauna	C
Ecostatus	**C**
EI	High
ES	High
REC	**B/C**

Overall, the major issues that had caused the change from reference conditions were as follows:

- Decreased frequency of the larger floods;
- Agricultural return flows, agricultural activities and associated water quality impacts;
- Mining activities;
- Higher low flows than natural during the dry season, drought and dry periods and lack of naturally occurring zero flows;
- Decreased low flows at other times;
- Presence of alien fish species and barrier effects of dams;
- Decreased sedimentation due to lack of large floods and upstream dams; and

- Alien vegetation.

5.3.4. Recommendations

- Improved (higher) wet season base flows;
- Clear vegetation aliens; and
- Control grazing and trampling.

5.3.5. EWR Quantification Results

The results from the study "Determination of Ecological Water Requirements for Surface Water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA (DWS, 2016)" were used. No adjustments were made as the nMAR from the previous study was within 10% of the current study nMAR. The specific floods and freshets that were specified and a summary of the EWR results are provided in Table 39 and Table 40 respectively.

Table 39: Lower Orange at LO_EWR04 – Freshets and flood requirements for implementation

Months	Freshets		Floods	
	Q (m^3/s)	days	Q (m^3/s)	days
November	170	6		
December	60	5	170	6
January	170	6		
February	340	8		
March	500	12		

Q – discharge in cubic metres per second

Table 40: Lower Orange - Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D82F
Site number	LO_EWR04
River	Lower Orange @ Vioolsdrift
Recommended Ecological Category	B/C
Natural MAR at EWR site	11 064.3
Total EWR	12.2%
Maintenance Low flows	10.1%
Drought Low flows	1.3%
Maintenance High flows	4.2%

5.4. LO_EWR05_SENDELINGSDRIFT

This EWR site was not surveyed for this study owing to existing information from the study "Determination of Ecological Water Requirements for Surface Water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA (2016)".

Comparisons between the natural MAR as used during the previous study (DWS, 2016) with the latest natural MARs for this study were made. If there was a small percentage change between the natural MARs (<10%) at the EWR sites, the requirements as determined previously were accepted. For larger percentage differences, the new natural MAR was used and the requirements recalculated using the information as provided during the previous studies.

5.4.1. Site Details

Site LO_EWR05 Sendelingsdrift is located along the Orange River mainstem approximately 28 km downstream of the confluence of the Orange River with the Fish River from Namibia. The site also located 6 km upstream of D8H015 (Sendelingsdrift weir). There are a number of areas around the site associated with rapids just upstream of Potjiespram Capm site with notable sediment deposits at the meandering bends along the river (DWS, 2016). Historical imagery suggests the presence of diamond mining waste deposits about 4.5 km from the site, both on the South African and Namibian banks of the site. Some of these mining activities encroach of the riparian zone of the Orange River. The site details are described in Table 41 with the site location illustrated in Figure 25 and a site photograph obtained from the DWS Upington Regional Office of the regional monitoring site is depicted in Figure 26.

Table 41: Site Details LO_EWR05 Sendelingsdrift

Site Name	LO_EWR05_Sendelingsdrift	**IUA**	LO_IUA 4
River	Orange River	**IUA description**	Downstream Vioolsdrift to Orange River Mouth. Orange River is the mainstem with a number of ephemeral tributaries.
Altitude (m.a.s.l.)	167 m	**Prioritised RU**	RU 4.2
Latitude	-28.0718	**Longitude**	16.95951
Level 1 EcoRegion	28. Orange River Gorge	**Quaternary catchment**	D82J
Level 2 EcoRegion	28.01	**SQ Reach**	D82J-02886
Geomorphological zone	F (Lowlands)	**PES, 2014**	C
Ecological Importance	High	**Ecological Sensitivity**	High

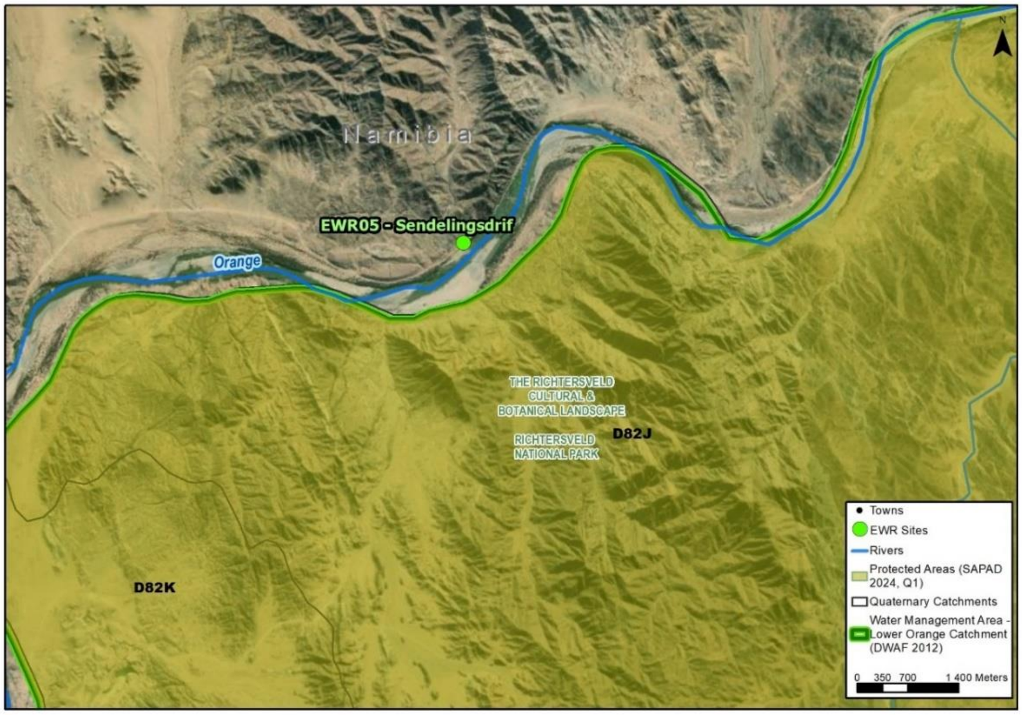

Figure 25: Location of site LO_ EWR05_Sendelingsdrift in relation to the study area

Figure 26: Site photograph of the regional monitoring site at Sendelingsdrift obtained from the DWS Upington Regional Office

5.4.2. Eco-Categorisation Results

The eco-categorisation results are illustrated in Table 42 below for this EWR site. The decreased small and moderate flood frequency, agricultural return flows and mining activities, leading to water quality problems have contributed to the PES of a B/C.

5.4.3. Overall Assessment

Table 42: Overall EcoStatus assessment for LO_EWR05_Sendelingsdift

River	**Orange**
EWR Site Code	**LO_EWR05_Sendelingsdrift**
Driver component	**PES**
Hydrology	C
Water quality	C
Geomorphology	B/C
IHI (instream)	D
IHI (riparian)	D
Response component	**PES**
FRAI	B/C
MIRAI	B/C
Instream	B/C
Riparian vegetation	B/C
Riverine Fauna	B
Ecostatus	B/C
EI	High
ES	High
REC	B

Overall, the major issues that had caused the change from reference conditions were as follows:

- Higher low flows than natural in the dry season;
- Drought and dry periods;
- Decreased low flows at other times;
- The presence of alien fish and vegetation species; and
- The barrier effect of the upstream dams.

5.4.4. Recommendations

- Increased (from present) wet season base flows; and
- Reinstate dry season droughts.

5.4.5. EWR Quantification Results

The results from the study "Determination of Ecological Water Requirements for Surface Water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA (DWS, 2016)" were used. No adjustments were made as the nMAR from the previous study was within 10% of the current study nMAR. The specific floods and freshets that were specified and a summary of the EWR results are provided in Table 43 and Table 44, respectively.

Table 43: Lower Orange at LO_EWR05 Sendelingsdrift - Freshets and flood requirements for implementation

Months	Freshets		Floods	
	Q (m^3/s)	days	Q (m^3/s)	days
November			190	7
December	60	5	190	7
January	60	5	190	7
February	60	5	300	10
March	60	5	500	12

Table 44: Lower Orange - Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D82L
Site number	LO_EWR05
River	Lower Orange @ Sendelingsdrift
Recommended Ecological Category	B
Natural MAR at EWR site	11 670.2
Total EWR	14.7%
Maintenance Low flows	10.2%
Drought Low flows	1.3%
Maintenance High flows	4.5%

6. MAJOR IMPACTS ON CATCHMENT BIOTA

6.1. *Simuliidae* Outbreaks

One macroinvertebrate taxon known to occur in this study, which is of particular concern, is the blackfly larvae (family *Simuliidae*). *Simuliidae* are a major agricultural pest and have been observed in their outbreak densities along the Orange River within the Lower Orange River Catchment Area.

Simuliidae occur in flowing water and, depending on the species, habitats range from highly saline clear trickling desert springs to fast flowing clear or highly turbid rapids in temperate or tropical big river systems (de Moor, 2003). Thus, the primary drivers of blackfly species occurrence and abundances are discharge, water clarity, and presence of benthic algae. These pest blackfly adult females will have negative impacts mostly on the agricultural industry in these catchment areas (*i.e.,* citrus farms). For the region's livestock (sheep) farming, impacts are also severe, with major financial losses per annum due to sheep deaths, or loss of meat or wool value in poor-condition sheep (Rivers-Moore *et al.* 2014). Although these densities may not be as high as what has been recorded from Prieska all the way downstream to Augrabies falls in the Lower Orange River catchment (Rivers-Moore *et al.* 2014), this study has certainly flagged the outbreak potential in this study area and thus should be intensely monitored during the quarterly REMP monitoring (generally picked up during the SASS5 hand picking observations).

An annual blackfly spray control programme is conducted to manage populations and prevent adverse impacts on the terrestrial environment along the Orange River. It is assumed that this programme was implemented prior to the survey for this study, as very low blackfly abundances, if any, were recorded at the EWR sites LO_EWR02_Boegoeberg and LO_EWR03_Blouputs. Additionally, both sites exhibited low abundances in the aquatic macroinvertebrate community, suggesting that the control programme may have influenced the structure of the macroinvertebrate assemblage.

With the above mentioned, cognizance of these outbreaks was considered when quantifying the EWR for those most affected sites. The critical periods for controlling population sizes of *Simuliidae* are generally July to August (winter months) when most of the population is present in the larval or pupal phase (O'Keeffe and de Moor, 1988). Thus, reduced flows, and lower water levels, during these months is critical to expose the substrate to dry out blackfly larvae and pupae in these months (de Moor, 1982b, 1997; O'Keeffe and de Moor, 1988). This may potentially thus avoid the typical spring outbreaks of blackfly's during the end of winter/spring seasonal period (*i.e.,* September). Furthermore, ensuring those freshets or floods come through during the months of October/November to March/April so to scour the substrate and re-set the systems are applied.

6.2. Flow Fluctuation and the Associated Disruptions of Cues for Fish

Flow fluctuations in aquatic environments are natural phenomena influenced by a range of factors, including seasonal changes, meteorological events, and human activities. These fluctuations can significantly impact the behaviour and survival of fish species by altering cues used for navigation, foraging and reproduction. Some of the main components related to these include the nature of flow fluctuations, the types of cues for fish and the disruptions caused by altered flow conditions.

Understanding Flow Fluctuations

Flow fluctuations refer to variations in the speed and volume of water moving through a habitat. These can occur on multiple scales, from short-term changes during releases for irrigation needs, to long-term alterations as a result of hydroelectrical generation or due to droughts or floods. Flow in the system is mainly influenced by natural factors (*i.e.,* the seasonal rainfall) and anthropogenic factors which include abstraction for different needs in the system and the related dam operations and controlled releases during various times in the year and land-use changes.

Land-use changes and flow fluctuations in a river are interconnected and can significantly impact river ecosystems, water quality, and the surrounding landscapes. Here is an overview of the relationship between these factors:

Land-use changes in this river system refer to the transformation of natural landscapes into urban, agricultural, industrial, or other human-dominated uses that have a variety of direct and indirect effects on rivers. Some key land-use changes that affect river flow include:

- **Urbanisation**: Increased impervious surfaces (e.g., roads, buildings) lead to higher runoff into rivers, reducing natural infiltration and increasing flood risks. Urban development often changes the natural flow regime by creating more frequent and intense flow events.
- **Agriculture**: Agricultural practices, including deforestation, drainage of wetlands and the use of fertilisers and pesticides increase sediment and nutrient loads in rivers. This alter the water quality, the increased nutrients contribute to eutrophication and there are changes in the sediment transport patterns, which affect river morphology and aquatic habitats.
- **Natural vegetation** clearing and over grazing in rural areas lead to soil erosion, which increases sediment loads in rivers and alters the natural flow which contribute to sedimentation which affects aquatic species and water quality.
- **Infrastructure development** in the catchment *i.e.,* dams and weirs and roads, bridges and stream crossings modify river flow by restricting or altering natural flow patterns. The overall impact is a loss of wetlands, modification of instream habitats and changes in seasonal flow flows and hydro periods.

Flow fluctuations in a river are the variations in river discharge (flow volume) over time, typically due to seasonal changes, rainfall, or human activities. Flow fluctuations are important for maintaining the ecological health of a river and can be influenced by land-use changes with the receiving environment being impacted by the seasonal variations, flooding, and droughts (related to changes in climatic conditions) and altered baseflow and surface runoff.

It is important to remember that the interplay between land-use changes and flow fluctuations have ecological consequences and include the increased erosion and sedimentation, poor water quality related to the nutrients (nitrogen and phosphorus), pesticides and heavy metals/ metal elements into rivers. The pollutants alter the chemistry of the river, affecting its oxygen levels and leading to algal blooms, fish kills and ecosystem degradation (e.g., loss of habitat and in-stream and marginal vegetation). The construction of the dams and weirs result in habitat fragmentation limiting migration of the larger species which disrupt breeding and sometimes access to food sources, ultimately reducing biodiversity and disrupt ecosystems.

To address the negative effects of land-use changes and flow fluctuations, integrated management strategies can be employed to mitigate the impacts. This can include:

- **Riparian Buffers**: Restoring native vegetation along riverbanks that will reduce runoff, stabilise soil and filter pollutants before they enter the water.
- **Wetland Restoration**: Restoring wetlands and floodplains can help to manage excess nutrients, reduce flood risks, and provide important habitats for fish.
- **Sustainable Agriculture**: Implementing practices such as no-till farming and reduced pesticides to decrease the runoff of sediments and chemicals into rivers.
- **River Engineering**: Restoring natural river morphology, e.g., creating fish ways that will contribute to restore connectivity.

The resulting changes in water velocity and depth can create dynamic environments that fish must adapt to. The fish in the ecosystem utilise various sensory cues that drive physiological processes and sensory cues. Altered flow conditions can disrupt these cues for the fish. These include:

- **Chemical Cues** where pheromones and other chemical signals help fish locate food, breeding partners and suitable habitats. Increased flow can dilute chemical signals, making it harder for fish to locate mates or food sources.
- **Visual Cues** is important where sight is critical for fish. Turbidity caused by increased flow can obscure visibility, hindering fish from spotting prey, locating reproductive partners or navigating their surroundings.
- **Auditory Cues** is critical for some species that respond to sounds in their environment, including the sounds of predators or conspecifics (members of the same species). Changes in flow velocity affect how sound travels through water, potentially masking important acoustic signals used in communication or predation.
- **Hydrodynamic Cues** is when fish are adept at sensing changes in water flow and pressure, which can indicate the presence of objects, currents or other fish. Fluctuations can create unexpected currents, making it difficult for fish to maintain their positions or migrate.

It is important that certain fish species are more sensitive to changes in flow than others when looking at migratory species. Irregular or non-seasonal pulses in flow volumes can disrupt spawning runs. The males and females need the increased flows and related chemical cues to develop eggs and sperm which can impact on recruitment and population dynamics. Understanding the resilience of different species to flow fluctuations is essential for conservation and management efforts.

7. ORANGE RIVER ESTUARY ECOLOGICAL WATER REQUIREMENTS

7.1. Estuary Status and Characteristics

The Orange River Estuary, located between Alexander Bay in South Africa and Oranjemund in Namibia, is a significant ecological and hydrological zone spanning approximately 2,700 hectares, and includes the north and south banks up to the 5 m contour. It is characterized by a tidal basin, a braided channel system, and extensive salt marsh habitat, which has been significantly degraded. The Orange River Estuary is furthermore a Ramsar wetland of international importance at the boundary between South Africa and Namibia.

The mouth of the Orange River Estuary is a dynamic feature influenced by both riverine and marine processes. It is characterized by a semi-permanent open state, with tidal variations extending up to the Sir Ernest Oppenheimer Bridge, approximately 11 kilometres upstream (UNDP-GEF, 2013), and slightly beyond as was characterised by the delineation of the Estuary Functional Zone (EFZ) during the National Biodiversity Assessment (NBA) of 2018 (Van Niekerk *et al*. 2019). The estuary's mouth location alternates between the northern and southern banks due to natural shifts and historical human interventions, such as managed breachings to mitigate flooding risks.

The estuary, which falls within the Cool Temperate biogeographical region, was classified as a river mouth in Whitfield's (1992) classification scheme and has since been classified as a large fluvially dominated estuary (Van Niekerk *et al*. 2019). The land-sea connection has been recognised as an Ecologically or Biologically Significant Marine Area (EBSA) and is referred to as the Orange Cone EBSA, which is largely driven by the flow from the Orange River (Van Niekerk *et al*. 2019).

The estuary is a partially enclosed permanent water body that is near-continuously open to the sea, only closing every two to three years under natural flow conditions (Van Niekerk *et al.*, 2020). Marine water interchange is limited under normal flow conditions, with river flows dominating the system. Human activities, including road crossings and mouth stabilization efforts, have further altered the natural dynamics, impacting sediment deposition and hydrodynamic patterns. These modifications, along with reduced flood magnitudes caused by upstream water resource developments, have contributed to ecological changes at the estuary mouth. Further issues the estuary faces include changes in sediment dynamics, nutrient enrichment, and physical habitat disturbances. Illegal fishing, grazing, and mining also contribute to its degradation (UNDP-GEF, 2013).

7.2. Information Limitations

Limited information and data have been published since the detailed Orange River Estuary EFR study published in 2013. Of the literature published after 2013, a few sources are worth mentioning. These include the rehabilitation measures suggested by Morant (2017) that included the removal of historic scrap mining metal equipment dumped on the southern beach berm and which interferes with the natural migration of the estuary mouth. Chisanga *et al*. (2022) predicted the effects of climate change on future temperature and rainfall in the Orange River catchment. Nashima (2020) and Nashima *et al*. (2020, 2021, 2023) presented findings of a study that focused on freshwater and euryhaline fish species over the river-estuary continuum for the 2004 to 2018 period.

All of these studies contribute to our understanding of the health and function of the Orange River Estuary but do not provide reasonable evidence to support changes to the PES and REC, which is presented in Van Niekerk *et al*. (2019). It is likely that only the reintroduction of low flows to allow for mouth closure and the back flooding of fresher water into saltmarsh areas, together with other rehabilitation measures, is likely to have a significant positive impact on the estuary health score and PES.

As part of this Lower Orange water resource classification and RQO study, a once off water quality and microalgae survey was undertaken for the Orange River Estuary between 3 and 7 November 2024. The Orange River Estuary was sampled at five sites during the field trip (Figure 27), the site information is included in Table 45 and depicted in Figure 27.

Table 45: Sites information of once-off sampling event of Orange River Estuary

Date	Estuary	Station No.	Co-ordinates	Distant from Mouth
5-6 November 2024	Orange River Estuary	1	28°37'52.78"S; 16°27'29.25"E	0.5
		2	28°37'11.61"S; 16°27'27.37"E	1.8
		3	28°36'14.77"S; 16°27'48.70"E	4.4
		4	28°35'30.48"S; 16°28'14.95"E	6.1
		5	28°33'36.57"S; 16°32'31.70"E	15.1

Figure 27: Google earth imagery of the extent of the Orange River Estuary Mouth (A) and (B) Sampling of nutrients and microalgae on Orange River Estuary at various points (05/11/2024)

The Orange River Estuary displayed distinct longitudinal and vertical salinity gradients, typical of open mouth conditions and sustained freshwater inflow. The influence of tidal exchange was evident in the lower reaches, with marine conditions (salinity > 30) observed at Site 1 and mesohaline (ca. 5) surface waters overlying polyhaline (ca. 27) bottom-waters at Site 2. The influence of freshwater inflow was particularly evident in the middle and upper reaches, where oligohaline (< 3) and fresh (< 0.5) conditions persisted, respectively.

Marine intrusion in the middle reaches was only observed in the bottom-waters at Site 3 (polyhaline ~ 25). These conditions are similar to those reported by Snow (2016). Well-oxygenated conditions (> 6 mg l^{-1}) were observed throughout the estuary, with the only exception being recorded in the high retention bottom-waters at Site 3 (< 5 mg l^{-1}).

Similarly, basic conditions (pH > 8) persisted throughout the estuary and displayed an increasing longitudinal trend from the mouth to the upper reaches. Turbidity was variable along the length of the estuary, with elevated levels (> 15 NTU) observed at Site 1 and Site 3 due to wind-driven resuspension and bottom-water detritus accumulation, respectively. Additionally, turbidity was lowest (< 10 NTU) in the upper reaches at Site 5.

The concentrations of ammonium, nitrogen oxides (NOx), and phosphate displayed a consistent decreasing trend from the lower to the upper reaches (Table 46), potentially highlighting the adjacent marine environment as a nutrient source (e.g., upwelling). In contrast, dissolved silica (range: 892 to 4116 µg l^{-1}) had an inverse association with salinity and increased with decreasing salinity. Measured *in-situ* concentrations of phosphate (< 10 µg l^{-1}), ammonium (< 40 µg l^{-1}), and NOx (< 30 µg l^{-1}) were predominantly low.

Table 46: Inorganic nutrients and phytoplankton community (*i.e.*, abundance, composition, and species) data (mean ± Standard Deviation) collected from the Orange River Estuary.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5
Distance from Mouth (km)	0.5	1.8	4.4	6.1	15.1
Temperature (^{0}C)	16.4 ± 0.8	16.9 ± 0.5	16.2 ± 0.4	16.8 ± 0.2	23.3 ± 0.0
Phosphate (µg 1^{-1})	10.9 ± 6.3	9.5 ± 3.4	2.2 ± 2.4	1.3 ± 1.6	1.2 ± 0.7
Dissolved Silica (µg 1^{-1})	1071 ± 208	2542 ± 557	3278 ± 657	3672 ± 457	4040 ± 98
Nox (µg 1^{-1})	21.3 ± 22.5	29.4 ± 29.6	17.0 ± 14.9	9.4 ± 10.0	0.7 ± 0.1
Ammonia (µg 1^{-1})	27.6 ± 5.4	37.8 ± 32.8	31.2 ± 24.6	11.1 ± 7.9	4.8 ± 2.5
Phytoplankton Abundance (cells m1^{-1})	61,646 ± 8,644	5,754 ± 1,043	5,367 ± 854	4,746 ± 502	4,514 ± 1,366
Dominant Phytoplankton Class	**Bacillariophyceae**			**Chlorophyceae**	
Notable Species Present	*Navicula* sp. (<10 µm)	**Greens** → *Monactinus simplex, Tetraedron minimum, Coelastrum sp, Ankistrodesmus* sp. **Diatom** → *Aulacoseria granulata* ***Cyanobacteria*** → *Merismopedia* sp.			

Notably, long-term DWS water quality monitoring data (Table 47) indicates increasing concentrations of dissolved inorganic nitrogen (DIN) and phosphorus (DIP) in the estuary inflow in the last 10 years (*i.e.*, 2014 to 2023. Mean DIN (ca. 450 µg l^{-1}) and DIP (ca. 70 µg l^{-1}) concentrations more than doubled during this period compared to the preceding 36 years (*i.e.,* 1977-2013). Additionally, there has been a decline in dissolved silica (DSi) concentrations over the same period. The reduction in DSi concentrations (*i.e.*, from ca. 7500 to 5100 µg l^{-1}) is likely in response to decreased freshwater inflows, as evidenced by the steadily increasing mean electrical conductivity (*i.e.*, from 29 to 46 mS/m).

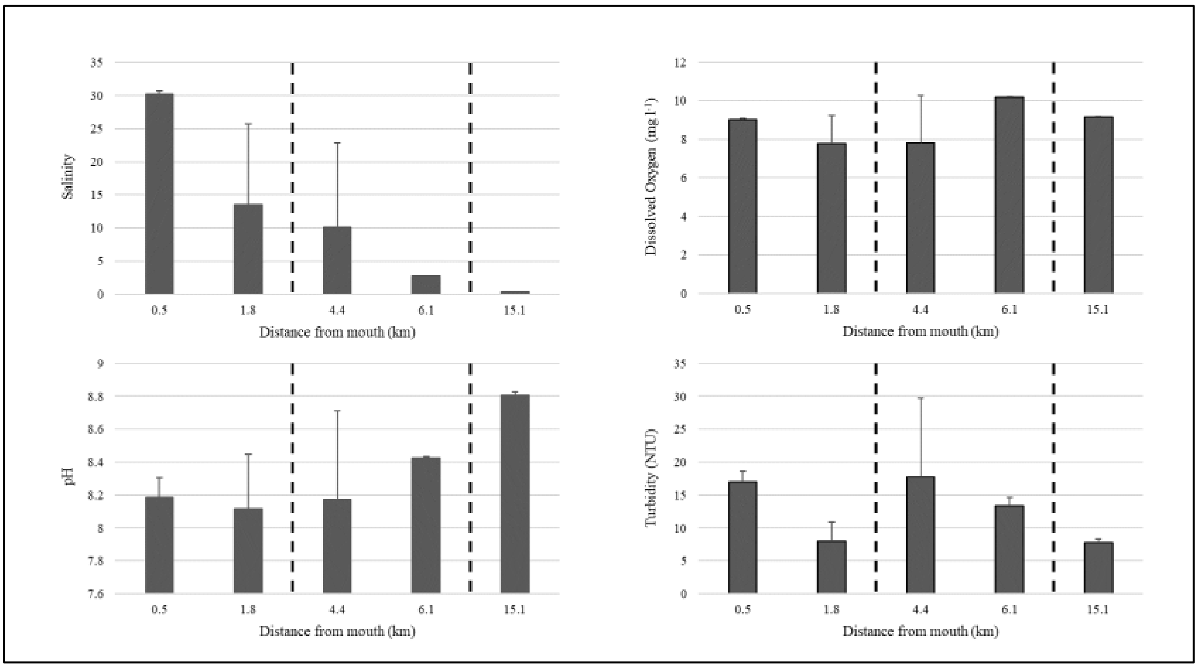

Figure 28: Physico-chemical properties recorded along the length of the Orange River Estuary. The dashed lines demarcate the sites representative of the lower (Site 1-Site 2), middle (Site 3 - Site 4), and upper (Site 5) reaches of the estuary.

Table 47: Mean dissolved inorganic nitrogen (DIN), phosphorus (DIP), and silica (DSi), as well as electrical conductivity (EC) measured in the Orange River at DWS Station D8H003.

Monitoring Period	**DIN** (µg 1^{-1})	**DIP** (µg 1^{-1})	**DSi** (µg 1^{-1})	**EC (m*S* m^{-1})**	**Count (n)**
1977-1983	203	24	7531	29	126
1984-1993	192	20	7117	38	187
1994-2003	138	28	5618	40	460
2004-2013	175	24	5542	48	266
2014-2023	451	69	5099	46	45

DIN – Dissolved inorganic nitrogen
DIP – Dissolved inorganic phosphorus
DSi – Dissolved Silica
EC – Electrical Conductivity
n - number

Phytoplankton communities at Site 2 and 4 were predominantly characterised by moderate levels of biomass (<20 µg Chl-a/l) throughout the estuary, however at Site 1 in the lower reaches and at Site 3 (ca. 28 µg Chl-a l^{-1}) in the brackish bottom-waters of the middle reaches higher levels of (>40 µg Chl-a/l) were observed. The bloom conditions in the well-mixed, lower reaches were comprised of a small diatom, *Navicula* sp. (Bacillariophyceae), that attained high cell density (> 60,000 cells ml^{-1}). The stratified conditions observed at Site 2 promoted increased phytoplankton diversity compared to the other sites, as evidenced by the presence of classes typical of brackish conditions (e.g., *Dinophyceae, Chlorodendrophyceae, Cryptophyceae*). Phytoplankton species identified during the sampling event are included in Appendix G.

However, phytoplankton community composition shifted as salinity decreased from the mouth towards the upper reaches, with freshwater taxa becoming increasingly dominant, with overall cell abundances greater than 4,500 cells/ml. Similarly, to the distribution of phytoplankton biomass, microphytobenthos (MPB) biomass was highest at Site 1 (> 85 mg Chl-a m^{-2}) and lowest (< 40 mg Chl-a m^{-2}) in the mid- to upper reaches.

These results will be considered during the estuarine workshop to assess whether any changes to the water quality and microalgae components can be inferred.

7.3. Methodology to Estuary Eco-categorisation

The PES and REC of estuaries in South Africa are determined through the application of the Estuary Health Index (EHI) methodology. The Estuary Health Index (EHI) is a tool that uses four abiotic (hydrology, hydrodynamics, water quality and physical habitat) and five biotic components (microalgae, macroalgae and macrophytes, invertebrates, fish and birds) to determine the PES and REC. The most recent comprehensive assessment of the PES and REC was undertaken by Louw *et al*. (2013) and determined the EWR for the Orange River Estuary based on data and information gained from 2012 and earlier. Previous studies include contributions from institutions and reports such as the CSIR (2001, 2004), and Turpie *et al*. (2002). These works were critical in assessing the degradation of the Orange River Estuary and its designation as a Ramsar site, highlighting the ecological and hydrological changes over time due to human activities.

7.4. PES of the Orange River Estuary

Based on the detailed 2013 Ecological Flow Requirements study (UNDP-GEF, 2013), a qualitative assessment of the reference state and PES is provided in Table 48. The PES scores determined through scoring of each specialist component by an estuarine specialist in each field, during a workshop are also provided in the Table 48.

Table 48: Qualitative description of reference condition of the Orange River Estuary in relation to PES and assigned health scores for each component

Component	Reference State	Present Ecological State (PES)	PES Score
Hydrology	Natural seasonal flow variability with MAR ~11,306 Mm³. Frequent flood resetting events (2-5 years) occurred.	MAR reduced to ~4,515 Mm³ (40% of reference), low flows dominate and reduced flood frequency.	44
Hydrodynamics	Dynamic estuary-marine exchange, seasonal mouth closures, and natural salinity gradients.	Mouth remains mostly open with altered salinity gradients and sediment transport due to changes in baseflows.	70
Water Quality	Balanced nutrient levels with no significant algal blooms or anoxic conditions.	Nutrient inputs from agriculture and mining ongoing and can cause algal blooms and occasional anoxic events.	53.2
Physical Habitats	Connected floodplains, salt marshes, and sandbanks with natural sediment transport and deposition.	Fragmented habitats due to levees, roads, and mining infrastructure. Disrupted sediment transport.	78

Component	Reference State	Present Ecological State (PES)	PES Score
Microalgae	Balanced biomass and diversity supported by natural salinity and nutrient profiles.	Increased biomass and reduced diversity with salinity and nutrient imbalances degrading productivity.	40
Macrophytes	Extensive salt marshes; supported by natural sedimentation and salinity gradients.	Habitat loss due to hydrology and salinity changes and infrastructure impacts resulting in loss of supratidal saltmarsh and degraded marsh functionality.	50
Invertebrates	Diverse and stable populations supported by high-quality habitats and minimal anthropogenic stress.	Declined diversity and abundance due to habitat degradation and water quality issues.	45
Fish	Abundant estuarine-dependent species; functional nursery habitats and migratory pathways.	Reduced populations due to overfishing and degraded habitats. Nursery function of the estuary compromised.	50
Birds	High populations of resident and migratory species supported by diverse nesting and feeding habitats.	Significant population declines due to habitat fragmentation and human disturbances.	23

The overall estuary health score and PES for the Orange River Estuary is provided in Table 49. Confidence levels in the data and PES scores are generally medium to high, besides hydrology, hydrodynamics, and microalgae. The estuary's present ecological state (PES) is categorized as "D" on the estuary health index, indicating a largely modified system.

Table 49: Estuary health score and PES for Orange River Estuary, as well as change in PES if non-flow related impacts are removed (UNDP-GEF, 2013)

Variable	*Weight*	*Health score*	*Health score net of 50% of non-flow-related impacts*	*Confidence*
Hydrology	25	44	44	Low/Medium
Hydrodynamics and mouth condition	25	70	70	Low
Water quality	25	53.2	53.2	Medium
Physical habitat alteration	25	78	87	Medium
Habitat (abiotic) health score		**61**	**63**	**Medium**
Microalgae	20	40	46	Low
Macrophytes	20	50	75	Medium
Invertebrates	20	45	51	High
Fish	20	50	70	Medium
Birds	20	23	65	Medium
Biotic health score		**42**	**61**	**Medium**
Estuary health score		**51**	**62**	**Medium**
Present ecological status		**D**	**C**	

7.5. Recommended Ecological Category of the Orange River Estuary

Despite the Orange River Estuary's PES being categorized as "D" on the EHI, it holds high ecological importance, serving as a Ramsar wetland and providing critical habitats for biodiversity, including fish nurseries and migratory birds.

The REC, based on the estuary being rated as 'highly important' and being designated a Ramsar site, was an Ecological Category (EC) or its best attainable state, which was estimated as a category C. In 2018, the NBA reviewed the PES, and REC for the Orange River Estuary, amongst others, and adopted the PES scores from the 2013 EFR study.

The impact of addressing non-flow related impacts were also considered. Addressing non-flow-related impacts can significantly improve the PES of the Orange River Estuary. These impacts include habitat destruction, pollution from agricultural runoff and mining, illegal fishing, and infrastructure-related disturbances like levees and causeways. Removing or mitigating these pressures, such as reducing nutrient inputs, managing grazing, and hunting, and improving connectivity by removing the causeway, could enhance habitat conditions and biodiversity. Simulations indicate that combining non-flow-related interventions with optimized flow regimes could elevate the estuary's PES from a "D" category (largely modified) to a "C" category (moderately modified), reflecting a healthier and more sustainable ecological state (UNDP-GEF, 2013).

The PES and REC were reviewed during compilation of the NBA (Van Niekerk *et al*., (2019), which saw the PES remain a D, however acknowledging a downgrade in the REC to a D EC. However, Van Niekerk *et. al*., (2019) considered the EWR for the Orange River Estuary to inform the Noordoewer / Vioolsdrift Dam Feasibility Study in 2020 and summarised the REC for the overall Orange River Estuary, as well as the abiotic and biotic components in Table 50.

Table 50: Comparison between PES and RECs for abiotic and biotic components in Orange River Estuary (Van Niekerk *et. al*. 2020)

Component	PES	REC	Key interventions required for improvement
Hydrology	D	D	Decrease base flows in winter.
Hydrodynamics	C	B	Facilitate mouth closure in winter 2 to 4 times in 10 years.
Water Quality	D	C	Reduce nutrient input in lower Orange River catchment.
Physical habitat alteration	B	B	No intervention.
Microalgae	E	D	Reduce base flows in winter and decrease nutrient input.
Macrophytes	D	C	Reduce soil salinities, reduce nutrient input, remove causeway, control grazing and alien vegetation.
Invertebrates	D	B	Reduce base flows in winter and facilitate mouth closure.
Fish	D	C	Reduce base flows in winter and facilitate mouth closure, control fishing.
Birds	E	D	Reduce base flows in winter and facilitate mouth closure.
Overall	D	C	Reduce flows, facilitate mouth closure, improve vegetation cover and food sources (invertebrates and fish).

Recent assessments therefore suggest that a REC of category C is achievable if targeted interventions relating to flow and non-flow related factors can be successfully implemented and if reasonable reversibility of pressures can be achieved.

From a flow perspective the main intervention relates to reducing winter base flows sufficiently to allow mouth closures and related backwater flooding of the supratidal saltmarshes. Non-flow related interventions mainly involve reducing nutrient input from the lower catchment of the estuary, removing the causeway, and controlling grazing and alien vegetation.

7.6. Observed changes at Orange River Estuary since 2013

Some changes have been observed since 2013. Observed changes summarised qualitatively in Table 51.

Table 51: Qualitative summary of observed changes since 2013

Component	2013 Assessment (Report)	Changes Since 2013 (Post-2013 Data)	Updated Status	Sources
Hydrology	Reduced seasonal variability; damming and flow regulation caused lower flood frequencies.	Continued flow reduction due to further water abstraction for agriculture, industry, and damming.	The inflow remains below the natural levels, further reducing flood events and seasonal variability.	Louw *et al*. 2013, ORASECOM reports, 2020
Hydrodynamics	Limited estuary-marine water exchange; altered salinity and sediment transport patterns.	Minor improvements from occasional natural floods, but still constrained by reduced freshwater inflows.	Mouth remains often open due to higher freshwater inflows; impacts salinity and sediment transport.	BirdLife South Africa, 2024, ORASECOM, 2020
Water Quality	Elevated nutrients and pollution leading to algal blooms and anoxic conditions.	Increased nutrient loading due to ongoing agricultural and industrial runoff. Occasional algal blooms and eutrophication events.	Water quality remains poor, with algal blooms a recurring issue; no significant recovery observed.	Louw *et al*. 2013, Richtersveld IDP, 2015, MDPI report, 2020
Physical Habitats	Habitat degradation due to infrastructure, mining, and agricultural runoff.	Invasive species (mesquite) further degrade habitat; salt marshes continue to shrink. Increased siltation due to erosion and land-use changes.	Habitat fragmentation persists; further degradation from invasive species and reduced sediment transport.	Louw *et al*. 2013, BirdLife South Africa, 2024, ORASECOM, 2020

Component	2013 Assessment (Report)	Changes Since 2013 (Post-2013 Data)	Updated Status	Sources
Microalgae	Reduced biomass and diversity due to altered salinity and nutrient imbalances.	Decline continues due to increased nutrient inputs and poor water quality.	Microalgal productivity remains low due to nutrient pollution and salinity imbalance.	Louw *et al*. 2013, MDPI, 2020
Macrophytes	Habitat loss due to salinity shifts and infrastructure impacts.	Further loss of salt marshes and macrophyte habitats, worsened by increased sedimentation and invasive species.	Continued decline in habitat quality and macrophyte diversity; invasive species dominate salt marshes.	Louw *et al*. 2013, BirdLife South Africa, 2024, ORASECOM, 2020
Invertebrates	Declines in species due to habitat degradation and water quality issues.	Some recovery observed but still impacted by ongoing habitat degradation and poor water quality.	Invertebrate diversity shows slight improvement but remains limited due to long-term habitat and water quality challenges.	Louw *et al*. 2013, ORASECOM reports, 2020
Fish	Reduced populations due to overfishing, habitat loss, and water quality issues.	Some recovery in local fish populations as fishing pressures decrease, but habitats still suffer.	Fish populations show slight recovery but remain at risk from habitat loss and pollution.	Lamberth, 2013, ORASECOM reports, 2020
Birds	Significant decline in populations, especially migratory species.	Stabilization in some populations due to conservation efforts, but habitat pressures and disturbances remain.	Bird populations stabilize in Ramsar protected areas, but habitat fragmentation keeps the overall score low.	BirdLife South Africa, 2024, Louw *et al*. 2013, ORASECOM, 2020

While some minor improvements have been noted in the estuarine environment (such as slight recovery of fish populations and invertebrate diversity), the overall condition of the Orange River Estuary has remained largely unchanged or worsened due to persistent human activities (*i.e.,* pollution, overfishing, and habitat degradation). The estuary still requires significant management and restoration efforts to address these ongoing challenges.

It is thus concluded that the PES and REC of the Orange River Estuary remain in an ecological category D and C, respectively, representing a largely modified system.

7.7. Orange River Estuary Flow Requirements

Typical abiotic conditions linked to the inflow of freshwater into an estuary is represented by Table 52.

Table 52: Typical abiotic conditions linked to river inflow (UNDP-GEF, 2013)

State	Description	Flow range (m3/s)
1	Closed for extended period and hyper saline	0
2	Closed, with strong marine influence	0 - 5
3	Marine dominated (open mouth)	5 – 20
4	Brackish (open mouth)	20 – 50
5	Freshwater dominated (open mouth)	>50

The key flow related requirement to achieve the REC will be to reduce present winter base flows sufficiently to allow for mouth closure and related backwater flooding of the saltmarshes with brackish water to reduce soil salinities, but not to the point where the estuary mouth remains closed for longer than 2 to 4 times in 10 years by decreasing river inflow to less than 5 m^3/s. An additional requirement is the need to elevate base flows above 10 m^3/s from December onwards.

To achieve this proposed flow perspective, and thus the REC, Van Niekerk *et al.* (2013) concluded that the recommended distribution of the abiotic states and associated flow ranges should resemble the recommended distribution and flow ranges for abiotic states as presented in Figure 29.

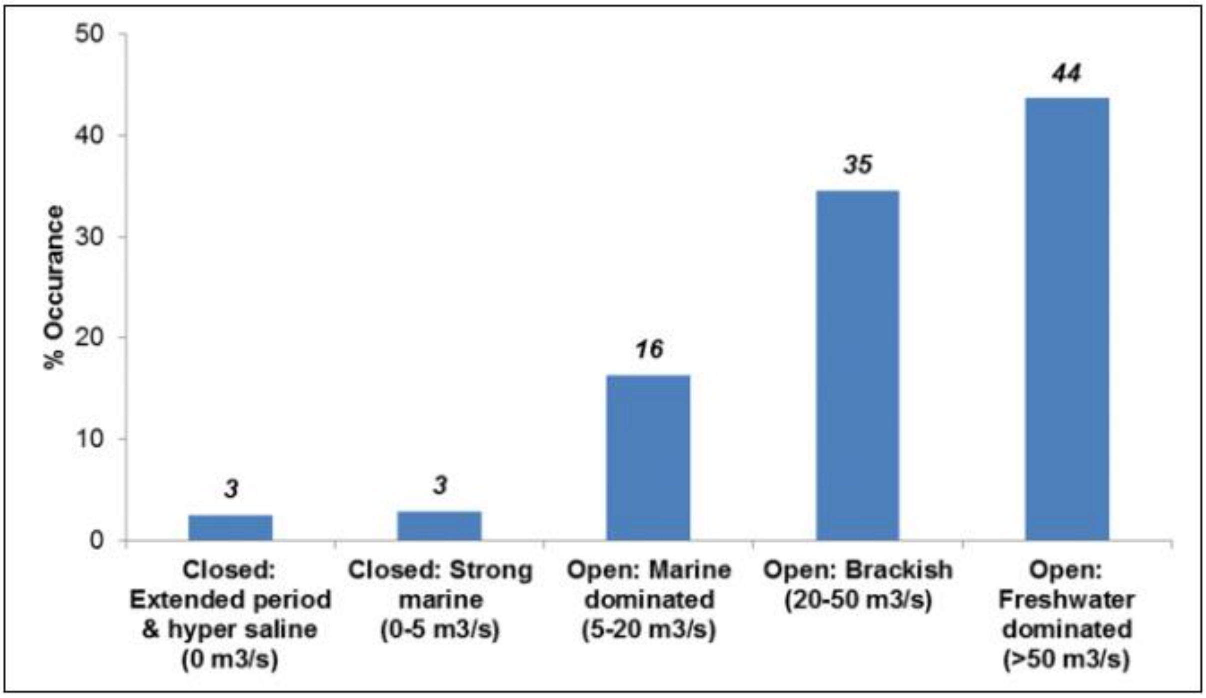

Figure 29: Recommended distribution of abiotic states (Van Niekerk *et. al.,* (2013))

Understanding the flow requirements to achieve the present ecological state as the starting point prior to developing the different flow scenarios for the Lower Orange Classification study remains the most important aspect.

The comprehensive assessment to determine the EFR for the Orange River Estuary (UNDP-GEF, 2013) assessed the present state flow requirements for the river inflow into the Orange River Estuary in terms of the five categories of flow states as defined in Table 53. The 2013 Orange EFR study defined the flow states to be dominated by the Marine Dominated Open Mouth State (State 3), while zero flow percentage occurrence were allocated to States 1 and 2.

However, during the Estuaries Flow Requirements Assessment for the Noordoewer/Vioolsdrift Dam Feasibility Study, Van Niekerk *et. al*., 2020, adjusted the percentage flow occurrence to allocate flows to State 2. 8% flow occurrence was allocated to State 2, while flow occurrences for State 1 and 3 remained largely the same.

The above-mentioned past studies were, however, informed by very limited data on State 1 and 2 due to the limited data available for the closed state of the Orange River Estuary. It was postulated that the estuary does close for short periods of time when the flows fell below 5 m^3/s. During this project data was obtained for the last 10 years between 2013 and 2024 from a measuring station at the Sir Ernest Oppenheimer Bridge and assessed.

Although a large section of data was missing over this period, about 6 years of additional data was considered. Review of the measured data showed that the previous present day MAR simulated data still had slightly elevated baseflows. Flows between 2-5 m^3/s occurred for about 6% of the time in the measured data set, while flows below 2 m^3/s occurring for about 1.8% of the time (Van Niekerk, *pers. comm*., 2024).

For this assessment refinement of the flow ranges for States 1 to 3 is therefore crucial to improve the outcomes of the Lower Orange Classification study. It was therefore proposed that slightly refined flow percentages be included in the present state (PES) flow requirements, see Table 53. The present flows would have to be refined however to address the issue of mouth closure.

Table 53: Abiotic flow states and corresponding flow percentage occurrence as determined by relevant studies for the Orange River Estuary

State	Description	Flow range (m^3/s)	Orange EFR Study (UNDP-GEF, 2013)		Van Niekerk et. al. 2020	Van Niekerk, *pers. comm.*, 2024
			Natural	Present (2013)	Present (2016)	Present (estimated 2024)
1	Closed for extended period and hyper saline	0	2.3	0	0	***2 (<2 m^3/s)***
2	Closed, with strong marine influence	0 – 5	1.9	0	8	***8 (<5 m^3/s)***
3	Marine dominated (open mouth)	5 – 20	8.8	51.4	51	***33 (<20 m^3/s)***
4	Brackish (open mouth)	20 – 50	13.9	19.3	10	***20***

State	Description	Flow range (m^3/s)	Orange EFR Study (UNDP-GEF, 2013)		Van Niekerk et. al. 2020	Van Niekerk, *pers. comm.*, 2024
			Natural	Present (2013)	Present (2016)	Present (estimated 2024)
5	Freshwater dominated (open mouth)	>50	73.1	29.3	26	***37***

The PES flow requirements and scenarios will however be assessed with the relevant estuarine specialists through a workshop to discuss and refine the present state flow rates and scenarios, during the scenario evaluation step.

A summary of the mean monthly flows for the present state of the Orange River Estuary, as determined in the Noordoewer/Vioolsdrift Dam Feasibility Study (Van Niekerk *et. al.* 2020) are presented in Table 54 as indicative mean monthly flows for the proposed flow requirement for the Orange River Estuary present state.

Table 54: Summary of mean monthly flows for the Orange River Estuary present (2016) condition (Van Niekerk *et. al.* 2020)

Scenario 1: PES Estuary (as at 2016)												
Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
10%	105.4	137.7	149.7	466.4	1408.5	608.9	702.6	180.3	109.3	53.2	66.3	25.8
20%	15.1	27.8	64.8	174.8	781.7	487.8	339.0	140.1	45.5	25.4	23.5	5.8
30%	14.2	18.2	21.1	75.8	185.1	349.3	197.0	75.2	31.4	7.7	8.1	4.1
40%	13.6	15.1	14.5	22.3	115.5	200.4	112.9	42.3	10.3	6.0	6.6	4.0
50%	13.3	14.4	13.5	13.9	41.6	91.5	47.9	23.4	8.7	5.6	6.4	4.0
60%	13.2	14.1	12.9	13.2	16.5	40.4	24.2	13.3	8.4	5.5	6.3	4.0
70%	13.1	13.9	12.8	12.9	13.3	19.4	16.8	11.8	8.2	5.4	6.3	4.0
80%	12.9	13.7	12.7	12.7	11.8	14.4	14.0	10.7	7.1	5.2	6.2	4.0
90%	12.9	13.5	12.7	12.7	11.6	13.5	13.4	10.2	6.6	4.2	5.5	3.9
99%	12.7	13.1	12.7	12.7	11.6	13.2	13.3	10.2	6.6	4.2	4.5	3.9

The location to allocate the EWR requirements to must be at the head of the Orange River Estuary, which is defined at the Sir Ernest Oppenheimer Bridge, approximately 11km from the mouth of the Orange River Estuary (latitude: -28.6240 and longitude: 16.4591).

8. SUMMARY AND CONCLUSION

The Eco-categorisation and EWR quantification requirements as presented in this report for the Lower Orange River catchment area concludes step 3 of the classification process. The EWRs are based on the REC for all the rivers as determined during the eco-categorisation task of this study. The PES, EIS and operational constraints due to dams, transfers, return flows and water quality were all considered with the determination of the final REC.

A few approaches were followed to determine the EWRs depending on the specific impacts at the EWR sites, including changed flow patterns, water quality, or the type of river (perennial, seasonal or ephemeral). These approaches included:

i. Verification of the Desktop Reserve Model (DRM)/ Revised DRM within SPATSIM for the integration of data produced from the surveys and Eco-categorisation to quantify the EWRs for the rapid III sites; and
ii. Accepting of the results for sites from previous studies (ORASECOM, 2011 and DWS, 2016) with the latest natural MARs for this study.

The next step (step 4 of the Integrated Framework) is the development of operational scenarios where the feasibility of the implementation of the determined EWRs will be assessed taking system constraints and water use into consideration and provide ecological as well as socio-economic consequences for the final trade-off to determine the Water Resource Classes per IUA.

Table 55 provides a summary of the PES, REC and proposed EWRs for Lower Orange River EWR sites.

Table 55: Summary of the Ecological Water Requirements quantification results for the study along the Lower Orange River

IUA	EWR site	Quat[1]	PES[2]	EI-ES[3]	REC[4]	Total EWR as %nMAR for REC[5]	nMAR $(10^6 m^3)$[6]
1	LO_EWR02_Boegoeberg	D73C	C	H-H	B/C	31.11	10 590.0
2	LO_EWR03_Augrabies	D81B	C	H-H	B/C	24.90	10 730.1
3	LO_EWR04_Vioolsdrift	D82F	C	H-H	B/C	12.2	10 569.8
4	LO_ EWR05_Sendelingsdrift	D82J	B/C	H-H	B	14.66	11 101.1
5	Orange River Estuary	D82L	D	H	C	2-5 m^3/s - 6% of the time; < 2 m^3/s – 1.8% of the time	

[1]Integrated Unit of Analysis
[2]Quaternary catchment
[3]Present Ecological State
[4]EI-ES: Ecological Importance – Ecological Sensitivity (H-H: High-High)
[5]Recommended Ecological Category
[6]Total Ecological Water Requirement as a percentage of the natural Mean Annual Runoff for the Recommended Ecological Category
[7]Natural Mean Annual Runoff in Million Cubic Meters

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APPENDIX A

Fish Inventory and FRAI Models

FRAI models submitted electronically

Blouputs		
***Genus and species* (new)**	***Genus and species* (new)**	**#'s collected**
Enteromius trimaculatus	*Barbus trimaculatus*	2
Enteromius paludinosus	*Barbus paludinosus*	2
Labeobarbus aeneus	*Labeobarbus aeneus*	5
Labeo capensis	*Labeo capensis*	5
Clarias gariepinus	*Clarias gariepinus*	4
Pseudocrenilabrus philander	*Pseudocrenilabrus philander*	3
Engraulicypris gariepinus	*Mesobola brevianalis*	1
Groblershoop		
***Genus and species* (new)**	***Genus and species* (new)**	
Enteromius paludinosus	*Barbus paludinosus*	2
Labeobarbus aeneus	*Labeobarbus aeneus*	5
Labeo capensis	*Labeo capensis*	5
Clarias gariepinus	*Clarias gariepinus*	4
Pseudocrenilabrus philander	*Pseudocrenilabrus philander*	3

APPENDIX B

SASS5 data and MIRAI Models

MIRAI models submitted electronically

LO_EWR02_Boegoeberg

Date (dd-mm-yr):	01-Oct-24			(dd.ddddd)	
Site Code:	LO_EWR02_Boegoeberg	**Grid reference (dd mm ss.s) Lat:**	S		
Collector/Sampler:	Kylie Farrell	**Long:**	E		
River:	Lower Orange	**Datum (WGS84/Cape):**			
Level 1 Ecoregion:	26: NAMA KAROO	**Altitude (m):**			
Quaternary Catchment:		**Zonation:**			
	Temp (°C):		**Routine or Project? (circle one)**	**Flow**	
Site Description: 52	**pH:**		**Project Name: Lower Orange Classificatio**	**Clarity (cm):**	
Site outside Goedehoop town on private farm land upstream from Boegoberg weir	**DO (mg/L):**			**Turbidity:**	
	Conductivity:			**Colour:**	
	Riparian Disturbance:				
	Instream Disturbance:				

Biotopes Sampled (tick & rate)	**Rating (1-5)**	**Time (min)**
	4	2
Stones Out Of Current (SOOC)	2	1
Bedrock	4	-
Aquatic Veg	0	
MargVeg In Current	1	
MargVeg Out Of Current	1	
Gravel	2	
Sand	3	
Mud	5	
Hand picking/Visual observation	x	
Biotope Score (%)	49	

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5				A
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3				
ANNELIDA					
Oligochaeta (Earthworms)	1	A		A	B
Hirudinea (Leeches)	3	A	A		B
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3				
Atyidae (Freshwater Shrimps)	8	A	A		A
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14				
Perlidae	12				
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4			1	
Baetidae 2 sp	6	A	A		B
Baetidae > 2 sp	12				
Caenidae (Squaregills/Cainfles)	6				
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13	A			A
Leptophlebiidae (Prongills)	9	B			B
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15				
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9				
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Demoiselles)	10				
Chlorocyphidae (Jewels)	10				
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4				
Lestidae (Emerald Damselflies/Spreadwings)	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6	1			1
Libellulidae (Darters/Skimmers)	4				
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12				

Taxon	QV	S	Veg	GSM	TOT
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3				
Corixidae* (Water boatmen)	3				
Gerridae* (Pond skaters/Water striders)	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7		1		1
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3				
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5				
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4		1		
Hydropsychidae 2 sp	6	B			B
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5				
Elmidae/Dryopidae* (Riffle beetles)	8	1			1
Gyrinidae* (Whirligig beetles)	5			1	1
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5				
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10				

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5			1	1
Chironomidae (Midges)	2				
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	A			A
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalves)					
Corbiculidae (Clams)	5	A		B	B
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					90
No. of Taxa					15
ASPT					6.0

Other biota:

Comments/Observations:

LO_EWR03_Augrabies

Date (dd-mm-yr):	30-Sep-24			(dd.ddddd)	
Site Code:	LO_EWR03_Blouputs	**Grid reference (dd mm ss.s) Lat:**	S		
Collector/Sampler:	Kylie Farrell	**Long:**	E		
River:	Lower Orange	**Datum (WGS84/Cape):**			
Level 1 Ecoregion:	28: ORANGE RIVER GORGE	**Altitude (m):**			
Quaternary Catchment:		**Zonation:**			
	Temp (°C):		**Routine or Project? (circle one)**	**Flow**	
Site Description: 52	**pH:**		**Project Name: Lower Orange Classificatio**	**Clarity (cm):**	
Site downstream from Blouputs weir downstream of Augrabie Falls	**DO (mg/L):**			**Turbidity:**	
	Conductivity:			**Colour:**	
	Riparian Disturbance:				
	Instream Disturbance:				

Biotopes Sampled (tick & rate)	**Rating (1-5)**		**Time (min)**
	3		2
Stones Out Of Current (SOOC)	3		1
Bedrock	4		-
Aquatic Veg	1		
MargVeg In Current	5		
MargVeg Out Of Current	3		
Gravel	4		
Sand	4		
Mud	4		
Hand picking/Visual observation	x		
Biotope Score (%)	69		

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5				
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3				
ANNELIDA					
Oligochaeta (Earthworms)	1	A		A	B
Hirudinea (Leeches)	3	A	1	A	B
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3				
Atyidae (Freshwater Shrimps)	8		A		A
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14				
Perlidae	12				1
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4			1	
Baetidae 2 sp	6	B			
Baetidae > 2 sp	12	B	A		B
Caenidae (Squaregills/Cainfles)	6	B			B
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13				
Leptophlebiidae (Prongills)	9	B	1	A	B
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15				
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9				
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Demoiselles)	10				
Chlorocyphidae (Jewels)	10				
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4				
Lestidae (Emerald Damselflies/Spreadwings)	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6			1	1
Libellulidae (Darters/Skimmers)	4				
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12				

Taxon	QV	S	Veg	GSM	TOT
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3				
Corixidae* (Water boatmen)	3		A	A	B
Gerridae* (Pond skaters/Water striders)	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7				
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3		A		A
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5				
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6	B			B
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6		1		1
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5				
Elmidae/Dryopidae* (Riffle beetles)	8	A	1		A
Gyrinidae* (Whirligig beetles)	5				A
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5			1	1
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10				

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5		A		A
Chironomidae (Midges)	2	B	A	A	B
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1		1		1
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3		1		1
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5	1		1	B
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					109
No. of Taxa					20
ASPT					5.5
Other biota:					
Comments/Observations:					

APPENDIX C

Summary of IHI Models

Instream

SQ REACH	SQ REACH NAME	GEOMORPH ZONE(S)	ECOREGION LEVEL 1	WATER ABSTRACTION (IMPACT 1 - 25)	FLOW MODIFICATION ((IMPACT 1 - 25)	BED MODIFICATION (IMPACT 1 - 25)	CHANNEL MODIFICATION (IMPACT 1 - 25)	PHYS-CHEM MOD (IMPACT 1 - 25)	INUNDATION (IMPACT 1 - 25)	ALIEN MACROPHYTES (IMPACT 1 - 25)	INTRODUCED AQUATIC FAUNA (IMPACT 1 - 25)	RUBBISH DUMPING (IMPACT 1 - 25)	INSTREAM HABITAT INTEGRITY SCORE	INSTREAM INTEGRITY CLASS
D73B-03617	LO_EWR02_Boegoeberg	F	28	16	18	14	10	10	1	1	8	5	46	D
D81B-03140	LO_EWR03_Blouputs	F	26	16	18	10	9	9	2	1	5	5	51	D

Riparian

SQ REACH	SQ REACH NAME	GEOMORPH ZONE(S)	ECOREGION LEVEL 1	VEGETATION REMOVAL (IMPACT 1 - 25)	EXOTIC VEGETATION (IMPACT 1 - 25)	BANK EROSION (IMPACT 1 - 25)	CHANNEL MODIFICATION (IMPACT 1 - 25)	WATER ABSTRACTION (IMPACT 1 - 25)	INUNDATION (IMPACT 1 - 25)	FLOW MODIFICATION (IMPACT 1 - 25)	PHYS-CHEM (IMPACT 1 - 25)	PRIPARIAN INTEGRITY INTEGRITY SCORE	RIPARIAN INTEGRITY CLASS
D73B-03617	LO_EWR02_Boegoeberg	F	28	8	12	4	10	4	1	9	8	65	C
D81B-03140	LO_EWR03_Blouputs	F	26	5	5	8	4	2	1	9	10	78	C/B

APPENDIX D

Physico-Chemical Results

Table D1: Summary of DWS Water Quality site information (2019-2023) and once of sampling during survey

Water Quality Monitoring site associated with EWR site with coordinates			Source Category	Date or Statistic	Field Survey *In-Situ* Parameter					Physico-chemical								Major Ions							Metals			Nutrients		
					pH (pH Units)	EC (mS/m)	TDS (mg/l)	DO (mg O2/l)	ORP (mV)	pH (pH units)		EC (mS/m)	TDS (mg/l)	DO (mg O_2/l)	TSS (mg/l)	Total Alkalinity as $CaCO_3$	SAR (ratio)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	Cl (mg/l)	K (mg/l)	SO_4 (mg/l)	F (mg/l)	Al (mg/l)	Fe (mg/l)	Mn (mg/l)	NO_3-N (mg/l)	PO_4 (mg/l)	NH_3-N (mg/l)
EWR 02	**-28.96949; 22.17843**	Boegoeberg	Field Survey Sample	2024/10/02	10.2	31.8	159	5.5	95.6		8.14	31.6	183	9	23	136	0.81	27.8	13	21	17	1.8	20.9	*0.15*	<0.02	<0.02	<0.002	0.15	0.015	0.05
		Groblershoop	DWS Regional Monitoring (2019-2023)	n = 34 | Values 95th and Nutrients 50th						7.20	8.49	47.4	254	-	73				18	38	33	4.1	47	**2.5**	0.215	0.281	0.438	1.78	0.009	**1.00**
EWR 03	**-28.51037; 20.17165**	Augrabies	Field Survey Sample	2024/09/30	6	60.4	302	5.3	96.6		8.16	60.1	338	9	15	190	1.69	39.4	23	54	49	2.5	56.9	0.3	<0.02	<0.02	<0.002	0.025	0.015	0.015
		Blouputs	DWS Regional Monitoring (2019-2023)	n = 36 | Values 95th and Nutrients 50th						7.50	8.58	63.6	396	-	94				26	71	55	5.3	68	**2.5**	0.136	0.220	0.069	0.29	0.008	**0.91**
EWR 04	**-28.7553; 17.71696**	Vioolsdrift	DWS Regional Monitoring (2019-2023)	n = 34 | Values 95th and Nutrients 50th	*not surveyed*					7.10	8.44	67.1	452	-	124				30	75	71	6.2	82	0.6	0.197	0.280	0.767	0.07	0.006	**1.06**
EWR 05	**-28.0718; 16.95951**	Sendelengsdrift	DWS Regional Monitoring (2019-2023)	n = 33 |Values 95th and Nutrients 50th						7.50	8.58	81.5	480	-	248				34	103	97	5.8	136	**2.5**	0.160	0.225	0.468	0.85	0.008	**1.01**
		Estuary	DWS Regional Monitoring (2019-2023)	n = 35 | Values 95th and Nutrients 50th						6.80	8.33	**4888.5**	**35180**	-	267				**1371**	**9845**	**20030**	429.8	**2558**	**1.9**	0.313	0.445	0.152	0.18	0.044	**1.56**

Ideal Water Quality Range
Acceptable Water Quality Range
Tolerable Water Quality Range
Unaccptable Water Quality Range

LO_EWR02_Boegoeberg

PHYSICO-CHEMICAL EC					
Physico-chemical Metrics	Rank	%wt	Rating	CONFIDENCE	WEIGHTED RATING
pH	3.00	40.00	1.00	2.00	0.40
SALTS	2.00	80.00	2.00	3.00	1.60
NUTRIENTS	2.00	80.00	2.00	3.00	1.60
TEMPERATURE	1.00	100.00	2.00	2.00	2.00
TURBIDITY	2.00	80.00	2.00	2.00	1.60
OXYGEN	1.00	100.00	1.00	3.00	1.00
TOXICS	1.00	100.00	3.00	3.00	3.00
PHYSICO-CHEMICAL PERCENTAGE SCORE	61.38				
PHYSICO-CHEMICAL CATEGORY	C				
BOUNDARY CATEGORY					

LO_EWR03_Augrabies

PHYSICO-CHEMICAL EC					
Physico-chemical Metrics	Rank	%wt	Rating	CONFIDENCE	WEIGHTED RATING
pH	3.00	40.00	1.00	2.00	0.40
SALTS	2.00	80.00	2.00	2.00	1.60
NUTRIENTS	2.00	80.00	2.00	3.00	1.60
TEMPERATURE	1.00	100.00	2.00	2.00	2.00
TURBIDITY	2.00	80.00	2.00	2.00	1.60
OXYGEN	1.00	100.00	2.00	2.00	2.00
TOXICS	1.00	100.00	3.00	3.00	3.00
PHYSICO-CHEMICAL PERCENTAGE SCORE	57.93				
PHYSICO-CHEMICAL CATEGORY	D				
BOUNDARY CATEGORY					

APPENDIX E

Diatom Results

LO_EWR02_Boegoeberg

Diatoms*				
No. species	**SPI****	**Categorisation (quality)**	**%PTV*****	**%Deformed cells******
36	13.5	B (Good)	6	0.5
Dominant Species		1. *Nitzschia sp*		
		2. *Gomphonema sp*		
		3. *Navicula sp*		
		4. *Fragilaria sp*		
		5. *Encyonopsis sp*		
Preference		• Good quality waters		
		• The dominant diatom taxa pointed to well-oxygenated, meso-to eutrophic conditions with low to moderate electrolyte content. These taxa are tolerant to moderately polluted conditions.		
		• The oxygen saturation levels were high for all the sites suggesting that there were low levels of organic nutrients present		
		• The %PTV score indicated that the percentage of diatom taxa that were tolerant to organic pollution was low, suggesting that these levels are not associated with eutrophication impacts at these sites. The overall ecological water quality at these sites was Good.		

LO_EWR03_Augrabies

Diatoms*				
No. species	**SPI****	**Categorisation (quality)**	**%PTV*****	**%Deformed cells******
40	13.3	B (Good)	4.2	1
Dominant Species		1. *Nitzschia sp*		
		2. *Gomphonema sp*		
		3. *Navicula sp*		
		4. *Synedra sp.*		
		5. *Fragilaria sp*		
		6. *Encyonopsis sp*		
		7. *Achnanthidium sp.*		
Preference		• Good quality waters		
		• The dominant diatom taxa pointed to well-oxygenated, meso-to eutrophic conditions with low to moderate electrolyte content. These taxa are tolerant to moderately polluted conditions.		
		• The oxygen saturation levels were high for all the sites suggesting that there were low levels of organic nutrients present		
		• The %PTV score indicated that the percentage of diatom taxa that were tolerant to organic pollution was low, suggesting that these levels are not associated with eutrophication impacts at these sites. The overall ecological water quality at these sites was Good.		

***Specific Pollution sensitivity Index (adapted from Eloranta and 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.*

APPENDIX F

EcoStatus Models

LO_EWR02_Boegoeberg

INSTREAM BIOTA	IMPORTANCE SCORE	WEIGHT	FRAI/FISHCON & MIRAI/INCO	FRAI/FISHCON & MIRAI/INCON EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	3.00	60.00		
2.What is the natural diversity of **fish** species with a preference for different cover types	5.00	100.00		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	5.00	100.00		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	3.00	60.00		
FISH ECOLOGICAL CATEGORY (FRAI/FISHCON %)	16.00	320.00	52.50	D
AQUATIC INVERTEBRATES				
1. What is the natural diversity of **invertebrate** biotopes	4.00	100.00		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	3.00	75.00		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	3.00	75.00		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY (MIRAI/INCON %)	10.00	250.00	70.25	C
INSTREAM ECOLOGICAL CATEGORY (EC AND %): NOT CONFIDENCE RATED, ONLY FISH IN INVERTEBRATE INDICATOR RATINGS FOR WEIGHTING OF FRAI/FISHCON AND MIRAI/INCON CONSIDERED		570.00	61.66	C/D

INSTREAM ECOLOGICAL CATEGORY: CONFIDENCE RATED	FRAI/FISHCON & MIRAI/INCON CONFIDENCE RATINGS	
Confidence rating for **fish** information	3.00	
Confidence rating for **macro-invertebrate** information	3.00	
INSTREAM ECOLOGICAL CATEGORY (%)	6.00	**61.52**
INSTREAM ECOLOGICAL CATEOGORY		**C/D**

RIPARIAN VEGETATION	RIPARIAN VEGETATION (VEGRAI/VEGCON) EC %	RIPARIAN VEGETATION (VEGRAI/VEGCON) EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	65.00	**C**

INTEGRATED (INSTREAM & RIPARIAN VEGETATION) ECOSTATUS	CONFIDENCE RATING	
Confidence rating for instream biological information	3.00	
Confidence rating for riparian vegetation zone information	2.00	
INTEGRATED ECOLOGICAL CATEGORY (%)	5.00	**62.91**
INTEGRATED ECOSTATUS CATEGORY		**C**

LO_EWR03_Augrabies

INSTREAM BIOTA	IMPORTANCE SCORE	WEIGHT	FRAI/FISHCON & MIRAI/INCO	FRAI/FISHCON & MIRAI/INCON EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	3.00	70.00		
2.What is the natural diversity of **fish** species with a preference for different cover types	5.00	100.00		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	5.00	100.00		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	2.00	60.00		
FISH ECOLOGICAL CATEGORY (FRAI/FISHCON %)	15.00	330.00	**49.90**	**D**
AQUATIC INVERTEBRATES				
1. What is the natural diversity of **invertebrate** biotopes	4.00	100.00		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	4.00	80.00		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	3.00	60.00		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY (MIRAI/INCON %)	11.00	240.00	**68.91**	**C**
INSTREAM ECOLOGICAL CATEGORY (EC AND %): NOT CONFIDENCE RATED, ONLY FISH IN INVERTEBRATE INDICATOR RATINGS FOR WEIGHTING OF FRAI/FISHCON AND MIRAI/INCON CONSIDERED		570.00	**60.43**	**C/D**

INSTREAM ECOLOGICAL CATEGORY: CONFIDENCE RATED	FRAI/FISHCON & MIRAI/INCON CONFIDENCE RATINGS	
Confidence rating for **fish** information	5.00	
Confidence rating for **macro-invertebrate** information	5.00	
INSTREAM ECOLOGICAL CATEGORY (%)	10.00	**59.92**
INSTREAM ECOLOGICAL CATEOGORY		**C/D**

RIPARIAN VEGETATION	RIPARIAN VEGETATION (VEGRAI/VEGCON) EC %	RIPARIAN VEGETATION (VEGRAI/VEGCON) EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	78.00	**C**

INTEGRATED (INSTREAM & RIPARIAN VEGETATION) ECOSTATUS	CONFIDENCE RATING	
Confidence rating for instream biological information	5.00	
Confidence rating for riparian vegetation zone information	3.00	
INTEGRATED ECOLOGICAL CATEGORY (%)	8.00	**66.70**
INTEGRATED ECOSTATUS CATEGORY		**C**

APPENDIX G

Phytoplankton Species identified during sampling event of Orange River Estuary

Table G1: Phytoplankton Species identified during November 2024 sampling event of Orange River Estuary

Site	Frames	Cryptophyceae	Bacillariophyceae	Dinophyceae	Chlorodendrophyceae	Chlorophyceae	Cyanophyceae	Total	Comments
Orange S1 Top	10	2	3200		4	6	3	3215	Small (< 10 µm length) naviculoid diatom bloom
Orange S1 Bot	10	1	2624		3	5	2	2635	
Orange S2 Top	10	10	92		2	102	32	238	*Tetraedron minimum* and *Monactinus simplex* dominant chlorophytes (greens); other greens present = *Coelastrum* and *Ankistrodesmus* spp.; *Aulacoseria granulata* present in surface waters, small *Navicula* sp. in bottom-waters; *Merismopedia* sp. dominant cyanophyte present
Orange S2 Bot	10	18	234	4	2	40	10	308	
Orange S3 Top	10		80			90	56	226	
Orange S3 Bot	12	4	264	2		60	10	340	
Orange S4 Top	10		94			100	48	242	*Tetraedron minimum* and *Monactinus simplex* dominant chlorophytes (greens); other greens present = *Coelastrum* and *Ankistrodesmus* spp.; *A. granulata* dominant diatom; *Merismopedia* sp. dominant cyanophyte present
Orange S4 Bot	12		102			128	20	250	
Orange S5 Top	10		88			100	70	260	
Orange S5 Bot	12		70			104	28	202	