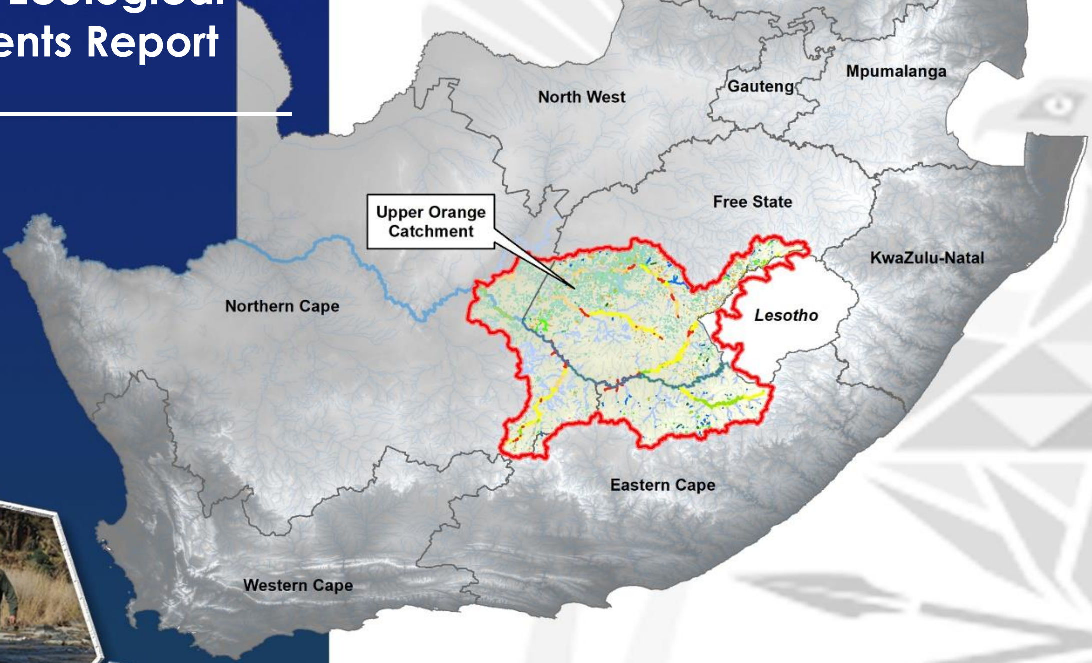
DEPARTMENT OF WATER AND SANITATION

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

WP11343
Quantification of Ecological Water Requirements Report



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Tel: (012) 336 7500/ +27 12 336 7500
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Prepared by:

GroundTruth

Title:	*Quantification of Ecological Requirements Report*
Authors:	*M. Graham, K. Farrell, R. Stassen, G. de Winnaar, B. Grant, B. van der Waal, T. Pike, K. Mncwabe*
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…………………………………………………………… ……………………………………………………….

Dr Mark Graham *Date*

Director, GroundTruth

DEPARTMENT OF WATER AND SANITATION

Chief Directorate: Water Ecosystems Management

Approved for DWS by:

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

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

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

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Director: Yakeen Atwaru

Date: …………………………………………………..

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LIST OF ACRONYMS

CD: WEM	Chief Directorate: Water Ecosystems Management
DRM	Desktop Reserve Model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EIS	Ecological Importance and Sensitivity
EI	Ecological Importance
ES	Ecological Sensitivity
EWR	Ecological Water Requirements
FCS	Fast course substrate
FD	Fast deep
FI	Fast intermediate
FS	Fast shallow
FS	Fast shallow
HFSR	Habitat Flow Stressor Response
IHI	Integrated Habitat Integrity
IWUI	Integrated Water Use Index
JBS	Joint Basin Survey
MAR	Mean Annual Runoff
NWA	National Water Act
PES	Present Ecological State
REC	Recommended Ecological Category
REMP	River Eco-Status Monitoring Programme
RDM	Resource Directed Measures
SD	Slow deep
SIC	Stones-in-current
SOOC	Stones-out-of-current
VFCS	Very fast course substrate
WMA	Water Management Area
WRCS	Water Resources Classification System
WRYM	Water resources yield model
WRPM	Water resources planning model
WRC	Water Research Commission

EXECUTIVE SUMMARY

Background and Purpose

This Ecological Water Requirements (EWR) Quantification Report forms the final task in step 3 of the Integrated steps for the determination of the Reserve (DWS, 2017) as part of the following study: A High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange. The purpose of this study is to determine the Reserve (quantity and quality of the EWR and BHN) for priority rivers, wetlands and groundwater areas at a high level of confidence. The results from the study will guide the Department of Water and Sanitation (DWS) to meet the objectives of maintaining, and if attainable, improving the ecological state of the water resources. The primary deliverable will be the preparation of the Reserve templates for the Upper Orange Catchment, specifying the Ecological Water Requirements (EWR) and ecological specifications/conditions for the management of the priority rivers, wetlands and groundwater areas.

This report draws on the results of the Eco-categorisation step (see Report No. RDM/WMA13/00/CON/COMP/1223 Volume 1 and Volume 2 (a, b respectively)) that was undertaken for all selected EWR sites.

Thus, the focus of this report is the quantification of the EWR using various approaches depending on the specific conditions and impacts at the EWR sites. These include:

- Habitat Flow Stressor Response (HFSR) and Desktop Reserve Model (DRM)/ Revised DRM within SPATSIM for the integration of data produced from the surveys and Eco-categorisation to quantify the EWRs;
- A conceptual Flow Management Plan is proposed for the Orange River downstream of Gariep and Vanderkloof Dams (see Section 8); and
- An initial approach for the integration/ interaction between rivers, wetlands and groundwater has been developed (see Section 9 and Appendix B).

Study Area and final EWR sites

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

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

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

Hydraulic and hydrological data and modelling

Hydraulic information was obtained during both river surveys (July 2022 and April/May 2023) and which include the selection and surveying of an appropriate cross section 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.

Natural and present-day hydrology was obtained from a number of sources, including the data in the water resources yield model (WRYM) and water resources planning model (WRPM) models for the Integrated Vaal-Orange Water Supply System. The flow time series obtained from these studies were used and adjusted by catchment area to obtain the flows at the EWR sites.

EWR results

The final EWR quantification results for all Intermediate and Rapid 3 EWR sites for the Recommended Ecological Category (REC) is presented in the table below-. These EWR results will be used in steps 4 and 5 of the Integrated steps for the determination of the Reserve (DWS, 2017) to develop operational scenarios and to evaluate the ecological consequences of these scenarios to finalise the EWRs.

Table 1-: Summary of the EWR quantification results for the study

EWR site	River	Quaternary	REC	Total EWR as %nMAR for REC	nMAR ($10^6 m^3$)
INTERMEDIATE					
UO_EWR01_I	Middle Caledon	D22D	D	23.16	674.0
UO_EWR02_I	Sterkspruit	D12B	C/D	38.43	30.7
UO_EWR03_I	Upper Orange	D12F	D	25.06	4 259.5
UO_EWR04_I	Lower Caledon	D24G	C/D	29.43	1 353.6
UO_EWR05_I	Seekoei	D32J	C	34.19	24.3
UO_EWR06_I	Upper Riet	C51F	C	31.05	105.2
UO_EWR07_I	Upper Modder	C52B	C	35.94	61.0
UO_EWR08_I	Lower Kraai	D13M	B/C	46.52	719.0
UO_EWR09_I	Lower Riet	C51L	B/C*	24.07	373.8
UO_EWR10_I	Lower Orange	D33K	C	21.39	6 674.2
RAPID 3					
UO_EWR01_R	Little Caledon	D21D	B/C	39.20	25.9
UO_EWR02_R	Brandwater/ Groot	D21G	B/C	30.95	56.0
UO_EWR03_R	Mopeli	D22G	C/D	29.34	49.4
UO_EWR04_R	Upper Kraai	D13E	B	40.04	200.9
UO_EWR05_R	Wonderboomspruit	D14E	C/D	32.38	25.9
UO_EWR06_R	Middle Modder	C52G	C/D	33.96	113.7
FIELD VERIFICATION					
UO_EWR01_FV	Meulspruit	D22B	D	12.51	63.6
UO_EWR02_FV	Witspruit	D24C	C	19.18	21.7
UO_EWR03_FV	Gryskopspruit	D12D	C	18.38	7.5

EWR site	River	Quaternary	REC	Total EWR as %nMAR for REC	nMAR (10^6m^3)
UO_EWR04_FV	Karringmelkspruit	D13K	B	45.11	25.9
UO_EWR05_FV	Bokspruit	D13A	B	44.99	60.4
UO_EWR06_FV	Holspruit	D13J	C	18.05	36.9
UO_EWR07_FV	Sterkspruit, tributary of Kraai	D13C	B/C	37.24	47.6
UO_EWR08_FV	Bell	D13B	B	45.08	72.5
UO_EWR09_FV	Groenspruit	D24H	C	18.01	5.02
UO_EWR10_FV	Skulpspruit	D24H	C	18.01	7.8
UO_EWR11_FV	Fouriespruit	C51A	C	17.92	13.8
UO_EWR12_FV	Renoster	C52F	D	11.18	7.9
UO_EWR13_FV	Os-spruit	C52E	B/C	21.84	8.6
UO_EWR14_FV	Hondeblaf	D31C	B	26.74	2.0
UO_EWR15_FV	Tributary of VanZylspruit	C51G	C	17.92	1.9
UO_EWR16_FV	Slykspruit	D24L	B/C	23.01	5.1
UO_EWR17_FV	Langkloofspruit	D13D	B	44.45	43.8
UO_EWR18_FV	Wasbankspruit	D13G	B/C	38.79	16.5
UO_EWR19_FV	Lower Modder	C52K	C	17.82	156.8
UO_EWR20_FV	Upper Kromellenboog	C51G	B	26.79	9.3
UO_EWR21_FV	Lower Kromellenboog	C51H	B/C	26.52	85.1
UO_EWR22_FV	Tele	D18K	C	21.54	142.3
UO_EWR23_FV	Upper Orange	D12A	C	36.17	4 115.1
UO_EWR24_FV	Makhaleng	D15G	C/D	17.39	524.5

**Although the flows as per the Vaal comprehensive study were specified for a D category, they were checked and identified to be adequate to maintain the PES of a C.*

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1. INTRODUCTION

1.1 Background

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

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

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

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

1.2 Purpose of this study

It is important to note the following:

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

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

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

1.3 Purpose of this report

The purpose of this report is to document the results of the quantification of the Ecological Water Requirements (EWR) within the Upper Orange catchment, forming part of the Orange WMA6. The Modder-Riet River, although part of the Vaal River system, was also included as part of this study area due to the inter-connectivity of the rivers through various transfer schemes. The quantification is based on information and data that is currently available through various previous studies and the surveys that were undertaken as part of the current study (October 2021, July 2022 and April/May 2023).

The quantification of the ecological water requirements were determined using the following:

- Information collected during the field surveys;
- Results from the Eco-categorisation process (Present Ecological State (PES), Ecological Importance (EI), Ecological Sensitivity (ES) and Recommended Ecological Category (REC));
- Habitat Flow Stressor Response (HFSR) and Desktop Reserve Model (DRM)/ Revised DRM within SPATSIM for the integration of data produced from the surveys and Eco-categorisation to quantify the EWRs. The most applicable approach was selected depending on the specific conditions at the EWR site and impacts in the upper catchments;
- Results from the hydraulic modelling (cross-sectional profile and discharge) to evaluate the requirements; and
- Baseflow separation undertaken for the intermediate and rapid 3 sites using the approach as developed by Smakhtin (2001). This provides an indication as to the groundwater contribution to surface flows without the influence of high flows (freshets and floods) and assist the ecologists with the setting of baseflows (maintenance low) for the rivers.

Further, the conceptual Flow Management Plan proposed for the Orange River downstream of Gariep and Vanderkloof Dams are presented in this report.

Additionally, an initial approach for the integration/ interaction between rivers, wetlands and groundwater has been developed and is proposed for two areas (Kraai and Modder Rivers).

This report describes the approaches, methods and models used to determine the EWRs for the priority river reaches at selected EWR sites. These determinations are on various levels of detail as described in volume 3 of the RDM methodology of 1999 (DWAF, 1999) and include intermediate, rapid 3, field verification and desktops. The various surveys undertaken, and approaches followed is presented in Table 1-1.

Table 1-1: EWR survey levels and components included

Intermediate	Rapid 3	Field verification	Desktop
• Dry and post-wet season surveys • Hydraulics • Fish • Macroinvertebrates • Riparian vegetation • Geomorphology • Hydrology • Water quality • Diatoms • Habitat Flow Stressor Response (HFSR) depending on specific conditions at the EWR site	• Dry season survey • Hydraulics • Fish • Macroinvertebrates • Rapid Habitat Integrity Assessment • Hydrology • Diatoms • Desktop Reserve Model	• Discharge at some sites • Rapid Habitat Integrity Assessment • Hydrology • Diatoms • Revised/ Desktop Reserve Model	• No surveys • Desktop PES/EI/ES from JBS3 or previous Reserve studies • Hydrology • Desktop Reserve Model

This report draws on the results from:

- The Eco-categorisation process and report (see Report No. RDM/WMA13/00/CON/COMP/1223 Volume 1 and Volume 2 (a, b respectively);
- HFSR approach or Revised/DRM within SPATSIM for the integration of data produced from the surveys to quantify the EWRs; and
- Results from the hydraulic modelling (cross-sectional profile and discharge) to evaluate the requirements.

The quantification of the EWR forms part of Step 3 of the integrated steps for the determination of the Reserve (see Figure 1-1 below).

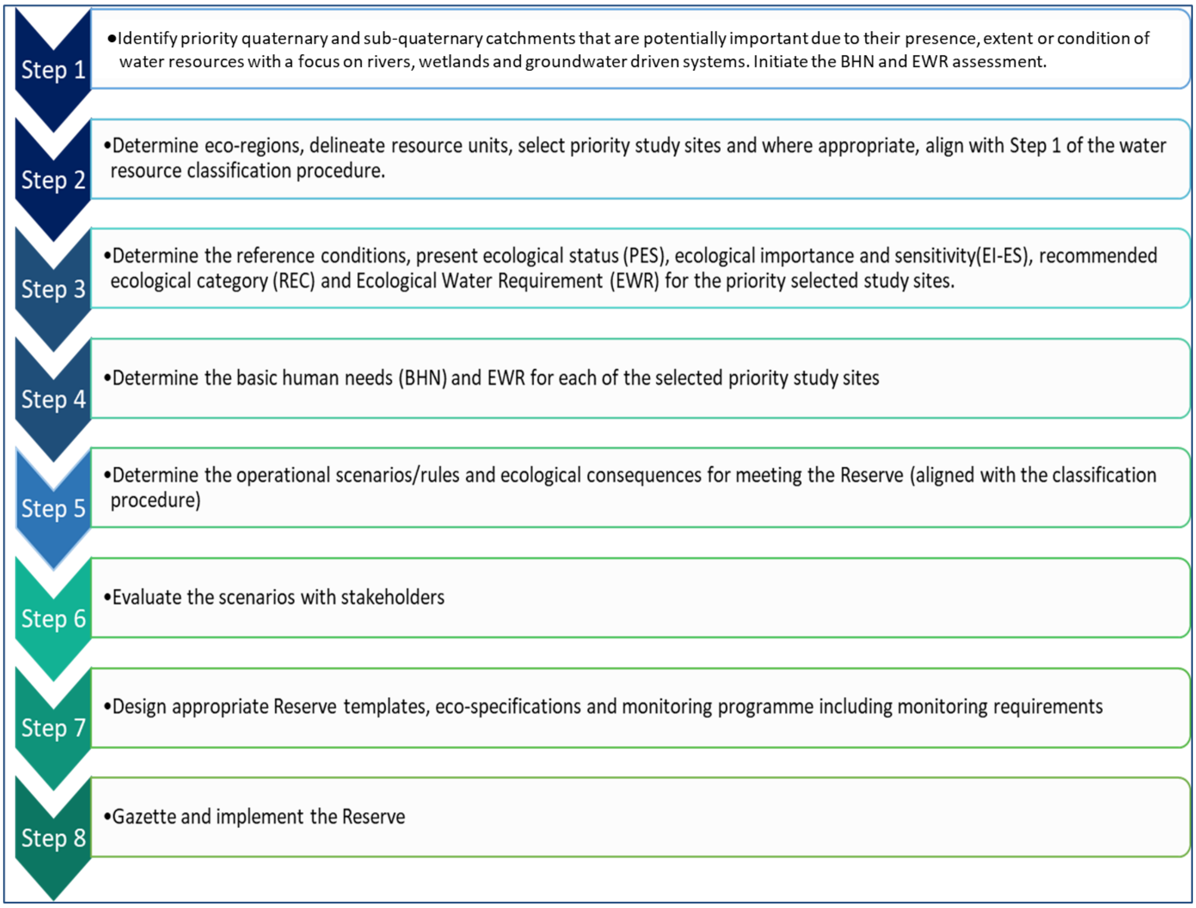


Figure 1-1: Integrated steps for the determination of the Reserve (DWS, 2017)

2. OVERVIEW OF THE STUDY AREA

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

v. The Orange River from the Lesotho Border to the Gariep Dam, including the main tributaries: Kornetspruit, Sterkspruit, Stormbergspruit and Brandwaterspruit (catchments D12, D14 and the SA part of D15 and D18);
vi. The Caledon River from its headwaters and its tributaries to the Gariep Dam (catchments D21, D22, D23, D24);
vii. The Kraai River catchment (catchment D13); and
viii. The Orange River from the Gariep Dam to Marksdrift weir (catchments D31, D33, D34 and D35), just upstream from the confluence with the Vaal River. This includes the Seekoei River

(catchment D32) in the south and the Modder-Riet River (catchments C51 and C52) in the north.

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

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

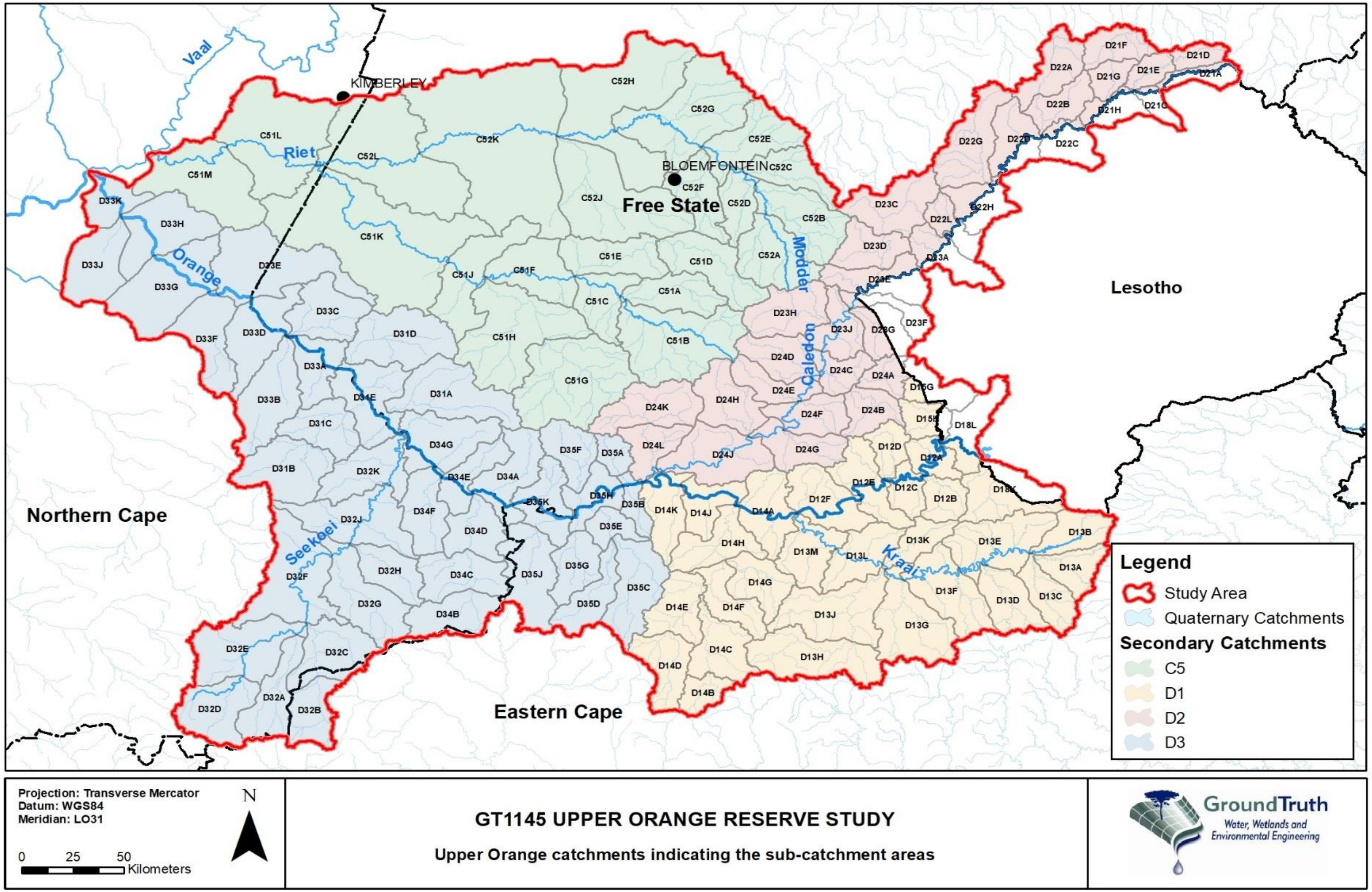


Figure 2-1: Upper Orange Catchment

3. FINAL EWR SITES

The final EWR sites selected per priority Resource Unit (see report RDM/WMA13/00/CON/COMP/0321) and level of assessment for the Upper Orange River catchment is presented in Table 3-1.

Table 3-1: Summary of the selected EWR sites for the study area

Resource Unit	EWR site code	River	Latitude	Longitude	Quat	Level
R_RU01	OU_EWR02_I	Sterkspruit	-30.517806	27.369058	D12B	Intermediate
R_RU02a	OU_EWR03_I	Upper Orange	-30.652793	26.823213	D12F	Intermediate
R_RU02b	UO_EWR23_FV	Upper Orange	-30.398757	27.342987	D12A	Field verification
R_RU03	OU_EWR08_I	Lower Kraai	-30.69007	26.74157	D13M	Intermediate
R_RU04	OU_EWR01_I	Middle Caledon	-28.9089	27.785	D22D	Intermediate
R_RU05	OU_EWR04_I	Lower Caledon	-30.436136	26.299258	D24G	Intermediate
R_RU06	OU_EWR05_I	Seekoei	-30.534359	24.962895	D32J	Intermediate
R_RU07	OU_EWR10_I	Lower Orange	-29.16202	23.695944	D33K	Intermediate
R_RU08	OU_EWR06_I	Upper Riet	-29.535065	25.52457	C51F	Intermediate
R_RU09a	OU_EWR07_I	Upper Modder (Sannaspos)	-29.160017	26.572492	C52B	Intermediate
R_RU09b	UO_EWR06_R	Middle Modder (Soetdoring)	-28.807191	26.109695	C52B	Rapid 3
R_RU10	OU_EWR09_I	Lower Riet	-29.03842	24.50283	C51L	Intermediate
R_RU11a	UO_EWR04_R	Upper Kraai	-30.85179	27.77689	D13B	Rapid 3
R_RU11b	UO_EWR07_FV	Sterkspruit (trib of Kraai/Bell)	-30.917621	27.800753	D13A	Field verification
R_RU11c	UO_EWR08_FV	Bell	-30.852601	27.786557	D13A	Field verification
R_RU11d	UO_EWR17_FV	Langkloofspruit	-30.954126	27.606129	D13D	Field verification
R_RU12	UO_EWR05_R	Wonderboomspruit	-31.005262	26.341938	D14E	Rapid 3
R_RU13	UO_EWR01_R	Little Caledon	-28.557796	28.405709	D21D	Rapid 3
R_RU14	UO_EWR02_R	Brandwater (Groot)	-28.680340	28.139926	D21G	Rapid 3
R_RU16	UO_EWR03_R	Mopeli	-29.101205	27.570751	D22G	Rapid 3
R_RU18	UO_EWR11_FV	Fouriespruit	-29.671211	26.074393	C51A	Field verification
R_RU19a	UO_EWR20_FV	Upper Kromellenboog	-30.066282	25.681056	C51G	Field verification
R_RU19b	UO_EWR21_FV	Lower Kromellenboog	-29.65360	25.43507	C51H	Field verification
R_RU21	UO_EWR13_FV	Os-spruit	-28.93917	26.511411	C52E	Field verification
R_RU22	UO_EWR03_FV	Gryskopspruit	-30.339629	27.176878	D12D	Field verification
R_RU23	UO_EWR05_FV	Bokspruit	-30.884690	27.884557	D13A	Field verification
R_RU25	UO_EWR18_FV	Wasbankspruit	-31.15554	27.284442	D13G	Field verification
R_RU26	UO_EWR04_FV	Karringmelkspruit	-30.811765	27.264973	D13K	Field verification
R_RU27	UO_EWR06_FV	Holspruit	-30.995316	27.056639	D13J	Field verification
R_RU30	UO_EWR01_FV	Meulspruit	-28.885731	27.834944	D22B	Field verification
R_RU31	UO_EWR02_FV	Witspruit	-30.008260	26.928315	D24C	Field verification
R_RU32a	UO_EWR09_FV	Groenspruit	-30.24119	26.56130	D24H	Field verification

Resource Unit	EWR site code	River	Latitude	Longitude	Quat	Level
R_RU32b	UO_EWR10_FV	Skulpspruit	-30.23444	26.51134	D24H	Field verification
R_RU33	UO_EWR14_FV	Hondeblaf	-30.205138	24.71803	D31C	Field verification
R_RU37	UO_EWR12_FV	Renoster	-29.11632	26.328701	C52F	Field verification
R_RU39	UO_EWR19_FV	Lower Modder	-28.89166	25.656445	C51K	Field verification
R_RU40	UO_EWR15_FV	Tributary of VanZylspruit	-30.031203	25.786463	C51G	Field verification
R_RU41	UO_EWR22_FV	Tele	-30.448588	27.582337	D18K	Field verification
R_RU42	UO_EWR24_FV	Maghaleng	-30.16412	27.398251	D15G	Field verification
R_RU43	UO_EWR16_FV	Slykspruit	-30.393003	26.120925	D24L	Field verification

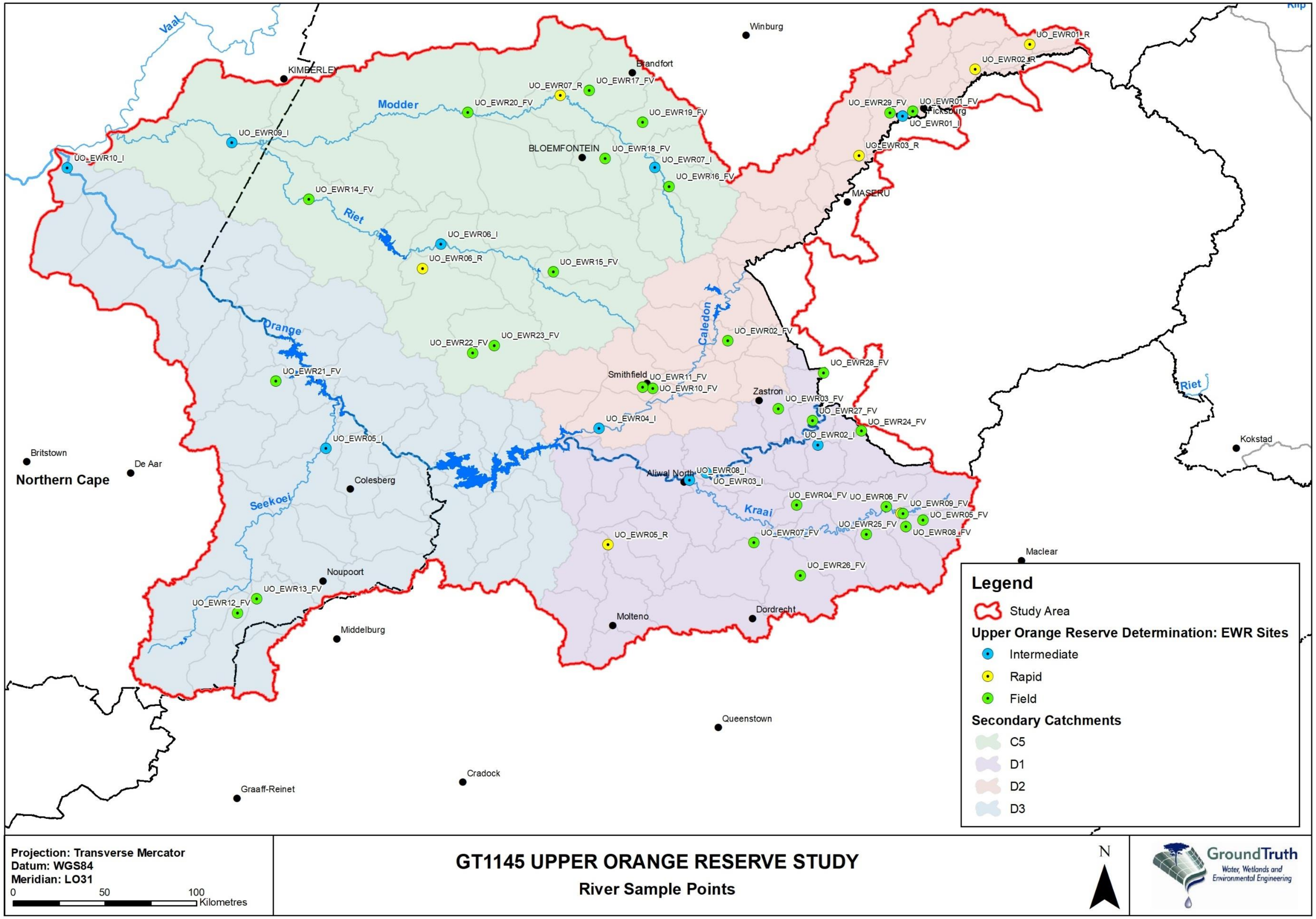


Figure 3-1: EWR sites for the Upper Orange Reserve study

The results of the eco-categorisation process to determine the PES, EI, ES and final Recommended Ecological Category (REC) were used to quantify the EWRs at each of the selected sites. A summary of the eco-categorisation results is presented in Table 3-2.

Table 3-2: Summary of results from eco-categorisation process

RU	EWR site code	River	Quat	PES	EI	ES	REC
R_RU04	UO_EWR01_I	Middle Caledon	D23A	D/E	Moderate	Moderate	D
R_RU01	UO_EWR02_I	Sterkspruit	D12B	D	Moderate	Moderate	C/D
R_RU02a	UO_EWR03_I	Upper Orange	D12F	D	Moderate	Moderate	D
R_RU05	UO_EWR04_I	Lower Caledon	D24J	D	Moderate	Moderate	C/D
R_RU06	UO_EWR05_I	Seekoei	D32J	C	Moderate	Moderate	C
R_RU08	UO_EWR06_I	Upper Riet	C51F	C	High	Moderate	C
R_RU09a	UO_EWR07_I	Upper Modder (Sannaspos)	C52G	D	Low	Moderate	C
R_RU03	UO_EWR08_I	Lower Kraai	D13M	C	High	High	B/C
R_RU10	UO_EWR09_I	Lower Riet	C51L	C	Very high	High	B/C*
R_RU07	UO_EWR10_I	Lower Orange	D33K	C	Moderate	Moderate	C
R_RU13	UO_EWR01R	Little Caledon	D21D	C	High	High	B/C
R_RU14	UO_EWR02R	Brandwater (Groot)	D21G	C	High	Moderate	B/C
R_RU16	UO_EWR03R	Mopeli	D22G	D	Moderate	Moderate	C/D
R_RU11a	UO_EWR04R	Upper Kraai	D13B	C	High	High	B
R_RU12	UO_EWR05R	Wonderboomspruit	D14E	D	Moderate	Moderate	C/D
R_RU09b	UO_EWR06R	Middle Modder (Soetdoring)	C52B	D	High	Moderate	C/D
R_RU30	UO_EWR01_FV	Meulspruit	D22B	D	Moderate	Moderate	D
R_RU31	UO_EWR02_FV	Witspruit	D24C	C/D	Moderate	Moderate	C
R_RU22	UO_EWR03_FV	Gryskopspruit	D12D	C	Moderate	Moderate	C
R_RU26	UO_EWR04_FV	Karringmelkspruit	D13K	B	Very high	High	B
R_RU23	UO_EWR05_FV	Bokspruit	D13A	B/C	Moderate	High	B
R_RU27	UO_EWR06_FV	Holspruit	D13J	C	High	Moderate	C
R_RU11b	UO_EWR07_FV	Sterkspruit (trib. of Bell/Kraai)	D13C	C	Moderate	High	B/C
R_RU11c	UO_EWR08_FV	Bell	D13B	B/C	Moderate	High	B
R_RU32a	UO_EWR09_FV	Groenspruit	D24H	C/D	Moderate	Moderate	C
R_RU32b	UO_EWR10_FV	Skulpspruit	D24H	C	Moderate	Moderate	C
R_RU18	UO_EWR11_FV	Fouriespruit	C51A	C	High	Moderate	C
R_RU37	UO_EWR12_FV	Renoster	C52F	D/E	Moderate	Moderate	D
R_RU21	UO_EWR13_FV	Os-spruit	C52E	B/C	High	Moderate	B/C
R_RU33	UO_EWR14_FV	Hondeblaf	C31C	B	Low	Moderate	B
R_RU40	UO_EWR15_FV	Trib van Zyl	C51G	C	High	Moderate	C
-	UO_EWR16_FV	Slykspruit	D24L	B/C	Moderate	Moderate	B/C
R_RU11d	UO_EWR17_FV	Langkloofspruit	D13D	B/C	High	High	B
R_RU25	UO_EWR18_FV	Wasbankspruit	D13G	C	Moderate	High	B/C

RU	EWR site code	River	Quat	PES	EI	ES	REC
R_RU39	UO_EWR19_FV	Lower Modder	C52K	C/D	Very high	High	C
R_RU19a	UO_EWR20_FV	Upper Kromellenboog	C51G	B	Moderate	Moderate	B
R_RU19b	UO_EWR21_FV	Lower Kromellenboog	C51H	C	Moderate	Moderate	B/C
R_RU41	UO_EWR22_FV	Tele	D18K	C	Moderate	Moderate	C
R_RU02b	UO_EWR23_FV	Upper Orange	D12A	C/D	High	Moderate	C
R_RU42	UP_EWR24_FV	Makhaleng	D15H	C/D	Moderate	Moderate	C/D

**Although the flows as per the Vaal comprehensive study were specified for a D category, they were checked and identified to be adequate to maintain the PES of a C.*

4. DATA COLLECTION AND MODELLING

4.1 Hydraulics

During the site visits, the following activities were undertaken:

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

The hydraulic data collected during the site visit is listed in Table 4-1. It should be noted that the discharges during both the surveys, especially the dry season surveys in July 2022 were much higher than expected (above average) due to increased baseflows as a result of continuous high rainfall throughout the previous summer and autumn.

Table 4-1: Hydraulic data measured for the Upper Orange catchment EWR sites

EWR site	Survey date	River	Discharge Q (m^3/s)	Maximum flow depth (m)
INTERMEDIATE SITES				
UO_EWR01_I	21 July 2022	Middle Caledon	1.726	0.39
	29 May 2023		17.19	0.77
UO_EWR02_I	6 July 2022	Sterkspruit	0.618	0.26
	30 May 2023		0.996	0.33
UO_EWR03_I	8 July 2022	Upper Orange	41.0	1.0
	30 May 2023		81.6	1.97
UO_EWR04_I	11 July 2022	Lower Caledon	14.19	0.68

EWR site	Survey date	River	Discharge Q (m^3/s)	Maximum flow depth (m)
INTERMEDIATE SITES				
	31 May 2023		35.36	0.97
UO_EWR05_I	12 July 2022	Seekoei	1.155	0.26
	31 May 2023		1.671	0.36
UO_EWR06_I	13 July 2022	Upper Riet	4.217	0.93
	01 June 2023		12.405	1.1
UO_EWR07_I	12 July 2022	Upper Modder	0.673	0.31
	02 June 2023		9.18	0.9
UO_EWR08_I	7 July 2022	Lower Kraai	17.3	0.9
	April 2023		19.03	1.1
UO_EWR09_I	Not surveyed	Lower Riet	Results from Vaal comprehensive Reserve study used, stable cross-section	
UO_EWR10_I	02 June 2023	Lower Orange	63.71	1.79
RAPID 3 SITES				
UO_EWR01_R	4 July 2022	Little Caledon	0.425	0.36
UO_EWR02_R	4 July 2022	Brandwater (Groot)	0.648	0.215
UO_EWR03_R	5 July 2022	Mopeli	0.808	0.28
UO_EWR04_R	9 July 2022	Upper Kraai	2.325	0.45
UO_EWR05_R	11 July 2022	Wonderboomspruit	1.129	0.39
UO_EWR06_R	14 July 2022	Middle Modder	2.257	0.65

Modelling was conducted using the measured data, as well as two modelled points to develop stage discharge curves. The following data was required in the use of the modelling: y (maximum flow depth), n (resistance coefficient), S (slope), Q (discharge), A (area) and WP (wetted perimeter). The measured and modelled data are shown in Table 4-2.

Table 4-2: Hydraulic data used to extend observed rating data at the EWR sites

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

EWR site	River	Discharge Q (m^3/s)	Maximum flow depth (m)	Manning's resistance, *n*	Surface Slope, *S* (m/m)	Ave. Velocity, V (m/s)
UO_EWR04_I	Lower Caledon	14.19	0.68	0.0908	0.011	0.683
		35.36	0.97	0.0575	0.011	1.217
UO_EWR05_I	Seekoei	1.155	0.26	0.1353	0.017	0.283
		1.671	0.36	0.1781	0.017	0.309
UO_EWR06_I	Upper Riet	4.217	0.93	0.0491	0.001	0.373
		12.405	1.1	0.0403	0.001	0.48
UO_EWR07_I	Upper Modder	0.673	0.31	0.0623	0.006	0.458
		9.18	0.9	0.0384	0.006	1.495
UO_EWR08_I	Lower Kraai	17.3	0.9	0.1394	0.011	0.508
		19.03	1.1	0.1496	0.011	0.588
UO_EWR09_I	Lower Riet	Not measured	-	-	-	-
UO_EWR10_I	Lower Orange	63.71	1.79	0.1485	0.002	0.327
RAPID 3 SITES						
UO_EWR01_R	Little Caledon	0.425	0.36	0.3768	0.025	0.191
UO_EWR02_R	Brandwater (Groot)	0.648	0.215	0.0273	0.008	0.872
UO_EWR03_R	Mopeli	0.808	0.28	0.0288	0.0029	0.577
UO_EWR04_R	Upper Kraai	2.325	0.45	0.0390	0.0046	0.682
UO_EWR05_R	Wonderboomspruit	1.129	0.39	0.0811	0.0153	0.627
UO_EWR06_R	Middle Modder	2.257	0.65	0.1068	0.0028	0.236

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

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

Where: 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 4-3.

Table 4-3: Regression coefficients in equation (1)

EWR site	River	Regression coefficients		
		a	b	c
INTERMEDIATE SITES				
UO_EWR01_I	Middle Caledon	0.33	0.2947	0
UO_EWR02_I	Sterkspruit	0.3111	0.3534	0
UO_EWR03_I	Upper Orange	0.1915	0.4347	0
UO_EWR04_I	Lower Caledon	0.2236	0.4115	0
UO_EWR05_I	Seekoei	0.2492	0.4429	0
UO_EWR06_I	Upper Riet	0.5802	0.2744	0
UO_EWR07_I	Upper Modder	0.3528	0.4135	0
UO_EWR08_I	Lower Kraai	0.3495	0.3655	0
UO_EWR09_I	Lower Riet	-	-	-
UO_EWR10_I	Lower Orange	0.4715	0.321	0
RAPID 3 SITES				
UO_EWR01_R	Little Caledon	0.5020	0.3820	0
UO_EWR02_R	Brandwater (Groot)	0.2627	0.4781	0
UO_EWR03_R	Mopeli	0.3089	0.4132	0
UO_EWR04_R	Upper Kraai	0.3387	0.3332	0
UO_EWR05_R	Wonderboomspruit	0.3720	0.3960	0
UO_EWR06_R	Middle Modder	0.5002	0.3163	0

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

The confidence rating in the hydraulic modelling results for the EWR sites ranges from 0=none to 5=high and is indicated in Table 4-4.

Table 4-4: Confidence in the hydraulic modelled results

EWR site	River	Limits of measured discharge range (m^3/s)	Confidence rating for discharge range		Comments
		$Q_{measured}$	$Q< Q_{measured}$	$Q> Q_{measured}$	
INTERMEDIATE SITES					
UO_EWR01_I	Middle Caledon	17.19	4	2	Slope of river is very flat and wide, and site located in slow moving water, therefore hydraulics under high flow conditions can be unpredictable.
UO_EWR02_I	Sterkspruit	0.996	3	2	

EWR site	River	Limits of measured discharge range (m^3/s)	Confidence rating for discharge range		Comments
		$Q_{measured}$	Q< $Q_{measured}$	Q> $Q_{measured}$	
UO_EWR03_I	Upper Orange	41	3	2	Slope of river is very flat and wide, therefore hydraulics under high flow conditions can be unpredictable. One set of data used for modelling.
UO_EWR04_I	Lower Caledon	35.359	4	2	Site located close to bridge which might affect hydraulics under high flow conditions.
UO_EWR05_I	Seekoei	1.671	3	2	Site located close to bridge which might affect hydraulics and measured points are too close together.
UO_EWR06_I	Upper Riet	12.405	3	2	Slope of river is very flat, therefore hydraulics under high flow conditions can be unpredictable. Site located just downstream of a bridge.
UO_EWR07_I	Upper Modder	9.18	3.5	2	Site located underneath bridge which may influence hydraulics under high flow conditions.
UO_EWR08_I	Lower Kraai	17.3	3.5	2	Weir located upstream of the site may affect hydraulics under high flow conditions. By-wash area will activate under high flow conditions.
UO_EWR09_I	Lower Riet	-	-	-	
UO_EWR10_I	Lower Orange	63.71	3	2	Slope of river is very flat and wide, and site located in slow moving water, therefore hydraulics under high flow conditions can be unpredictable.
RAPID 3 SITES					
UO_EWR01_R	Little Caledon	0.425	3	2	One set of data captured. Upstream bridge may influence hydraulics under high flow conditions
UO_EWR02_R	Brandwater (Groot)	0.663	3	2	One set of data captured. Site located close to bridge which might affect hydraulics under high flow conditions
UO_EWR03_R	Mopeli	0.808	2	2	One set of data captured. Site located in slow moving water,

EWR site	River	Limits of measured discharge range (m^3/s)	Confidence rating for discharge range		Comments
		Q measured	Q< Q measured	Q> Q measured	
					therefore hydraulics under varying conditions may be unpredictable
UO_EWR04_R	Upper Kraai	2.325	2	2	One set of data captured.
UO_EWR05_R	Wonderboomspruit	1.129	3	2	One set of data captured.
UO_EWR06_R	Middle Modder	2.257	2	2	One set of data captured.

4.2 Hydrological data

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

- Vaal River Systems Analysis Updated Study (1994)
- Lesotho Highlands Pre-Feasibility Study (1985)
- Orange River Systems Analysis (1993)
- Review of the Lesotho Highlands Hydrology by the Institute if Hydrology (1994)
- Vaal Augmentation Planning Study (1994)
- Lower Orange River Management Study (1995)
- Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse (2007)
- The original natural hydrology record period was from 1930 to 1994 and was extended in a comprehensive study up to 2004: Support to Phase 2 of the ORASECOM Basin-wide Integrated Water resources Management Plan – Extension of Hydrological Records by ORASECOM.

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

Table 4-5 below provides the approximate catchment areas and natural MAR (nMAR) for the EWR sites for the period 1920 to 2004. The final natural time series per EWR site will be provided electronically to DWS.

Table 4-5: Natural MAR per EWR site in the Upper Orange River catchment

EWR site	River	Latitude	Longitude	Quat*	nMAR (10^6m^3)	Catchment area (km^2)
INTERMEDIATE SITES						
UO_EWR01_I	Middle Caledon	-28.9089	27.785	D22D	674.0	5 185
UO_EWR02_I	Sterkspruit	-30.517806	27.369058	D12B	30.7	293
UO_EWR03_I	Upper Orange	-30.652793	26.823213	D12F	4 259.5	27 578
UO_EWR04_I	Lower Caledon	-30.436136	26.299258	D24G	1 353.6	18 544
UO_EWR05_I	Seekoei	-30.534359	24.962895	D32J	24.3	8 319
UO_EWR06_I	Upper Riet	-29.535065	25.52457	C51F	105.2	5 247
UO_EWR07_I	Upper Modder	-29.160017	26.572492	C52B	61.0	1 696
UO_EWR08_I	Lower Kraai	-30.69007	26.74157	D13M	719.0	9 354
UO_EWR09_I	Lower Riet	-29.03842	24.50283	C51L	373.8	33 785
UO_EWR10_I	Lower Orange	-29.16202	23.695944	D33K	6 674.2	99 297
RAPID 3 SITES						
UO_EWR01_R	Little Caledon	-28.557796	28.405709	D21D	25.9	252
UO_EWR02_R	Brandwater/ Groot	-28.68034	28.139926	D21G	56.0	700
UO_EWR03_R	Mopeli	-29.101205	27.570751	D22G	49.4	950
UO_EWR04_R	Upper Kraai	-30.85179	27.77689	D13E	200.9	1 525
UO_EWR05_R	Wonderboomspruit	-31.005262	26.341938	D14E	25.9	1 336
UO_EWR06_R	Middle Modder	-28.807191	26.109695	C52G	113.7	6 000
FIELD VERIFICATION SITES						
UO_EWR01_FV	Meulspruit	-28.885731	27.834944	D22B	63.6	457
UO_EWR02_FV	Witspruit	-30.00826	26.928315	D24C	21.7	979
UO_EWR03_FV	Gryskopspruit	-30.339629	27.176878	D12D	7.5	139
UO_EWR04_FV	Karringmelkspruit	-30.811765	27.266497	D13K	25.9	211
UO_EWR05_FV	Bokspruit	-30.88469	27.884557	D13A	60.4	409
UO_EWR06_FV	Holspruit	-30.995316	27.056639	D13J	36.9	2 311
UO_EWR07_FV	Sterkspruit, tributary of Kraai	-30.917621	27.800753	D13C	47.6	517
UO_EWR08_FV	Bell	-30.852601	27.786557	D13B	72.5	533
UO_EWR09_FV	Groenspruit	-30.24119	26.5613	D24H	5.02	215
UO_EWR10_FV	Skulpspruit	-30.23444	26.51134	D24H	7.8	333
UO_EWR11_FV	Fouriespruit	-29.671211	26.074393	C51A	13.8	560
UO_EWR12_FV	Renoster	-29.11632	26.328701	C52F	7.9	485
UO_EWR13_FV	Os-spruit	-28.93917	26.511411	C52E	8.6	650
UO_EWR14_FV	Hondeblaf	-30.205138	24.71803	D31C	2.0	1 231
UO_EWR15_FV	Tributary of VanZylspruit	-30.031203	25.786463	C51G	1.9	73
UO_EWR16_FV	Slykspruit	-30.393003	26.120925	D24L	5.1	1 285
UO_EWR17_FV	Langkloofspruit	-30.954126	27.606129	D13D	43.8	572
UO_EWR18_FV	Wasbankspruit	-31.15554	27.284442	D13G	16.5	248

EWR site	River	Latitude	Longitude	Quat*	nMAR (10^6m^3)	Catchment area (km^2)
UO_EWR19_FV	Lower Modder	-28.89166	25.656445	C52K	156.8	7 580
UO_EWR20_FV	Upper Kromellenboog	-30.066282	25.681056	C51G	9.3	367
UO_EWR21_FV	Lower Kromellenboog	-29.6536	25.43507	C51H	85.1	3 466
UO_EWR22_FV	Tele	-30.448588	27.582337	D18K	142.3	920
UO_EWR23_FV	Upper Orange	-30.398757	27.342987	D12A	4 115.1	24 850
UO_EWR24_FV	Makhaleng	-30.16412	27.398251	D15G	524.5	2 998

** Quaternary catchment*

4.3 Quantification of EWRs

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

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

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

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

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

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

Additionally, freshets and annual floods were specified for the intermediate and rapid 3 sites taking the release capacities of dams (where available) into consideration. These freshets were adjusted where required when higher than the release capacities of the dams.

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

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

5. EWR RESULTS - INTERMEDIATE SITES

The results of the ecological Reserve determination of the various rivers in the Upper Orange River catchment at the selected EWR sites are presented in this section. These include the intermediate, rapid 3 and field verification/ desktop sites. The HFSR approach (as described in Chapter 4.3 above), followed for some of the EWR sites include the specification of stress indices that describes the consequences of flow reductions on flow dependant biota, or life stages, and were selected for fish and macroinvertebrates to determine baseflow requirements. Thus, it describes the available habitat conditions for indicator fish species or guilds and macroinvertebrates taxon at various flow conditions. These habitat conditions at different flows and the ecologically derived habitat conditions required by the indicator species and taxa, are rated at a scale ranging from 0 to 10. Similarly, refer to Chapter 4.3 for further detail on these stress indices.

5.1 UO_EWR01_I: MIDDLE CALEDON

Sample Date	29 May 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR01_I	**Prioritised RU**	R_RU04
River	Middle Caledon	**Altitude (m.a.s.l.)**	1526
Latitude	-28.909102	**Longitude**	27.784924
Level 1 EcoRegion	Eastern Escarpment Mountains	**Quaternary catchment-SQ Reach**	D22D-03415
Level 2 EcoRegion	15.01	**DWS, 2014 PES, EI, ES**	C, Moderate, Moderate
Geomorphological zone	F (Lowland)		

MAP ILLUSTRATION (Figure 5-1) AND SITE PHOTOGRAPHS (Figure 5-2**)**

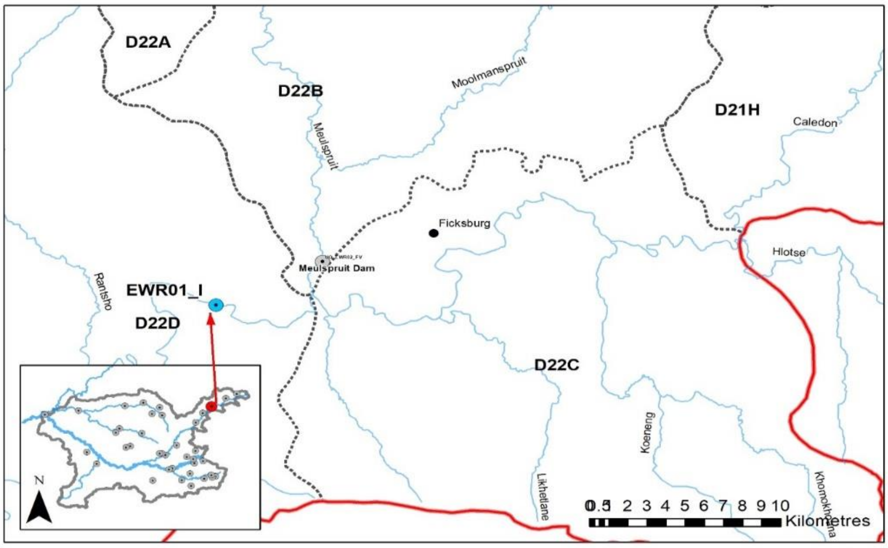


Figure 5-1: Location of site UO_EWR01_I (Middle Caledon) in relation to the study area

Site Photographs

Figure 5-2: Site photographs of the Middle Caledon EWR site

Upstream	**Downstream**

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

Macroinvertebrates: The Middle Caledon is a wide homogenous river composed largely of sand and silt and both banks are sandy, steep and highly erodible and thus zero marginal vegetation. Habitat diversity for macroinvertebrates is thus very poor in this river system, with only sand and mud as a biotope available for macroinvertebrates, although a pocket of gravel along the left bank was available. Consequently, the indicator macroinvertebrate selected for this reach is Caenidae. Taxa of this family taxa have a primary preference for gravel, sand and mud, and typically occur at depths of 10 – 30 cm. They have a wide range of preferences for velocities from 0.1 m/s to 0.6 m/s. Consequently, the macroinvertebrate habitat availability assessed as critical habitat will be the VFFS, FFS).

Fish: The reach is expected to provide very limited cover for fish, comprising a sandy/small gravel substrate with laminar flows across the channel expected for much of the hydrological year. Some undercut banks are expected to be present that would provide cover for some fish life history stages. However, critical habitat required for spawning, egg development and larvae are not expected to be present due to the high sedimentation rates. The reach is located within the middle reaches of the Caledon River upstream from Welbedacht Dam which will prevent any movement of fish from the Orange River or the lower parts of the Caledon River. As such, fish species expected to be present include those that will be able to over-winter within Welbedacht Dam or tributaries and undertake seasonal upstream migrations up the Caledon River during the warmer summer rainfall periods when flows increase. Due to the lack of true rheophilic species, a large semi-rheophilic (*Labeobarbus aeneus*) were selected to act as a flow-dependent indicator. The reach does not have any critical habitat (i.e., coarse substrate in different Very Deep (VD) classes) for early-life stages (spawning, egg development & larval nursery area), thus are likely to be used as a conduit for upstream movement during periods of high flow. Primary focus in this respect was given to the faster flowing velocity-depth classes, notably fast-intermediate and fast-deep classes.

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

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 5-1 and the final integrated stress curve is shown in Figure 5-3.

Table 5-1: Selected stress values, flows and rationale for the Middle Caledon EWR site

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	11.974	All three critical habitats are plentiful and in excess and very high quality (25% and 51% for FFS and VFFS respectively) with an average flow velocity of 0.7 m/s. The average depth is 4cm, which is close to the target flow for this indicator group - Caenidae. The wetted perimeter is 44m of the full cross-section.	12.34	Fast-intermediate class present in highest abundance, with fast-deep class dominant. Slow-deep class also present and likely associated with undercut banks, providing cover
1				
2			9.048	Significant reduction in fast-intermediate class, but some slow-deep still present (likely adjacent to banks with bank-undercut providing some cover). Fast-deep class dominant and still providing a pathway for upstream movement.
3	8.328	Although the critical habitat of FFS and VFFS remains in excess and good quality (31% and 41% respectively), the average depth and velocity has reduced to 30cm and 0.5 m/s. Although these remain within the preference range for the family Caenidae, should these velocities and average depth further reduce, stress will set in. The wetted perimeter however remains at 44m of the full cross-section.		
4			3.331	Wetted perimeter starts to drastically reduce, thus limiting undercut banks to only one side of the river. At this point, flow starts to get confined into the lower portion of the channel, thus reducing the extent of habitat available to fish
5	1.58	The average flow of 0.3 m/s is towards the lower end of the preferences for Caenidae. Furthermore, even though there is still 35% of FFS, there is a considerable reduction in the availability of the VFFS habitat (5%), thus the community will be in less		

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		abundances and at risk. Other habitats moderate to low quality. The wetted perimeter has also reduced to 23m of the full cross-section which will be of a concern.		
6				
7	0.436	Very shallow habitat (average depth of 12 cm) and an average velocity of 0.2 m/s, will not support the Caenidae family and their abundances will diminish. Habitat quality is expected to deteriorate. The FFS and VFFS habitat availability has decreased considerably to only 9% and 1% available at these flows. A more resilient invertebrate community will colonise instead.	0.291	Loss of all critical habitat, and further reduction of contact with bank. Flow now confined to central portion of channel with no cover features available. All life stages of semi-rheophilics at significant risk and likely not viable.
8				
9				
10	0.001	Average depth is 0 cm, with no critical habitat (0% for SFS and many other habitats), pooled in-stream. Only specialists will persist.	0	No flow with some isolated pools of limited depth, thus no fish species expected

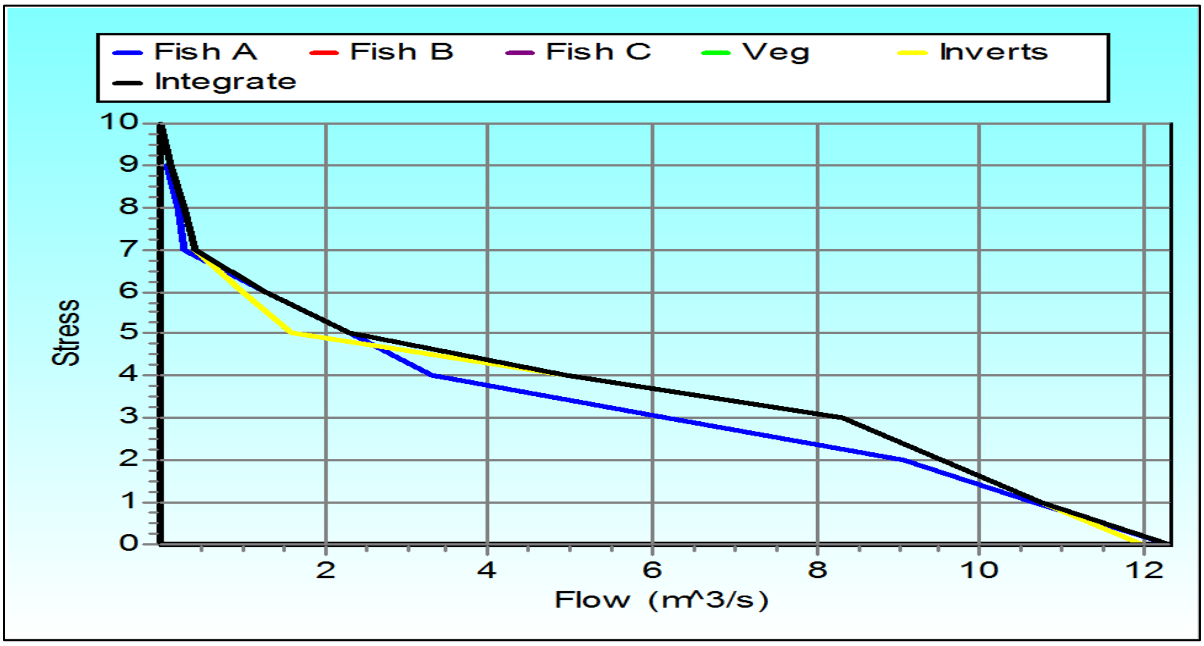


Figure 5-3: Final integrated stress curve for the Middle Caledon EWR site (UO_EWR01_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (February) and the final adjusted EWRs are shown in Figure 5-4 and Figure 5-5 below. The adjustments made to the DRM results are as follows:

Increase drought flows from 3.52% to 3.77%

Increase July maintenance low flows from 0.497 m^3/s to 1.304 m^3/s

Increase February maintenance low flows from 1.591m^3/s to 4.171 m^3/s

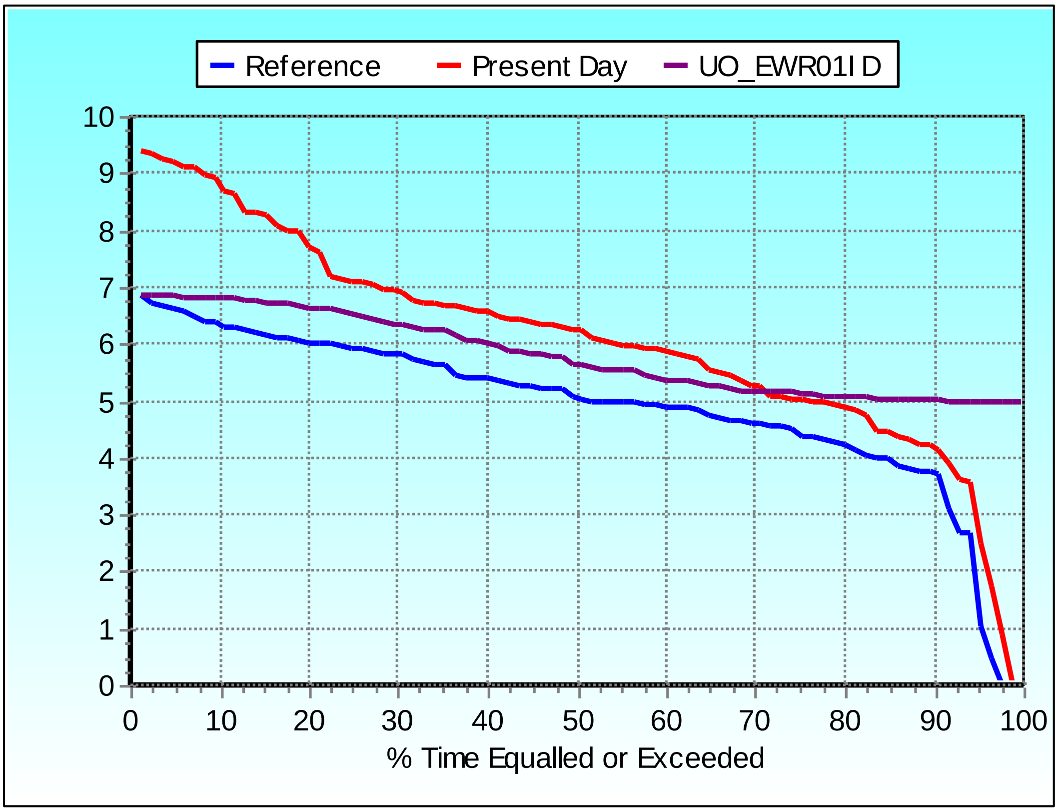


Figure 5-4: Final stress duration curves – dry season (July)

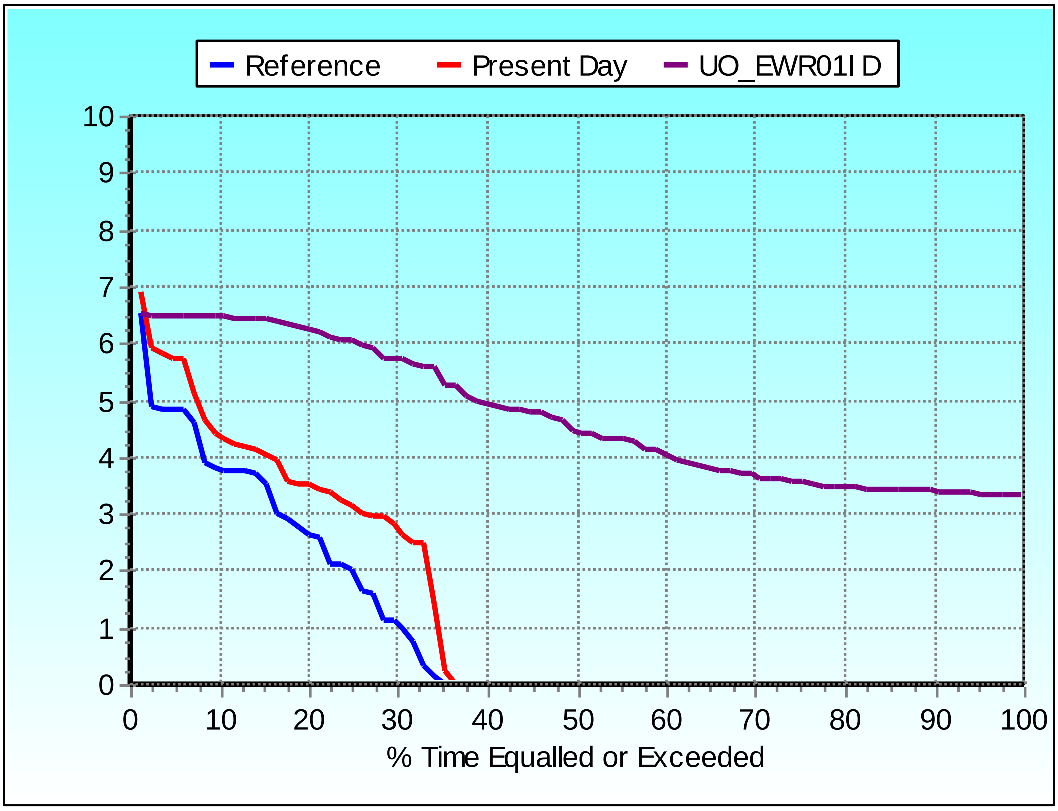


Figure 5-5: Final stress duration curves – wet season (February)

The flood requirements for the Middle Caledon EWR site were specified by the specialists and include small freshets to provide cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching), as well as larger floods for clearing of the river channel. No large floods for riparian vegetation were specified due to the already heavily infested riparian zone by alien species and severe erosion/bank collapse and high flows will only degrade this further. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 5-2.

Table 5-2: Flood requirements for the Middle Caledon at the EWR site (UO_EWR01_I)

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

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorphology	FINAL
	Months	Nov, Dec, Jan, Feb				Nov-Mar
	Type	Average				Average
Class 3 (60 m^3/s)	m^3/s	60				60
	# days	3				3
	Months	Jan, Feb				Jan, Feb
	Type	Peak				Peak

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

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 5-3.

Table 5-3: Middle Caledon - Summary of the EWR results (flows in million m^3 per annum)

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

5.2 UO_EWR02_I: STERKSPRUIT

Sample Date	6 July 2022 30 May 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR02_I	**Prioritised RU**	R_RU01
River	Sterkspruit	**Altitude (m.a.s.l.)**	1429
Latitude	-30.51784446	**Longitude**	27.36907996
Level 1 EcoRegion	Eastern Escarpment Mountains	**Quaternary catchment-SQ Reach**	D12B-05232
Level 2 EcoRegion	15.01	**DWS, 2014 PES, EI, ES**	C, Moderate, High
Geomorphological zone	D (0.005; Upper Foothills)		

MAP ILLUSTRATION (Figure 5-6) AND SITE PHOTOGRAPHS (Figure 5-7)

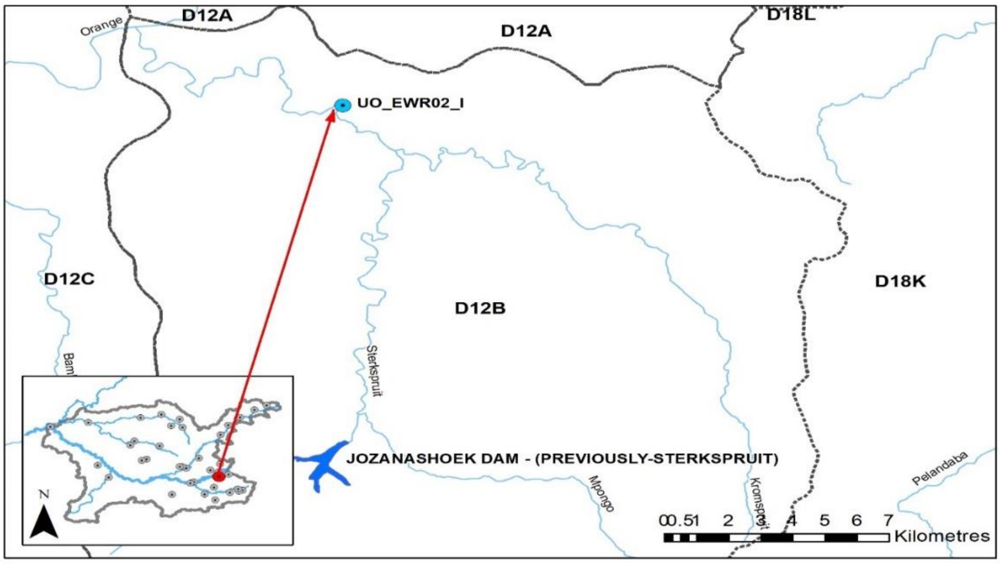


Figure 5-6: Location of site UO_EWR02_I (Sterkspruit) in relation to the study area

Site Photographs

Figure 5-7: Site photographs of the Sterkspruit EWR site

Upstream	**Downstream**

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

Macroinvertebrates: Biotope availability within the Sterkspruit for macroinvertebrates included stones-in-current (SIC), stones-out-of-current (SOOC) and slated/fractured bedrock, along with GSM and limited marginal vegetation, owing to undercut banks and vegetation die-back. Recorded at this site during the July 2022 survey was Perlidae, although they were not recorded during the May 2023 survey, likely owing to the very poor water quality (highly turbid and organic enrichment). Perlidae have been identified to be the indicator taxon for this reach, as they are flow dependent. They have a preference for cobbles and bedrock with a preference for high velocities of >0.6 m/s, although appear optimally at flows between 0.3m/s and 0.6m/s. Should flows fall below this target, Perlidae will be absent from the macroinvertebrate community. Thus, the macroinvertebrate habitat availability assessed as critical habitat will be the very fast course substrate (VFCS) and fast course substrate (FCS). They are further very sensitive to any water quality change.

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

Next, the optimum baseflows based on the 90th percentile for the wet and dry season were determined from the reference baseflows with July (0.005 m^3/s) and February (0.019 m^3/s) representing the dry and wet season. It should be noted that the Sterkspruit shows seasonal tendencies as zero flows occurs during drought periods.

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 5-4 and the final integrated stress curve is shown in Figure 5-8.

Table 5-4: Selected stress values, flows and rationale for the Sterkspruit EWR site

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	0.618	Habitat suitable for the indicator taxon, with good quality and in excess VFCS critical habitat (37%). Average velocity is 0.95 m/s thus the Perlidae and other flow dependent macroinvertebrates should be in abundance, barring the condition of the water quality.	0.845	Highest abundance of fast-shallow and fast-intermediate classes across cross-section, providing suitable habitat for spawning and egg and embryo development. Larvae expected to be washed downstream into areas classified as slow-deep for further development.
1				
2				
3	0.105	Instream biotopes still suitable for the flow dependent indicator taxon, and others expected for this reach, although the critical habitat, VFCS is decreasing and which was recorded to be 23% along the cross section compared to 37% at a stress of 0. The average velocity has decreased to 0.59 m/s, although still within the range of velocity preference for the Perlidae.	0.291	Residual fast-intermediate class thus likely reduction of larger spawning adults. Habitat for egg and embryo development remains.
4				
5	0.053	The VFCS critical habitat reduced further to 14%, although the FCS habitat is at 20%. The average depth is 7cm while the average velocity is 0.45m/s, slowly going below the preference for the indicator taxon.	0.128	Extent of critical habitat for egg & embryo development begins to decrease significantly. Water levels likely to be limiting factor for spawning activities at the cross section.
6				
7	0.014	Very low critical habitat (VFCS is 2% and the FCS critical habitat starting to decrease. Owing to the average velocity of 0.26 m/s, the Perlidae, and other flow dependent taxa will start to disappear. The slow current speeds and limited dilution will likely lead to excessive growth of benthic algae (owing to organic enrichment within this system), and this will limit the suitability of instream habitats. With warmer temperatures, this will likely lead to oxygen depletion at night, so the Perlidae, which are sensitive to	0.039	Loss of all critical habitat

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		water quality deterioration, will certainly disappear.		
8				
9				
10	0	No flow. Macroinvertebrates diapause phase triggered.	0	No flow with some isolated pools of limited depth. Only some individuals of the smaller size classes are expected where cover persists (e.g. *Enteromius oraniensis*), although water quality may provide a limiting factor.

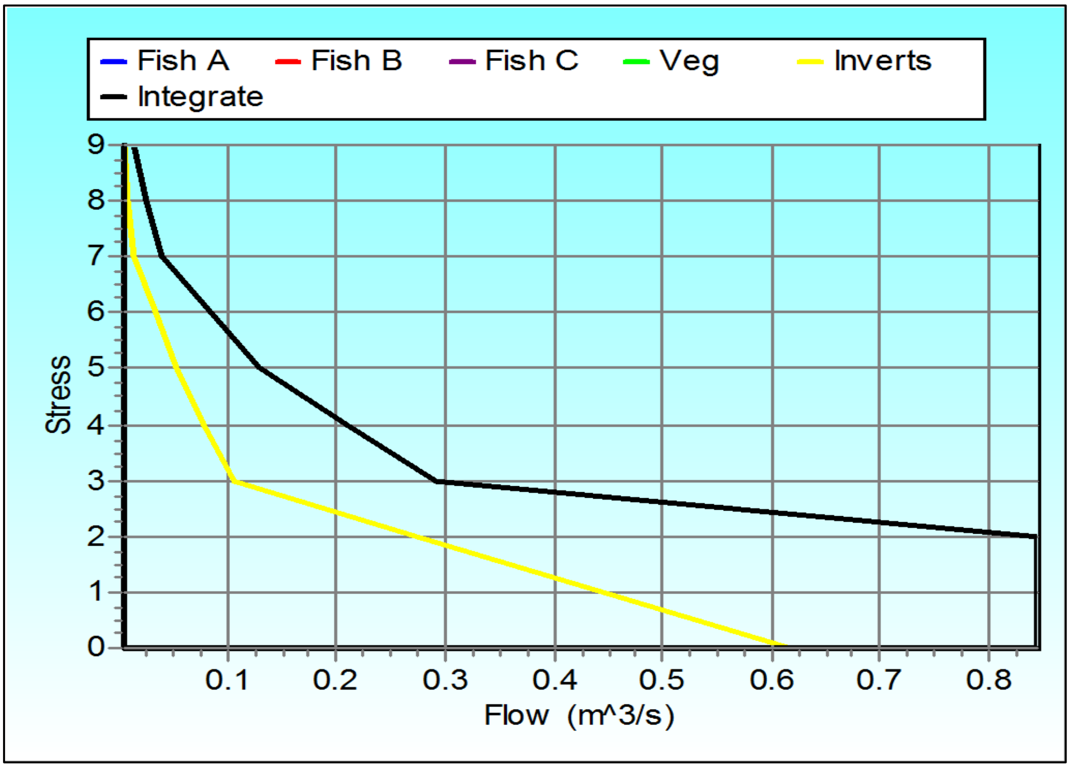


Figure 5-8: Final integrated stress curve for the Sterkspruit EWR site (UO_EWR02_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (February) and the final adjusted EWRs are shown in and below. The adjustments made to the results are to ensure increased velocity for those flow dependent macroinvertebrates, as well as to provide fast course substrate:

Increase July maintenance low flows from 0.022 m^3/s to 0.068 m^3/s

Increase February maintenance low flows from 0.083m^3/s to 0.254 m^3/s

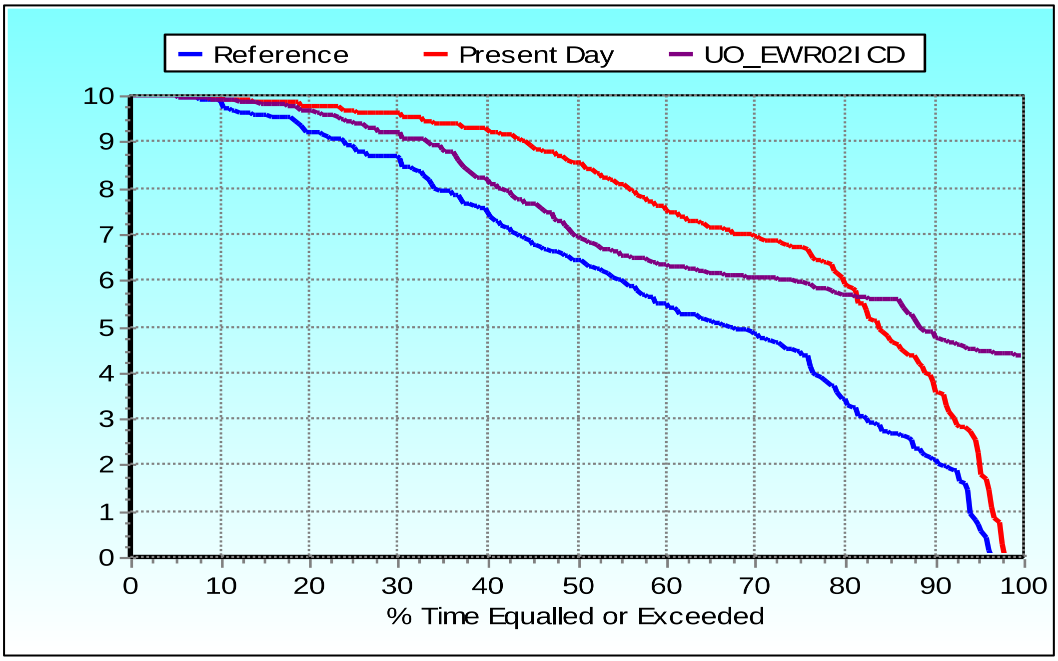


Figure 5-9: Final stress duration curves – dry season (July)

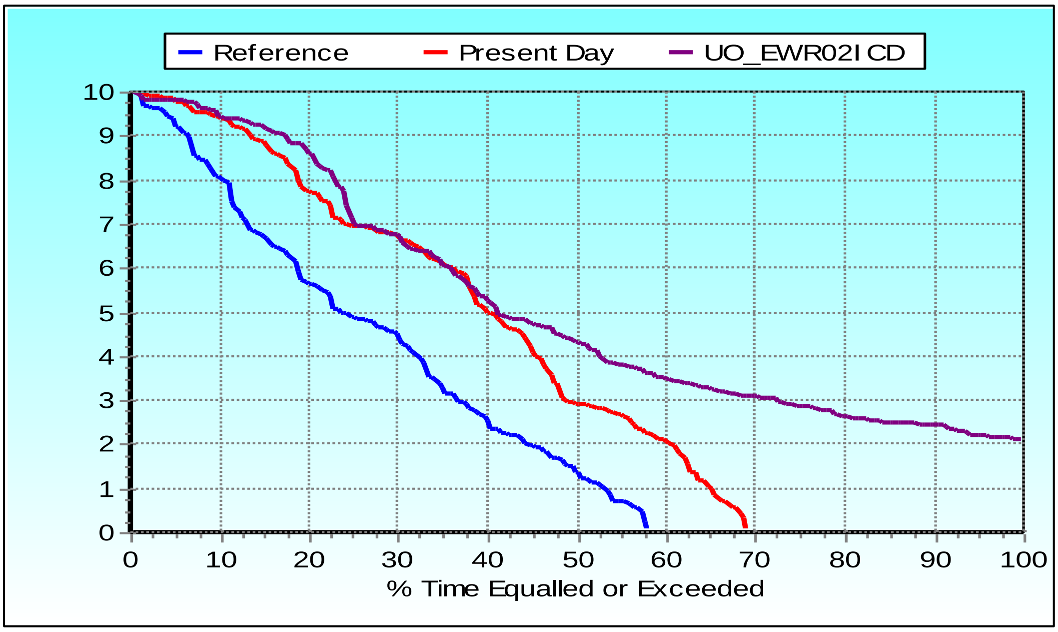


Figure 5-10: Final stress duration curves – wet season (February)

The flood requirements for the Sterkspruit EWR site were specified by the specialists and include small freshets to provide specific cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching), as well as larger floods for clearing of the river channel, and especially scouring of the in-stream biotopes, namely the stones biotope of any fine sediments and algae smothering this habitat. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 5-5.

Table 5-5: Flood requirements for the Sterkspruit at the EWR site (UO_EWR02_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorphology	FINAL
Class 1 (3-5 m³/s)	m³/s	3.6		3.8		4
	# days	5		4		4
	Months	Dec, Jan, Feb		Jan, Feb, Mar		average
	Type	Average		Average		Nov, Dec, Feb, Apr
Class 2 (10 m³/s)	m³/s	9.9				10
	# days	5				**3**
	Months	Jan, Feb				average
	Type	Average				Jan, Feb
Class 3 (15-60 m³/s)	m³/s		55		57	15
	# days		3		5	2
	Months		Feb, Mar		Mar	peak
	Type		Peak		Peak	Mar

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

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 5-6.

Table 5-6: Sterkspruit - Summary of the EWR results (flows in million m^3 per annum)

Quaternary Catchment	D12B
Site name	UO_EWR02_I
River	Sterkspruit
EWR Site Co-ordinates	-30.517844; 27.369079
Recommended Ecological Category	C/D
nMAR at EWR site	30.7
Total EWR	11.814 (38.43 %MAR)
Maintenance Low flows	4.712 (15.33 %MAR)
Drought Low flows	0.016 (0.05 %MAR)
Maintenance High flows	7.102 (23.10 %MAR)
Overall confidence	Moderate to high

5.3 UO_EWR03_I: UPPER ORANGE

Sample Date	7 July 2022 30 May 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR03_I	**Prioritised RU**	R_RU02a
River	Upper Orange	**Altitude (m.a.s.l.)**	1302
Latitude	-30.652888889	**Longitude**	26.82304963
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D12F-05348
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, High
Geomorphological zone	F (0.001; Lowland)		

MAP ILLUSTRATION (Figure 5-11**) AND SITE PHOTOGRAPHS (**Figure 5-12**)**

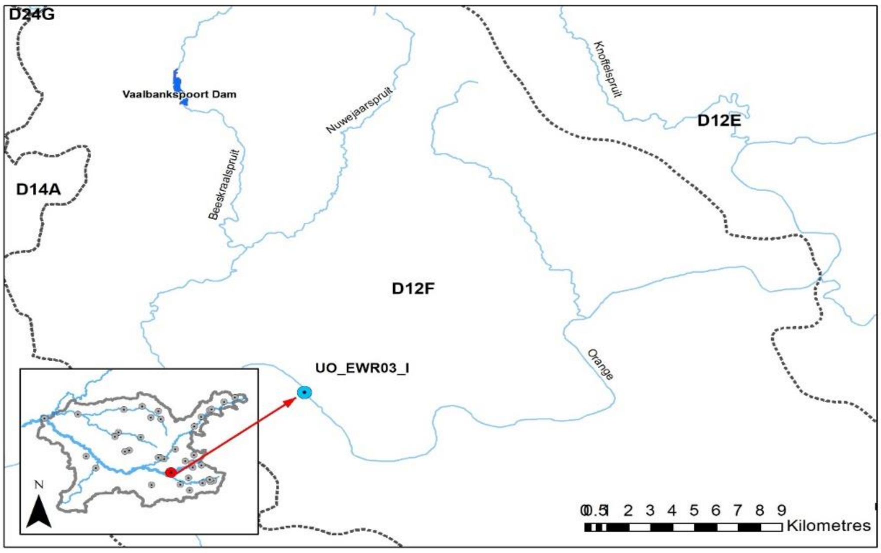


Figure 5-11: Location of site UO_EWR03_I (Upper Orange) in relation to the study area

Site Photographs

Figure 5-12: Site photographs of the Upper Orange EWR site

Upstream	**Downstream**

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

Macroinvertebrates: The Upper Orange is a wide homogenous alluvial river composed largely of sand and mud with very limited habitat diversity and exposed sand bars along the banks. There is limited to no marginal vegetation for macroinvertebrates to colonise along this reach. The indicator macroinvertebrate selected for this reach is Caenidae. They have a primary preference for gravel, sand and mud, and typically occur mostly at depths of 10 – 30 cm. They further have a wide range of preferences for velocities from 0.1 m/s to 0.6 m/s. Consequently, the macroinvertebrate habitat availability assessed as critical habitat will be the VFFS, FFS.

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

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

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 5-7 and the final integrated stress curve is shown in Figure 5-13.

Table 5-7: Selected stress values, flows and rationale for the Upper Orange EWR site

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	108.763	The average depth of 60cm and average velocity of 0.66 m/s are	102.613	Abundance of FD (79%) with SD (21%) also present with maximum

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		suitable conditions for the indicator taxon Caenidae. The critical habitats (i.e., SFS, FFS and VFFS) are 11%, 21% and 43% respectively across the cross-section and which are in excess and in good quality for this reach.		depth of 1.51 m and an average depth of 1.07 m to accommodate movement of LSR species through reach along edges of channel
1				
2				
3	41	The average velocity of 0.49 m/s is still suitable for the indicator species, as well as critical habitat with 16% and 31% of SFS and FFS available. The VFFS critical habitat has reduced to 26% for this indicator species, although they do have a wide tolerance range for velocities.	41.918	Reduction of wetted extent, thus cover elements provided by banks. Water column still able to provide cover (water depth 1.1 m maximum with average depth of 0.58 m)
4				
5	12.667	The critical habitat of VFFS very reduced, although the SFS and FFS are still at 28% and 31% respectively. Moderate velocities with an average of 0.3 m/s, thus still within the range for the indicator taxon.	8.763	Maximum Depth 0.5m with average depth 0.42 m, thus water column likely to offer some protection but with adults likely to be at high risk. Loss of SD habitat, with FI only at 4%. SS habitat dominant
6				
7				
8	4.218	Slow trickle with an average speed of 0.19 m/s, out of the preference for this indicator taxon and not suitable velocities. The critical habitat (VFFS) at only 2% and the FFS drastically reduced to 12%.	1.14	No critical habitat (SD, FI or FD) remaining with a dominance of SS (86%) and likely no cover for any fish movement within the reach
9				
10	0.001	No critical habitat (0%), exposed sand bars across the channel.	0	No flow with some isolated pools possible with no cover present (no substrate or water column), thus no fish species expected

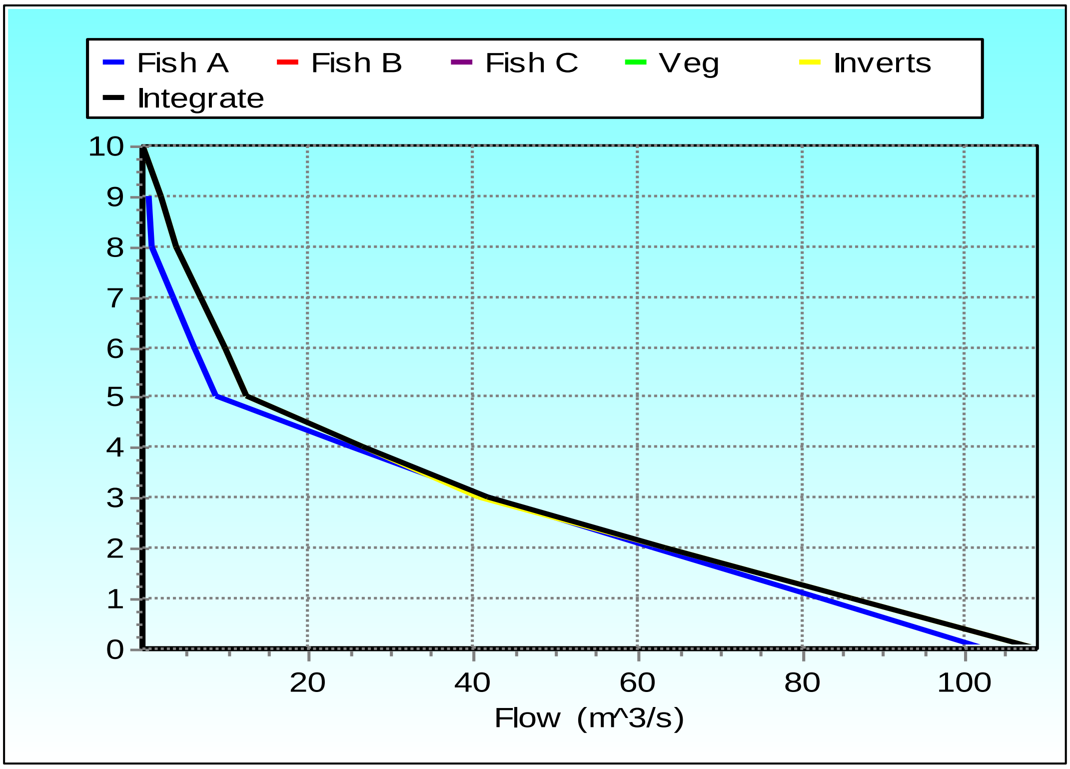


Figure 5-13: Final integrated stress curve for the Upper Orange EWR site (UO_EWR03_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (February) and the final adjusted EWRs are shown in Figure 5-14 and Figure 5-15 below. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality.

Increase drought flows for all the months as follows:

April – July = 5 m^3/s

August – October = 3 m^3/s

February, March = 12 m^3/s

November, December = 8 m^3/s, January = 10 m^3/s

Increase July maintenance low flows from 4.999 m^3/s to 11.006 m^3/s

Increase February maintenance low flows from 12.293m^3/s to 27.067 m^3/s

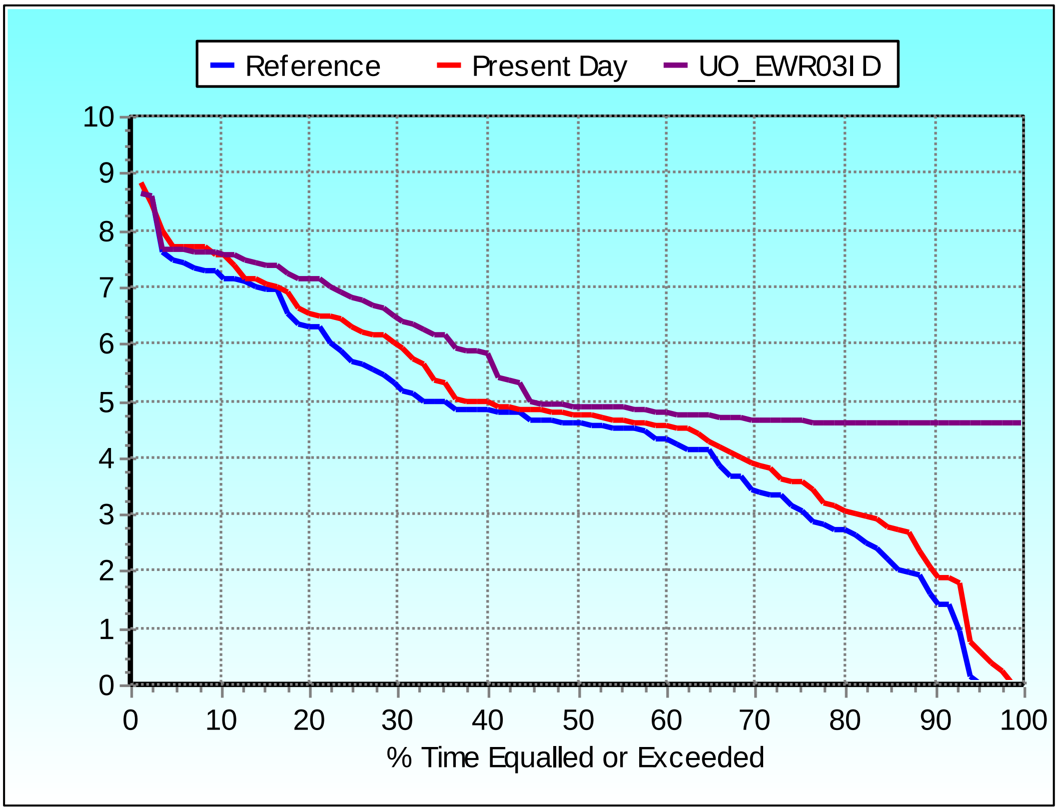


Figure 5-14: Final stress duration curves – dry season (July)

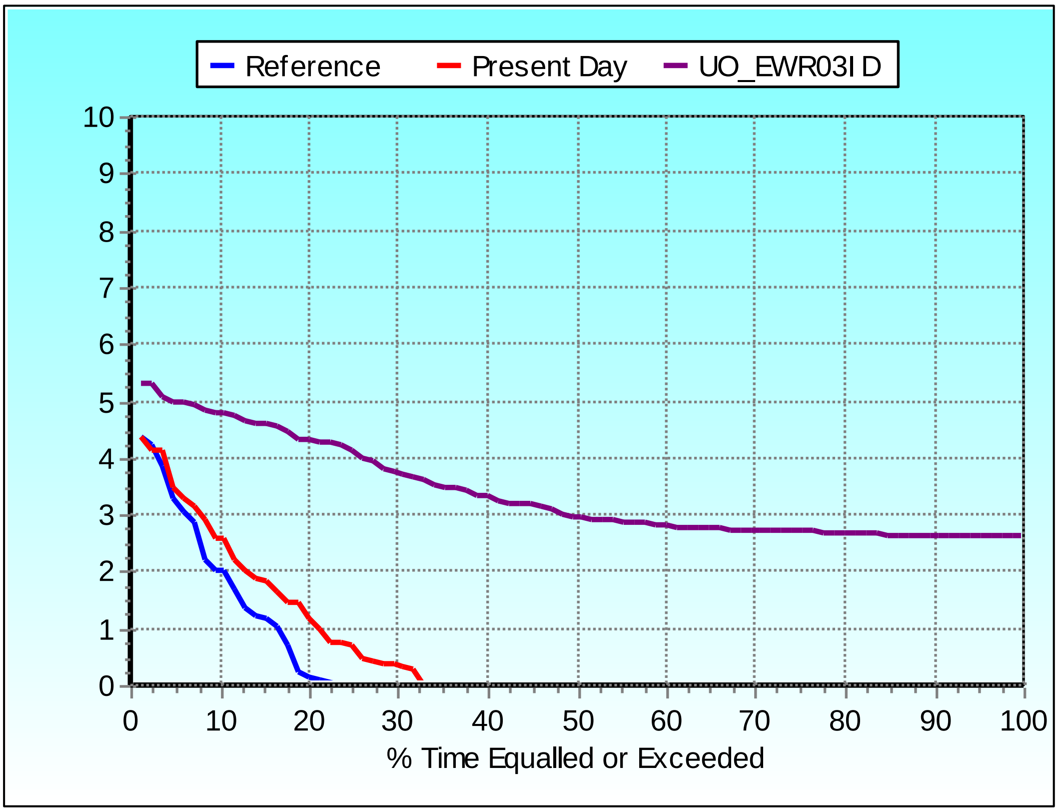


Figure 5-15: Final stress duration curves – wet season (February)

The flood requirements for the Upper Orange EWR site were specified and driven primarily by geomorphology and riparian vegetation. The large flood's primary function is to clear the river channel and mobilise substrate (gravel) downstream and aim to activate the riparian vegetation marginal zone. The smaller freshets were set to provide specific fish cues for movement and spawning purposes. No freshets were specified for macroinvertebrates due to a lack of available macroinvertebrate biotopes (site primarily only comprising a muddy substrate). The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 5-8.

Table 5-8: Flood requirements for the Upper Orange at the EWR site (UO_EWR03_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorphology	FINAL
Class 1 (200-300 m³/s)	m³/s	200		200 - 300	220	200
	# days	Nov, Dec, Jan, Feb		Average	Average	5
	Months	5		5	4	Oct-Dec, Mar, Apr
	Type	Average		Nov to Mar	Nov, Jan, Feb, March	Average
Class 2 (400 m³/s)	m³/s	400				400
	# days	3				3
	Months	Jan, Feb				Jan, Mar
	Type	Average				Average
Class 3 (800 m³/s)	m³/s			800	800	800
	# days			6 to 8 days	6	6
	Months			Jan, Feb	Feb	Feb
	Type			Peak	Peak	Peak

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

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 5-9.

Table 5-9: Upper Orange - Summary of the EWR results (flows in million m^3 per annum)

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

5.4 UO_EWR04_I: LOWER CALEDON

Sample Date	11 July 2022 31 May 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR04_I	**Prioritised RU**	R_RU05
River	Lower Caledon	**Altitude (m.a.s.l.)**	1277
Latitude	-30.28011493	**Longitude**	26.65306029
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D24G-04958
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, High
Geomorphological zone	F (0.001; Lowland)		

MAP ILLUSTRATION (Figure 5-16**) AND SITE PHOTOGRAPHS (Figure 5-17)**

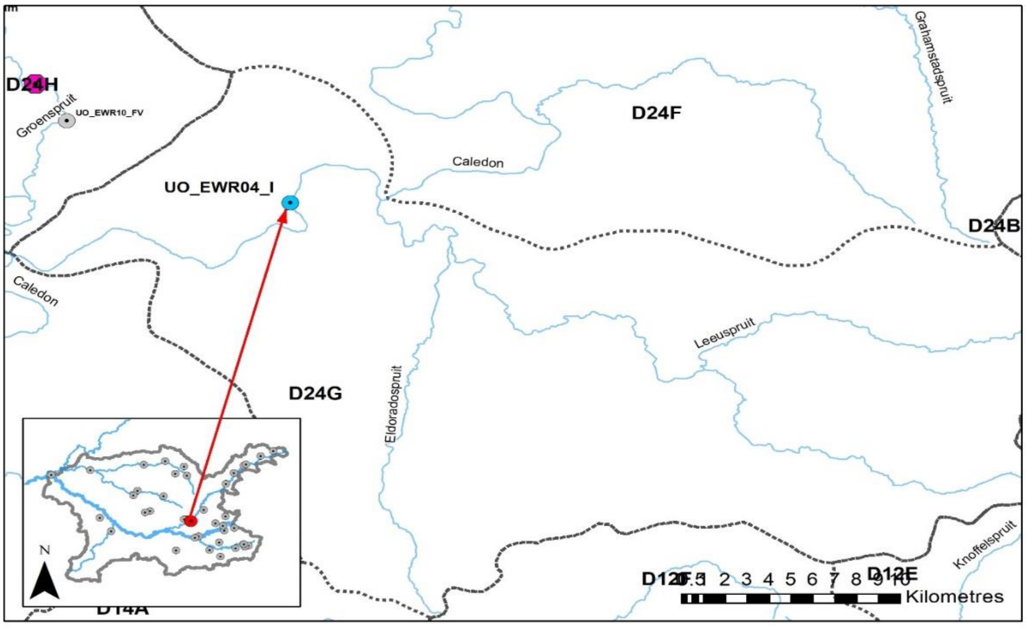


Figure 5-16: Location of site UO_EWR04_I (Lower Caledon) in relation to the study area

Site Photographs

Figure 5-17: Site photographs of the Lower Caledon EWR site

Upstream	**Downstream**

The EWR for the Lower Caledon River was determined for a REC of a C/D and the HFSR approach was used to determine the EWRs. This river reach is wide and homogenous and composed largely of sand and silt. Both banks are sandy, steep and highly erodible and thus zero marginal vegetation. The indicator species for macroinvertebrates and fish selected for the Lower Caledon were Hydropsychidae and BAEN (large semi-rheophilics) due to the lack of true rheophilic species.

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

Fish: At this EWR site, artificial substrate is available as a habitat for fish species as a result of the bridge (as explained above), with suitable habitat available to function as a spawning medium for large semi-rheophilic fish species such as *Labeobarbus aeneus*. This is particularly relevant given that Welbedacht Dam located upstream of the EWR site acts as a barrier for upstream migrations of fish from the Orange River (Gariep Dam). Consequently, critical life stages considered include spawning, egg and embryo development, with juvenile and adult life stages also being considered to a lesser extent, thus fast-shallow and fast-intermediate classes. Slow-deep class is present downstream and upstream of the cross-sectional area, and thus not considered. Nevertheless, egg development success is expected to be impacted by the high sediment loads present within the system - Welbedacht Dam is expected to function as a sink for larger sediment size classes, but fines will pass over the dam.

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

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 5-10 and the final integrated stress curve is shown in Figure 5-18.

Table 5-10: Selected stress values, flows and rationale for the Lower Caledon EWR site

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	14.924	The FCS and VFCS habitats are plentiful and in excess and very high quality (17% and 41% respectively)	13.88	Flow considered adequate, with 83% of all habitat within the cross-section being fast and representing

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		with an average flow velocity of 0.7 m/s. The average depth is 46 cm, which is around the target flow for this indicator group - Hydropsychidae.		elements from all fast velocity-depth classes, with discharge representing the highest percentage of fast-intermediate class.
1			11.924	Increase in fast-shallow class, activating suitable spawning habitat
2			8.913	Fast-shallow class on the margins of the wetted perimeter at its greatest extent, providing spawning habitat and suitable habitat for egg and embryo development.
3	7.777	Critical habitat remains relatively healthy, although the VFCS habitat has reduced (29%). The average depth is 37cm and average flow of 0.5 m/s, still within the preference range of the Hydropsychidae family.	7.777	Critical spawning habitat present but starts to drop off with respect to extent.
4				
5	3.183	Average depth of 30cm and average velocity of 0.37 m/s along the cross-section, with the critical habitat (VFCS) drastically reduced to just 11%, although FCS habitat slightly increased to 28%. Thus, this habitat is becoming limiting for the indicator taxon at this flow rate.	2.213	Loss of fast-deep class for adult fish with a concomitant increase in fast-intermediate class. Spawning habitat (fast-shallow class) greatly reduced and limited.
6				
7	0.591	Very little critical habitat (FCS - 8% and VFCS - 1%). Most flow-sensitive taxa will disappear. Slow current speeds of 0.15 m/s, not suitable for the indicator species.	0.142	Loss of all critical habitat and fast flow classes. Water depth presents a challenge to larger specimens of fish, with only juvenile cohorts likely to be present and associated with substrate as a means of cover.
8				
9				
10	0.001	No flow and an average depth of 0.2cm. Macroinvertebrates diapause phase triggered.	0	Loss of all flow components - no movement between reaches.

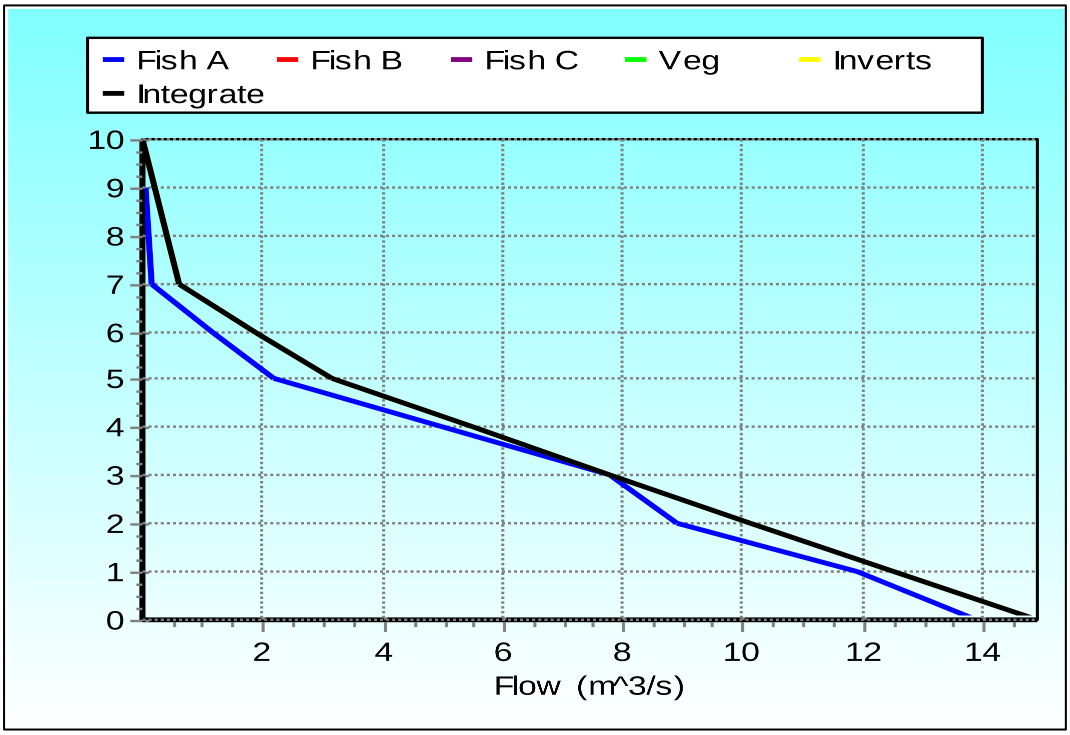


Figure 5-18: Final integrated stress curve for the Lower Caledon EWR site (UO_EWR04_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (February) and the final adjusted EWRs are shown in Figure 5-19 and below Figure 5-20. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality.

Increase July maintenance low flows from 1.636 m^3/s to 3.393 m^3/s

Increase February maintenance low flows from 5.310m^3/s to 11.015 m^3/s

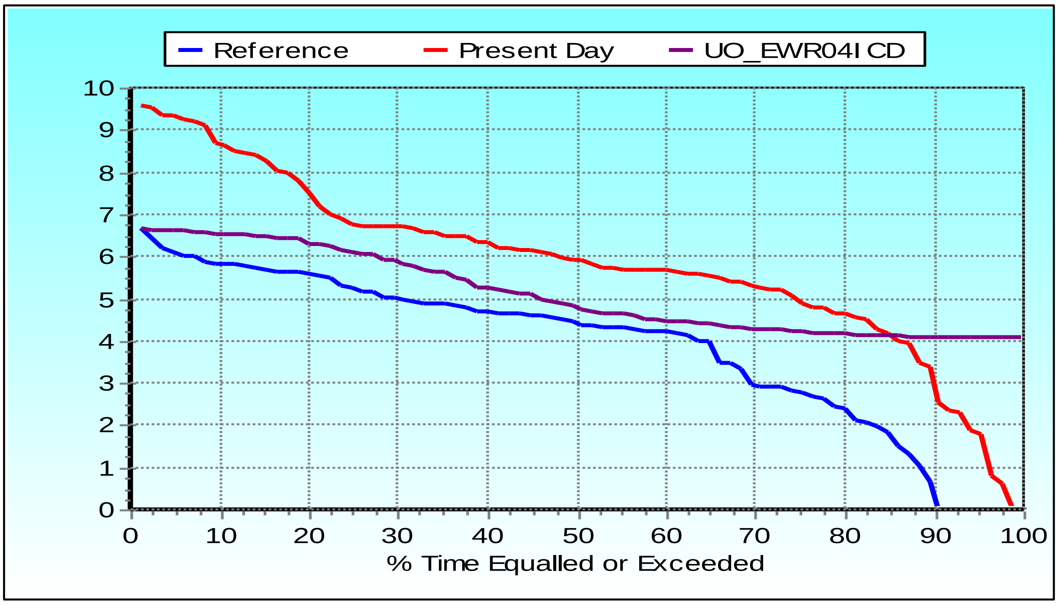


Figure 5-19: Final stress duration curves – dry season (July)

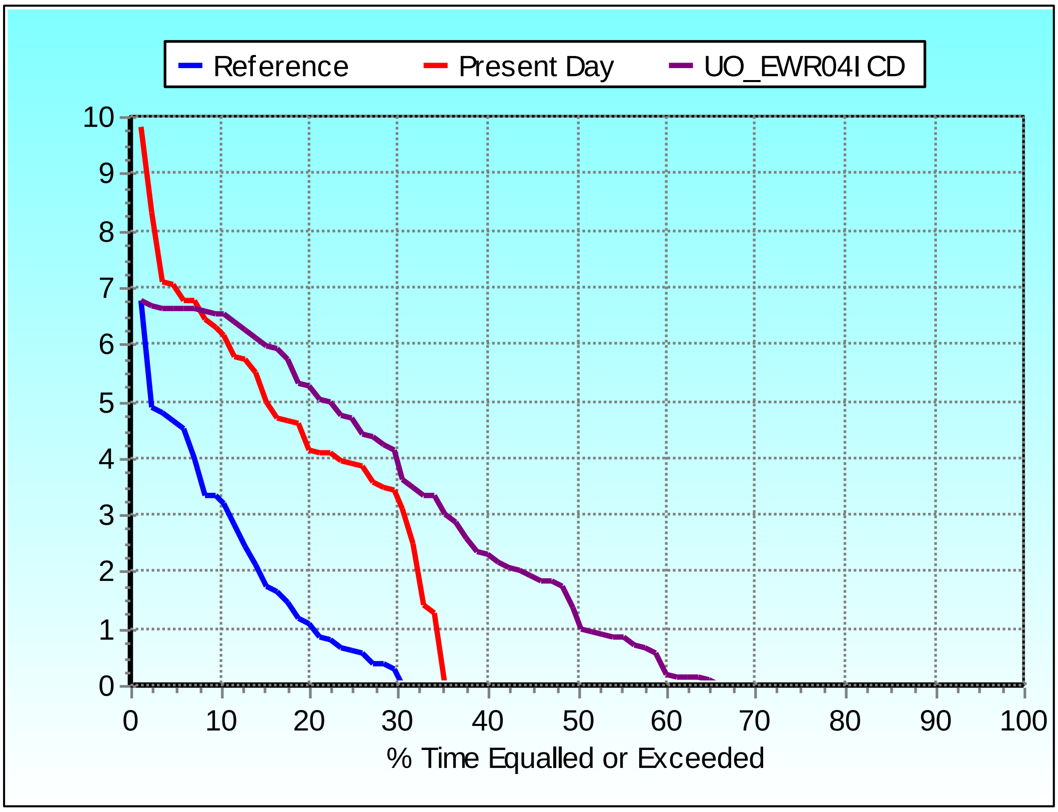


Figure 5-20: Final stress duration curves – wet season (February)

The flood requirements for the Lower Caledon EWR site were specified by the specialist team and include small freshets to provide specific cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching). Larger floods were specified for clearing of the river channel, especially the clearing of fine silts due to extensive sediment built-up. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 5-11.

Table 5-11: Flood requirements for the Lower Caledon at the EWR site (UO_EWR04_I)

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

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

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 5-12.

Table 5-12: Lower Caledon - Summary of the EWR results (flows in million m^3 per annum)

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

5.5 UO_EWR05_I: SEEKOEI

Sample Date	12 July 2022 31 May 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR05_I	**Prioritised RU**	R_RU06
River	Seekoei	**Altitude (m.a.s.l.)**	1221
Latitude	-30.53390069	**Longitude**	24.96253678
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment-SQ Reach**	D32J-05237
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	D, Moderate, Moderate
Geomorphological zone	E (0.002; Lower Foothills)		

MAP ILLUSTRATION (Figure 5-21**) AND SITE PHOTOGRAPHS (**Figure 5-22**)**

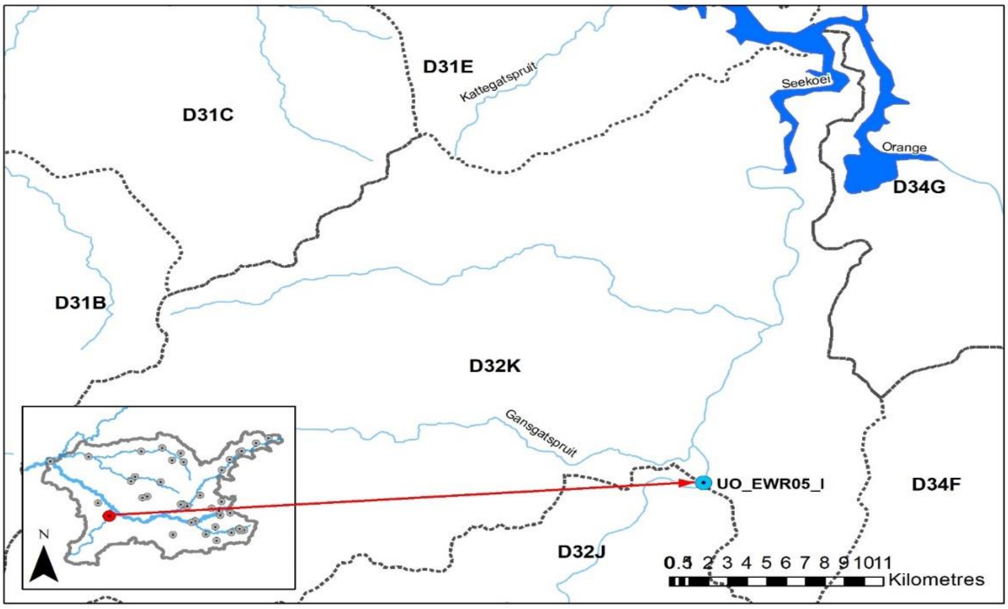


Figure 5-21: Location of site UO_EWR05_I (Seekoei) in relation to the study area

Site Photographs

Figure 5-22: Site photographs of the Seekoei EWR site

Upstream	**Downstream**

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

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

The site-specific flow requirements were based mainly on the requirements to inundate the inset and flood benches, entrain cobbles and scour pools to mobilise fine gravels and remove fine sediments from coarse habitats. No floods were specified for fish as the movement is hampered by the numerous weirs in the system. The freshets and floods as required are presented in Table 5-13 and the final EWR for the Seekoei River at the EWR site is summarised in

Table 5-14.

Table 5-13: Flood requirements for the Seekoei River at the EWR site (UO_EWR05_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorphology	FINAL
Class 1 (0-40 m³/s)	m³/s			5 to 10		5
	# days			7		2
	Months			Jan, Feb, Mar		Oct-Jan, Apr, May
	Type			Average		Average
Class 2 (60-90 m³/s)	m³/s		14		15	10
	# days		3		3	2
	Months		Apr, May		Nov, Jan, Mar	Feb
	Type		Average		Average	Average
Class 3 (100-120 m³/s)	m³/s		17	35		20
	# days		3	3		2
	Months		Nov, Jan, Mar	Feb, Mar		Mar
	Type		Average	Average		Peak

Table 5-14: Seekoei - Summary of the final EWR results (flows in million m^3 per annum)

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

5.6 UO_EWR06_I: UPPER RIET

Sample Date	13 July 2022 1 June 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR06_I	**Prioritised RU**	R_RU08
River	Upper Riet	**Altitude (m.a.s.l.)**	1278
Latitude	-29.53478727	**Longitude**	25.52449567
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	C51F-04071
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, Moderate
Geomorphological zone	E (0.001; Lower Foothills)		

MAP ILLUSTRATION (Figure 5-23**) AND SITE PHOTOGRAPHS (Figure 5-24)**

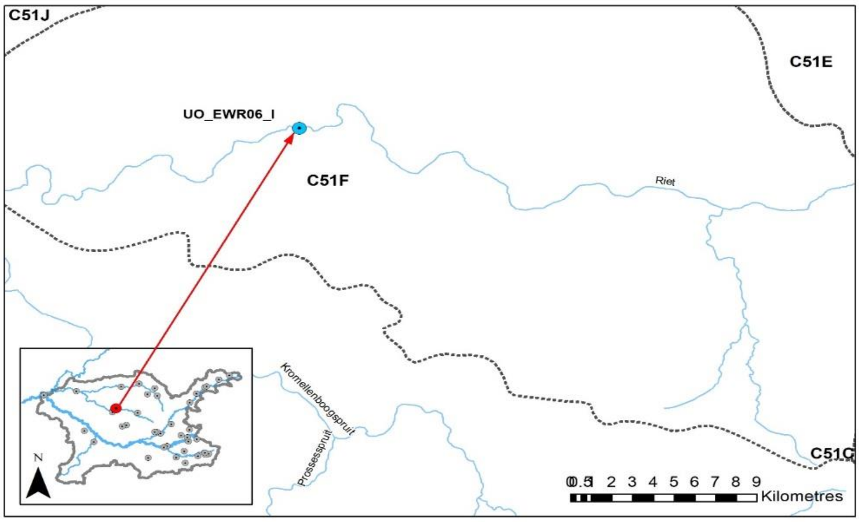


Figure 5-23: Location of site UO_EWR06_I (Upper Riet) in relation to the study area

Site Photographs

Figure 5-24: Site photographs of the Upper Riet EWR site

Upstream	**Downstream**

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

Macroinvertebrates: The upper Riet River has a diversity of macroinvertebrate biotopes available, including both marginal and in-stream aquatic vegetation. The indicator taxon selected for this site is Hydropsychidae, being a flow dependent taxon. They have a high preference for fast currents of >0.6 m/s, although optimal speeds are approximately 0.4 m/s, along cobble substrate. Their greatest response to water depth is between 15 cm and 40 cm (Thirion, 2016), which forms part of their critical habitat and which can be assessed on the HabFlo. Thus, the macroinvertebrate habitat availability assessed as critical habitat will be the FCS and VFCS. The Hydropsychidae family further tolerate a wide fluctuation in water quality.

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

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

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats, and velocities. The selected stress values and associated flows are provided in Table 5-15 and the final integrated stress curve is shown in Figure 5-25.

Table 5-15: Selected stress values, flows and rationale for the Upper Riet EWR site

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

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
		along with any other flow-sensitive taxa.		
7			0.385	Loss of habitat for all life stages of *Labeobarbus aeneus*
8				
9	0.002	No flow. Macroinvertebrates diapause phase triggered.	0.01	Loss of habitat for all fish species
10			0	

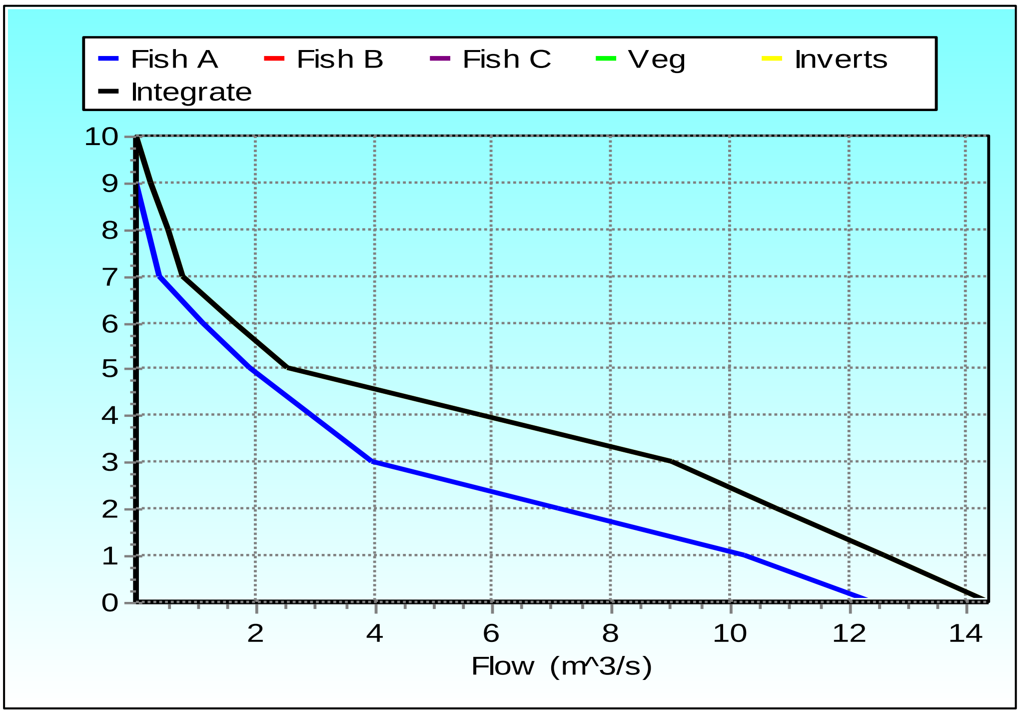


Figure 5-25: Final integrated stress curve for the Upper Riet EWR site (UO_EWR06_I)

The information of the above stress curve was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (March) and the final adjusted EWRs are shown in Figure 5-26 and Figure 5-27 below. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality.

Increase July maintenance low flows from 0.068 m^3/s to 0.096 m^3/s

Increase March maintenance low flows from 0.428m^3/s to 0.743 m^3/s

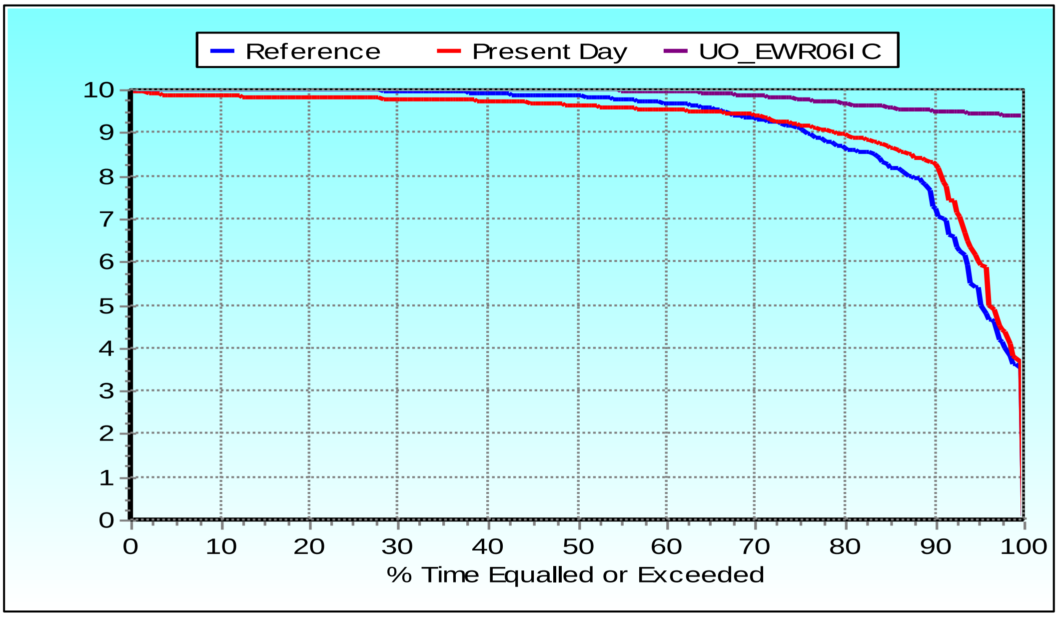


Figure 5-26: Final stress duration curves – dry season (July)

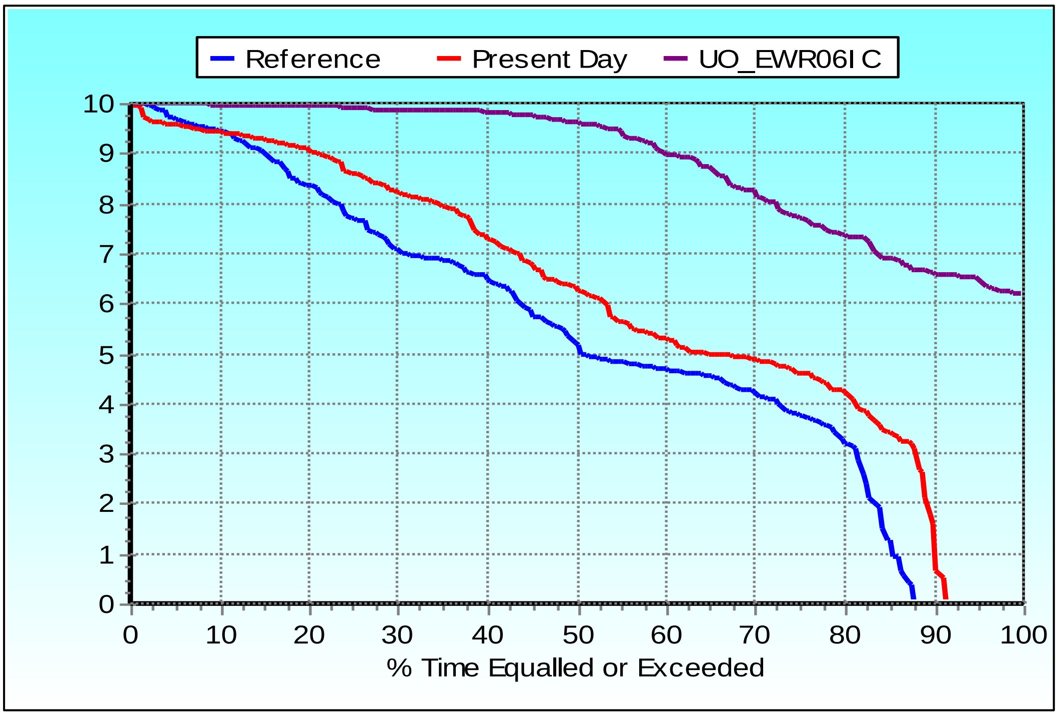


Figure 5-27: Final stress duration curves – wet season (February)

The flood requirements for the Upper Riet EWR site were specified by the specialists and include small freshets to provide specific cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching). Larger floods specified for clearing of the river channel and mobilising the gravel substrate. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 5-16.

Table 5-16: Flood requirements for the Upper Riet at the EWR site (UO_EWR06_I)

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

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

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 5-17.

Table 5-17: Upper Riet - Summary of the EWR results (flows in million m^3 per annum)

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

5.7 UO_EWR07_I: UPPER MODDER (SANNASPOS)

Sample Date	14 July 2022 2 June 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR07_I	**Prioritised RU**	R_RU9a
River	Modder	**Altitude (m.a.s.l.)**	1333
Latitude	-29.160017°	**Longitude**	26.572492°
Level 1 EcoRegion	Highveld	**Quaternary catchment- SQ Reach**	C52B-03819
Level 2 EcoRegion	11.03	**DWS, 2014 PES, EI, ES**	D, Moderate, High
Geomorphological zone	E (0.001; Lower Foothills)		

MAP ILLUSTRATION (Figure 5-28**) AND SITE PHOTOGRAPHS (Figure 5-29)**

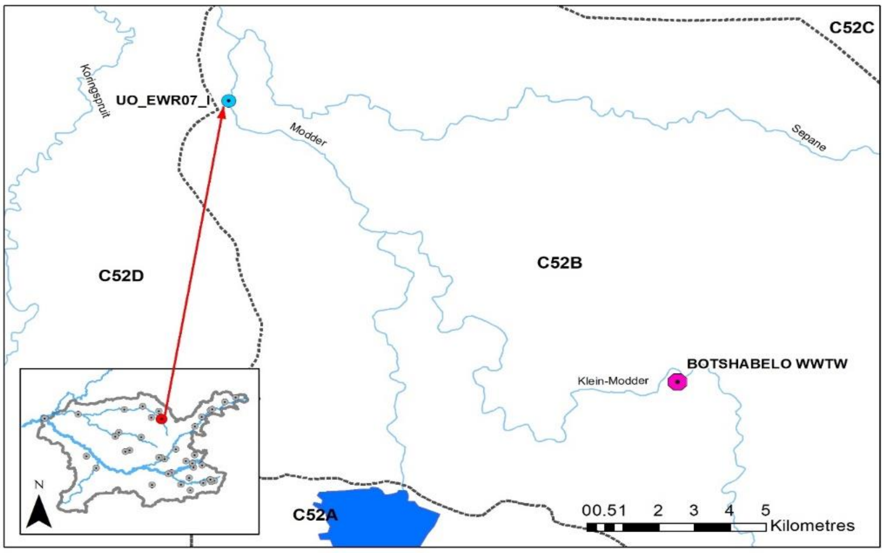


Figure 5-28: Location of site UO_EWR07_I (Upper Modder) in relation to the study area

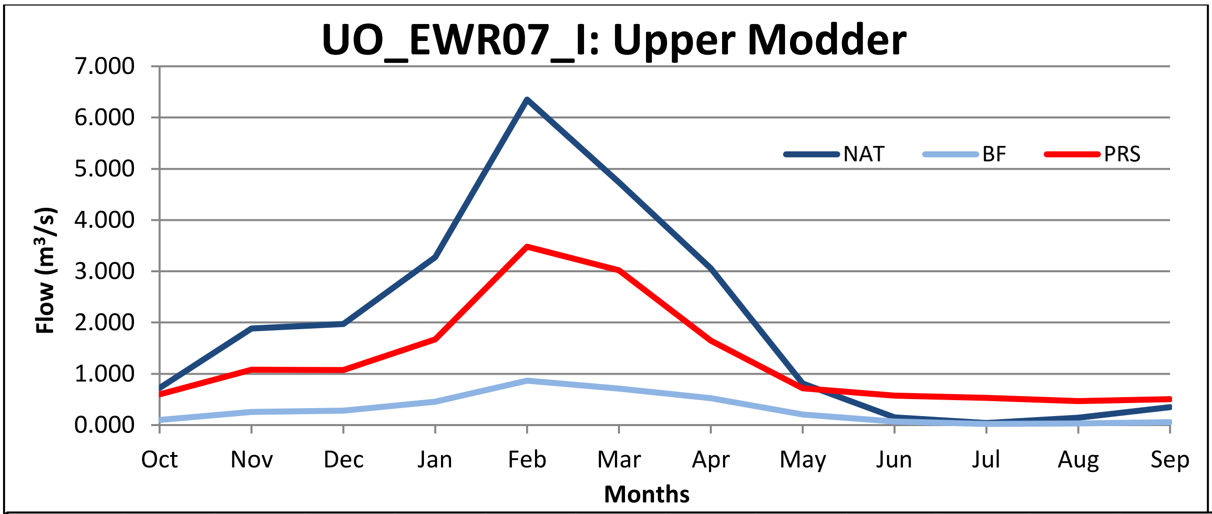
Site Photographs

Figure 5-29: Site photographs of the Upper Modder EWR site

Upstream	**Downstream**

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

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



m3/s	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
NAT	0.721	1.885	1.975	3.279	6.351	4.737	3.060	0.812	0.149	0.040	0.141	0.347
PRS	0.597	1.077	1.076	1.671	3.480	3.020	1.644	0.716	0.577	0.533	0.468	0.504
%PRS/NAT	83	57	54	51	55	64	54	88	388	1330	331	145

Figure 5-30: Hydrograph indicating high flows under present day (PRS) compared to natural (NAT and baseflows (BF) during dry months

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

Increase July and August maintenance low flows to 0.053 m^3/s

Increase February maintenance low flows from 0.322m^3/s to 0.848 m^3/s

Drought flows: A minimum of 0.053 m^3/s for May, June, July, August, September and October

Drought flows: A minimum of 0.094 m^3/s for January to April and November, December

The site-specific flow requirements were based mainly on the requirements to mobilise fine gravel on the bed and scour fine sediments from riffles. The gravel and sediments will in turn scour the instream biotopes for macroinvertebrates (namely the stones biotope) to remove filamentous algae accumulation. Furthermore, mobilising the medium gravels as specified in Table 5-18 and the final EWR for the Upper Modder River at the EWR site is summarised in Table 5-19.

Table 5-18: Flood requirements for the Upper Modder at the EWR site (UO_EWR07_I)

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

Table 5-19: Upper Modder **-** Summary of the final EWR results (million m^3 per annum)

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

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

5.8 UO_EWR08_I: LOWER KRAAI

Sample Date	7 July 2022 30 May 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR08_I	**Prioritised RU**	R_RU03
River	Kraai	**Altitude (m.a.s.l.)**	1298
Latitude	-30.69007°	**Longitude**	26.74157°
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment- SQ Reach**	D13M-05442
Level 2 EcoRegion	26.03	**DWS, 2014 PES, EI, ES**	C, High, High
Geomorphological zone	E (0.001; Lower foothills)		

MAP ILLUSTRATION (Figure 5-31**) AND SITE PHOTOGRAPHS (Figure 5-32)**

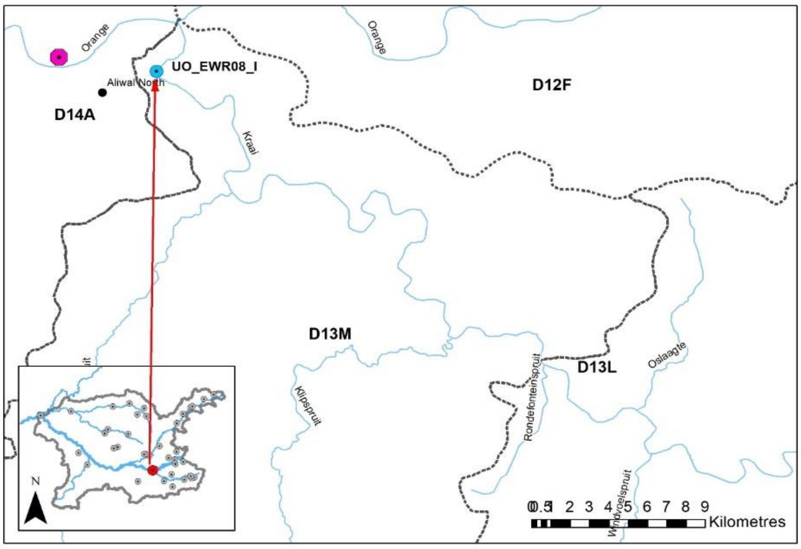


Figure 5-31: Location of site UO_EWR08_I (Lower Kraai) in relation to the study area

Site Photographs

Figure 5-32: Site photographs of the Lower Kraai EWR site

Upstream	**Downstream**

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

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

Fish: the reach associated with the site is important for the purpose of fish movement upstream from the Orange River, with limited spawning habitat present within the immediate reach. Spawning beds are located upstream of the site, but opportunistic spawning is expected to take place following delayed/impeded upstream migration which, during lower flow periods, may result in fish kill events. Life stages of importance within the immediate reach will therefore primarily include juvenile and adult stages for large semi-rheophilics (LSR) *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* which require fast intermediate (FI) (Juveniles) and slow deep (SD), fast deep (FD), FI (Adults). Some fast shallow (FS) (spawning and egg development) and SD (larvae) habitat required to cater for opportunistic spawning events.

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

The stress-flow relationships were determined for flows lower than these using the hydraulic cross-section, available habitats and velocities. The selected stress values and associated flows are provided in Table 5-20 and the final integrated stress curve is shown in Figure 5-33.

Table 5-20: Selected stress values, flows and rationale for the Lower Kraai EWR site

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
0	21.883	All habitats plentiful and in excess and very high quality. 23% FCS and 37% VFCS available at an average depth of 0.72 m and exceeds 0.6 m/s which is the target flow speed for the indicator group - Perlidae.	8.086	Max depth of 0.75 m and an average of 0.44 m with a wetted perimeter of 46.3 m. FD elements dominant (45%) with SD also present (16%). Some elements of spawning habitat available (5%) with some elements of FI available (8%)

Stress	Inverts (m^3/s)	Rationale	Fish (m^3/s)	Rationale
1				
2				
3	10.664	Reduced critical (20% VFCS, although slight increase in FCS critical habitat at 31%), with an average velocity of 0.44 m/s, thus reducing the target flow speed for the indicator taxon. Bedrock on the left bank will remain exposed, although this is not a suitable habitat for this indicator taxon. Marginal vegetation not available at these flows. Wetted perimeter slightly reduced (47.2% of the cross section).	5.244	Max depth 0.64 m with average depth of 0.35 m with a wetted perimeter of 44 m. SD class decreases below 10%; FI class has increased marginally (8%) due to loss of FD class (now at 33%); FS at 5% and reducing further
4				
5	5.023	Reduced critical habitat and reduced critical quality i.e., 10% VFCS, although sustained FCS (30%). However, the average velocity is 0.34 m/s - not suitable for the indicator taxon with a preference for 0.6 m/s or more. Wetted perimeter 43% of the cross section.	2.821	Max depth of 0.51 m with an average depth of 0.27 m with a wetted perimeter of 36.6m. Loss of SD habitat, so larval stages and some habitat for juvenile and adult stages will be affected. Spawning habitat (FS) still expected to be present (9%). FI (12%) and FD (17%) classes still available, although reduced. SS dominant class
6				
7				
8	1.165	Very little critical habitat available (VFCS - 6%, FCS - 20%). Slow, trickle (0.24 m/s) thus habitats only very low quality. Despite FCS available at 20%, the average flow is too low for this indicator species thus very stressed conditions.		
9			0.032	Loss of all fast habitat types, with maximum depth of 0.1 m and average depth of 0.05 m and a wetted perimeter of 4.7 m, thus no cover provided for fish species and all species likely to be absent entirely.
10	0.003	No critical habitat (0% for both FCS and VFCS) and only hyporheic refugia.	0	No flow present

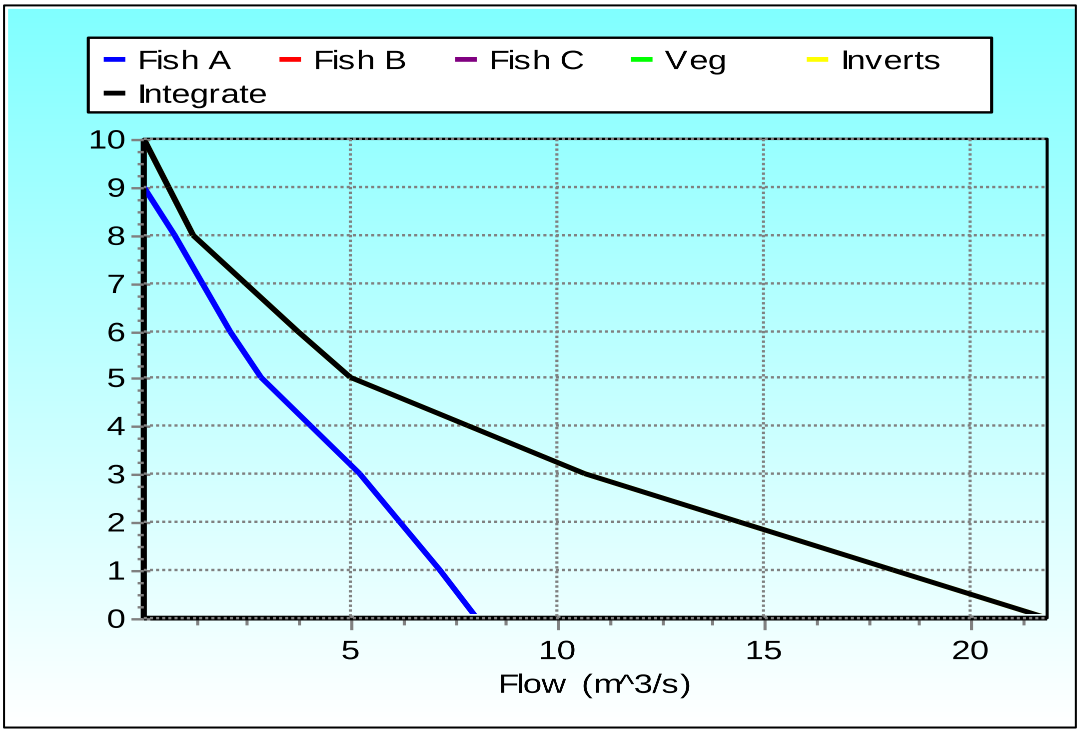


Figure 5-33: Final integrated stress curve for the Lower Kraai EWR site (UO_EWR08_I)

The information from the stress curves in Figure 5-33 was used to convert the flows into stress duration curves for the EWR site for the dry season (July) and wet season (March) and the final adjusted EWRs are shown in Figure 5-34 and Figure 5-35 below. The adjustments made to the DRM results are listed below. These were based on the hydrology provided for the REC for this site, of which was further analysed to ensure the stresses for the identified indicator taxon and species were not too high, where they still can persist and where critical habitat is still available, although at times reduced and at moderate to lower quality.

Increase drought flows for all months to 1.300 m^3/s

Increase July maintenance low flows from 2.575 m^3/s to 5.289 m^3/s

Increase March maintenance low flows from 4.501 m^3/s to 9.243 m^3/s

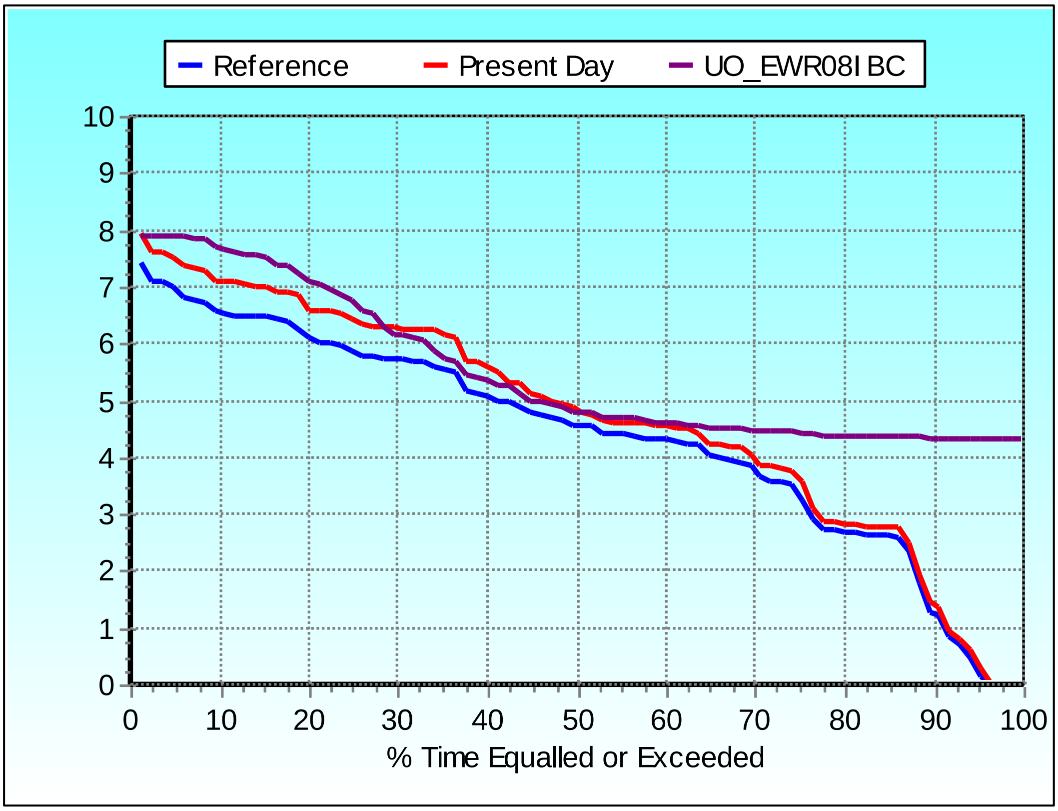


Figure 5-34: Final stress duration curves – dry season (July)

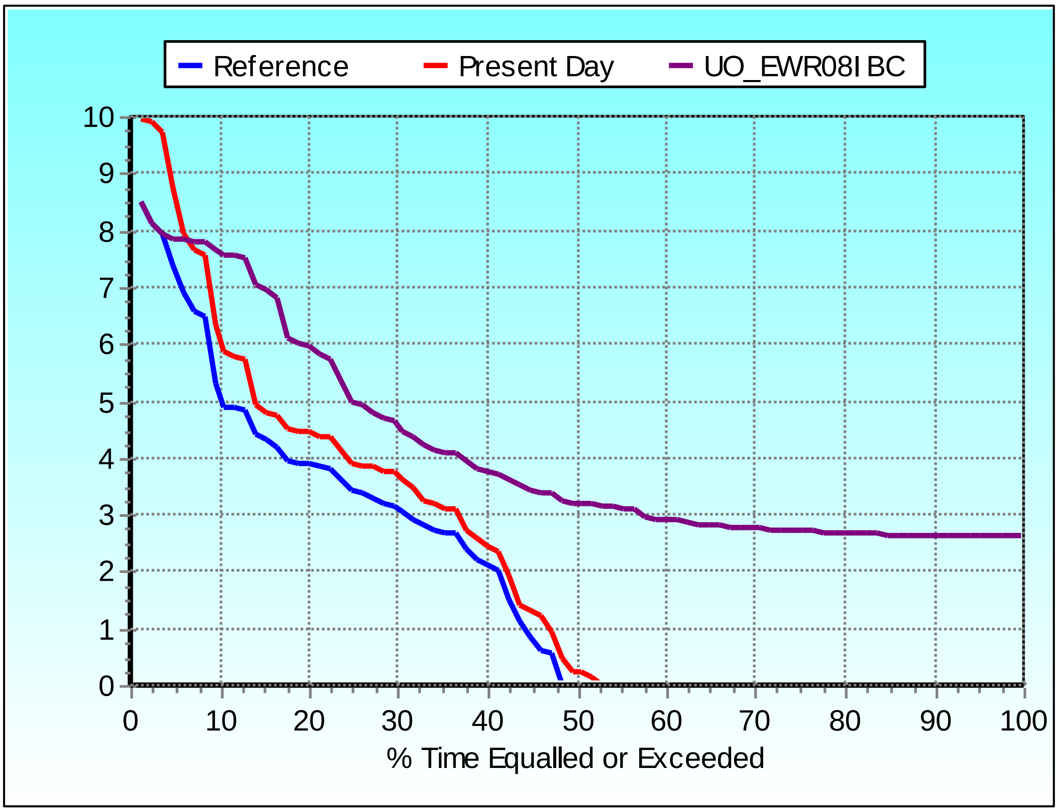


Figure 5-35: Final stress duration curves – wet season (February)

The flood requirements for the Lower Kraai EWR site were specified by the specialists and include small freshets to provide specific cues for fish (upstream movement and spawning) and macroinvertebrate (breeding and hatching). The larger floods were specified with the aim of clearing of the river channel, to inundate the inset benches along the left bank, mobilise instream gravel deposits to flush out fines and to rework deposited sand and to scour the stones biotope located on the left side of the channel, to remove the filamentous algae smothering that biotope for the benefit of the flow and habitat dependent macroinvertebrates. The individual requirements were integrated for inclusion in the final EWR results and are summarised in Table 5-21.

Table 5-21: Flood requirements for the Lower Kraai at the EWR site (UO_EWR08_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorphology	FINAL
Class 1 (20-30 m^3/s)	m^3/s	30		20 - 50	29	30
	# days	3		4	4	4
	Months	Nov, Dec, Jan		Nov, Dec, Jan	Dec, Jan, Feb March	Oct, Nov, Dec, Jan, Apr
	Type	Average		Average		Average
Class 2 (50-75 m^3/s)	m^3/s		57		Average	75
	# days		4			4
	Months		Dec, Jan, Feb March			Jan, Feb, Apr
	Type		Average			Average
Class 3 (75-100 m^3/s)	m^3/s		76	100		100
	# days		4	6		4
	Months		Apr, May	Jan, Feb, Mar		Feb
	Type		Peak	Average		Average
Class 4 (360 m^3/s)	m^3/s				360	250
	# days				7	5
	Months				Feb, March	Mar
	Type				Peak	Peak

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

The final ecological water requirements using the stress duration curves and the integrated flood requirements are summarised in Table 5-22.

Table 5-22: Lower Kraai - Summary of the EWR results (flows in million m^3 per annum)

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

5.9 UO_EWR09_I: LOWER RIET

Sample Date	-	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR09_I	**Prioritised RU**	R_RU10
River	Lower Riet	**Altitude (m.a.s.l.)**	1080
Latitude	-29.026963	**Longitude**	24.512919
Level 1 EcoRegion	Southern Kalahari	**Quaternary catchment-SQ Reach**	C51L-03878
Level 2 EcoRegion	29.02	**DWS, 2014 PES, EI, ES**	D, Very High, High
Geomorphological zone	E (0.002; Lower foothills)		

MAP ILLUSTRATION (Figure 5-36) **AND SITE PHOTOGRAPHS** (Figure 5-37)

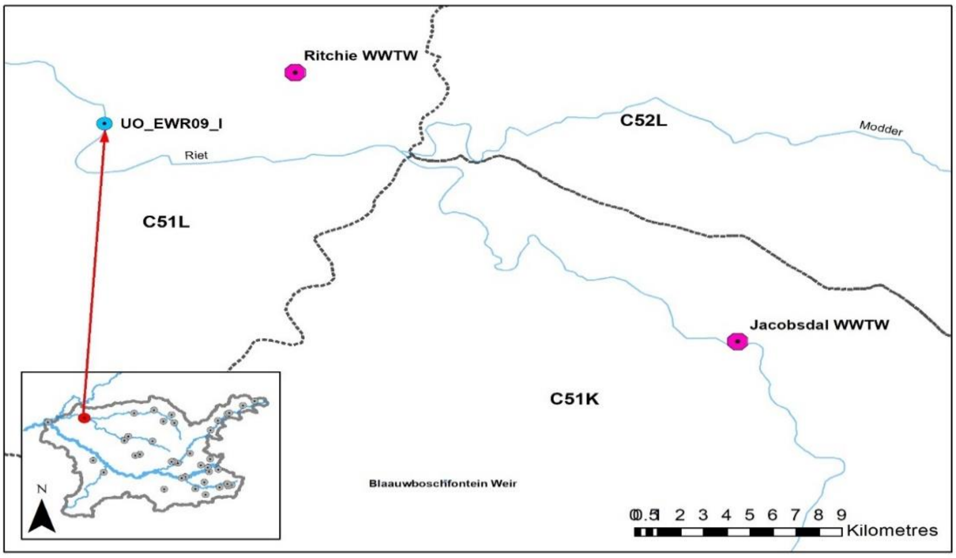


Figure 5-36: Location of site UO_EWR09_I (Lower Riet) in relation to the study area

Figure 5-37: Site photographs of the Lower Riet EWR site

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

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

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

It is recommended that the 2010 EWR for a D category, together with the floods as specified during the study (see Table 5-23 and Table 5-24 below) is implemented as an absolute minimum. Continuous REMP monitoring of both fish and macroinvertebrates and interpretation of the results are recommended at this site to identify any negative trend to be addressed and modified timeously.

Table 5-23: Flood requirements for the Lower Riet at the EWR site (UO_EWR09_I) (from Vaal_EWR19, 2010)

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

Table 5-24: Final EWR from DWA, 2010 study for Lower Riet EWR site (UO_EWR09_I)

Quaternary Catchment	C51L
Site name	UO_EWR09_I
EWR site coordinates	-29.026963; 24.512919
River	Lower Riet
Recommended Ecological Category	D (from DWA, 2010)*
nMAR (Mm^3)	373.8
Total EWR	89.974 (24.07 %MAR)
Maintenance Low flows	54.274 (14.52 %MAR)
Drought Low flows	0.544 (0.15 %MAR)
Maintenance High flows	35.700 (9.55 %MAR)
Overall confidence	High

**The flows as per the Vaal comprehensive study were specified for a D category, they were checked and identified to be adequate to maintain the PES of a C.*

5.10 UO_EWR10_I: LOWER ORANGE

Sample Date	3 June 2023	**Reserve Level Assessment**	Intermediate
Site Name	UO_EWR10_I	**Prioritised RU**	R_RU07
River	Lower Orange	**Altitude (m.a.s.l.)**	1000
Latitude	-29.14485	**Longitude**	23.691403
Level 1 EcoRegion	Nama Karoo	**Quaternary catchment-SQ Reach**	D33K-03723
Level 2 EcoRegion	26.01	**DWS, 2014 PES, EI, ES**	C, High, Moderate
Geomorphological zone	F (0.001; Lowlands)		

MAP ILLUSTRATION (Figure 5-38**) AND SITE PHOTOGRAPHS (Figure 5-39)**

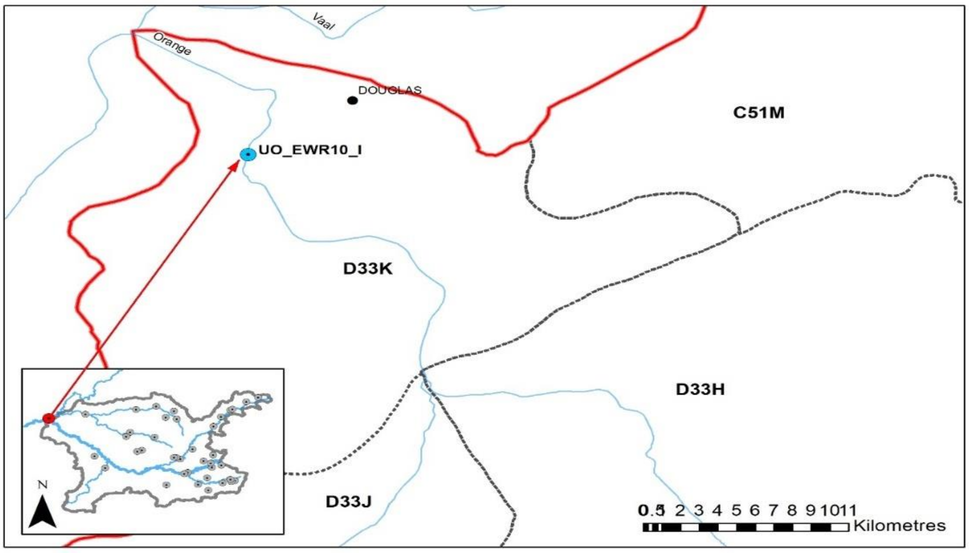


Figure 5-38: Location of site UO_EWR10_I (Lower Orange) in relation to the study area

Site Photographs

Figure 5-39: Site photographs of the Lower Orange EWR site (upstream and downstream)

Upstream	**Downstream**

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

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

Consequently, the HFSR approach was not used to quantify the EWR at this site. The EWR was determined using the rapid 3 approach and based on specialist knowledge and understanding of the biotic community recorded, along with their preferences, and comparing that to the available biotopes/habitats present at the time of the surveys. These guided the setting of the drought and baseflows for this site. Further to this, freshets and floods were also specified.

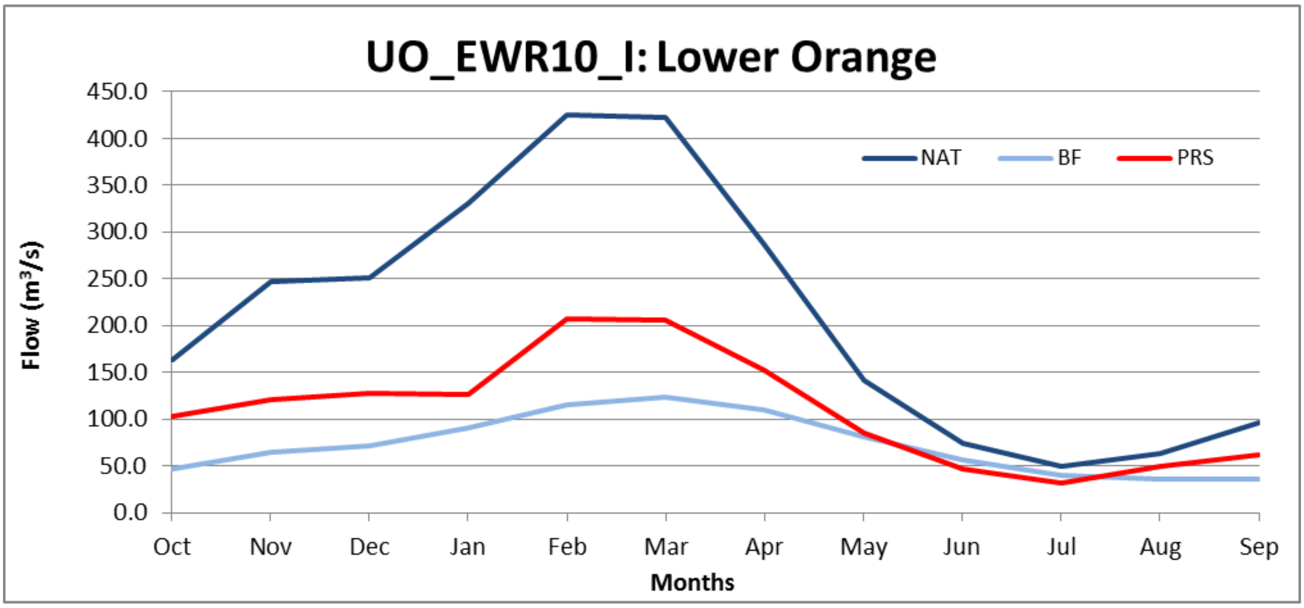


Figure 5-40: Hydrograph for Lower Orange EWR site indicating changed flows under present day (PRS) compared to natural (NAT and baseflows (BF)

The EWR flow data from the DRM was converted to hydraulic conditions at the EWR site (i.e., depths and flow velocities at discharges measured in m^3/s) using a hydraulic model. Both drought and maintenance flows were specified to ensure that the system maintain some ecological integrity. The flows for a C category were adjusted based on the velocity and habitat requirements of the flow-sensitive aquatic macroinvertebrates and to provide adequate flows and depths for fish movement.

Increase July maintenance low flows from 15.059 m^3/s to 20.209 m^3/s

Increase February maintenance low flows from 38.633 m^3/s to 51.847 m^3/s

Drought flows: A minimum of 8.900 m^3/s for April to December

The site-specific flow requirements for floods and freshets were based mainly on the requirements to inundate inset benches to deposit fine sediment, to mobilise fine sediment from coarse instream habitats (at velocities of 1m/s), assist with gravel movement on benches that are at approximately 2m elevation, overtop higher flood benches and the scouring of the channel and pools and are specified in Table 5-18 and the final EWR for the Upper Modder River at the EWR site is summarised in Table 5-19.

Table 5-25: Flood requirements for the Lower Orange at the EWR site (UO_EWR10_I)

Floods	Flood size (range)	Fish	Inverts	Vegetation	Geomorphology	FINAL
Class 1 (50-70 m^3/s)	m^3/s		64			65
	# days		3			3
	Months		Nov, Dec, Jan, Mar			Oct-Jan, Apr
	Type		Average			Average
Class 2 (70-100 m^3/s)	m^3/s		99	100 to 200		100
	# days		7	3		3
	Months		Apr, May	Nov to April		Mar, Apr, May
	Type		Average	Average		Average
Class 3 (100-200 m^3/s)	m^3/s	155				155
	# days	3				3
	Months	Nov, Dec, Jan				Nov, Dec, Jan
	Type	Average				Average
Class 4 (200-300 m^3/s)	m^3/s				229	229
	# days				3	3
	Months				Nov, Dec, Jan, Mar	Feb, Mar
	Type				Average	Average
Class 5 (500-750 m^3/s)	m^3/s			500 to 750	550	550
	# days			10	7	7
	Months			Jan to Mar	Nov, Dec, Jan, Mar	Feb
	Type			Peak	Peak	Peak

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

Table 5-26: Lower Orange **-** Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	**D33K**
Site name	UO_EWR10_I
EWR site coordinates	-29.144855; 23.691404
River	Lower Orange
Recommended Ecological Category	C
Total EWR	1427.814 (21.39 %MAR)
Maintenance Low flows	1047.519 (15.69 %MAR)
Drought Low flows	366.113 (5.49 %MAR)
Maintenance High flows	380.295 (5.70 %MAR)
Overall confidence	Moderate

6. EWR RESULTS: RAPID 3 ASSESSMENTS

6.1 UO_EWR01_R: LITTLE CALEDON

Site Name	UO_EWR01R	**Reserve Level Assessment**	Rapid 3
River	Little Caledon	**Quaternary catchment**	D21D
Longitude	28.405709°	**Latitude**	-28.557796°
EI	High	**ES**	High
PES	C	**REC**	B/C
Comments: No large dams upstream, although abstractions for irrigation in upper catchment Water quality impacting on the biota, especially quality sensitive macroinvertebrates No gauging weir in close vicinity to interpret daily data, especially for specifying freshets and floods			
			
Upstream		**Downstream**	

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

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

The discharge at the EWR site during the survey on 4 July 2022 was 0.425 m^3/s and was used as reference to adjust the recommended EWRs (see Figure 6-1). It should be noted that the baseflows were very high during the survey as a result of the continual high rainfall during the summer months.

The consensus reached by the aquatic ecologists was that the recommended flows for both July and March did not provide adequate velocities and availability of instream habitats for the macroinvertebrates. The maintenance low flows were adjusted 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). Furthermore, flows were increased with the aim to improve velocity depth classes and activate additional fast intermediate critical habitat, and to further provide additional cover features for the fish. Therefore, the recommended flows (drought and maintenance) were adjusted as follows:

(i) Maintenance low flows:

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

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

(ii) Drought flows:

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

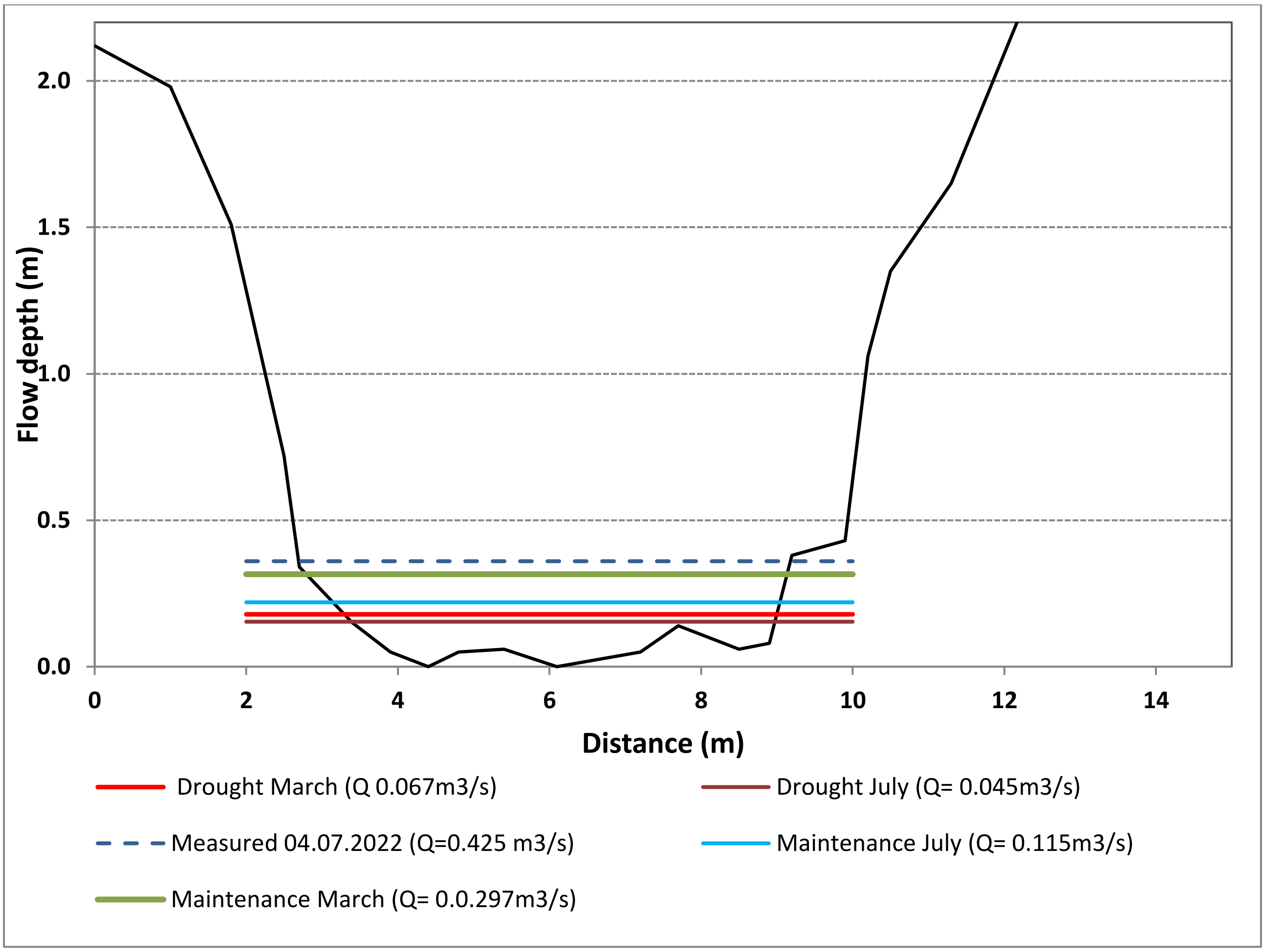


Figure 6-1: Water levels on cross-section of the EWR site for Little Caledon River in D21D

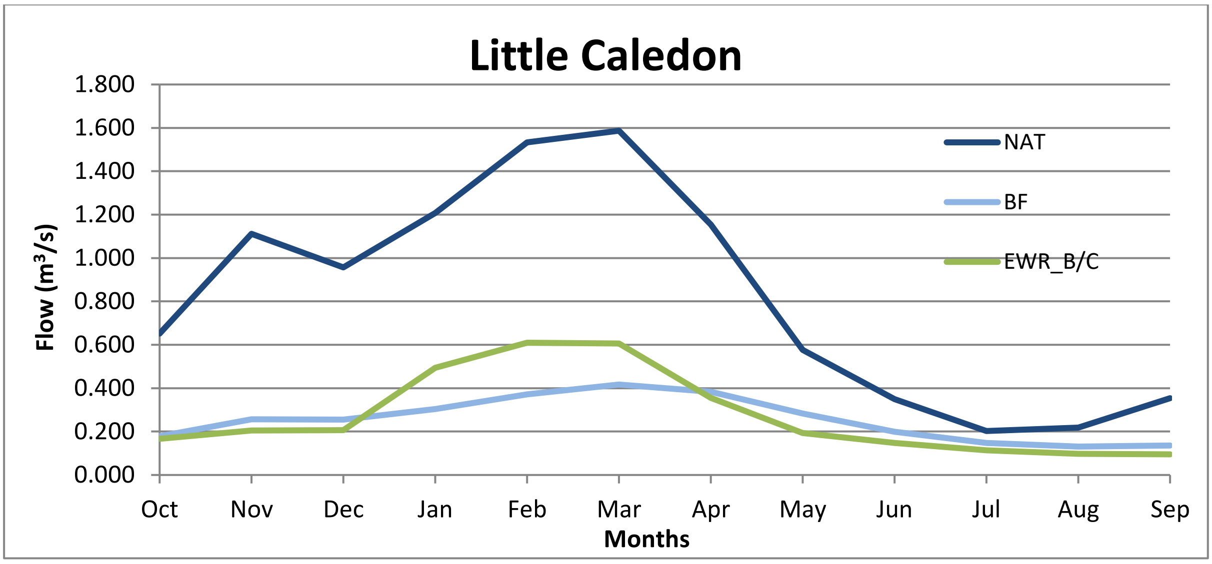
The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 6-1, the final EWR for the Little Caledon River at the EWR site is summarised in Table 6-2 and presented in Figure 6-2.

Table 6-1: Little Caledon - Freshets and flood requirements for implementation

Months	Freshets		Floods	
	m^3/s	days	m^3/s	days
October	6	2		
November	5	2	10	3
December	14	3		
January	34	3		
February	45	4		
March	34	4	14	3
April	5	2		

Table 6-2: Little Caledon **-** Summary of the final EWR results (flows in million m^3 per annum)

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



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

Figure 6-2: Monthly hydrograph indicating final EWR for Little Caledon River in D21D

6.2 UO_EWR02_R: BRANDWATER (GROOT)

<table>
<tr><td>Site Name</td><td>UO_EWR02R</td><td>Reserve Level Assessment</td><td>Rapid 3</td></tr>
<tr><td>River</td><td>Brandwater (Groot)</td><td>Quaternary catchment</td><td>D21G</td></tr>
<tr><td>Longitude</td><td>28.139926°</td><td>Latitude</td><td>-28.680340°</td></tr>
<tr><td>EI</td><td>High</td><td>ES</td><td>Moderate</td></tr>
<tr><td>PES</td><td>C</td><td>REC</td><td>B/C</td></tr>
<tr><td colspan="4">Comments:
No large dams upstream, although abstractions for irrigation in upper catchment.
Water quality impacting on the biota, especially quality sensitive macroinvertebrates due to dysfunctional WWTW upstream.
No gauging weir in close vicinity to interpret daily data, especially for specifying freshets and floods.</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Upstream</td><td colspan="2">Downstream</td></tr>
</table>

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

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

The discharge at the EWR site during the survey on 4 July 2022 was 0.648 m^3/s and was used as reference to adjust the recommended EWRs (see Figure 6-3). It should be noted that the baseflows were very high during the survey as a result of the continual high rainfall during the summer months.

The consensus reached by the aquatic ecologists was that the recommended flows for both July and March did not provide adequate velocities and availability of instream habitats for the macroinvertebrates. The maintenance low flows were adjusted in order to ensure increased depth and velocity for those flow dependent and present macroinvertebrates over the small area of available stones biotope at this site. Therefore, the recommended flows (drought and maintenance) were adjusted as follows:

(i) Maintenance low flows:

July - Adjusted from 0.093 m^3/s to 0.160 m^3/s

March - Adjusted from 0.422 m^3/s to 0.728 m^3/s

(ii) Drought flows:

A minimum of 0.049 m^3/s for the drier months (June to November) and 0.078 m^3/s for the wet months.

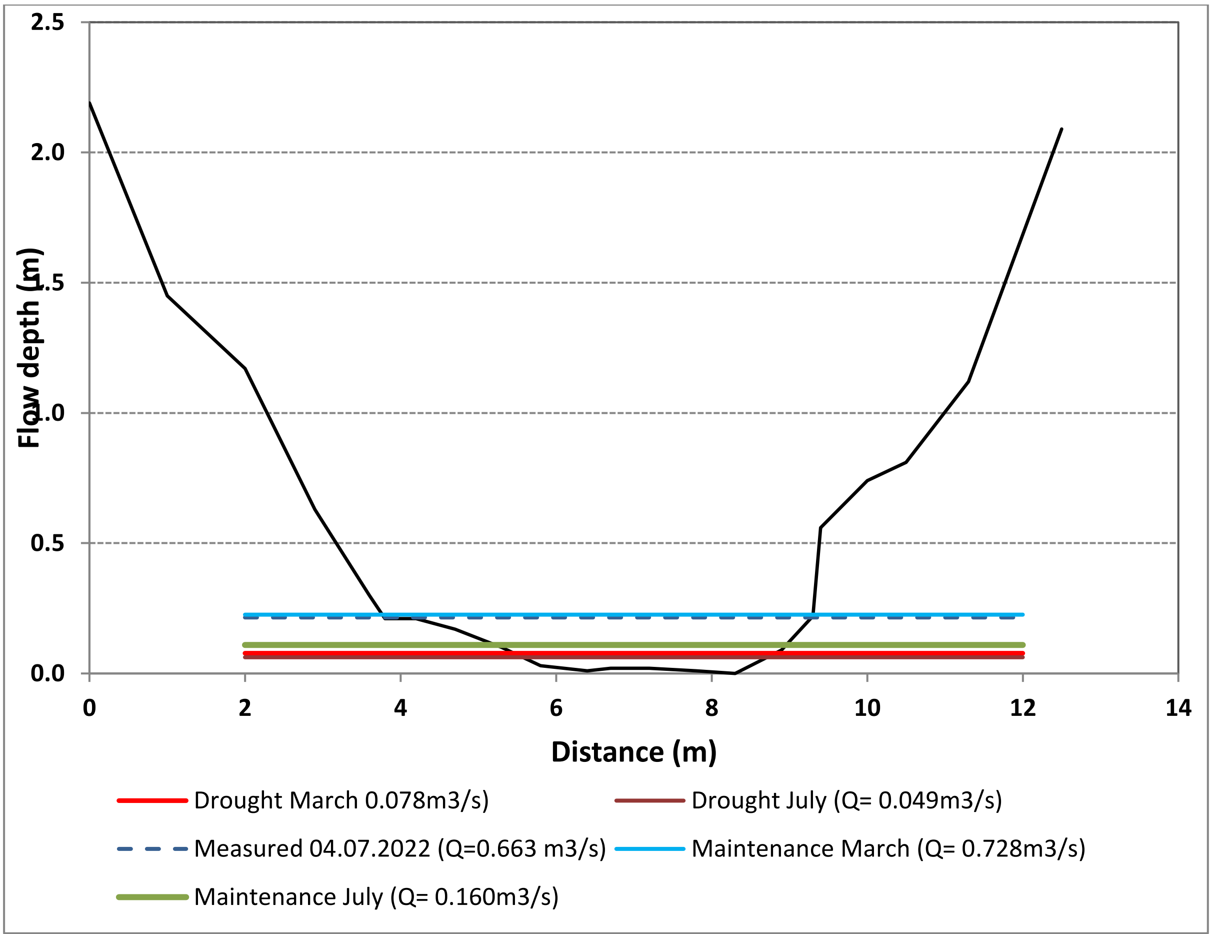


Figure 6-3: Water levels on cross-section of the EWR site for Brandwater River in D21G

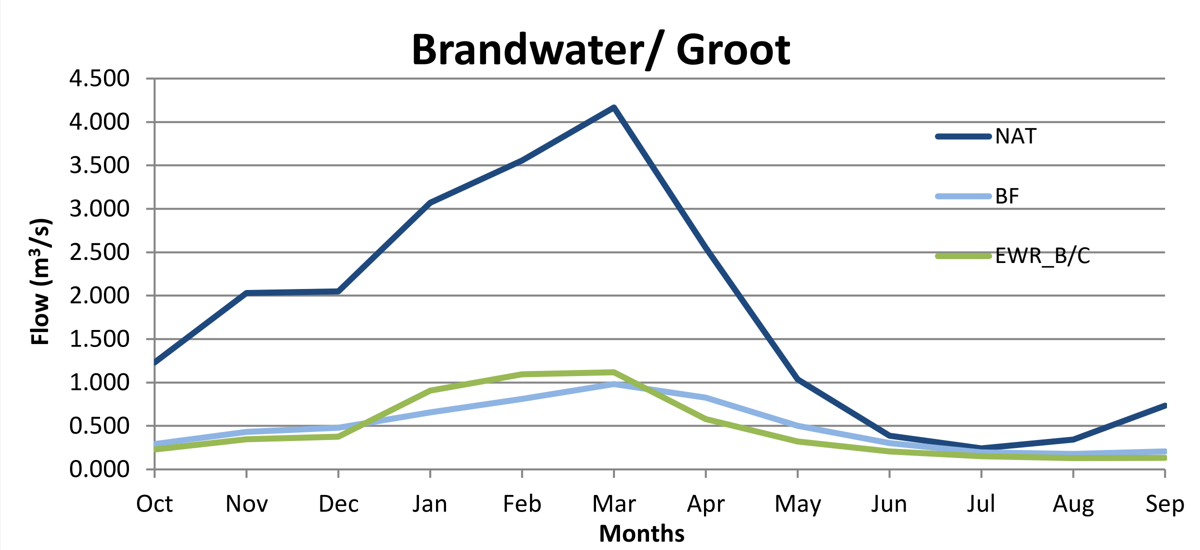
The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 6-1, the final EWR for the Brandwater River at the EWR site is summarised in Table 6-2, Table 6-4 and presented in Figure 6-4.

Table 6-3: Brandwater **-** Freshets and flood requirements for implementation

Months	Freshets		Floods	
	m^3/s	days	m^3/s	days
October	1.3	2		
November	1.5	5		
December	1.5	5		
January	1.5	5	10	2
February	1.5	5	10	2
March	1.5	5	10	2
April	1.3	2		

Table 6-4: Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D21G
River	Brandwater
Recommended Ecological Category	B/C
nMAR at EWR site	56.0
Total EWR	17.325 (30.95 %MAR)
Maintenance Low flows	11.846 (21.16 %MAR)
Drought Low flows	2.001 (3.57 %MAR)
Maintenance High flows	5.479 (9.79 %MAR)
Overall confidence	Moderate



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

Figure 6-4: Monthly hydrograph indicating final EWR for Brandwater River in D21G

6.3 UO_EWR03_R: MOPELI

Site Name	UO_EWR03R	**Reserve Level Assessment**	Rapid 3
River	Mopeli	**Quaternary catchment**	D22G
Longitude	27.570751°	**Latitude**	-29.101205°
EI	Moderate	**ES**	Moderate
PES	D	**REC**	C/D
Comments: Number of dams in the upstream catchment, impacting on the low flows and moderate floods No gauging weir in close vicinity to interpret daily data, especially for specifying freshets and floods			
			
Upstream		**Downstream**	

The EWR for the Mopeli River were determined for a REC of a C/D. The EWR flow data from the DRM was converted to hydraulic conditions at the EWR site (i.e., depths and flow velocities at discharges measured in m^3/s) using a hydraulic model. The maintenance flows were examined for July and February. 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).

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 5 July 2022 was 0.808 m^3/s and was used as reference to adjust the recommended EWRs (see Figure 6-5Figure 6-3). It should be noted that the baseflows were very high during the survey as a result of the continual high rainfall during the summer months.

The consensus reached by the aquatic ecologists was that the recommended flows for both July and February did not provide adequate velocities and availability of instream habitats for the macroinvertebrates. The maintenance low flows were slightly adjusted and increased to provide increased velocity and depth to inundate some of the marginal vegetation to ensure the colonisation of macroinvertebrates with a preference for vegetation. This site is dominated by bedrock, thus not a good biotope for either fish or macroinvertebrates. Thus these increased flows, would likely further increase the marginal cover features for the fish along the left bank. Therefore, the recommended flows (drought and maintenance) were adjusted as follows:

(i) Maintenance low flows:

July - Adjusted from 0.047 m^3/s to 0.129 m^3/s

February - Adjusted from 0.184 m^3/s to 0.540 m^3/s

(ii) Drought flows:

A minimum of 0.025 m^3/s for the drier months (May to October) and 0.035 m^3/s for the wet months.

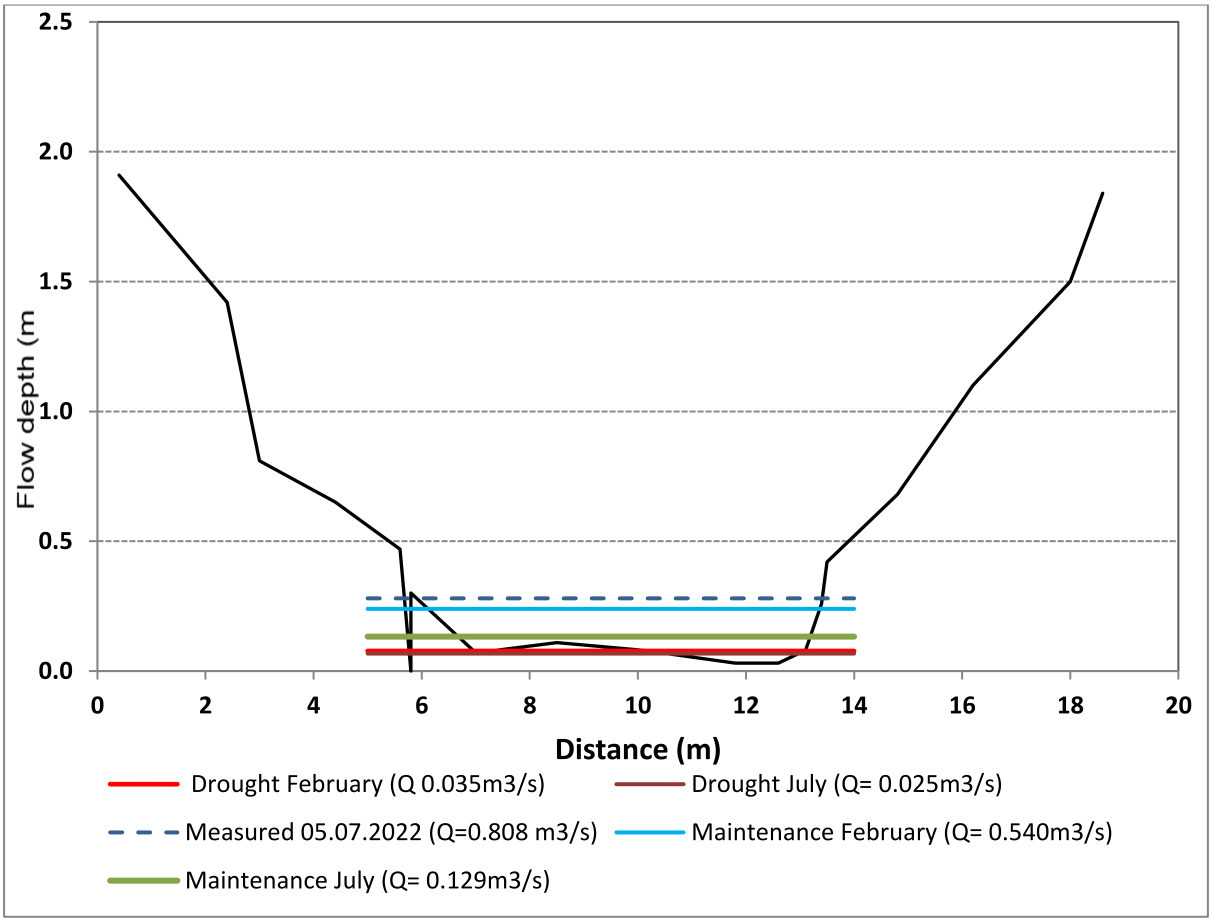


Figure 6-5: Water levels on cross-section of the EWR site for Mopeli River in D22G

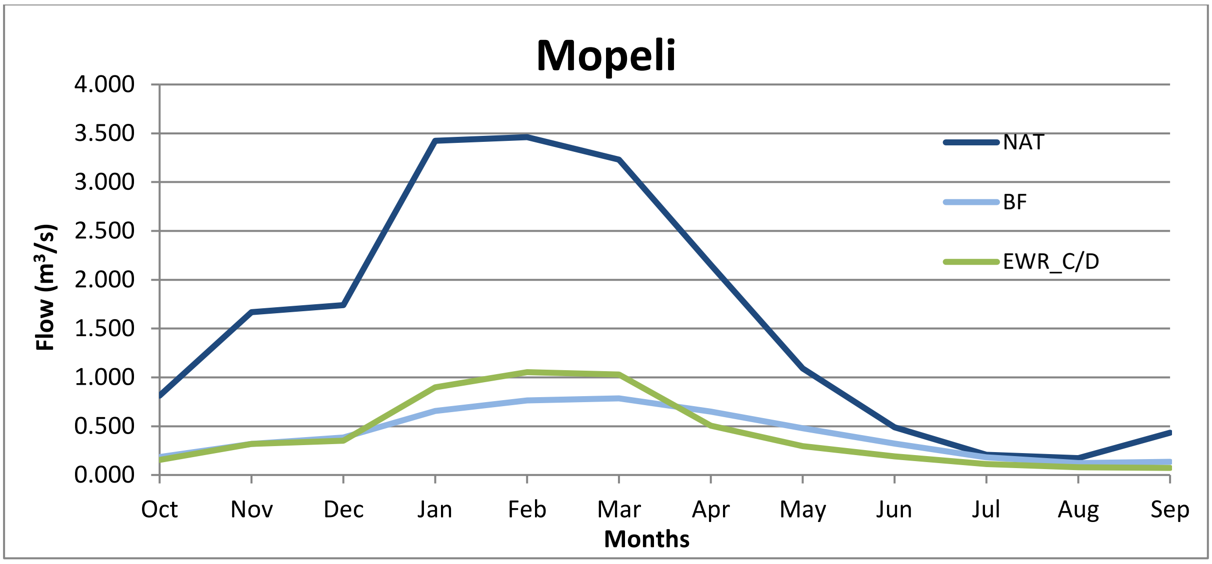
The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 6-1 and Table 6-5The final EWR for the Mopeli River at the EWR site is summarised in Table 6-6 and Table 6-2 and presented in Figure 6-6.

Table 6-5: Mopeli - Freshets and flood requirements for implementation

Months	Maintenance freshets		Maintenance floods	
	m^3/s	days	m^3/s	days
October	1.5	2		
November	3.0	2		
December	3.0	2		
January	3.0	2	10	3
February	3.0	2	10	3
March	3.0	2	10	3
April	1.5	2		

Table 6-6: Mopeli River - Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D22G
River	Mopeli
Recommended Ecological Category	C/D
nMAR at EWR site	49.35
Total EWR	14.483 (29.34 %MAR)
Maintenance Low flows	8.962 (18.16 %MAR)
Drought Low flows	0.945 (1.91 %MAR)
Maintenance High flows	5.521 (11.19 %MAR)
Overall confidence	Moderate



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

Figure 6-6: Monthly hydrograph indicating final EWR for Mopeli River in D22G

6.4 UO_EWR04_R: UPPER KRAAI

Site Name	UO_EWR04R	**Reserve Level Assessment**	Rapid 3
River	Upper Kraai	**Quaternary catchment**	D13E
Longitude	27.77689°	**Latitude**	-30.85179°
EI	High	**ES**	High
PES	C	**REC**	B

Comments:
Forms part of the SWSA
No dams in upper catchments with only irrigation abstractions
Upper Kraai and tributaries stocked with trout that impacts on the fish and macroinvertebrates (predators)
No gauging weir in close vicinity to interpret daily data, especially for specifying freshets and floods

Upstream

Downstream

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

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

The discharge at the EWR site during the survey on 9 July 2022 was 2.325 m^3/s and was used as reference to adjust the recommended EWRs (see Figure 6-7Figure 6-3). It should be noted that the baseflows were very high during the survey as a result of the continual high rainfall during the summer months.

The consensus reached by the aquatic ecologists was that the recommended flows for both July and March did not provide adequate velocities and availability of instream habitats for the macroinvertebrates. The maintenance low flows were adjusted to provide additional flow and velocity (for those flow and water quality sensitive macroinvertebrates occurring at the site), as well as to increase the critical habitat for macroinvertebrates namely fast course substrate and/or very fast course substrate (being the stones biotope). Therefore, the recommended flows (maintenance and drought) were adjusted as follows:

(i) Maintenance low flows:

July - Adjusted from 0.898 m^3/s to 1.620 m^3/s

March - Adjusted from 1.719 m^3/s to 3.102 m^3/s

(ii) Drought flows:

A minimum of 0.351 m^3/s for the wetter months (January to May).

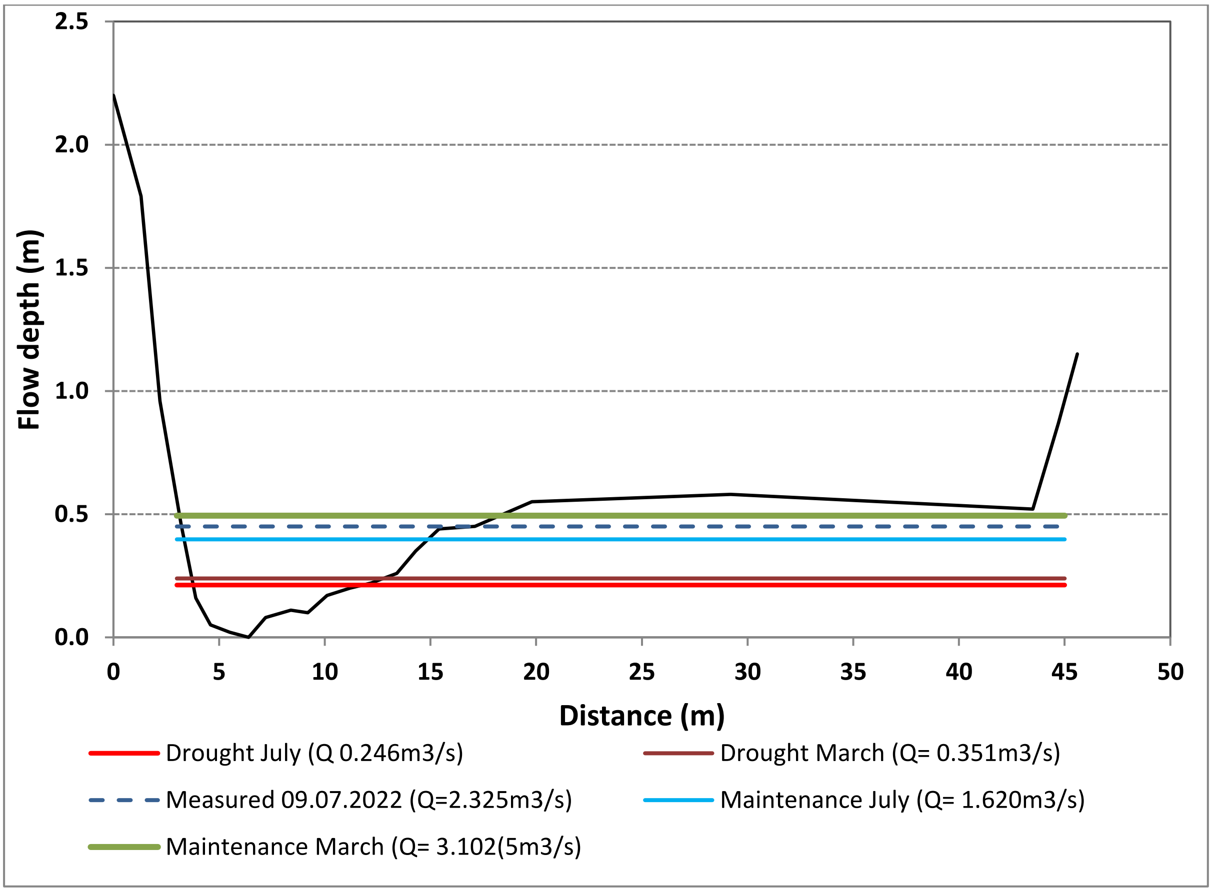


Figure 6-7: Water levels on cross-section of the EWR site for Upper Kraai River in D13E

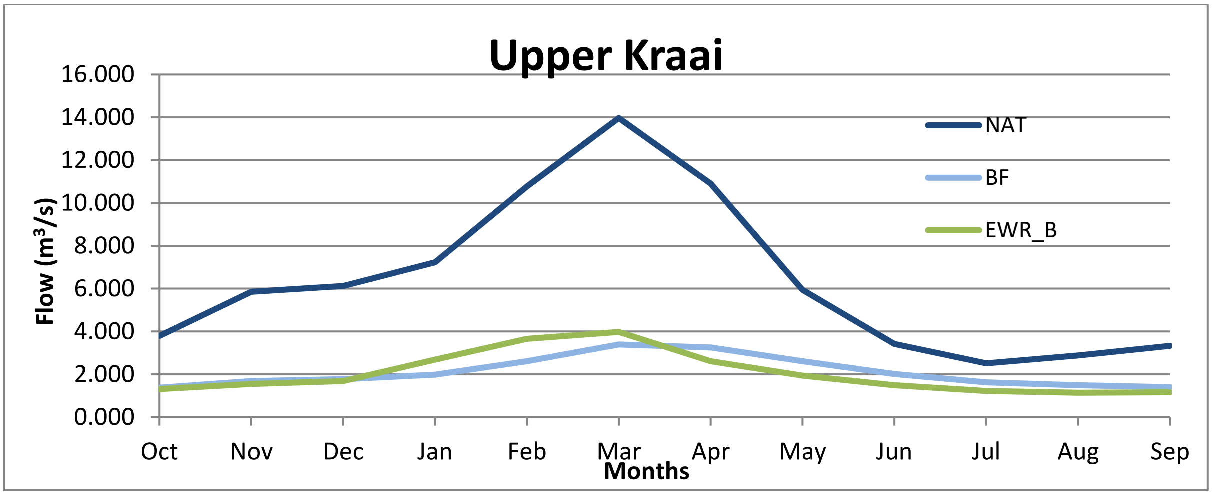
The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 6-1 and Table 6-7. The final EWR for the Upper Kraai River at the EWR site is summarised in Table 6-2 and Table 6-8 and presented in Figure 6-8.

Table 6-7: Upper Kraai - Freshets and flood requirements for implementation

Months	Freshets		Floods	
	m³/s	days	m³/s	days
October	7.0	2		
November	7.0	2		
December	10.0	3		
January	10.0	3	20	2
February	10.0	3	20	2
March	10.0	3	20	2
April	7.0	2		

Table 6-8: Upper Kraai - Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D13E
River	Upper Kraai
Recommended Ecological Category	B
nMAR at EWR site	200.9
Total EWR	80.456 (40.04 %MAR)
Maintenance Low flows	64.438 (32.07 %MAR)
Drought Low flows	9.082 (4.52 %MAR)
Maintenance High flows	16.019 (7.97 %MAR)
Overall confidence	Moderate



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

Figure 6-8: Monthly hydrograph indicating final EWR for Upper Kraai River in D13E

6.5 UO_EWR05_R: WONDERBOOMSPRUIT

Site Name	UO_EWR05R	**Reserve Level Assessment**	Rapid 3
River	Wonderboomspruit	**Quaternary catchment**	D14E
Longitude	26.341938°	**Latitude**	-31.005262°
EI	Moderate	**ES**	Moderate
PES	D	**REC**	C/D

Comments:
Semi-arid area with more seasonal systems with a number of small dams in upper catchments. The water quality impacts are severe on the aquatic ecosystem at this site.
Gauging weir D1H001 just downstream of the EWR site provided valuable information for the setting of the EWR at this site**.**

Upstream

Downstream

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

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

The discharge at the EWR site during the survey on 11 July 2022 was 1.129 m^3/s and was used as reference to adjust the recommended EWRs (see Figure 6-9). It should be noted that the baseflows were extremely high during the survey as a result of the continual high rainfall during the summer months and some rain just prior to the survey.

The consensus reached by the aquatic ecologists was that the recommended flows for both July and March didn't provide adequate velocities and availability of instream habitats for the macroinvertebrates. The water quality at this site is highly compromised as a result of the upstream dysfunctional wastewater treatment works. Thus, the maintenance low flows were adjusted to increase flow through the site to aim to dilute the water quality and ensure all critical habitats are activated for macroinvertebrates, as well as improving velocity-depth classes for the fish, activate additional fast intermediate critical habitats and increase the cover features for the fish along both banks. Therefore, the recommended flows (maintenance and drought) were adjusted as follows:

(i) Maintenance low flows:

July - Adjusted from 0.013 m^3/s to 0.064 m^3/s

March - Adjusted from 0.073 m^3/s to 0.367 m^3/s

(ii) Drought flows:

A minimum of 0.028 m^3/s for the wetter months (January to March).

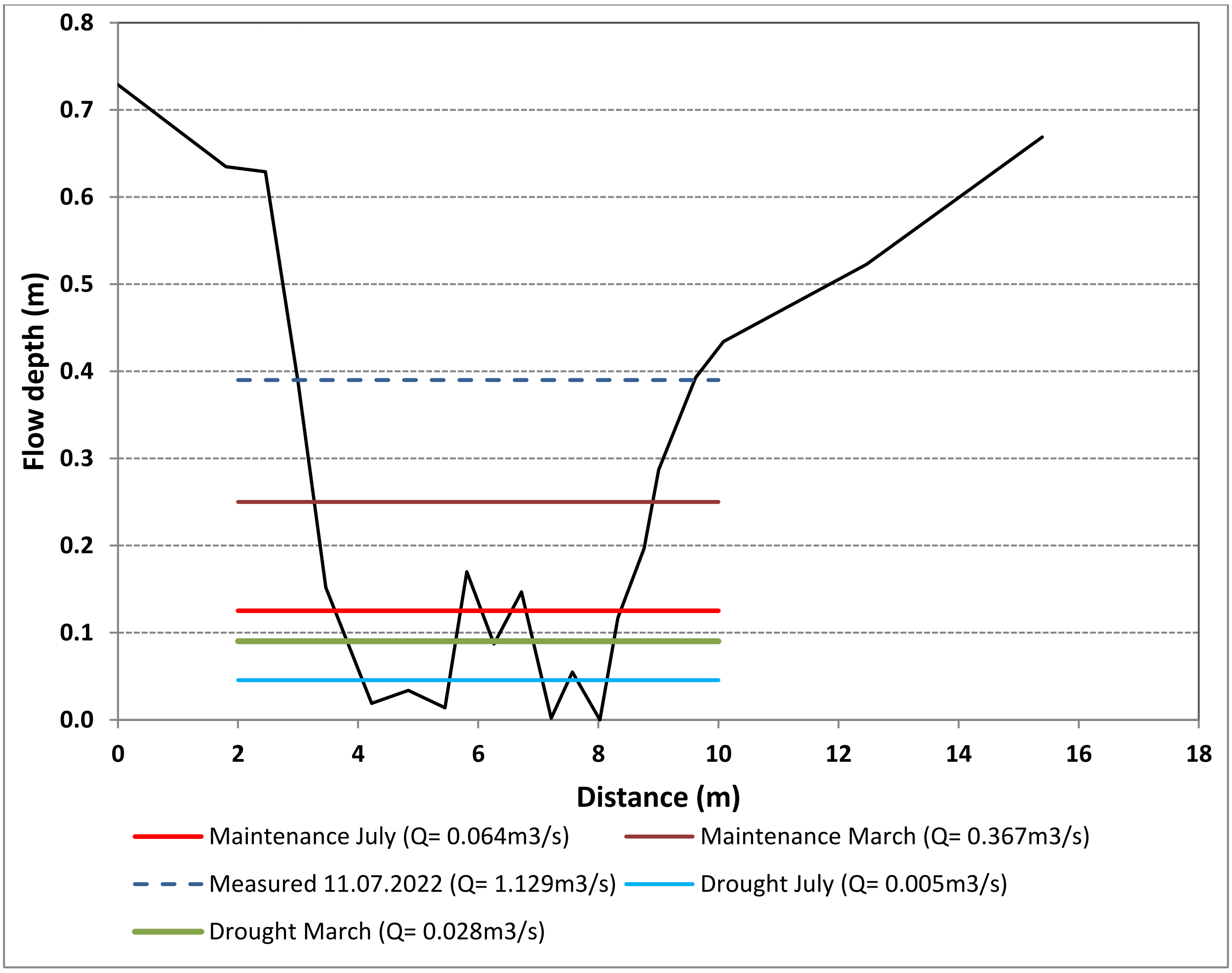


Figure 6-9: Water levels on cross-section of the EWR site for Wonderboomspruit in D14E

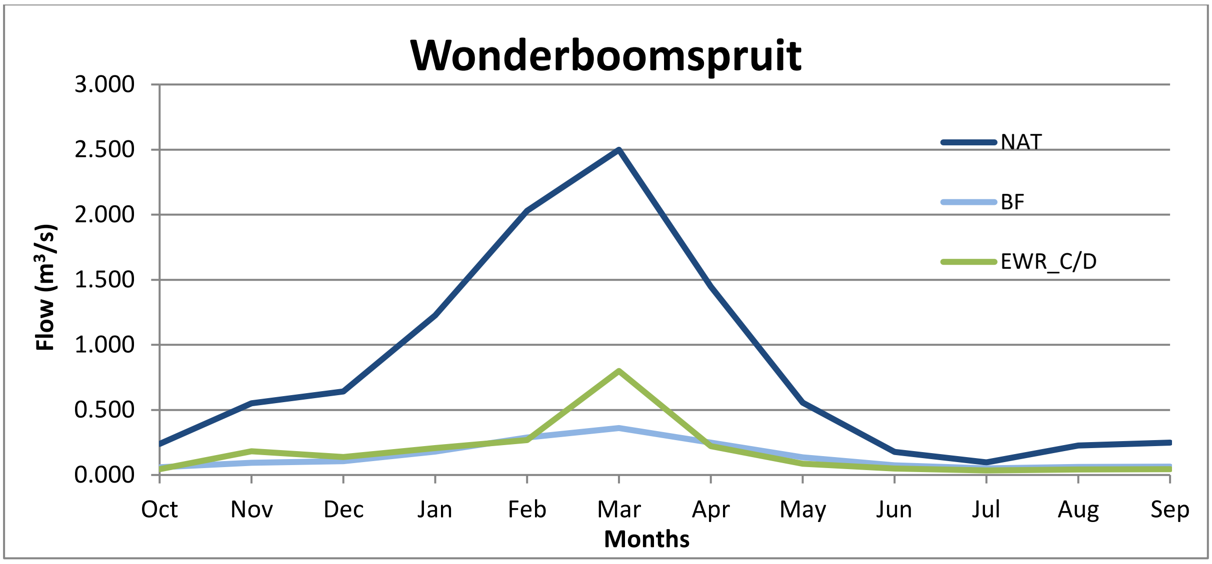
The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 6-9, the final EWR for the Wonderboomspruit at the EWR site is summarised in Table 6-10 and presented in Figure 6-10.

Table 6-9: Wonderboomspruit - Freshets and flood requirements for implementation

Months	Freshets		Floods	
	m^3/s	days	m^3/s	days
October			6	2
November	2.5	2		
December	2.5	2		
January	2.5	2		
February	2.5	2		
March	2.5	2	20	3
April			6	2

Table 6-10: Wonderboomspruit - Summary of the final EWR results (flows in million m^3 per annum)

Quaternary Catchment	D14E
River	Wonderboomspruit
Recommended Ecological Category	C/D
nMAR at EWR site	25.9
Total EWR	8.396 (32.38 %MAR)
Maintenance Low flows	4.884 (18.84 %MAR)
Drought Low flows	0.365 (1.41 %MAR)
Maintenance High flows	3.512 (13.55 %MAR)
Overall confidence	Moderate



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

Figure 6-10: Monthly hydrograph indicating final EWR for Wonderboomspruit in D14E

6.6 UO_EWR06_R: MIDDLE MODDER (SOETDORING)

Site Name	UO_EWR06R	**Reserve Level Assessment**	Rapid 3
River	Modder	**Quaternary catchment**	C52H
Longitude	26.109695°	**Latitude**	-28.807191°
EI	Moderate	**ES**	Moderate
PES	D	**REC**	C/D

Comments:
Increased flows due to releases from WWTW, system might have adapted to these increased flows
Intensive irrigation on some of the tributaries as well as mainstem Modder
Poor water quality due to dysfunctional WWTWs
No gauging weir in close vicinity to interpret daily data, especially for specifying freshets and floods


Upstream


Downstream

The EWR for the Middle Modder River were determined for a REC of a C/D. The EWR flow data from the DRM was converted to hydraulic conditions at the EWR site (i.e., depths and flow velocities at discharges measured in m^3/s) using a hydraulic model. The maintenance flows were examined for July and February. 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).

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 and depths for fish.

The discharge at the EWR site during the survey on 14 July 2022 was 2.257 m^3/s and was used as reference to adjust the recommended EWRs (see Figure 6-11Figure 6-3). It should be noted that the baseflows were high during the survey and can be as a result of the continual high rainfall during the summer months and/ or return flows from WWTWs.

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

(i) Maintenance low flows:

July - Adjusted from 0.099 m^3/s to 0.369 m^3/s

February - Adjusted from 0.429 m^3/s to 1.602 m^3/s

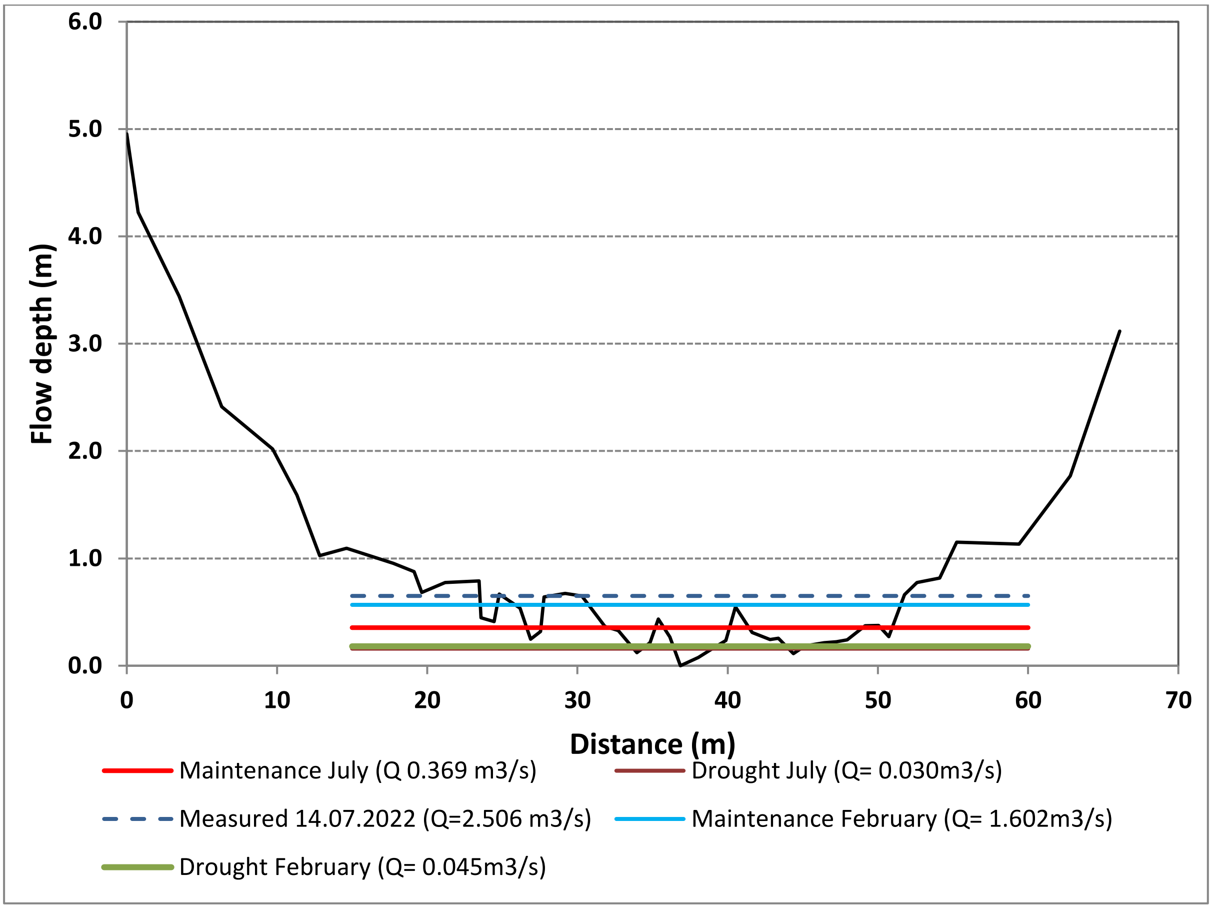


Figure 6-11: Water levels on cross-section of the EWR site for Middle Modder River in C52G

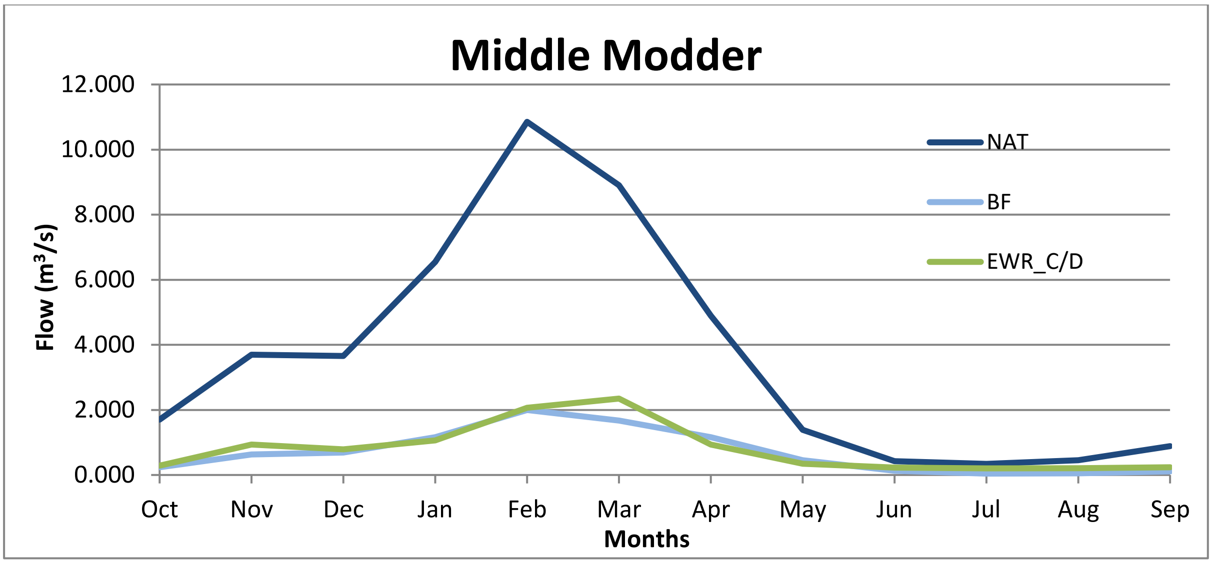
The freshets and annual floods as required by the aquatic ecosystem for fish and macroinvertebrates are presented in Table 6-11. The final EWR for the Middle Modder River at the EWR site is summarised in Table 6-12 and presented in Figure 6-12.

Table 6-11: Middle Modder - Freshets and flood requirements for implementation

Months	Freshets		Floods	
	m^3/s	days	m^3/s	days
October	9.0	3		
November	7.0	5		
December	7.0	5		
January	7.0	5		
February	7.0	5	20	3
March	7.0	5	20	3
April	9.0	3		

Table 6-12: Middle Modder - Summary of the final EWR results (million m^3 per annum)

Quaternary Catchment	C52G
River	Middle Modder
Recommended Ecological Category	C/D
nMAR at EWR site	113.68
Total EWR	38.603 (33.96 %MAR)
Maintenance Low flows	23.746 (20.89 %MAR)
Drought Low flows	1.798 (1.58 %MAR)
Maintenance High flows	14.857 (13.07 %MAR)
Overall confidence	Moderate



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

Figure 6-12: Monthly hydrograph indicating final EWR for Middle Modder River in C52G

7. EWR RESULTS: FIELD VERIFICATION ASSESSMENTS

Important to note that the PES for these field verification sites were identified as per professional opinion and further based on the diatoms and IHI results, taking into consideration the results of the 2014 desktop PES/EI/ES. As no hydraulic cross-sections were surveyed at these sites, the EWRs as proposed by the DRM/ RDRM were accepted, except where extrapolation has been undertaken, using the characteristic of the EWRs from rapid 3 or Intermediate sites.

7.1 UO_EWR01_FV: MEULSPRUIT

Site Name	UO_EWR01_FV	**Reserve Level Assessment**	Field verification
River	Meulspruit	**Quaternary catchment**	D22B
Longitude	27.834944°	**Latitude**	-28.885731°
EI	Moderate	**ES**	Moderate
PES	D	**REC**	D

Comments:
The Meulspruit Dam is just upstream the EWR site impacting on all the flow components due to lack of release mechanisms. Water from the dam is used by the town of Ficksburg.
Extensive irrigation occurs upstream of the dam.

Upstream

Downstream

The EWR for the Meulspruit was determined for a REC of D. Due to the Meulspruit Dam with a lack of release mechanisms just upstream of the site, no freshets were specified. However, the dam spills during and after high rainfall periods as seen during the field surveys in July 2022 when 0,741 m^3/s was measured. These spills will provide the necessary function to clear the habitats from fine silt and sediments. The ecological consequences of reduced frequency, magnitude and duration will be assessed during the next step of the study. Baseflows for this river reach are dependent on lateral seepage from the catchment that provides some limited habitats for the biota.

Table 7-1: Meulspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	63.6
Total EWR	1.990 (3.13 %MAR)
Maintenance Low flows	1.990 (3.13 %MAR)
Drought Low flows	0.260 (0.41 %MAR)
Overall confidence	Low

7.2 UO_EWR02_FV: WITSPRUIT

Site Name	UO_EWR02_FV	**Reserve Level Assessment**	Field verification
River	Witspruit	**Quaternary catchment**	D24C
Longitude	26.928315°	**Latitude**	-30.008260°
ES	Moderate	**EI**	Moderate
PES	C/D	**REC**	C

Comments:
Small perennial to seasonal system with a few dams and irrigation in upper catchment.

Upstream

Downstream

Table 7-2: Witspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	21.7
Total EWR	4.159 (19.18 %MAR)
Maintenance Low flows	1.687 (7.78 %MAR)
Drought Low flows	0.289 (1.33 %MAR)
Maintenance High flows	2.473 (11.40 %MAR)
Overall confidence	Low

7.3 UO_EWR03_FV: GRYSKOPSPRUIT

Site Name	UO_EWR03_FV	**Reserve Level Assessment**	Field verification
River	Gryskopspruit	**Quaternary catchment**	D12D
Longitude	27.176878°	**Latitude**	-30.339629°
EI	Moderate	**ES**	Moderate
PES	C	**REC**	C

Comments:
Mainly water quality impacts due to WWTW upstream with limited water use for irrigation.

Downstream

Table 7-3: Gryskopspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	7.5
Total EWR	1.381 (18.38 %MAR)
Maintenance Low flows	0.487 (6.48 %MAR)
Drought Low flows	0.004 (0.05 %MAR)
Maintenance High flows	0.894 (11.89 %MAR)
Overall confidence	Low

7.4 UO_EWR04_FV: KARRINGMELKSPRUIT

<table>
<tr><td>Site Name</td><td>UO_EWR04_FV</td><td>Reserve Level Assessment</td><td>Field verifcation</td></tr>
<tr><td>River</td><td>Karringmelkspruit</td><td>Quaternary catchment</td><td>D13K</td></tr>
<tr><td>Longitude</td><td>27.264973°</td><td>Latitude</td><td>-30.811765°</td></tr>
<tr><td>EI</td><td>Very high</td><td>ES</td><td>High</td></tr>
<tr><td>PES</td><td>B</td><td>REC</td><td>B</td></tr>
<tr><td colspan="4">Comments:
Limited irrigation in upper reaches with a proposed transfer to the town of Lady Grey.
Trout (predator) is present in the system, impacting on the aquatic biota.</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Upstream</td><td colspan="2">Downstream</td></tr>
</table>

This EWR site falls in the same ecoregion level 2 and the Geozone is similar for parts of the Karringmelkspruit as the rapid 3 EWR site on the Upper Kraai River (UO_EWR04_R). Thus the characteristics of this site was used to extrapolate the requirements for the Karringmelkspruit for maintenance low and drought flows. As there are no dams on the Karringmelkspruit and the proposed transfer from a tributary of the Karringmelkspruit to Lady Grey will only impact on the low flows, the DRM freshets were accepted.

Table 7-4: Karringmelkspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	25.9
Total EWR	11.683 (45.11 %MAR)
Maintenance Low flows	8.304 (32.06 %MAR)
Drought Low flows	1.176 (4.54 %MAR)
Maintenance High flows	3.379 (13.05 %MAR)
Overall confidence	Low to moderate

7.5 UO_EWR05_FV: BOKSPRUIT

Site Name	UO_EWR05_FV	**Reserve Level Assessment**	Field verification
River	Bokspruit	**Quaternary catchment**	D13A
Longitude	27.884557°	**Latitude**	-30.884690°
EI	Moderate	**ES**	High
PES	B/C	**REC**	B
Comments: Irrigation in upper reaches, although limited to the floodplain due to the steep terrain. Trout (predator) present in the system, impacting on aquatic biota.			
			
Upstream		**Downstream**	

This EWR site falls in the same ecoregion level 2 and Geozone as the rapid 3 EWR site on the Upper Kraai River (UO_EWR04_R) and thus the characteristics of this site was used to extrapolate the requirements for the Bokspruit for maintenance low and drought flows. As there are no dams on the Bokspruit, the DRM freshets were accepted.

Table 7-5: Bokspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	60.4
Total EWR	27.175 (44.99 %MAR)
Maintenance Low flows	19.334 (32.01 %MAR)
Drought Low flows	1.782 (2.95 %MAR)
Maintenance High flows	7.841 (12.98 %MAR)
Overall confidence	Low to moderate

7.6 UO_EWR06_FV: HOLSPRUIT

Site Name	UO_EWR06_FV	**Reserve Level Assessment**	Field verification
River	Holspruit	**Quaternary catchment**	D13J
Longitude	27.056639°	**Latitude**	-30.995316°
EI	High	**ES**	Moderate
PES	C	**REC**	C

Comments:
Some small dams and limited irrigation upstream of the EWR site.
Holspruit have the characteristics of a seasonal system.


Upstream


Downstream

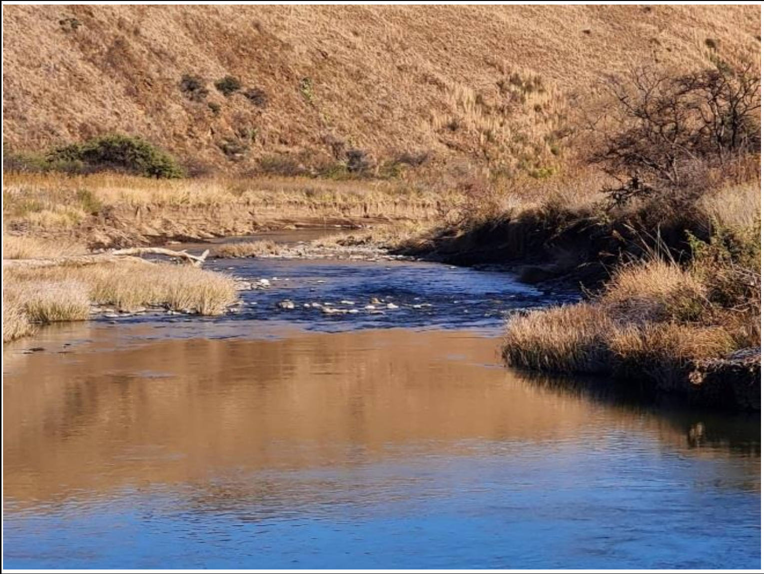
Table 7-6: Holspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	36.9
Total EWR	6.662 (18.05 %MAR)
Maintenance Low flows	2.201 (5.96 %MAR)
Drought Low flows	0.262 (0.71 %MAR)
Maintenance High flows	4.461 (12.08 %MAR)
Overall confidence	Low

7.7 UO_EWR07_FV: STERKSPRUIT (TRIBUTARY OF THE KRAAI/BELL)

Site Name	UO_EWR07_FV	**Reserve Level Assessment**	Field verification
River	Sterkspruit	**Quaternary catchment**	D13C
Longitude	27.800753°	**Latitude**	-30.917621°
EI	Moderate	**ES**	High
PES	C	**REC**	B/C

Comments:
Irrigation in the upper reaches, although limited to the floodplain due to steep terrain.
Trout (predator) present in the system, impacting on aquatic biota.



Downstream

This EWR site falls in the same ecoregion level 2 and Geozone as the rapid 3 EWR site on the Upper Kraai River (UO_EWR04_R) and thus the characteristics of this site was used to extrapolate the requirements for the Bokspruit for maintenance low and drought flows. The EWR was adjusted for a B/C REC as the Upper Kraai a REC of B was used. As there are no dams on the Sterkspruit, the DRM freshets were accepted.

Table 7-7: Sterkspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	47.6
Total EWR	17.725 (37.24 %MAR)
Maintenance Low flows	12.207 (25.64 %MAR)
Drought Low flows	1.292 (2.71 %MAR)
Maintenance High flows	5.518 (11.59 %MAR)
Overall confidence	Low to moderate

7.8 UO_EWR08_FV: BELL

Site Name	UO_EWR08_FV	**Reserve Level Assessment**	Field verification
River	Bell (DWS – Kraai)	**Quaternary catchment**	D13B
Longitude	27.786557°	**Latitude**	-30.852601°
EI	Moderate	**ES**	High
PES	B/C	**REC**	B

Comments:
Limited irrigation on floodplain due to the steep terrain in upper reaches.
Trout (predator) is present in the system, impacting on aquatic biota.


Upstream


Downstream

This EWR site falls in the same ecoregion level 2 and Geozone as the rapid 3 EWR site on the Upper Kraai River (UO_EWR04_R) and thus the characteristics of this site was used to extrapolate the requirements for the Bokspruit for maintenance low and drought flows. The EWR was adjusted for a B/C REC as the Upper Kraai a REC of B was used. As there are no dams on the Bokspruit, the DRM freshets were accepted.

Table 7-8: Bell - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	72.5
Total EWR	32.688 (45.08 %MAR)
Maintenance Low flows	23.271 (32.09 %MAR)
Drought Low flows	2.270 (3.13 %MAR)
Maintenance High flows	9.417 (12.99 %MAR)
Overall confidence	Low to moderate

7.9 UO_EWR09_FV: GROENSPRUIT

Site Name	UO_EWR09_FV	**Reserve Level Assessment**	Field verification
River	Groenspruit	**Quaternary catchment**	D24H
Longitude	26.56130°	**Latitude**	-30.24119°
EI	Moderate	**ES**	Moderate
PES	C/D	**REC**	C

Comments:
It is a small seasonal system with limited baseflows and no drought flows resulting in limited opportunities for irrigation.
The water quality is impacted by the upstream WWTW.


Upstream


Downstream

Table 7-9: Groenspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	5.02
Total EWR	0.905 (18.01 %MAR)
Maintenance Low flows	0.297 (5.91 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	0.608 (12.10 %MAR)
Overall confidence	Low

7.10 UO_EWR10_FV: SKULPSPRUIT

Site Name	UO_EWR10_FV	**Reserve Level Assessment**	Field verification
River	Skulpspruit	**Quaternary catchment**	D24H
Longitude	26.51134°	**Latitude**	-30.23444°
EI	Moderate	**ES**	Moderate
PES	C	**REC**	C

Comments:
It is a small seasonal system with limited baseflows and no drought flows, thus resulting in limited opportunities for irrigation.
A number of small dams/ weirs in the upper catchment to support irrigation.

Upstream

Downstream

Table 7-10: Skulpspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	5.02
Total EWR	0.905 (18.01 %MAR)
Maintenance Low flows	0.297 (5.91 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	0.608 (12.10 %MAR)
Overall confidence	Low

7.11 UO_EWR11_FV: FOURIESPRUIT

Site Name	UO_EWR11_FV	**Reserve Level Assessment**	Field verification
River	Fouriespruit	**Quaternary catchment**	C51A
Longitude	26.074393°	**Latitude**	-29.671211°
EI	High	**ES**	Moderate
PES	C	**REC**	C
Comments: It is a small seasonal system with limited baseflows and no drought flows, thus resulting in limited opportunities for irrigation. A number of small dams/ weirs in the upper catchment to support irrigation.			
			
Upstream		**Downstream**	

As Fouriespruit is a small seasonal system, no drought flows are specified as the system naturally has zero flows during dry periods.

Table 7-11: Fouriespruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	13.8
Total EWR	2.479 (17.92 %MAR)
Maintenance Low flows	0.797 (5.76 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	1.682 (12.16 %MAR)
Overall confidence	Low

7.12 UO_EWR12_FV: RENOSTER

Site Name	UO_EWR12_FV	**Reserve Level Assessment**	Field verification
River	Renoster	**Quaternary catchment**	C52F
Longitude	26.328701	**Latitude**	-29.11632
EI	Moderate	**ES**	Moderate
PES	D/E	**REC**	D

Comments:
Mainly a water quality problem with dysfunctional WWTW return flows, increasing the baseflows.


Upstream


Downstream

Naturally a small seasonal system that has been impacted by return flows from upstream WWTW, thus changing the river to a perennial system. If the water quality of the return flows could improve, it would add valuable baseflows to the Modder River downstream where extensive irrigation takes place.

Table 7-12: Renosterspruit - Summary of the final EWR results (million m^3 per annum)

nMAR at EWR site	7.9
Total EWR	0.884 (11.18 %MAR)
Maintenance Low flows	0.073 (0.92 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	0.811 (10.26 %MAR)
Overall confidence	Low

7.13 UO_EWR13_FV: OS-SPRUIT

Site Name	UO_EWR13_FV	**Reserve Level Assessment**	Field verification
River	Os-Spruit	**Quaternary catchment**	C52E
Longitude	26.511411	**Latitude**	-28.93917
EI	High	**ES**	Moderate
PES	B/C	**REC**	B/C
Comments: The catchment is mostly rural farmland with some irrigation.			


Upstream


Downstream

Small seasonal system with limited baseflows. No drought flows were specified as the system naturally has zero flows during dry periods.

Table 7-13: Osspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	8.6
Total EWR	1.882 (21.84 %MAR)
Maintenance Low flows	0.668 (7.75 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	1.215 (14.10 %MAR)
Overall confidence	Low

7.14 UO_EWR14_FV: HONDEBLAF

Site Name	UO_EWR14_FV	**Reserve Level Assessment**	Field verification
River	Hondeblaf	**Quaternary catchment**	D31C
Longitude	24.71803	**Latitude**	- 30.205138
EI	Low	**ES**	Moderate
PES	B	**REC**	B
Comments: Small seasonal, almost ephemeral system with limited water use in upper catchment			

Upstream

Downstream

The Hondeblaf is a small seasonal to ephemeral system and flood driven, thus limited baseflows and no drought flows were specified. The freshets as proposed by the DRM were accepted.

Table 7-14: Hondeblaf - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	2.0
Total EWR	0.545 (26.74 %MAR)
Maintenance Low flows	0.220 (10.77 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	0.326 (15.97 %MAR)
Overall confidence	Low

7.15 UO_EWR15_FV: TRIBUTARY OF VAN ZYLSPRUIT

Site Name	UO_EWR15_FV	**Reserve Level Assessment**	Field verification
River	Trib Van Zyl	**Quaternary catchment**	C51G
Longitude	25.786463	**Latitude**	-30.031203°
EI	High	**ES**	Moderate
PES	C	**REC**	C

Comments:
A small, seasonal river with limited water use in the upper catchment.
There are some impacts due to the WWTW upstream of the EWR site.

Upstream

Downstream

A small seasonal river/ wetland system with no drought flows and limited baseflows, thus no drought requirements were specified. The freshets as proposed by the DRM were accepted.

Table 7-15: Tributary of Van Zylspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	1.9
Total EWR	0.333 (17.92 %MAR)
Maintenance Low flows	0.107 (5.76 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	0.226 (12.16 %MAR)
Overall confidence	Low

7.16 UO_EWR16_FV: SLYKSPRUIT

Site Name	UO_EWR16_FV	**Reserve Level Assessment**	Field verification
River	Slykspruit	**Quaternary catchment**	D24L
Longitude	26.120925	**Latitude**	-30.393003
EI	Moderate	**ES**	Moderate
PES	B/C	**REC**	B/C

Comments:
It is a small seasonal system with limited baseflows and drought flows, thus resulting in limited opportunities for irrigation.
Riparian zone disturbances from cattle trampling and grazing were observed at the site.

Upstream

Downstream

Table 7-16: Slykspruit - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	5.1
Total EWR	1.170 (23.01 %MAR)
Maintenance Low flows	0.487 (9.58 %MAR)
Drought Low flows	0.061 (1.20 %MAR)
Maintenance High flows	0.683 (13.43 %MAR)
Overall confidence	Low

7.17 UO_EWR17_FV: LANGKLOOFSPRUIT

Site Name	UO_EWR17_FV	**Reserve Level Assessment**	Field verification
River	Langkloofspruit	**Quaternary catchment**	D13D
Longitude	27.606129	**Latitude**	-30.954126
EI	High	**ES**	High
PES	B/C	**REC**	B
Comments: Limited water use impacts, with some irrigation in the upper reaches due to steep terrain.			

Upstream

Downstream

This EWR site falls in the same ecoregion level 2 and Geozone as the rapid 3 EWR site on the Upper Kraai River (UO_EWR04_R) and thus the characteristics of this site was used to extrapolate the requirements for the Bokspruit for maintenance low and drought flows. As there are no dams on the Lankloofspruit, the DRM freshets were accepted.

Table 7-17: Langkloofspruit - Summary of the final EWR results (million m^3 per annum)

nMAR at EWR site	43.8
Total EWR	19.467 (44.45 %MAR)
Maintenance Low flows	14.055 (32.09 %MAR)
Drought Low flows	2.051 (4.68 %MAR)
Maintenance High flows	5.413 (12.36 %MAR)
Overall confidence	Low to moderate

7.18 UO_EWR18_FV: WASBANKSPRUIT

Site Name	UO_EWR18_FV	**Reserve Level Assessment**	Field verification
River	Wasbankspruit	**Quaternary catchment**	D13G
Longitude	27.284442	**Latitude**	-31.15554
EI	Moderate	**ES**	High
PES	C	**REC**	B/C
Comments: Limited water use impacts, with some irrigation in upper reaches			

Upstream

Downstream

This EWR site falls in the same ecoregion level 2 and the Geozone is similar for parts of the Wasbankspruit as the rapid 3 EWR site on the Upper Kraai River (UO_EWR04_R). Thus the characteristics of this site was used to extrapolate the requirements for the Wasbankspruit for maintenance low and drought flows. The EWR was adjusted for a B/C REC as the Upper Kraai a REC of B was used. As there are no dams on the Wasbankspruit, the DRM freshets were accepted.

Table 7-18: Wasbankspruit - Summary of the final EWR results (million m^3 per annum)

nMAR at EWR site	16.5
Total EWR	6.414 (38.79 %MAR)
Maintenance Low flows	4.239 (25.64 %MAR)
Drought Low flows	0.154 (0.93 %MAR)
Maintenance High flows	2.175 (13.15 %MAR)
Overall confidence	Low to moderate

7.19 UO_EWR19_FV: LOWER MODDER

Site Name	UO_EWR19_FV	**Reserve Level Assessment**	Field verification
River	Modder	**Quaternary catchment**	C52K
Longitude	25.656	**Latitude**	-28.89166
EI	Very high	**ES**	High
PES	C/D	**REC**	C

Comments:
The flows in the lower Modder are impacted by Krugersdrift Dam (all flow components) and numerous abstraction weirs along the river. The habitats are segmented by these weirs, resulting in almost no options for fish movement.

Upstream

Downstream

Table 7-19: Lower Modder - Summary of the final EWR results (million m^3 per annum)

nMAR at EWR site	156.8
Total EWR	27.939 (17.82 %MAR)
Maintenance Low flows	8.775 (5.60 %MAR)
Drought Low flows	0.332 (0.21 %MAR)
Maintenance High flows	19.163 (12.22 %MAR)
Overall confidence	Low

7.20 UO_EWR20_FV: UPPER KROMELLENBOOG

Site Name	UO_EWR20_FV	**Reserve Level Assessment**	Field verification
River	Upper Kromellenboog	**Quaternary catchment**	C51G
Longitude	25.6811	**Latitude**	-30.066282
EI	Moderate	**ES**	Moderate
PES	B	**REC**	B
Comments: A small seasonal system consisting of mainly wetlands in the upper reaches with limited water use.			
			
Upstream		**Downstream**	

A small seasonal river/ wetland system with no drought flows, thus no drought requirements were specified. The freshets as proposed by the DRM were accepted.

Table 7-20: Upper Kromellenboog - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	9.3
Total EWR	2.490 (26.79 %MAR)
Maintenance Low flows	1.009 (10.86 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	1.481 (15.94 %MAR)
Overall confidence	Low

7.21 UO_EWR21_FV: LOWER KROMELLENBOOG

Site Name	UO_EWR21_FV	**Reserve Level Assessment**	Field verification
River	Lower Kromellenboog	**Quaternary catchment**	C51H
Longitude	25.43507°	**Latitude**	-29.65360°
EI	Moderate	**ES**	Moderate
PES	C	**REC**	B/C
Comments: There is limited water use in the upper catchment, with the town of Jagersfontein and associated mining activities on the Prosesspruit (tributary) that might impact on the Lower Kromellenboog.			

Upstream

Downstream

This EWR site falls in the same ecoregion level 2 and the Geozone is similar to the intermediate EWR site on the Upper Riet River (UO_EWR06_I) for large parts. Thus the characteristics of this site was used to extrapolate the requirements for the Upper Kromellenboog for maintenance low flows. Both the rivers have been seasonal systems under natural conditions with zero flows during dry periods. However, the Rietspruit is currently a perennial system due to upstream releases and return flows. Thus, the drought flows for the Upper Kromellenboog were not adjusted and the DRM requirements were accepted. The EWR was adjusted for a B/C REC as the Upper Riet a REC of C was used. As there are no large dams on the Upper Kromellenboog, the DRM freshets were accepted.

Table 7-21: Lower Kromellenboog - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	85.1
Total EWR	22.568 (26.52 %MAR)
Maintenance Low flows	10.807 (12.70 %MAR)
Drought Low flows	0.000 (0.00 %MAR)
Maintenance High flows	11.761 (13.82 %MAR)
Overall confidence	Low to moderate

7.22 UO_EWR22_FV: TELE

Site Name	UO_EWR22_FV	**Reserve Level Assessment**	Field verification
River	Tele	**Quaternary catchment**	D18K
Longitude	27.5777	**Latitude**	-30.4494
EI	Moderate	**ES**	Moderate
PES	C	**REC**	C

Comments:
The Tele River is a shared water resource with Lesotho and due to its rural setting, limited water use. High sediment loads due to land use practices and stepp gradient of the catchment.


Upstream

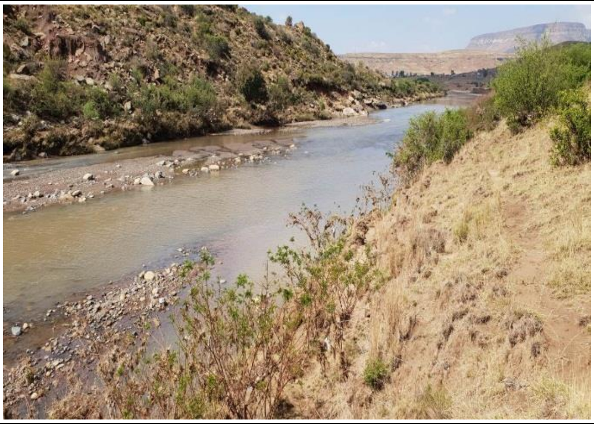

Downstream

Table 7-22: Tele - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	142.3
Total EWR	30.639 (21.54 %MAR)
Maintenance Low flows	16.874 (11.86 %MAR)
Drought Low flows	6.939 (4.88 %MAR)
Maintenance High flows	13.765 (9.68 %MAR)
Overall confidence	Low

7.23 UO_EWR23_FV: UPPER ORANGE RIVER

Site Name	UO_EWR23_FV	**Reserve Level Assessment**	Field verification
River	Orange	**Quaternary catchment**	D12A
Longitude	27.343186	**Latitude**	-30.398957
EI	High	**ES**	Moderate
PES	C/D	**REC**	C

Comments:
Katse and Mohale Dams in Lesotho and the transfer to SA impacts on all the flow components. There is limited water use in SA upstream of this site, although high sediment loads are present due to land use practices and sand mining activities.

Upstream

Downstream

This EWR site falls in the same ecoregion level 2 as IFR6 (-30.3653; 27.5737) on the Senqu River in Lesotho where the EWR was determined on an intermediate level. Thus, the characteristics of this site was used to extrapolate the requirements for the Upper Orange River (UO_EWR23_FV) for maintenance low and drought flows. The freshets and floods that were specified for the downstream EWR site on the Orange River (UO_EWR03_I) in quaternary catchment D12F were used as only small tributaries enters the Orange River between the sites.

Table 7-23: Upper Orange - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	4 115.1
Total EWR	1488.405 (36.17 %MAR)
Maintenance Low flows	1017.006 (24.71 %MAR)
Drought Low flows	232.792 (5.66 %MAR)
Maintenance High flows	471.398 (11.46 %MAR)
Overall confidence	Low to moderate

7.24 UO_EWR24_FV: MAKHALENG RIVER

<table>
<tr><td>Site Name</td><td>UO_EWR24_FV</td><td>Reserve Level Assessment</td><td>Field verification</td></tr>
<tr><td>River</td><td>Makhaleng</td><td>Quaternary catchment</td><td>D15H</td></tr>
<tr><td>Longitude</td><td>27.399101</td><td>Latitude</td><td>-30.164105</td></tr>
<tr><td>EI</td><td>Moderate</td><td>ES</td><td>Moderate</td></tr>
<tr><td>PES</td><td>C/D</td><td>REC</td><td>C/D</td></tr>
<tr><td colspan="4">Comments:
Transboundary river with Lesotho with limited water use in both Lesotho and SA.
High sediment loads are present due to land use practices and sand mining activities.</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Upstream</td><td colspan="2">Downstream</td></tr>
</table>

Table 7-24: Makhaleng - Summary of the final EWR results (flows in million m^3 per annum)

nMAR at EWR site	524.5
Total EWR	91.236 (17.39 %MAR)
Maintenance Low flows	43.887 (8.37 %MAR)
Drought Low flows	9.770 (1.86 %MAR)
Maintenance High flows	47.349 (9.03 %MAR)
Overall confidence	Low

8. CONCEPTUAL FLOW MANAGEMENT PLAN

8.1 Background

8.1.1 Ecological and social impacts of flow alteration because of dams

Poff *et al.,* (1997) defined the flow regime (i.e., the patterns and changes of river flows) as the 'master variable' determining river health. Thus, for a river to function in a healthy state it requires a range of flows from extreme low/drought flows to extreme floods covering the full spectrum of volumes of flow with specific magnitudes, frequencies, durations and timing that are comparable to the natural situation. Impoundments alter the flow and flooding regime of river systems (i.e., through controlled release rates, overflow, and release for hydro-electric schemes). As a result, though the establishment of large dams has a range of effects on a river system (e.g., barriers to migration and fragmentation of habitat, nutrient loading, trapping sediment, flooding riparian habitat, biodiversity reduction, facilitating invasion by alien species), the primary driver of most of the impacts is the alterations to flow (Choi *et al.* , 2005; Poff & Hart, 2002; Wang *et al.* , 2019; Wu *et al.* , 2019). This is especially the case when the dam releases are associated with hydroelectric power generation (Botelho *et al.,* 2017; Manyari & de Carvalho Jr, 2007).

The river reaches directly downstream of impoundments experience the most drastic flow-related changes in physical structure, temperature, sediment, dissolved oxygen and salinity levels, as well as the associated changes ecology and biota in response (Manyari & de Carvalho Jr, 2007; Poff & Hart, 2002; Wang *et al.*, 2019). Among various flow alterations, reductions in large floods have a particularly significant influence on the morphology of the river channel and the ecology of the river system (Hooke, 2016; Poff & Hart, 2002; Słowik *et al.*, 2018). Large floods provide a natural disturbance function that is important for various riverine processes such as river channel and boundaries structuring, sediment erosion and deposition, and habitat alterations (Choi et al., 2005; Poff, 2002). For example, a lack of flooding can contribute significantly to the armouring of the riverbed substrate, which would possibly be broken up, altered, and / or replenished with loose rocks, pebbles, and soft sediment during flooding (Habersack & Nachtnebel, 1995). Structurally, a lack of flooding can also lead to river channel incision, altering path and flow dynamics away from natural states. In terms of biota, a lack of flooding may allow, for example, i) the spread and dominance of flood intolerant species (such as *Phragmites* sp. and *Typha* sp. reeds) that would otherwise be removed or controlled by flooding, ii) river bed armouring that can significantly reduce habitat available to aquatic macroinvertebrates and reduce suitable breeding substrate for fish and other aquatic fauna (Choi *et al.*, 2005; Wang *et al.*, 2019; Wu *et al.*, 2019), and iii) an increase in older, established riparian vegetation, rather than pioneering individuals, changing the ecology of the riparian system. In addition, the risk to the system as dams prevent seed dispersal along rivers. (Choi *et al.* , 2005; Stromberg et al. , 2010). Collectively, these biotic changes tend to homogenise the instream and riparian habitat, facilitate colonisation by invasives, and diminish biodiversity by reducing habitat availability for varied flora and fauna (García *et al*., 2011; Garssen *et al.*, 2017; Jia *et al.*, 2017; Mürle *et al*., 2003). Smaller scale flow changes can also have significant impacts (Poff *et al.*, 1997; Poff & Zimmerman, 2010). For example, hydropeaking caused by hydroelectric power generation alters flow and river dynamics at a daily resolution, with a range of associated environmental impacts (García et al., 2011; Manyari & de Carvalho Jr, 2007).

Socially, it must be acknowledged that the services the dams provide, especially in terms of power generation and irrigation, are currently critical to the Southern African economy (Manyari & de Carvalho Jr, 2007). This situation is unlikely to change within the next 5 – 10 years, given that South Africa's energy crisis is currently deepening, and that irrigated agriculture will remain essential to food and financial security (Calzadilla *et a*l., 2014; Mabhaudhi *et al*., 2018; Pretorius et al., 2015). However, the alterations to flow caused by the dams and their hydroelectric power generation may have significant negative social implications as well (Richter *et al.*, 2010). The impact of ecological degradation because of unnatural or poorly managed flows presents a direct threat to humans (Lynch et al., 2023; Poff et al., 1997; Tickner et al., 2020). Degradation reduces the capacity for dealing with increasing demand and threatens the essential ecosystem goods and services for human use and well-being naturally that functioning and healthy ecosystems provide (Forslund *et al*., 2009). These include water treatment, clean drinking water (and the associated health benefits), fish, fibre, disaster mitigation (the resilience and adaptability of natural systems is crucial in the face of climate change), recreation, and intrinsic 'quality of life' value (Acreman, 2016; IUCN, 2008). For example, the more constant fast flows and more turbid conditions from dam releases create favourable conditions for outbreaks of blackfly (*Simulium chutteri* and *Simulium damnosum*), a potentially devastating livestock? pest in Southern Africa (Rivers-Moore *et al*., 2014; Rivers-Moore & de Moor, 2021).

Reduced macroinvertebrate and fish population health may reduce catch for people who rely on subsistence fishing (Adams, 1985; Agostinho *et al*., 2008; Granzotti *et al*., 2018). Degraded systems due to poorly regulated flow may also contribute to other water resource and quality issues. For example, nutrient loading and temperature fluctuations associated with perennial low flows and hydropeaking can lead to eutrophication, depletion of dissolved oxygen, and strong negative effects on aquatic biota (Camargo *et al*., 2005). Notably, degraded water quality may impact irrigation potential, or increase the health risks associated with irrigation using poor quality water (Amoah *et al*., 2011; Islam *et al.*, 2018). Overall, human well-being and sustainable futures are ultimately totally dependent on healthy freshwater ecosystems, which are in turn greatly dependent on well managed flow (Abramovitz, 1995; König et al., 2021; Lynch *et al.*, 2023; Vörösmarty *et al.,* 2010).

8.1.2 Establishment, uses, and flow impacts of the Vanderkloof and Gariep dams

In the Upper Orange catchment, the establishment of the large Gariep (opened in 1971, covering 352 km^2) and Vanderkloof (opened in 1977, covering 133.4 km^2) dams has been arguably the largest driver of change over the last century. The dams were founded as reservoirs for a multitude of uses, including domestic and industrial supply. However, the primary purpose of both is to supply water for hydroelectric power generation and for agricultural use via irrigation (ORASECOM, 2022).

Downstream of the Gariep and Vanderkloof dams, at the Marksdrift gauging station, zero flows were recorded in the first nine years of monitoring between 1962 and 1971. However, since then (i.e., over the last ~60 years) the Orange River has not stopped flowing due to continuous releases to supply water to downstream users and for hydroelectric power generation. Continuous releases have increased annual low flow rates, while median flows have almost doubled compared to pre-dam levels. While high flow rates remain relatively similar, the magnitude and frequency of small and medium sized floods have decreased. The frequency of large floods has been particularly affected. Nine floods have exceeded a discharge rate of 2000 $m^3.s^{-1}$ over the course of monitoring (data included from 1962 – 2022). Four occurred over the ten years (i.e., one approximately every two years) before Gariep Dam became operational. Only four have occurred over the 50 years since then (i.e., one approximately every 10 years up to 2022; Figure 8-1). Both dams have been used near-continuously for hydroelectric power generation, causing daily hydropeaking (Figure 8-2). The monthly hydrograph (see Figure 8-3) at the EWR site UO_EWR10_I downstream Marksdrift Weir (D3H008) shows the monthly changes from natural (NAT) and present day (PRS) flows. The natural baseflows (BF) are also included on the graph for comparison with the present-day flows.

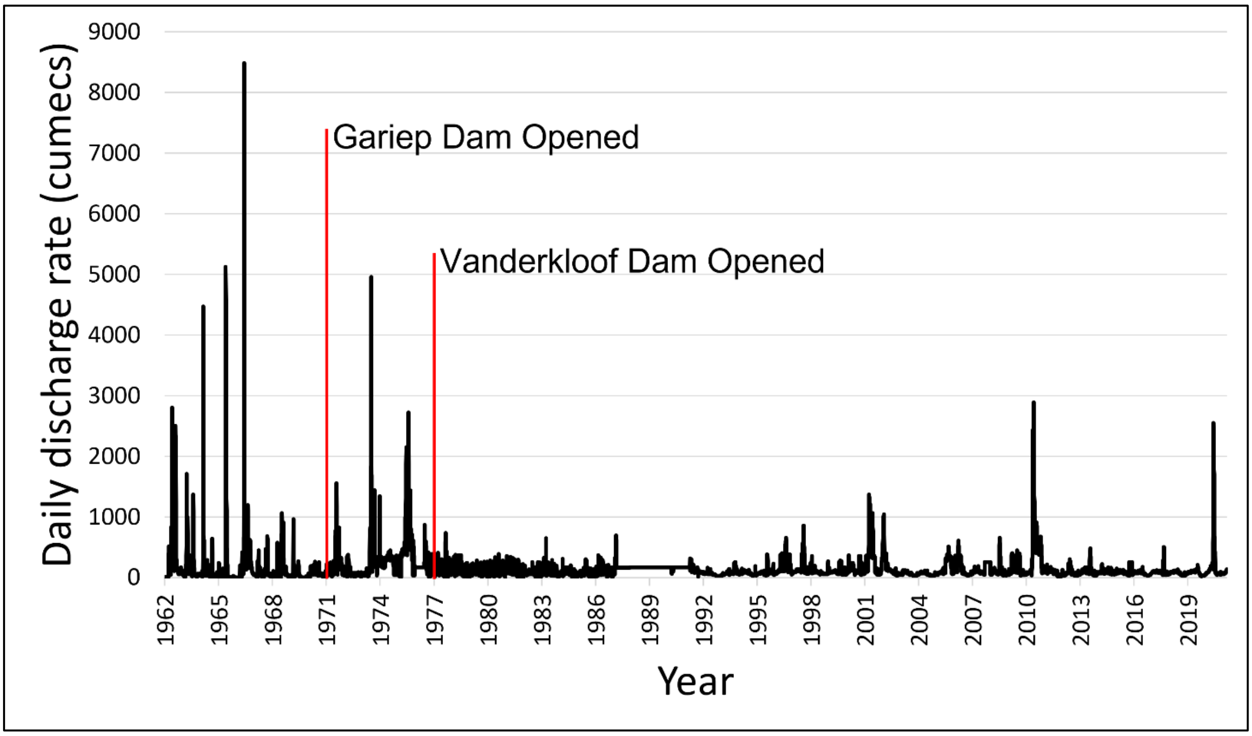


Figure 8-1: Daily discharge rate from 1962 – 2021 measured at Marksdrift gauging station (station D3H008; -29.16201 °S, 23.69594 °E) downstream of the town of Douglas, upstream the confluence of the Orange and Vaal rivers. Opening dates of the Gariep and Vanderkloof Dams (indicated by the red lines)

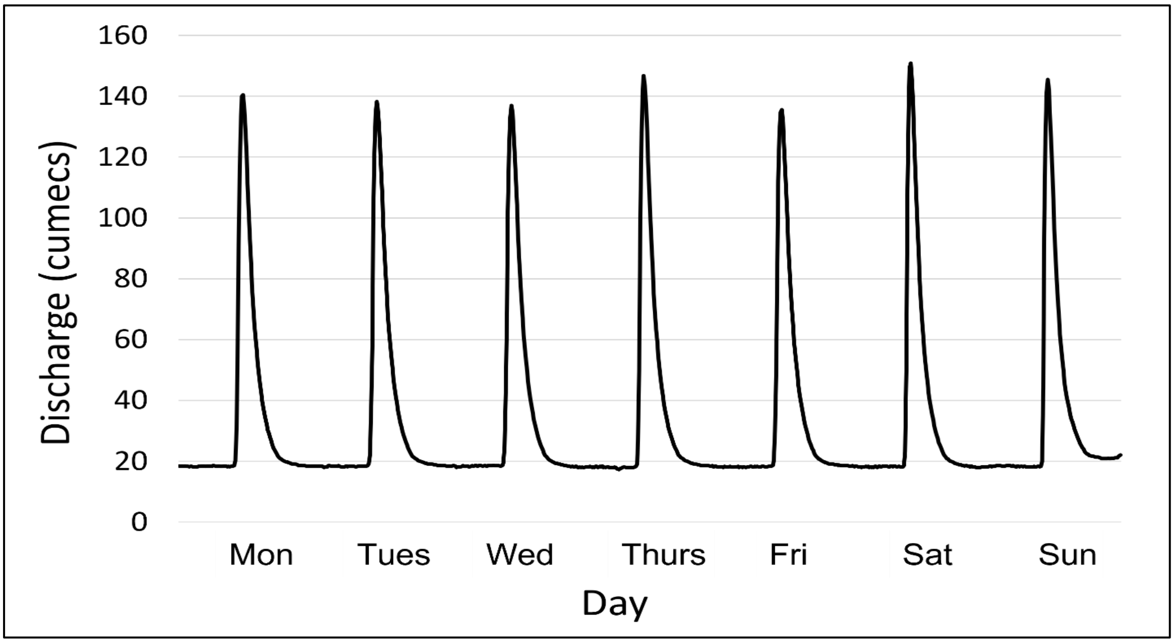
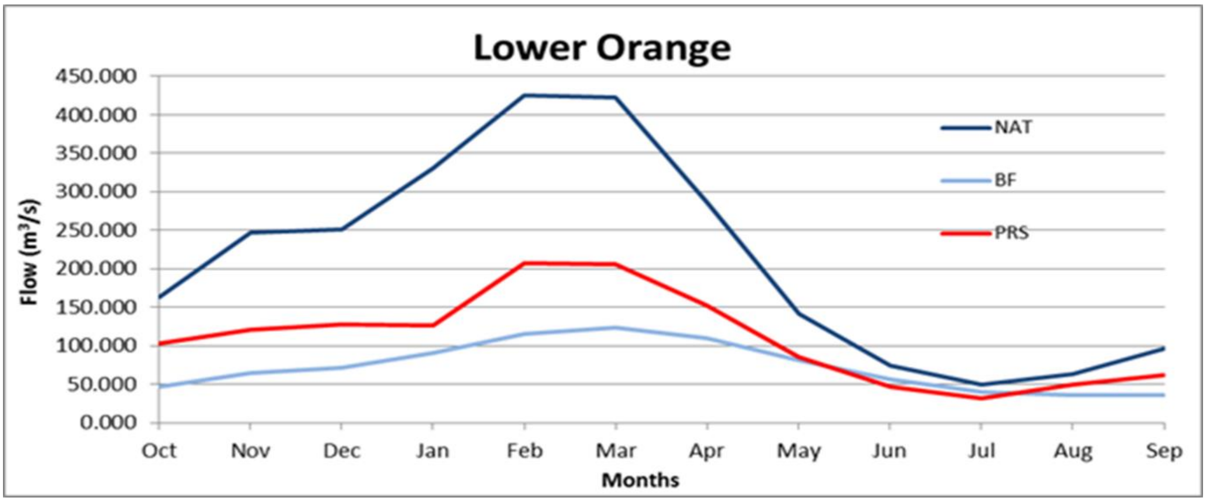


Figure 8-2: Discharge recorded from Vanderkloof Dam at gauging station (station D3R003; -29.99149 °S, 24.73189 °E) over a one-week period (01/01/2020 – 08/01/2020). Pattern shows the daily hydropeaking resulting from hydroelectric power generation releases



NAT – Natural flows, PRS – Present day flows, BF - Baseflows

Figure 8-3: Monthly hydrograph at EWR site UO_EWR10_I downstream Marksdrift Weir indicating changes in flows

Previous assessments on the Upper Orange catchment system have highlighted the range of flow-related impacts on the system associated with the dams. These included the second (Figure 8-4) and third (Figure 8-5) joint basin (JBS) surveys (ORASECOM, 2015, 2023). These surveys are conducted every five years, since 2010.

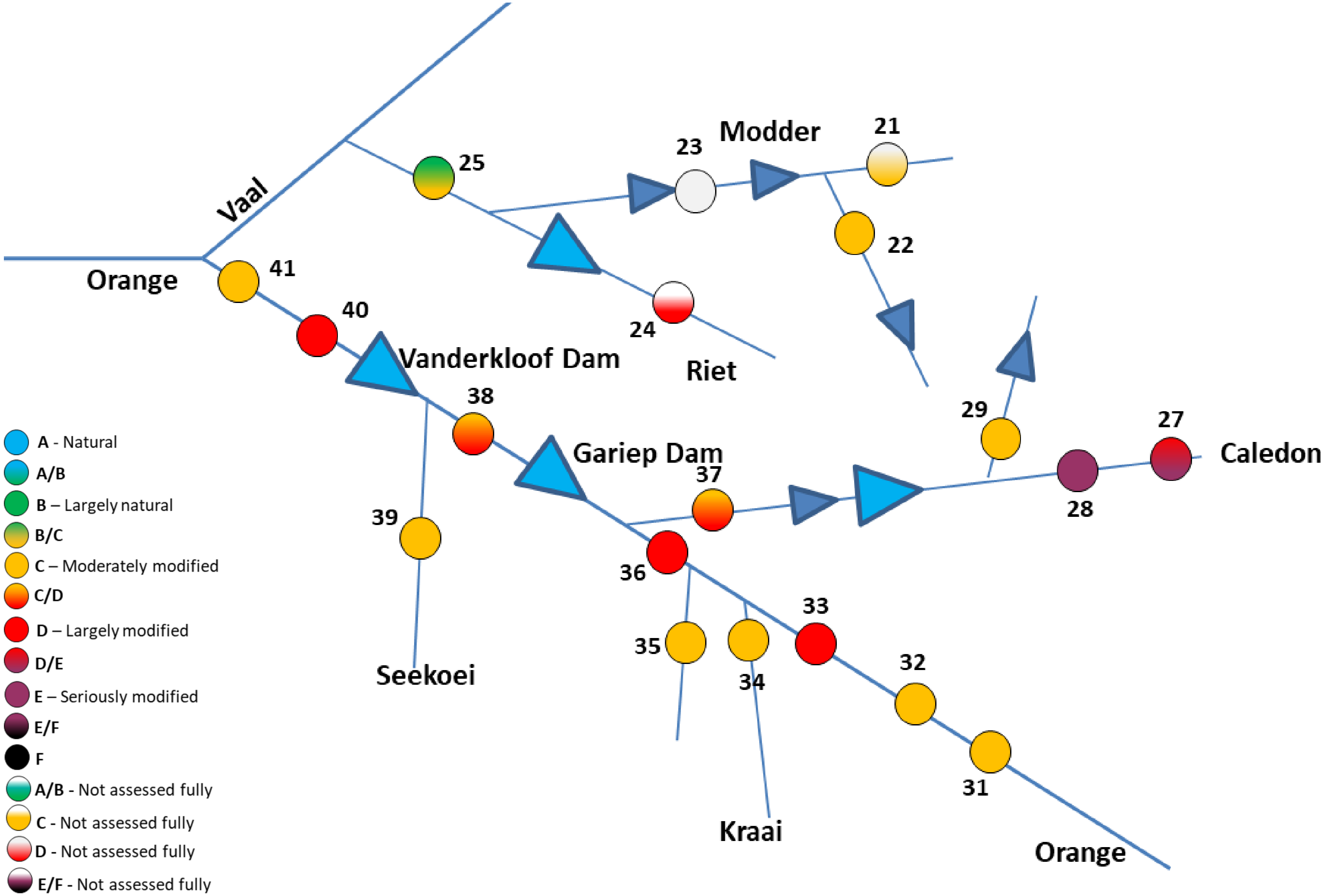


Figure 8-4: Schematic representation of the overall EcoStatus (key on left hand side) of relevant sample sites from the JBS2 aquatic ecosystem health assessment by the Orange-Senqu River Commission (ORASECOM, 2015).

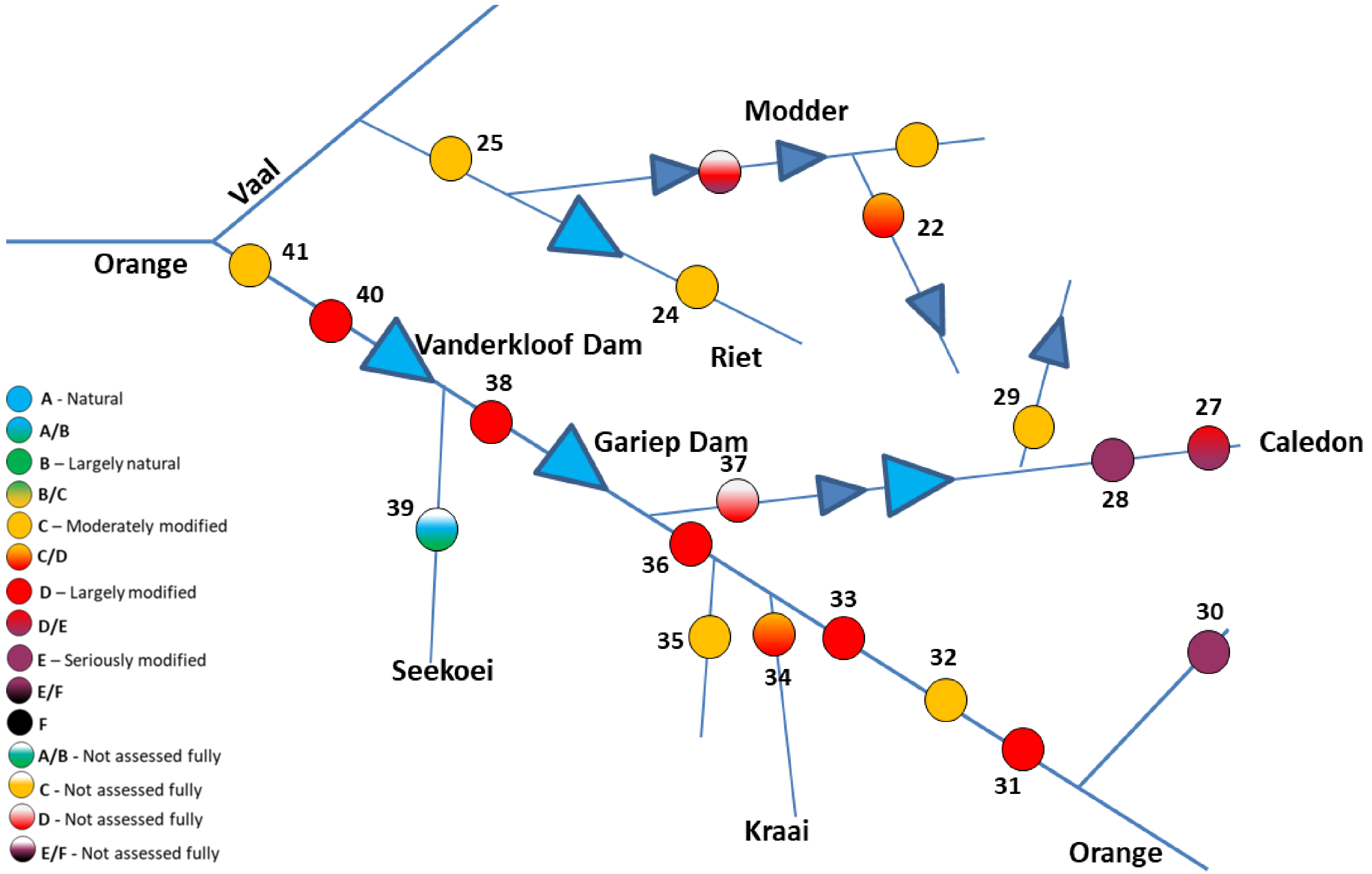


Figure 8-5: Schematic representation of the overall EcoStatus (key on left hand side) of relevant sample sites from the JBS3 aquatic ecosystem health assessment by the Orange-Senqu River Commission (ORASECOM, 2023). (blue triangles represent the major dams in the catchment)

These studies have illustrated that the primary impacts above the Gariep dam are associated with pollution (primarily domestic, industrial, and mine wastewater, as well as rubbish dumping, e.g., plastic) and erosion from poor agricultural/ land use practices causing high sedimentation. Furthermore, flow modifications (i.e., low flows) as well as to a certain extent, floods due to the upstream Katse and the Mohale Dams in Lesotho.

Below the dams, flow changes were isolated as the primary diver of ecosystem modification. In particular, a lack of flooding was associated with 1) a build-up of persistent organic pollutants within riverine sediments, 2) elevated *Escherichia coli* (*E. coli*) counts (linked to livestock farming in the riparian zone), 3) excessive algal growth, dense matts of submerged aquatic plants (likely associated with nutrient loading from surrounding agriculture given that organic phosphate levels were also elevated at these sites), and dominance of invasive plants in the marginal and non-marginal zones of the river channel, and 4) hindering flood-related habitat creation or maintenance for various biota (Dewson *et al.* , 2007; Górski *et al.* , 2011; Mei *et al.* , 2017; Mürle et al. , 2003; Schmutz & Moog, 2018; Wu et al. , 2019). At the conclusion of the JBS3 in 2022, the sites immediately downstream of the dams were assessed to be in largely modified states, with degraded fish, macroinvertebrate, and vegetation communities (Figure 8-5). Ecological condition improved progressing further downstream as the impacts of the flow alterations are slowly ameliorated (Choi *et al.*, 2005; Wu *et al.,* 2019). Upstream sites were also impacted, but largely by water quality issues associated with wastewater pollution and degradation associated with agriculture (Figure 8-5; ORASECOM, 2023).

8.1.3 Investigations still required and the need for a conceptual flow management plan

Based on the current social and economic climate of South Africa, the dams undoubtedly fulfil a critical role in providing water and power generation that cannot be ignored. However, based on the previous assessments of the Upper Orange River catchment, there are significant negative environmental, social, and economic consequences of their current flow regimes. Going forward, several avenues remain to be investigated to work toward development of an ideal EWRs that maintains some of the core functionality of the dams, but allows for a healthier and sustainable river system, boosts the essential ecosystem services it can provide:

- The specific effects of the current flow regime on the habitat, biota, and people need to be thoroughly investigated to understand the advantages and disadvantages of potential changes. This will need to involve reflection on assessments performed in the region to date, targeted physical, chemical, and biological monitoring, as well as investigations of the current social and economic linkages to flow from the dams;
- The extent of the above impacts of the current flow regimes downstream of the dams needs to be measured. This will be a gradient of impact; most severe directly below the dam walls and reducing as one progresses downstream away from the dams. There may be a need for delineation of ‘sacrificial zones’ where impacts from dam flow releases are drastic and unlikely to respond to remediation over the short to medium-term; and
- Using the above information, there will be the need to develop a short-term project to investigate hydraulic and hydrological models at a daily time-step that can digitally simulate impacts of changes to flow on river geomorphology, aquatic-associated fauna and flora, and people downstream of the dams. These models will inform what impacts potential changes to flow will have, allowing development of ideal EWR recommendations.

8.2 Action Plan

Going forward, the Action Plan for flow-related management of the Upper Orange River catchment (specifically relating to the Vanderkloof and Gariep dams) can be delineated into four stages: Immediate (current, emergency interventions should any be identified), Short-term (actions over the next 0 – 5 years), Medium-term (action between 5 – 20 years from now), and Long-term (actions 20 years from now and beyond).

8.2.1 Immediate

Immediate actions could involve:

- Immediate research required for this component, including a comprehensive review of the international literature of similar circumstances. A potential opportunity through the Water Research Commission, although a well-defined terms of reference must be clearly outlined and approved;
- Identification of any immediate sensitivities / critically time sensitive interventions. This would be based on existing knowledge from previous assessments of the Upper Orange River catchment. Immediate intervention may include, for example, the need for translocation of endangered taxa for conservation. Considering the dams have been in operation for >50 years, the need for any emergency intervention is unlikely. However, the JBS assessments have indicated a steady decline in river health over the last 15 years in the Upper Orange River catchment. The decline suggests there is a need to evaluate if there are any geomorphological, hydrological, or biological thresholds that are about to be crossed with critical, irredeemable negative consequences which need to be presently mitigated;
- Defining short, medium, and long-term goals for flow management going forward to structure activities and actions efficiently. By their nature, EWRs are a subjective concept, since they are contingent on a set of societally pre-determined ecological, social, and economic standards (Acreman, 2016; Pahl-Wostl *et al.*, 2013). As such, the goal of EWRs is usually not to maintain or restore a pristine system (Acreman, 2016; Arthington, Kennen, *et al.*, 2018). Rather, aim to determine river-specific goals and rules for water use which are a compromise between the needs of the ecosystem (e.g., maintaining biodiversity) and those of humans (e.g., irrigation, drinking water, fish, industrial use), satisfying requirements for both (King *et* al., 2008; Poff *et al.*, 2017). This aim makes EWRs a means for conservation, but also for meeting the needs of people as well as broad objectives such as the sustainable development goals (SDGs; Arthington, Bhaduri, *et al.*, 2018; Forslund *et al.*, 2009; WHO & UNICEF, 2021). The balance between the social and environmental needs must be considered in defining the goals. These can be accomplished through the Water Resource Classification study that DWS has initiated, where specific scenarios can be identified to be assessed to inform the ultimate Water Resource Class and management of the system; and
- Establishing a longitudinal profile of the focal river section (a preliminary profile concept is provided below in Appendix A, Figure A1).

Some of these actions in terms of the identification of any immediate sensitivities and possible improvements in the flow releases will be addressed during the management scenario phase where the ecologists will interpret ecological consequences of the current operation. The ecological consequences will further inform the definition of short, medium, and long-term goals for flow management. These will include the interpretation of the impacts of the operation of the dams on the baseflows and changes to flood frequencies, magnitude and duration.

8.2.2 Short-term (0 – 5 years)

The short-term plan of action will involve:

- No changes to flow, given that no changes to the current flow regime are possible;
- Conducting any emergency interventions identified in immediate assessment of the catchment;
- Analysis of the impacts of the dams from a social and environmental perspective will include assessment of historical data, especially any data from prior to construction, to aid in identifying the impacts dam-related flow changes have had;
- The overall synthesis of previous assessments, this current high confidence Reserve study, the balance between the social and environmental needs must be considered in defining the goals. All of these can be accomplished through the Water Resource Classification study that DWS has initiated, where specific scenarios can be identified to be assessed to inform the ultimate Water Resource Class and management of the system;
- Use the information from the assessments to design a monitoring network; monitoring will involve assessment of physical, chemical, and biological aspects, as well as hydraulic and hydrological assessment of the river for the determination of EWRs. This conceptual plan should be converted into a quantitative plan during the Classification process of the Upper Orange River. Between the desktop assessments and foundation of monitoring, a detailed, informed, longitudinal profile of dam flow impacts can be developed. This will serve to identify zones of impact and allow delineation of sacrificial zones, as well as models of how flow changes will affect different regions downstream; and
- Working with Eskom, DWS Planning and Regional officials to define the plans for the planned, necessary power generation regime and establishing the necessary flow requirements for planned releases for irrigation, domestic/ industrial and estuarine requirements downstream of the dams over the next 20 years. All EWR recommendations will necessarily be compromises between ecological requirements and the requirements for power generation and irrigation (as the major drivers of flow requirements from the dams).

8.2.3 Medium-term (5 – 20 years)

The medium-term plan of action will involve:

- Continuation of the active physical, chemical, and biological monitoring;
- Research and synthesis of the literature to develop best practice flow management protocols below large dams based on international standards and practices;
- Based on monitoring and hydraulic and hydrological assessments, develop hydrological models to simulate environmental outcomes of various flow change scenarios;
- Based on best practice research, EWR model scenarios, and the cost-versus-benefit analysis, establish an ideal interim flow management plan. The plan will then need to factor in what flow regime changes are possible based on Eskom's capacity and potential compromises on downstream irrigation and other needs, as well as the overall operation of the system with the planned Vioolsdrift Dam in the lower reaches of the Orange River. Ultimately, an interim

flow management plan accounting for what is possible can be implemented. Some changes to flow may be possible;
- Once the interim EWR recommendations are developed and implemented, ongoing monitoring will allow for analysis of efficacy and adaptive management;
- Re-evaluation of the ecological potential for possible improvements in the sacrificial zones. Over the course of the medium-term implementation and monitoring, assess whether the sacrificial zones have any viable remediation or re-purposing options; and
- Based on best practice, EWR modelling, the cost-versus-benefit analysis, monitoring the efficacy of the interim EWR implementation, and the potential for changes to the flow regime, an ideal, long-term scenario should be designed.

8.2.4 Long-term (>20 years)

The long-term plan of action will involve:

- The priority in the long-term is implementation of the ideal scenario recommended flow management plan. By doing so, restoration of the entire reach can begin. This will aim to minimise or completely negate the need for any sacrificial zones;
- Continue monitoring for adaptive management. The monitoring framework will need to be most intensive (i.e., covering the most parameters at the highest spatial and temporal resolution) over the short-term. However, it can be refined to monitoring priority indicator activities at reduced frequency over the course of the medium-term. Over the medium-term, the monitoring framework will need continual analysis and adjustment to find a balance between the ideal spatial and temporal resolution for sampling, the best (i.e., most representative or necessary) suite of parameters to be measured, and the available budget. Ultimately, in the long-term, monitoring will be refined to an efficient, reduced protocol of the key target metrics that are representative of the success of the EWR implementation. It is highly likely that pressures and drivers on the system will shift and change over time, especially considering rapid climate change. Therefore, ongoing monitoring will be essential to continually keep track of the state of the system and the need for interventions; and
- Retroactively reassess the accuracy of the initial cost-versus-benefit analysis for the interim EWR strategy. This will inform a renewed cost-versus-benefit analysis for the long-term implementation of the ideal scenario.

9. INTERACTION BETWEEN SURFACEWATER (RIVERS AND WETLANDS) AND GROUNDWATER

An approach and method to define the interactions between surface water (wetlands and rivers) and groundwater was developed to integrate the water requirements between all the components as part of this study. This section describes the method that was developed and used to infer the interaction between the water resource components that were assessed as a part of this Reserve study.

The method is a locally novel approach[1] to assessing the probability of hydrological dependence between groundwater and surface water resources as well as the probability of hydrological dependence between discrete surface water resources (i.e., streams, wetlands, and estuaries). The necessity of this assessment was recognised particularly in areas where multiple resource units (i.e., rivers, wetlands, groundwater and estuarine resource units) overlap. Due to the known interactions and reliance between these different water resource components, it is vital that some understanding of their dependency on one another is obtained. It is particularly important to understand these dependencies in the context of this Reserve study (and other Reserve studies hereafter) because environmental authorisations that result in the degradation of one suite of resources (for example, abstraction of groundwater resources) may have an additional impact on another suite of resources (for example, groundwater-dependent wetlands). As such, the integrated assessment of all these resources should be included in authorisation processes in the areas that have inferred interactions between water resources.

The product of this process is intended to be a spatial GIS layer of the selected study area in which the probability of dependence on groundwater or surface water is inferred. Additionally, the nature of that dependence (either non-dependent, seasonally dependent or entirely dependent) will be inferred for each discrete portion of the study area.

The proposed method is presented and the detailed approached and some initial results for the Kraai River (D13A-D13M) catchment are included in Appendix B.

[1] It should be noted that this approach was adapted from the approach that was developed by Serov *et al.* (2012) to assess groundwater dependence of surface water ecosystems in Australia.

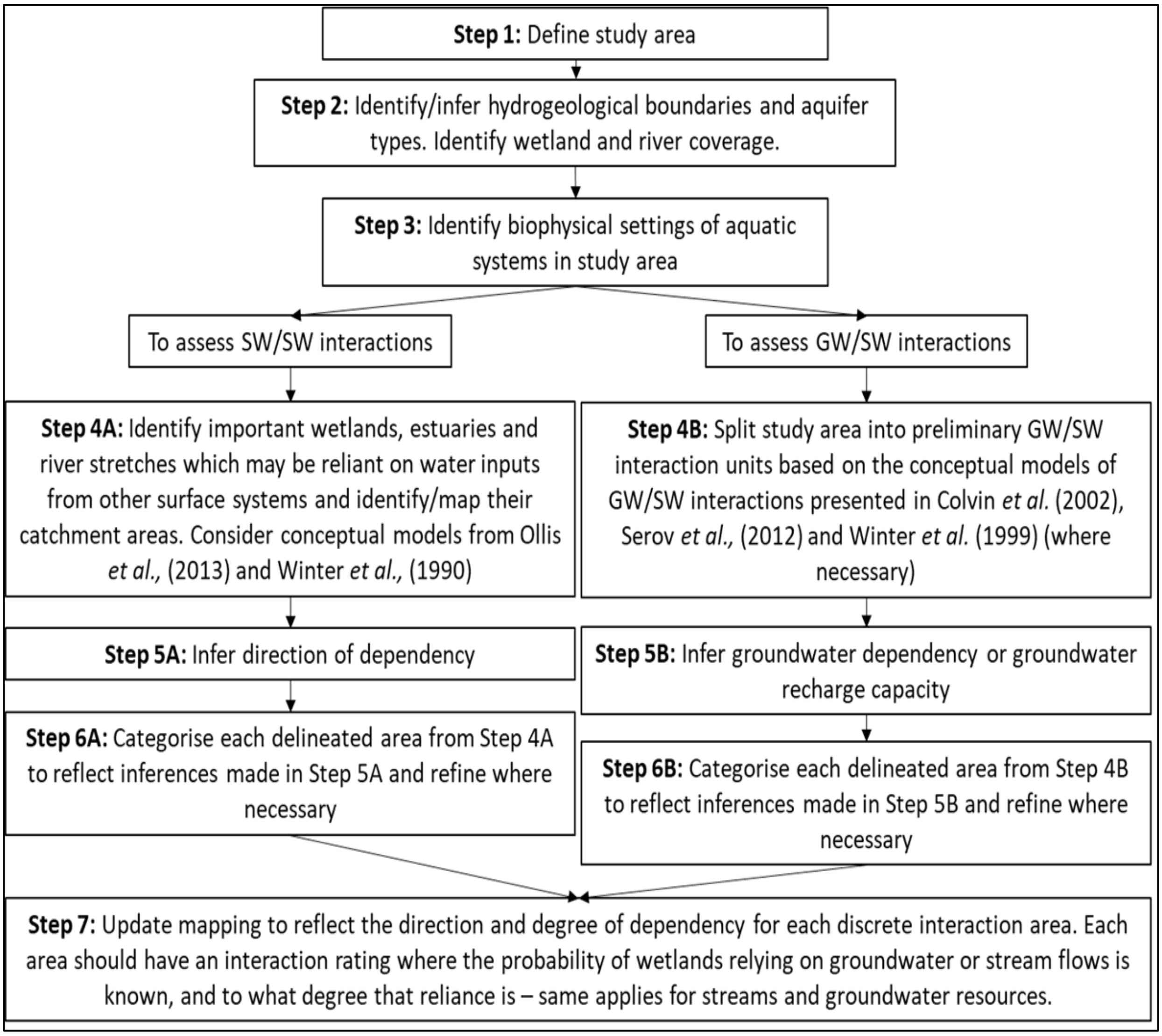


Figure 9-1: Proposed method to determine the degree and direction of dependency of different freshwater ecosystems on hydrological inputs from other freshwater ecosystem types (method adapted from Serov et al. (2012) and Colvin et al. (2002)

10. CONCLUSIONS

The ecological water requirements as presented in this report for the rivers in the Upper Orange catchment area concludes step 3 of the Integrated steps for the determination of the Reserve (DWS, 2017) and is based on the Recommended Ecological Categories as determined during the eco-categorisation task of this study (see DWS, 1223a and DWS 1223b). The Present Ecological State, Ecological Importance, Ecological Sensitivity and operational constraints due to dams, transfers, return flows and water quality were all considered with the determination of the final REC.

The overall conclusion of this EWR report is that the PES of most of the mainstem rivers as well as some tributaries have been degraded due to water resource developments and water use. However, it is also acknowledged that the surveys were undertaken during a wet period with several flooding events before the surveys, resulting in increased baseflows (especially during the dry season surveys in July 2022), scouring of habitats and re-deposition of sediments. These might have resulted in biota not established in the new habitats when the surveys were undertaken.

A few approaches have been 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 include:

i. Habitat Flow Stressor Response (HFSR) and Desktop Reserve Model (DRM)/ Revised DRM within SPATSIM for the integration of data produced from the surveys and Eco-categorisation to quantify the EWRs;
ii. A conceptual Flow Management Plan is proposed for the Orange River downstream of Gariep and Vanderkloof Dams; and.
iii. An initial approach for the integration/ interaction between rivers, wetlands and groundwater has been developed and was evaluated on the Kraai River.

The next step is the development of operational scenarios where the feasibility of the implementation of these EWRs will be assessed taking system constraints and water use into consideration and provide ecological consequences where EWRs can't be met to select the optimum EWRs. The implementation of these EWRs, together with ongoing monitoring will assist in the sustainable management of the water resources of the Upper Orange River catchment.

Please refer to Table 10-1 for a summary of the REC and proposed EWRs for all the EWR sites (Intermediate, Rapid 3 and Field Verification).

Table 10-1: Summary of EWR results for Upper Orange River catchment

EWR site	River	Latitude	Longitude	Quat*	REC	MLow (%)	Drought (%)	Floods (%)	Total EWR as %nMAR REC	for nMAR (10^6m^3)
INTERMEDIATE										
UO_EWR01_I	Middle Caledon	-28.9089	27.785	D22D	D	11.80	3.80	11.35	23.16	674.0
UO_EWR02_I	Sterkspruit	-30.517806	27.369058	D12B	C/D	15.33	0.05	23.10	38.43	30.7
UO_EWR03_I	Upper Orange	-30.652793	26.823213	D12F	D	13.01	4.85	12.05	25.06	4 259.5
UO_EWR04_I	Lower Caledon	-30.436136	26.299258	D24G	C/D	15.06	2.73	14.37	29.89	1 353.6
UO_EWR05_I	Seekoei	-30.534359	24.962895	D32J	C	4.3	0	29.89	34.19	24.3
UO_EWR06_I	Upper Riet	-29.535065	25.52457	C51F	C	8.29	0.08	22.76	31.05	105.2
UO_EWR07_I	Upper Modder	-29.160017	26.572492	C52B	C	15.02	3.79	20.92	35.94	61.0
UO_EWR08_I	Lower Kraai	-30.69007	26.74157	D13M	B/C	27.94	5.70	18.59	46.52	719.0
UO_EWR09_I	Lower Riet	-29.03842	24.50283	C51L	B/C**	14.52	0.15	9.55	24.07	373.8
UO_EWR10_I	Lower Orange	-29.16202	23.695944	D33K	C	15.70	5.49	5.70	21.39	6 674.2
RAPID 3										
UO_EWR01_R	Little Caledon	-28.557796	28.405709	D21D	B/C	23.09	7.41	16.11	39.20	25.9
UO_EWR02_R	Brandwater/ Groot	-28.68034	28.139926	D21G	B/C	21.16	3.57	9.79	30.95	56.0
UO_EWR03_R	Mopeli	-29.101205	27.570751	D22G	C/D	18.16	1.91	11.19	29.34	49.4
UO_EWR04_R	Upper Kraai	-30.85179	27.77689	D13E	B	32.07	4.52	7.97	40.04	200.9
UO_EWR05_R	Wonderboomspr uit	-31.005262	26.341938	D14E	C/D	18.83	1.41	13.55	32.38	25.9
UO_EWR06_R	Middle Modder	-28.807191	26.109695	C52G	C/D	20.89	1.58	13.07	33.96	113.7
FIELD VERIFICATION										
UO_EWR01_FV	Meulspruit	-28.885731	27.834944	D22B	D	3.13	0.41	9.38	12.51	63.6
UO_EWR02_FV	Witspruit	-30.00826	26.928315	D24C	C	7.78	1.33	11.40	19.18	21.7

EWR site	River	Latitude	Longitude	Quat*	REC	MLow (%)	Drought (%)	Floods (%)	Total EWR as %nMAR REC	for nMAR ($10^6 m^3$)
UO_EWR03_FV	Gryskopspruit	-30.339629	27.176878	D12D	C	6.48	0.05	11.89	18.38	7.5
UO_EWR04_FV	Karringmelkspruit	-30.811765	27.266497	D13K	B	32.06	4.54	13.05	45.11	25.9
UO_EWR05_FV	Bokspruit	-30.88469	27.884557	D13A	B	32.01	2.95	12.98	44.99	60.4
UO_EWR06_FV	Holspruit	-30.995316	27.056639	D13J	C	5.96	0.71	12.08	18.05	36.9
UO_EWR07_FV	Sterkspruit, tributary of Kraai	-30.917621	27.800753	D13C	B/C	25.64	2.71	11.59	37.24	47.6
UO_EWR08_FV	Bell	-30.852601	27.786557	D13B	B	32.09	3.13	12.99	45.08	72.5
UO_EWR09_FV	Groenspruit	-30.24119	26.5613	D24H	C	5.91	0	12.10	18.01	5.02
UO_EWR10_FV	Skulpspruit	-30.23444	26.51134	D24H	C	5.91	0	12.10	18.01	7.8
UO_EWR11_FV	Fouriespruit	-29.671211	26.074393	C51A	C	5.76	0	12.16	17.92	13.8
UO_EWR12_FV	Renoster	-29.11632	26.328701	C52F	D	0.9	0	10.26	11.18	7.9
UO_EWR13_FV	Os-spruit	-28.93917	26.511411	C52E	B/C	7.75	0	14.10	21.84	8.6
UO_EWR14_FV	Hondeblaf	-30.205138	24.71803	D31C	B	10.77	0	15.97	26.74	2.0
UO_EWR15_FV	Tributary of VanZylspruit	-30.031203	25.786463	C51G	C	5.76	0	12.16	17.92	1.9
UO_EWR16_FV	Slykspruit	-30.393003	26.120925	D24L	B/C	9.58	1.2	13.43	23.01	5.1
UO_EWR17_FV	Langkloofspruit	-30.954126	27.606129	D13D	B	32.09	4.68	12.36	44.45	43.8
UO_EWR18_FV	Wasbankspruit	-31.15554	27.284442	D13G	B/C	25.64	0.93	13.15	38.79	16.5
UO_EWR19_FV	Lower Modder	-28.89166	25.656445	C52K	C	5.60	0.21	12.22	17.82	156.8
UO_EWR20_FV	Upper Kromellenboog	-30.066282	25.681056	C51G	B	10.86	0	15.94	26.79	9.3
UO_EWR21_FV	Lower Kromellenboog	-29.6536	25.43507	C51H	B/C	12.70	0	13.82	26.52	85.1
UO_EWR22_FV	Tele	-30.448588	27.582337	D18K	C	11.86	4.88	9.68	21.54	142.3
UO_EWR23_FV	Upper Orange	-30.398757	27.342987	D12A	C	24.71	5.66	11.46	36.17	4 115.1

EWR site	River	Latitude	Longitude	Quat*	REC	MLow (%)	Drought (%)	Floods (%)	Total EWR as %nMAR for REC	nMAR ($10^6 m^3$)
UO_EWR24_FV	Makhaleng	-30.16412	27.398251	D15G	C/D	8.37	1.86	9.03	17.39	524.5

* Quaternary catchment

***Although the flows as per the Vaal comprehensive study were specified for a D category, they were checked and identified to be adequate to maintain the PES of a C.*

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12. APPENDX A: Longitudinal profile of the Upper Orange River

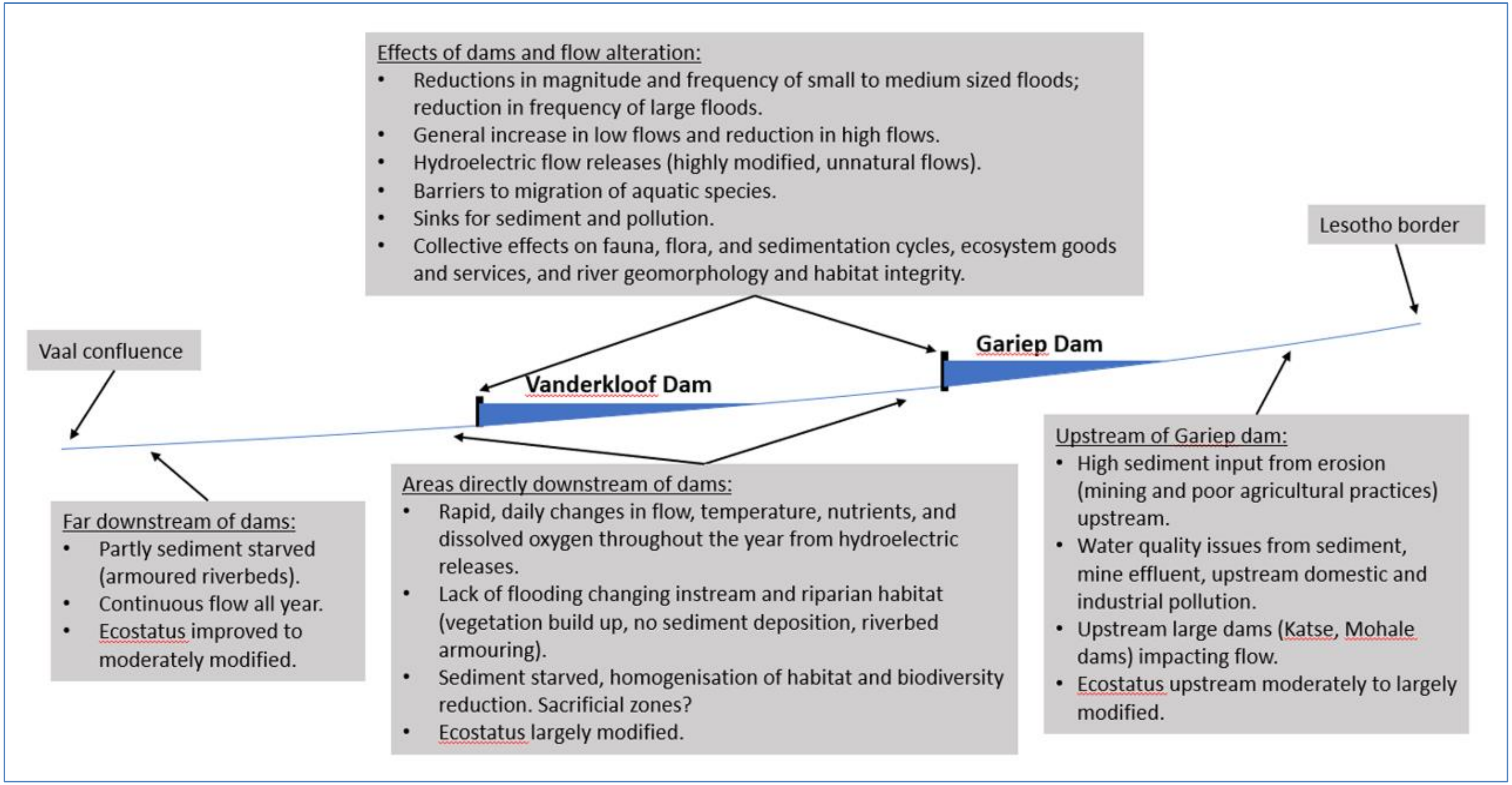


Figure A1: Preliminary longitudinal profile of the Upper Orange River from the Lesotho border to the Vaal confluence. The two major impoundments on this reach are shown; the Vanderkloof and Gariep Dams.

13. APPENDIX B Proposed approach for integration between groundwater, wetlands and rivers

Background

This section describes the method that was developed and used to infer the interaction between the water resource components that were assessed as a part of this reserve study. The following method is a locally novel approach[2] to assessing the probability of hydrological dependence between groundwater and surface water resources as well as the probability of hydrological dependence between discrete surface water resources (i.e. streams, wetlands, and estuaries). The necessity of this assessment was recognised particularly in areas where multiple resource units (i.e., rivers, wetlands, groundwater and estuarine resource units) overlap. Due to the known interactions and reliance between these different water resource components, it is vital that some understanding of their dependency on one another is obtained. It is particularly important to understand these dependencies in the context of this reserve study (and other reserve studies hereafter) because environmental authorisations that result in the degradation of one suite of resources (for example, abstraction of groundwater resources) may have an additional impact on another suite of resources (for example, groundwater-dependent wetlands). As such, the integrated assessment of all these resources should be included in authorisation processes in the areas that have inferred interactions between water resources.

The product of this process is intended to be a spatial GIS layer of the selected study area in which the probability of dependence on groundwater or surface water is inferred. Additionally, the nature of that dependence (either non-dependent, seasonally dependent or entirely dependent) will be inferred for each discrete portion of the study area.

Method

The following sections describe the method that was developed to infer dependence between the different resource units. This method was co-developed by the different specialists involved in the Upper Orange Reserve Determination project and should be considered as a preliminary approach. However, the following method represents the best approximation of the interaction and dependence between the different resource units in the areas where multiple resource units overlapped. The following method statement is accompanied by a worked example of the Kraai River system in which there was a large groundwater resource unit, three river resource units and three wetland resource units (Figure 13-1). It should be noted that this method was developed in the context of a large-scale reserve study, parts of which have been characterised by large gaps in data. As such, several assumptions were made in the development of this method, and a number of limitations exist when applying this method. These assumptions and limitations should be considered when applying this method:

[2] It should be noted that this approach was adapted from the approach that was developed by Serov *et al.* (2012) to assess groundwater dependence of surface water ecosystems in Australia.

- Due to poor depth to groundwater data, proxy data were utilised to infer groundwater depth at a broad scale. Borehole depth data and the presence of large trees that may be groundwater-dependent were used as proxy measures of groundwater depth in localised areas. This depth to groundwater was extrapolated to indicate the depth to groundwater at a local scale based on similar geological and vegetation characteristics.
- A distinction between regional/deep aquifers and shallow/perched aquifers was made. This distinction was deemed necessary to separate out surface water systems that would be impacted by the lowering of either the deep or the shallow aquifer upon which they are partially or totally reliant.
- The interaction between surface water resources was based on the conceptual models of wetland hydrogeomorphic units and their associated interaction with groundwater and other surface water ecosystems as presented in Ollis *et al.* (2013), Kotze *et al.* (2020), MacFarlane *et al.* (2020), Winter *et al.* (1999), Serov *et al.* (2012) and Colvin *et al.* (2002). Additionally, the interactions between the groundwater and surface water resources were based on the conceptual models presented in Winter *et al.* (1999), Serov *et al.* (2012) and Colvin *et al.* (2002). No additional conceptual models were created or considered during this process.

Step 1: Define the study area

In the context of this study, the study area is defined by a series of overlapping resource units from the different water resource types identified in this reserve study. It is generally useful to define the study area based on the hydrological connectivity of the resource units and therefore using quaternary catchments as the building block for the study area is useful. However, it is acknowledged that some deep aquifers stretch across multiple quaternary catchments that may or may not be hydrologically connected on the surface. In these cases, the known extent of the regional aquifer could be used as the study area.

In the case of the Upper Kraai River integration site, a portion of the Groundwater Resource Unit (GRU) 7 was used as the study area, which coincided with the upper reaches of the Kraai River catchment and included multiple quaternary catchments. Due to surface water resource disconnectivity in the northern portion of the GRU 7, the quaternary catchments that drained to the north were excluded from the study area and only those quaternary catchments that drain into the Kraai River were included in the study area (Figure 13-1).

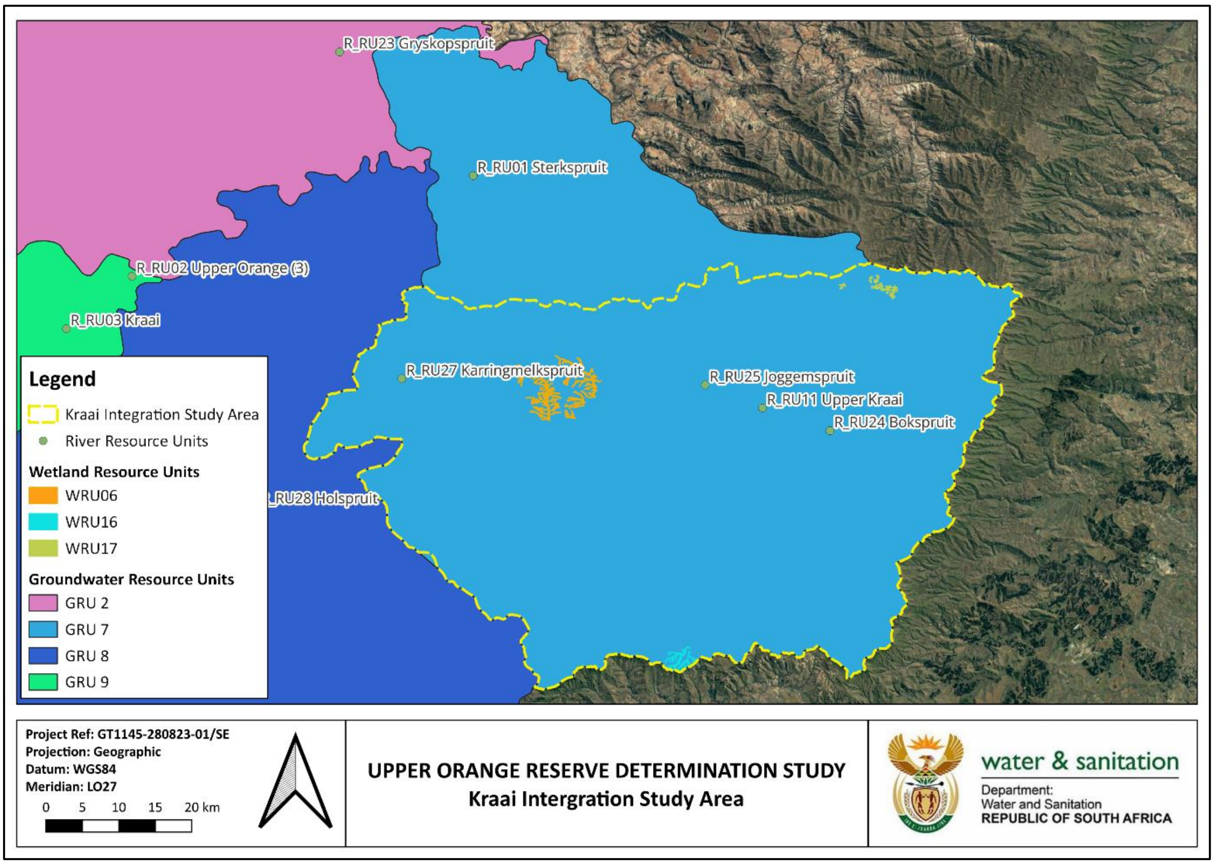


Figure 13-1: Study area for the integration of the Kraai water resources. This includes the Groundwater RU 7, the River RU numbers 11, 24, 25 and 27 and the Wetland RU 6, 16 and 17.

<u>Step 2: Identify hydrogeological boundaries, aquifer, wetland, river and estuary coverages within the study area</u>

Refer to the South African hydrogeological maps (SADC, 2010) and the South African geological map (Geological Survey, 1993) to determine the nature of the geology and the modelled transmissivity of the below-ground water resources. Refer to the surface water GIS data such as the National Wetland Map 5 (Van Deventer *et al.,* 2018), the national river PES/EIS data (SANBI, 2019), the national estuary coverage (van Niekerk *et al.,* 2019). It should be noted that the referenced data above are all national datasets and have some limitations in terms of their accuracy and data quality. Although these national datasets will be sufficient for the following steps, additional regional, local and field verified data should be incorporated into the dataset wherever possible. These layers should be considered as they form the building blocks for which groundwater-surface water and surface water-surface water interactions can be understood. For example, the presence of groundwater dependent wetland systems such as groundwater fed depression wetlands, wetland flats and some hillslope seep wetlands indicate a groundwater/surface water interaction, and the presence of a floodplain wetland along a stream channel indicates a surface water-surface water interaction. Additionally, perennial streams often have groundwater-surface water interactions, and the hydrogeological setting and the transmissivity of those below-ground water resources can indicate the relative contribution that those groundwater resources might be making to the base flows in the river systems. It is additionally important to review the conceptual models of groundwater-surface water and surface water-surface water interactions presented in Colvin *et al.* (2002), Winter *et al.* (1999), Ollis *et al.* (2013) and Serov *et al.* (2012). These conceptual models are utilised throughout the following steps to infer connectivity between the different water resources.

In the Upper Kraai example, the entire study area is characterised by intergranular and fractured lithologies with varying modelled transmissivity values. Additionally, the Kraai and Bell Rivers run through the study area, both of which have extensive catchments and many feeder tributaries. Extensively mapped river reaches within steeply-sided valleys exist in the study area. Few wetlands have been mapped in the NWM5 dataset in the study area. However, the wetland data has been supplemented with field verified and expert desktop mapped wetland areas (where available). Figure 13-2 and Figure 13-3 depict the different data layers that were considered for Step 2.

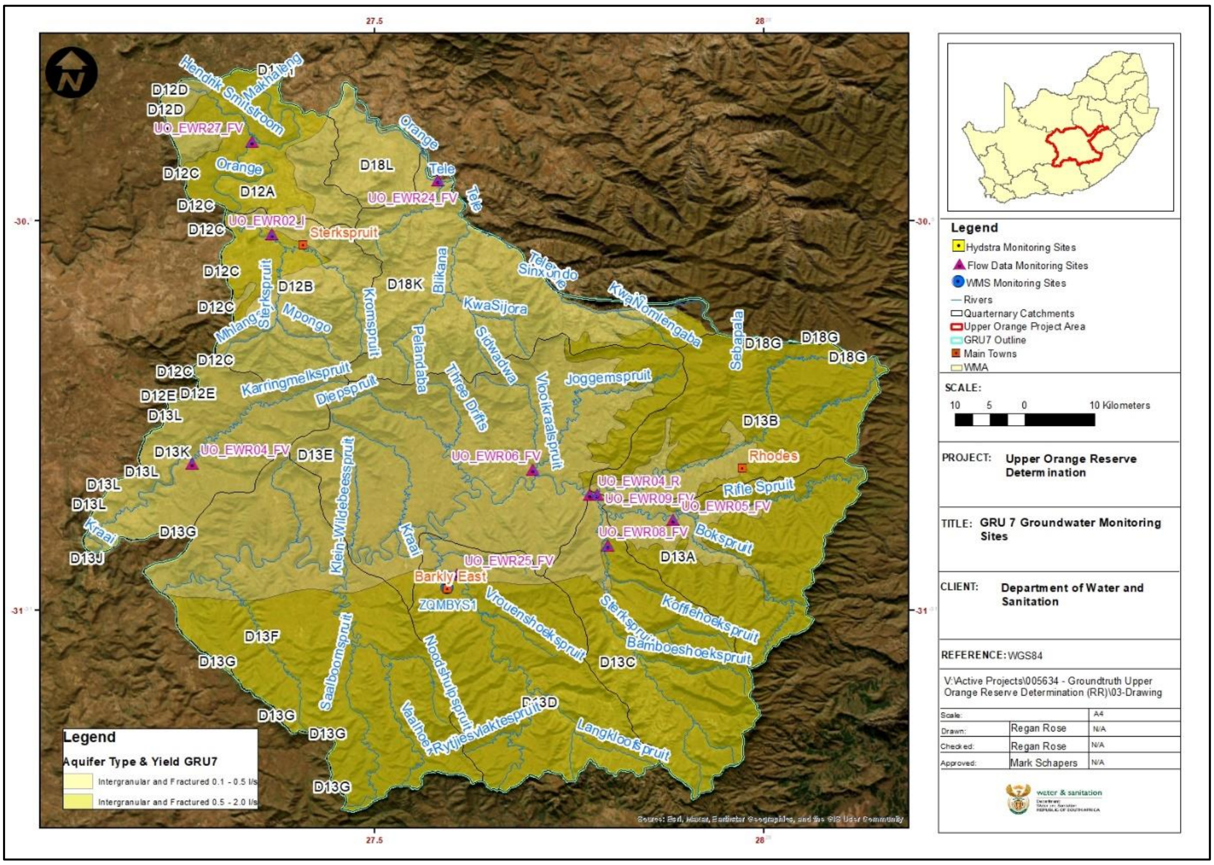


Figure 13-2: Hydrogeological map of the Upper Kraai study area

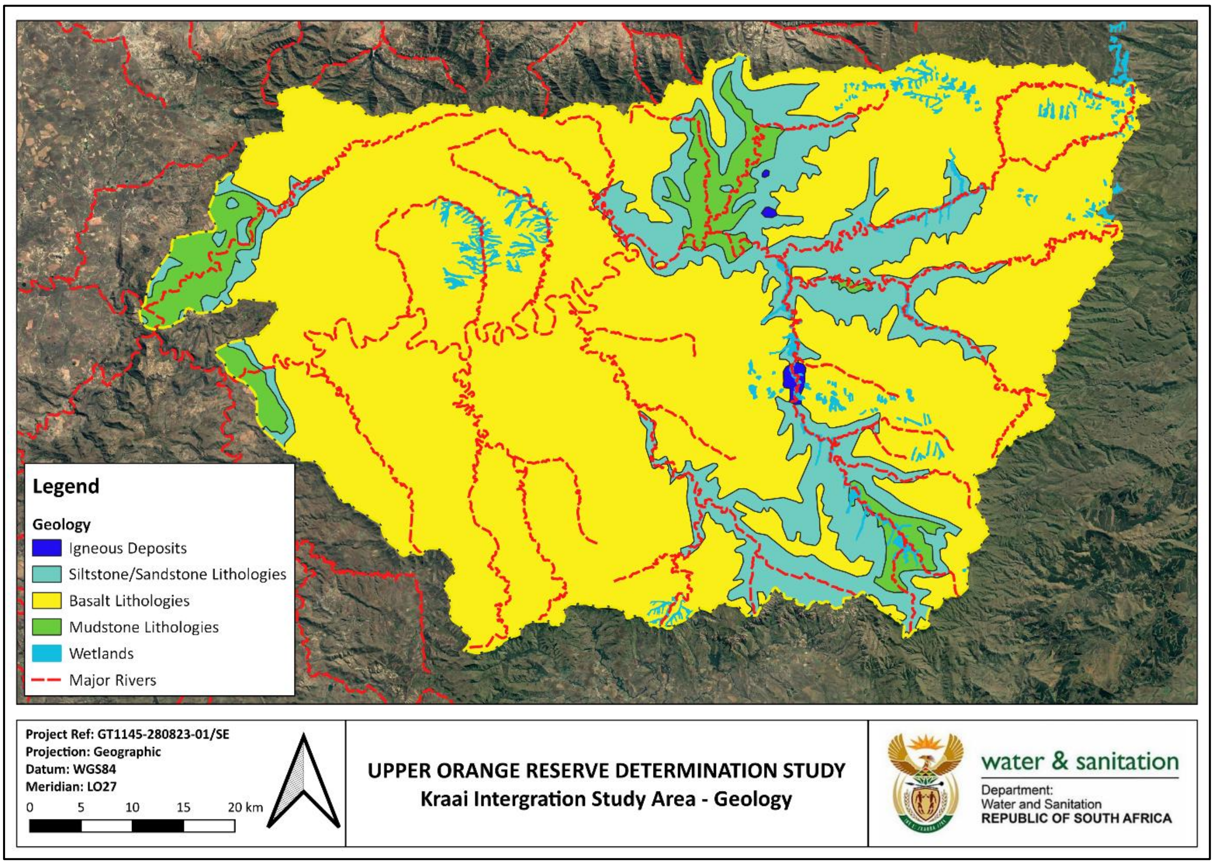


Figure 13-3: Geological, river and wetland data utilised for the Upper Kraai study area

Given the geological and hydrogeological context of the study area, the conceptual model presented in Figure 13-4 is the schematic model that best represents the possible interaction between surface and groundwater resources in the Kraai study area. Given the presence of extensive basalt lithologies in the study area, and the scattered areas where streams have eroded through the basalt layers into the underlying siltstone, sandstone and mudstone lithologies, the conceptual schematic shown below illustrates the possible interactions of groundwater and surface water resources. It should be noted that there was no deep groundwater depth data for the Kraai groundwater resource unit, and it is thought that most of the groundwater resources that interact with surface water resources are shallow/perched aquifers. However, it is possible that the lower portions of the Kraai river, towards the west of the study area is supported by baseflows from deep aquifers. Figure 13-5, Figure 13-6, Figure 13-7 and Figure 13-8 'zoom in' to the different groundwater-surface water interaction points and provide additional conceptual information that can be used to infer groundwater or surface water dependency. Additionally, most of the surface water-surface water interactions in the study area are conceptualised in the models presented in Figure 13-7, Figure 13-8 and Figure 13-9. Given that most of the mapped wetlands in the study area are either valley-bottom wetlands or seep wetlands, it is likely that there is a seasonal change in the direction of surface water-surface water interactions.

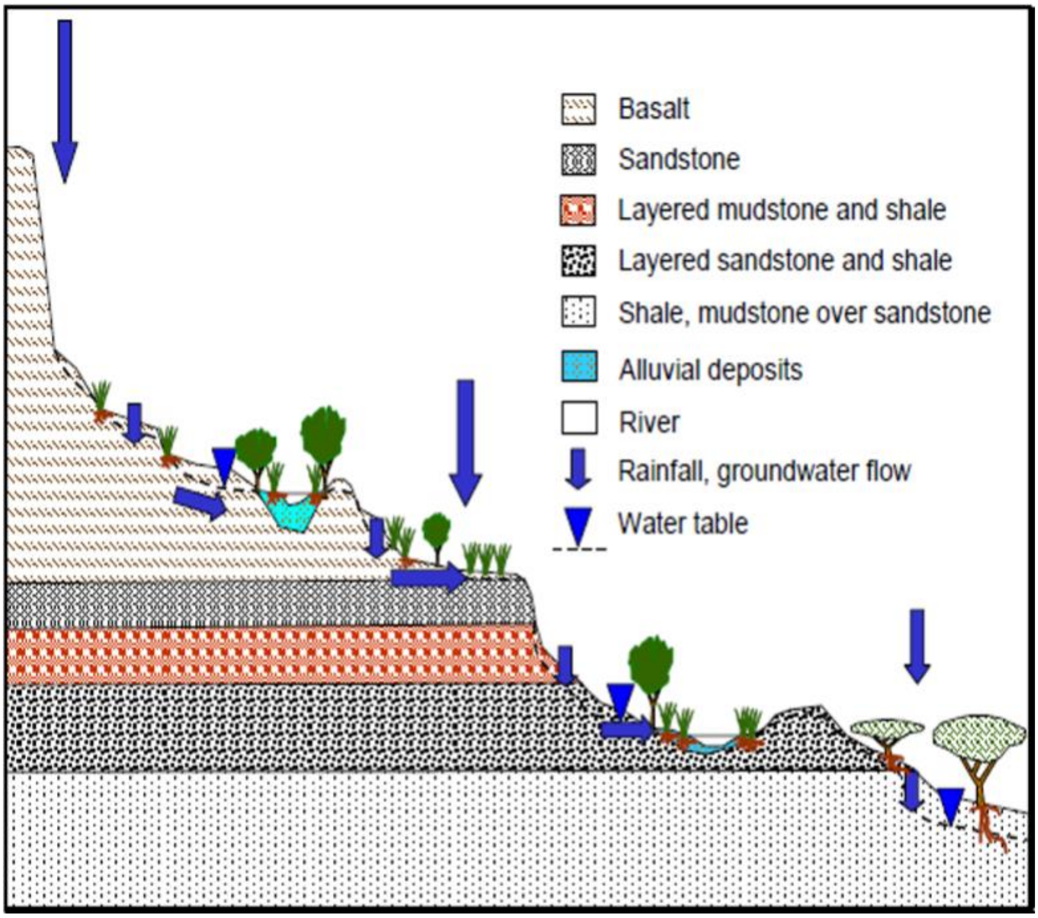


Figure 13-4: Conceptual Model 1. Broad conceptual model used for the Upper Kraai study area on fractured sedimentary terrain showing the geological formations and groundwater flows associated with the KwaZulu-Natal Drakensberg (Colvin et al., 2002).

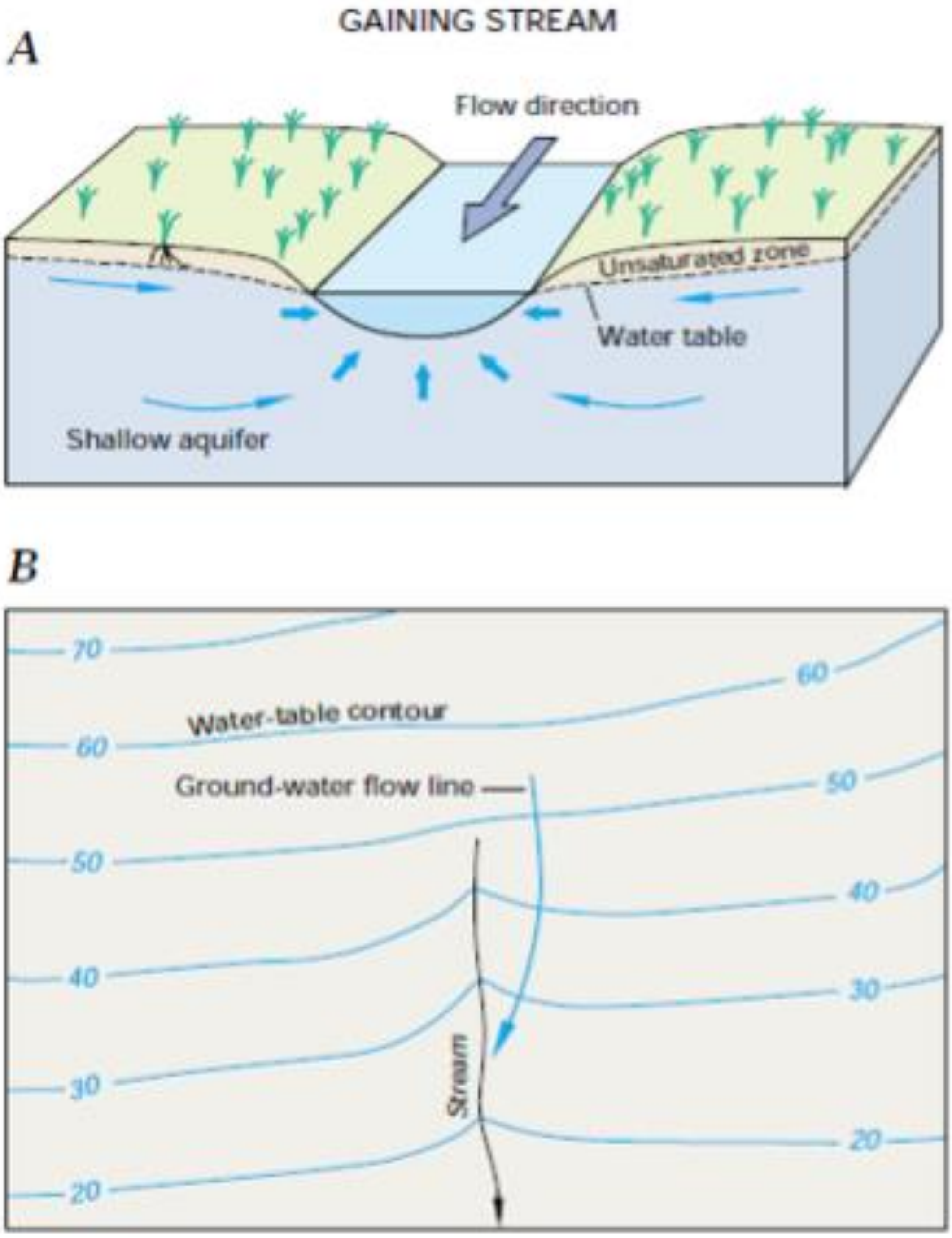


Figure 13-5: Conceptual Model 2. A) Typical groundwater surface water interaction of a gaining stream that is fed by groundwater sources – often evident when baseflows are sustained during very dry/low flow periods. B) Groundwater contours indicate a gaining stream when they point in an upstream direction (Winter *et al.,* 1999).

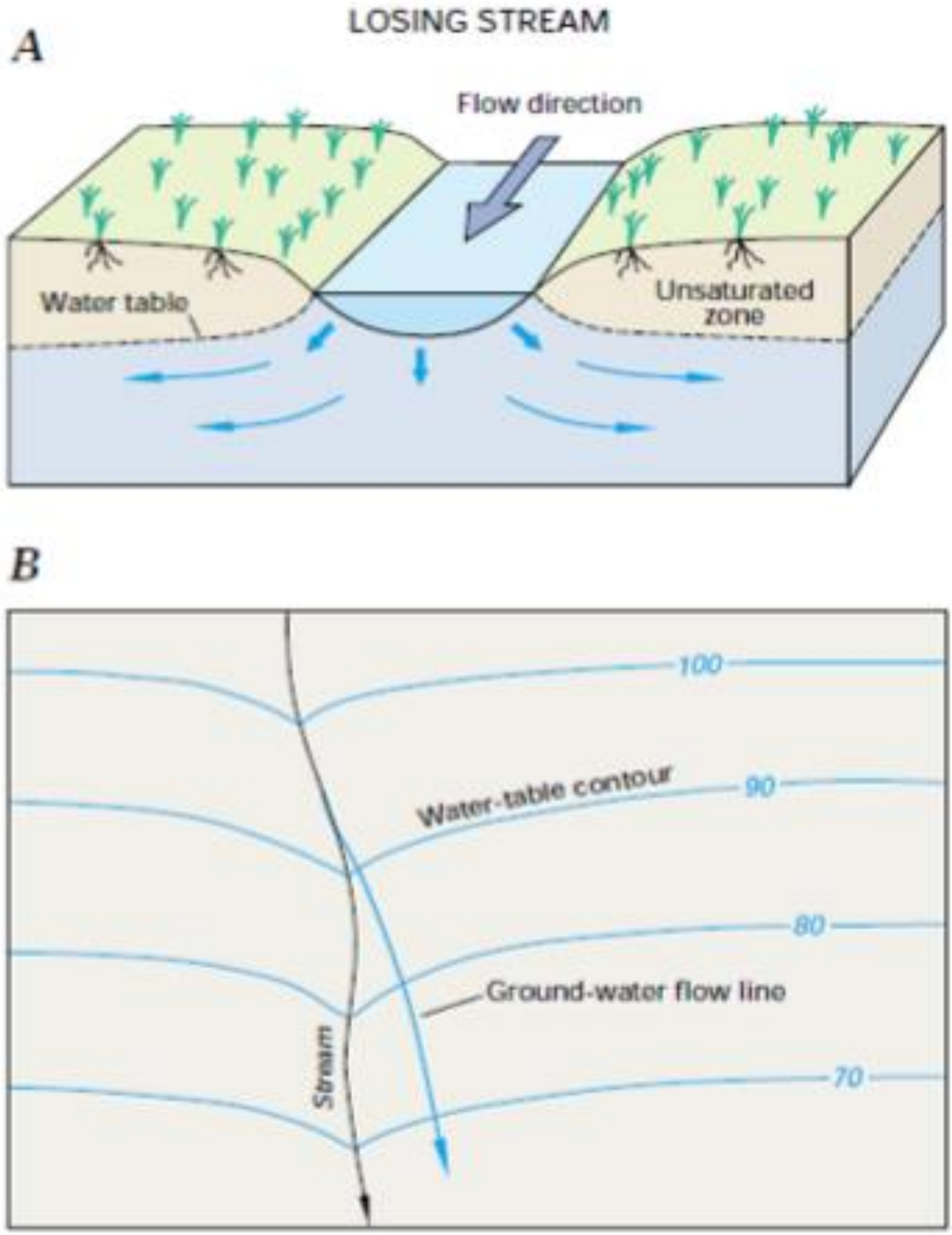


Figure 13-6: Conceptual Model 3 A) Typical surface water groundwater interaction of a losing stream – often occurring in fractured lithologies and stream reaches with extensive cobble and riffle areas. B) Groundwater contours indicate a losing stream when they 'point' in a downstream direction (Winter et al., 1999).

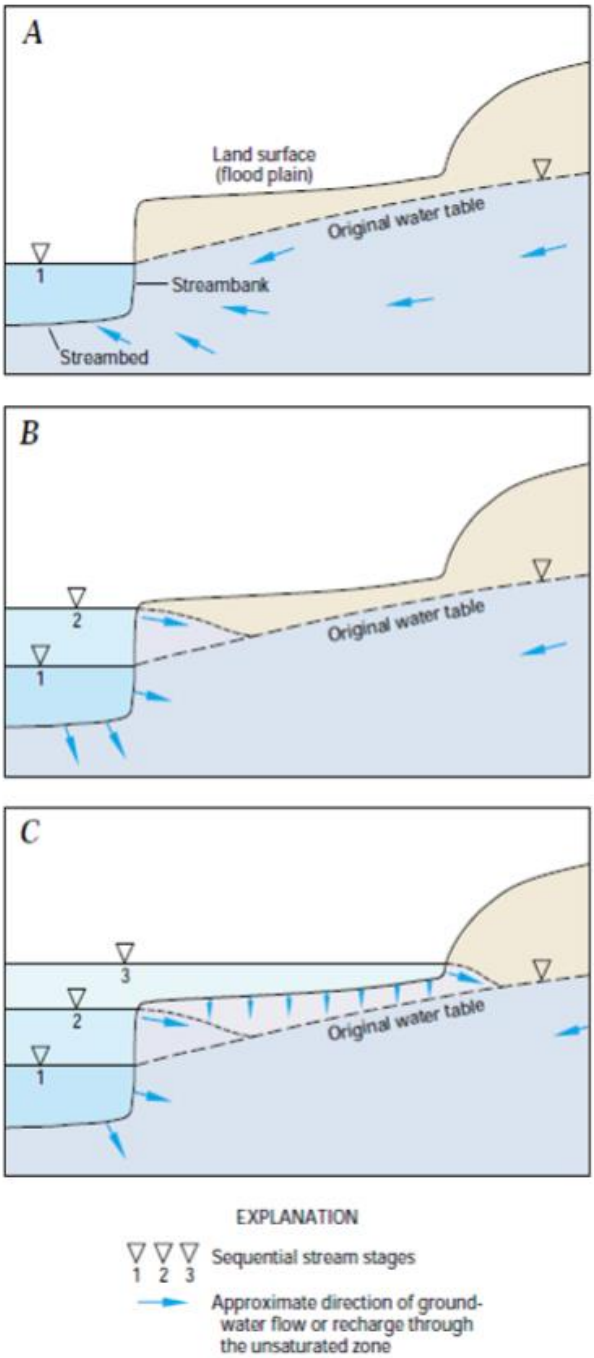


Figure 13-7: Conceptual Model 4. Typical groundwater-surface water interaction of a seasonally inundated stream channel with floodplain features adjacent to the channel. A) Possible groundwater surface water recharge during low flows. B) Possible surface water groundwater and surface water surface water recharge during high flows. C) Definite surface water groundwater and surface water surface water (from stream to wetland) recharge during flood flows. This interaction type could be applied to the interaction between a stream and a floodplain or channelled valley-bottom wetland (Winter et al., 1999)

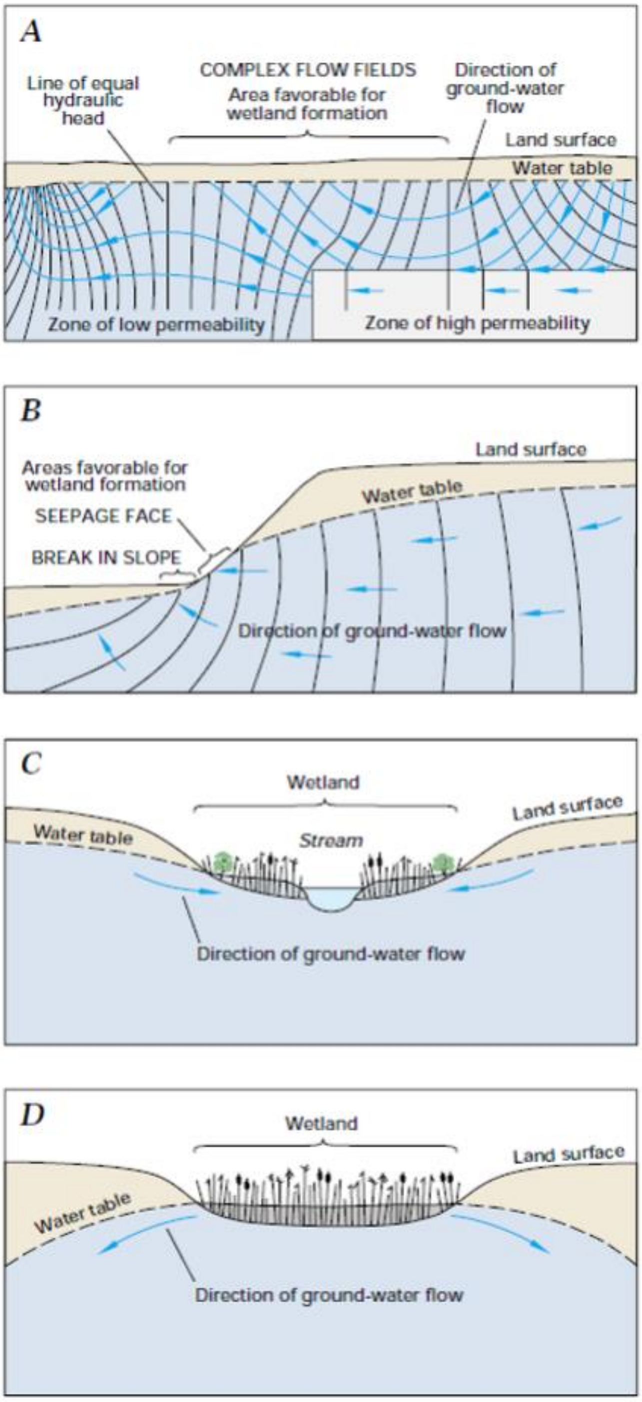


Figure 13-8: Conceptual Model 5. Typical groundwater-surface water interaction types of wetlands in the Upper Kraai study area. A) The source of water to wetlands can be a result of groundwater surface water interaction where the land surface is underlain by complex groundwater flow fields. B) Wetlands can form from groundwater surface water discharge at seepage faces and at breaks in slope of the water table. C) Both surface and groundwater sources can contribute to wetland formation in a valley-bottom context. D) In cases where wetlands have no stream or groundwater inflow, groundwater gradients slope away from the wetland resulting in a surface water groundwater interaction (Winter et al., 1999)

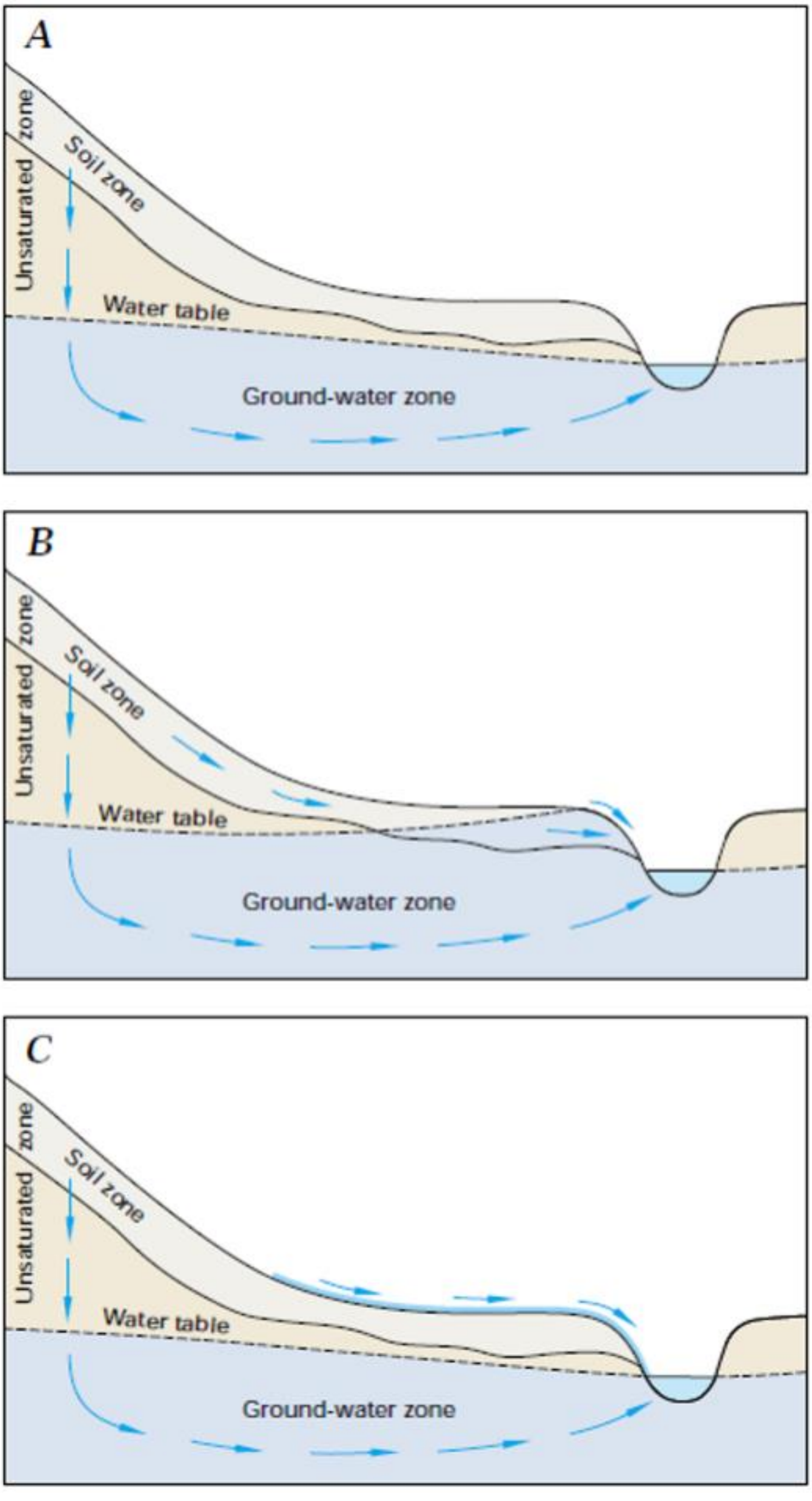


Figure 13-9: Conceptual Model 6. Water from precipitation moves to mountain streams along several pathways. A) Between storms, most inflow to streams is commonly via ground water. B) During storms, much of the inflow to streams is from shallow flow in saturated macropores in the soil zone (depending on infiltration). C) In arid areas where soils are very dry and plants are sparce, infiltration is impeded and runoff from precipitation can occur as overland flow (Winter et al., 1999)

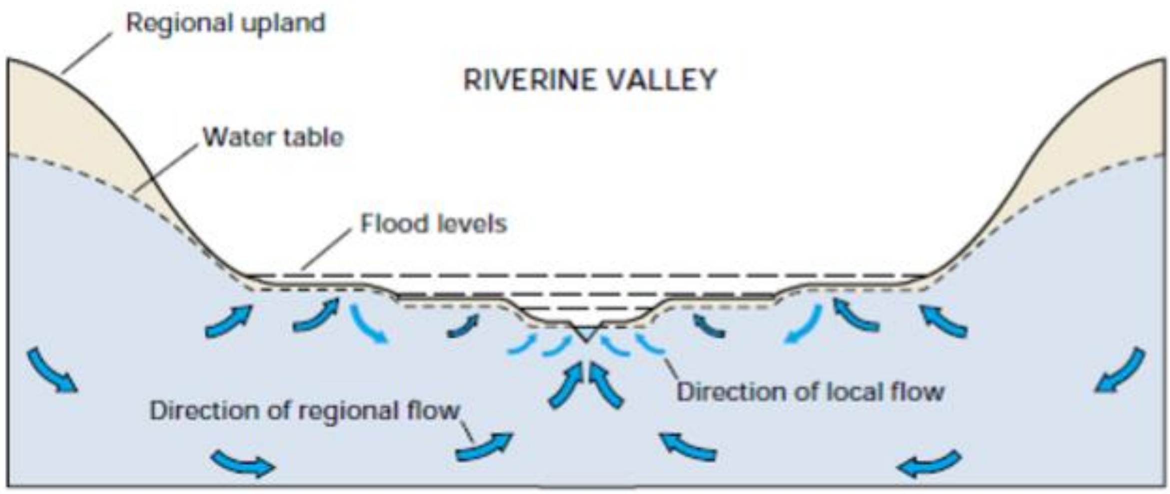


Figure 13-10: Conceptual Model 7. In broad river valleys, small local groundwater flow systems associated with terraces overlie more regional groundwater flow systems. Recharge from flood waters superimposed on these groundwater flow systems further complicates the hydrology of rivers (Winter *et al.,* 1999)

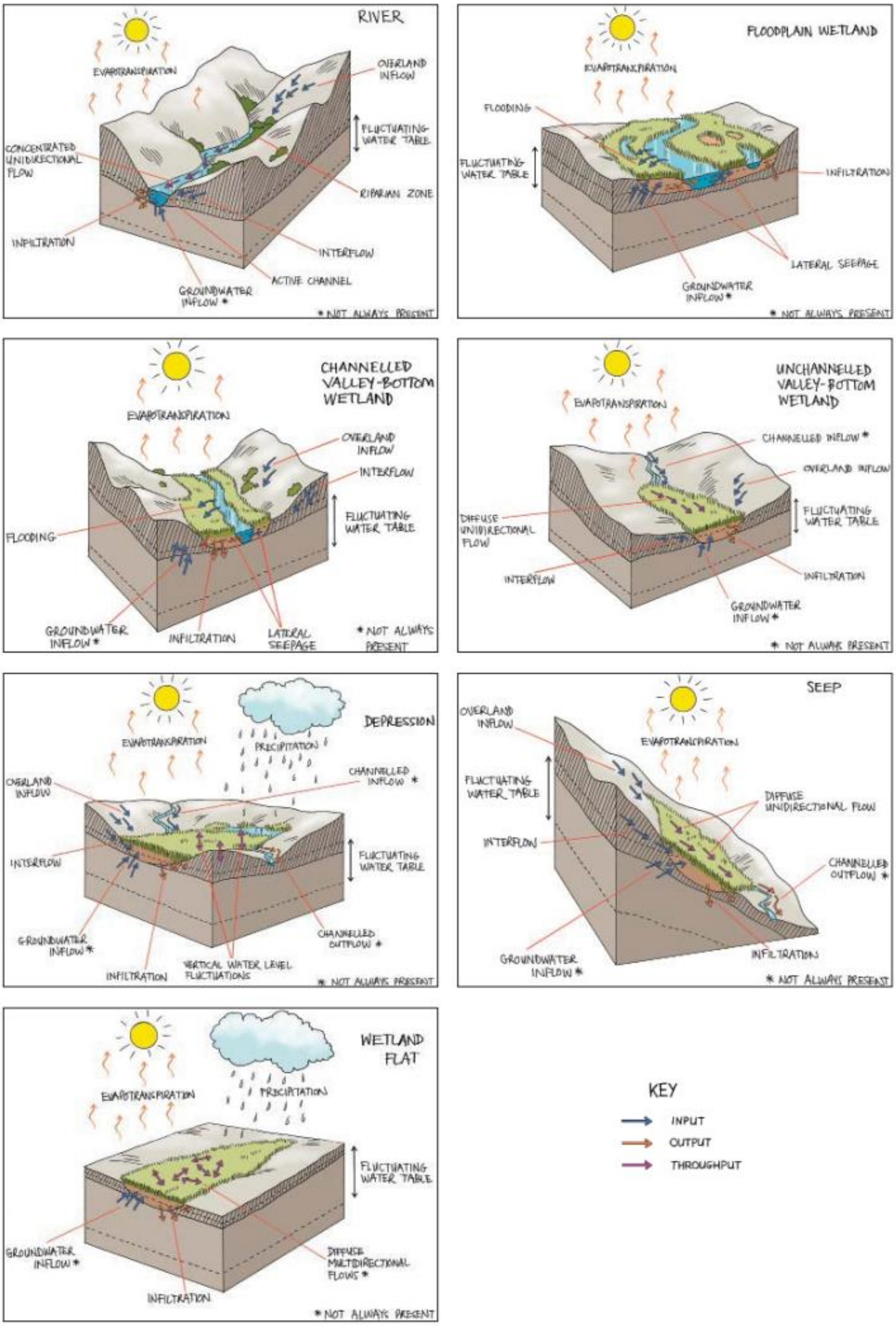


Figure 13-11: Conceptual Model 8. Amalgamated river and wetland hydrogeomorphic units, highlighting their dominant water inputs, throughputs and outputs (Ollis et al., 2013).

Step 3: Identify biophysical settings of the surface water resources

Multiple additional datasets should be considered to enhance the understanding of surface-groundwater and surface-surface water interactions. According to Colvin *et al.* (2002), Winter *et al.* (1999) and Serov *et al.* (2012), terrestrial indicators are key proxy data sources that may assist in understanding the interactions between surface and groundwater resources, the latter generally being very challenging to measure without significant investment into extensive monitoring infrastructure and equipment. Figure 13-12 below illustrates how vegetation structure and composition, geology and the presence and abundance of wells could be used to infer the nature and depth to groundwater at a broad scale. As such, the following data should be collated and considered in addition to the data listed in Step 2:

- **Soil type data** is generally an indication of the interaction between the underlying geology and the biotic factors on the surface. Pedogenesis is a complex process, but soil type data can indicate a number of important characteristics which pertain to water movement on or below ground. Soil type data can indicate permeability ratings, soil texture, some degree of transmissivity, water holding capacity, potential to erode, land capacity and the presence of hydric soils.
- **Vegetation type data** can provide further insight into soil related data as vegetation types can often change along with soil types. Specific vegetation types are also known to have strong groundwater dependence, especially vegetation types that comprise of large tree species with root systems that can reach shallow groundwater sources. The presence of these vegetation types can be used as an approximation for depth to groundwater in localised parts of the study area (Serov *et al.,* 2012; Colvin *et al.,* 2002). See Figure 13-12 for the vegetation data overlaid with the wetland and river coverages for the Upper Kraai study area.
- **Borehole location and depth to groundwater data** is very important for showing regions where groundwater is close to or at the ground surface and where it is deep and generally inaccessible to surface water systems. Additionally, when the groundwater is very deep, the presence of surface water resources in proximity to this deep aquifer are either responsible for recharging groundwater resources or are being recharged by locally shallow or perched aquifers.
- **Flow data in streams** can provide insight into the source of flows in a given stream during low flows. Some high order streams may have catchments large enough to sustain flows during the dry season, but many South African rivers are supported by direct groundwater recharge and/or wetland water input. Extensive seep wetlands in the catchment of a given river may indicate reliance of the river on both wetland (surface water) and groundwater water sources (given that seep wetlands are typically fed by groundwater sources). Additionally, rivers that flow year-round (i.e., are baseflow supported streams) generally indicate groundwater recharge, and often occur in fractured lithologies where groundwater upwelling is common (Serov *et al.,* 2012).
- **Topographic data (elevation and slope data)** can be used to infer the proximity of the earth's surface to the regional groundwater table (specifically elevation data). Additionally, slope data can be utilised to infer the probability of specific wetland types (generally seep wetlands on steeper slopes and valley-bottom wetlands on more gentle slopes) in areas where wetland mapping has not been conducted in detail.

- **Water quality data (both surface and groundwater data)** identifies areas of groundwater discharge through changes in water quality – specifically looking at dissolved oxygen, temperature, pH and electrical conductivity. Sudden changes in these parameters without any evidence of surface related water inputs often indicate groundwater upwelling (Serov *et al.,* 2012).

Wherever possible, the above-mentioned data should be supplemented with local knowledge of the systems (both surface and ground water resource knowledge), along with any scientific publications that have been released that pertain to the study area or geologically and climactically analogous to the study area. The above-mentioned data can be used to supplement and increase the confidence of the interaction map that will be produced in Steps 4A and 4B. It is a fundamental tenet of ecology that ecosystems will use resources in proportion to their availability. It can therefore be assumed that if groundwater can be accessed, ecosystems will generally develop some degree of dependence, and that dependence will likely increase with increasing aridity (Hatton & Evans, 1998).

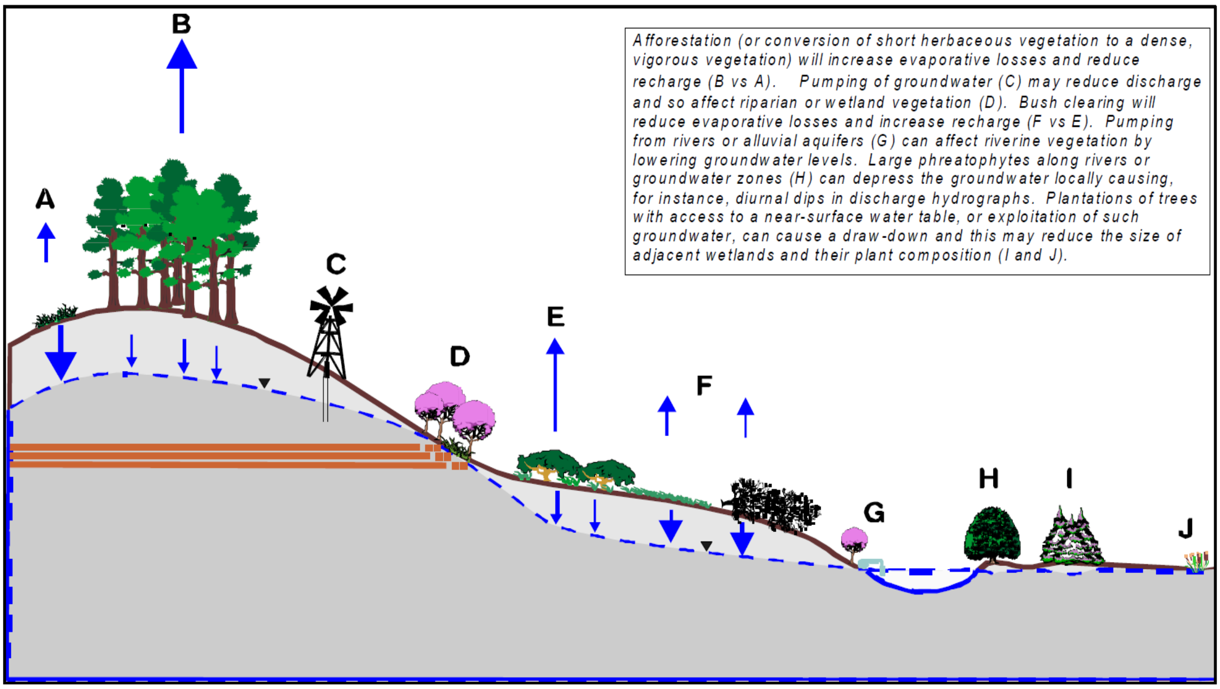


Figure 13-12: Schematic diagram illustrating some typical interactions between vegetation and groundwater (Scott & Le Maitre, 1998, Le Maitre et al. 1999)

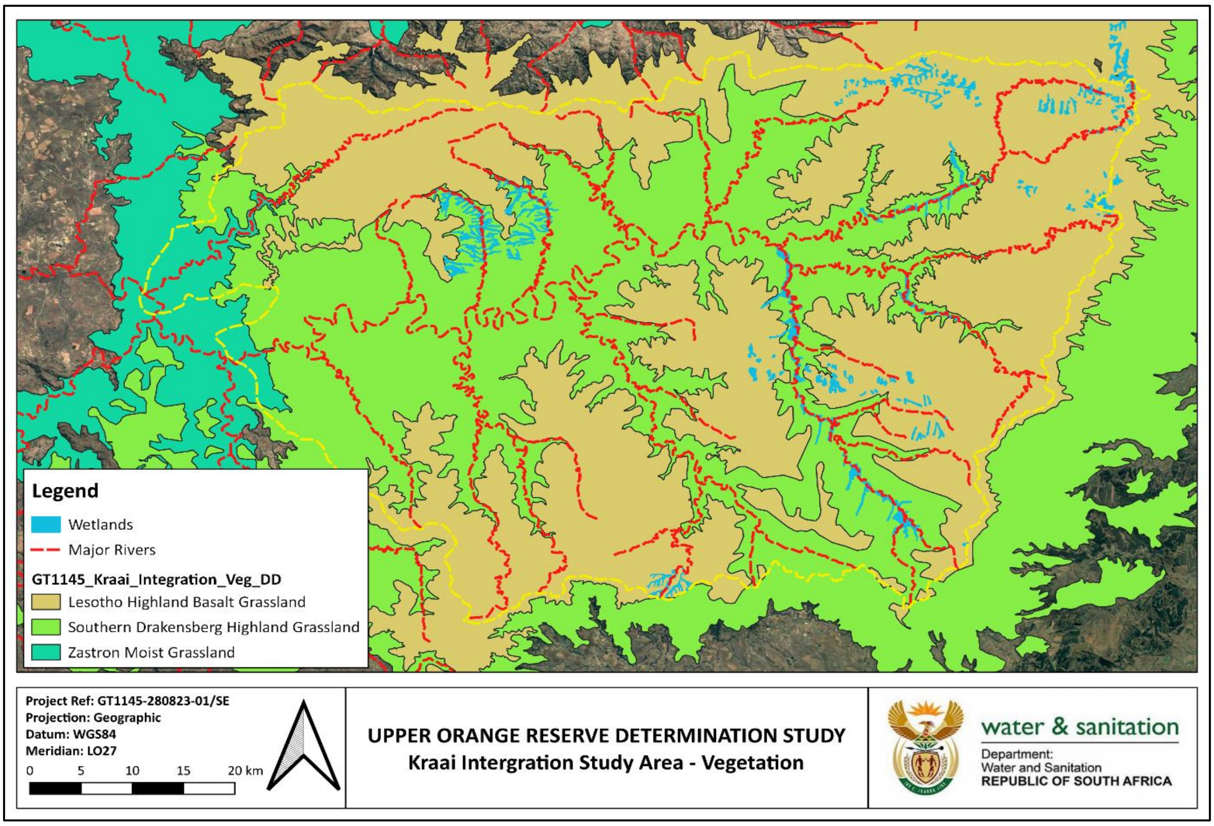


Figure 13-13: Mucina and Rutherford (2006) vegetation dataset for the study area overlaid by the available river and wetland coverages. Strong overlap between mapped wetlands and the Southern Drakensberg Highland Grassland vegetation type in the valleys and the sandstone/mudstone and siltstone lithologies. Strong overlap of mapped seep wetlands and the Lesotho Highland Basalt Grassland type in the eastern portion of the study area, which coincides with the basalt lithologies.

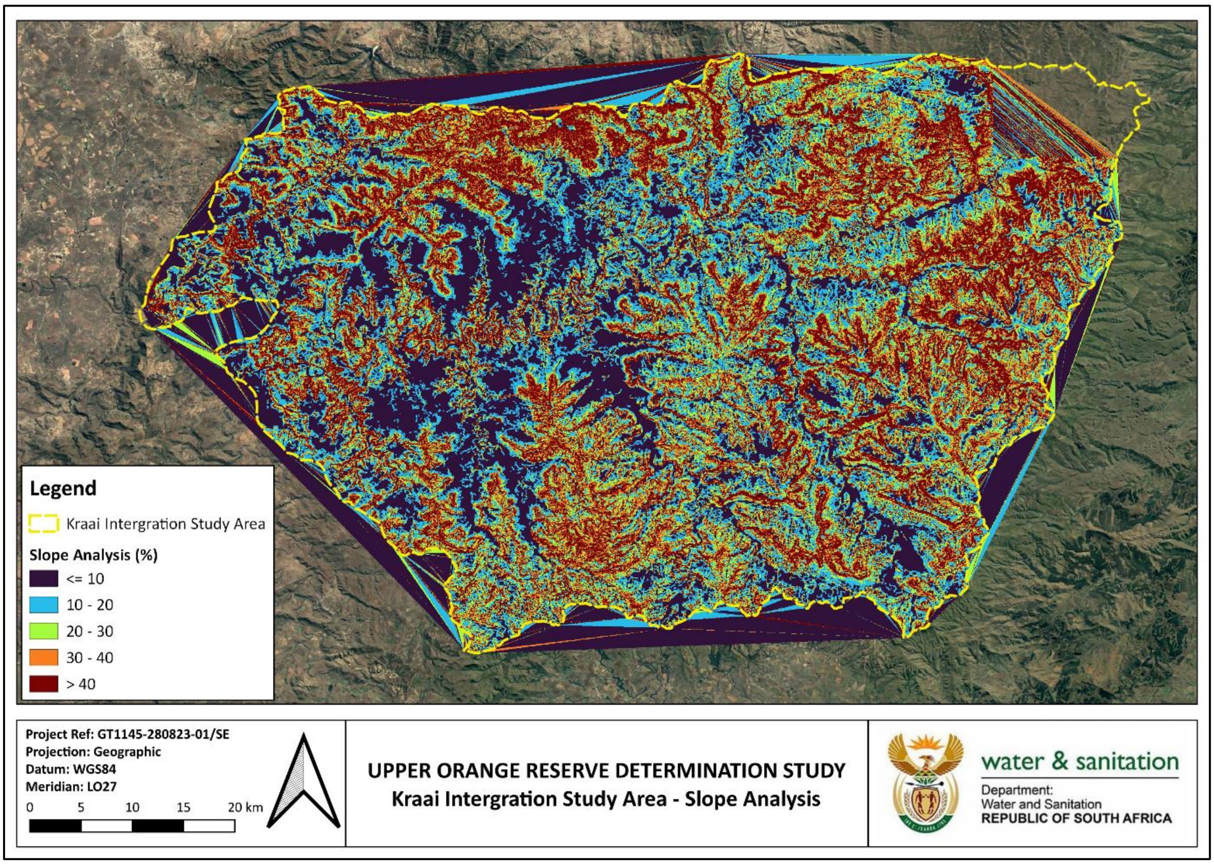


Figure 13-14: Derived slope analysis for the Upper Kraai study area. Note the strong correlation between average slope and vegetation type (from Figure 13-13), strong correlation between average slope and geology (from Figure 13-3). Can infer that valley-bottom wetlands will generally occur in areas where slope is <=10% - which generally coincides with sandstone/mudstone and siltstone geologies in areas below 1800masl. Can infer that seep wetlands occur on slopes >15%, which often coincides with basalt lithologies above 1800masl.

Step 4A: Split portions of the study area into preliminary groundwater-surface water interaction areas based on the conceptual models presented in Colvin et al. (2002), Winter et al (1999) and Serov et al (2012).

Based on the consideration of the available information, split the relevant portions of the study area into areas where there is a known or suspected groundwater-surface water interaction. Initial delineation of these areas should be based primarily on the hydrogeological maps, geological maps, the presence of known groundwater dependant ecosystems and the data included in Step 3. For all delineated areas in this step (i.e., where there is known or suspected groundwater-surface water interaction), proceed to and complete Step 5A for each delineated interaction unit.

In the Upper Kraai example, the study area was split into a series of groundwater-surface water interaction areas where known and suspected groundwater-surface water interactions were thought to occur. Given the different transmissivities and groundwater holding capacity of the basalt geologies and the sandstone/mudstone and siltstone lithologies, the preliminary groundwater-surface water interaction areas were initially split along the different geologies. For the sandstone/mudstone and siltstone lithologies, these were further divided up into areas where the slope was less than 10% (which typically coincided with valley-bottom areas) and areas where the slope was greater than 10%. For the areas where the slope is less than 10% and coincided with a valley-bottom area which always either had a wetland, a stream or both, the probability of the groundwater-surface water interaction presented in Figure 13-7 and Figure 13-8C is high, and it is likely that these areas are characterised by some seasonal groundwater dependence, although there is also a likely surface water-surface water interaction at these points as well. For the areas where the slope is greater than 10%, it is anticipated that the most abundantly occurring surface water resources are low order streams and seepage wetlands. As such it is anticipated that there is a high probability of the groundwater-surface water interaction depicted in Figure 13-8B. See Figure 13-15 for the estimated spatial distribution of these different interaction areas.

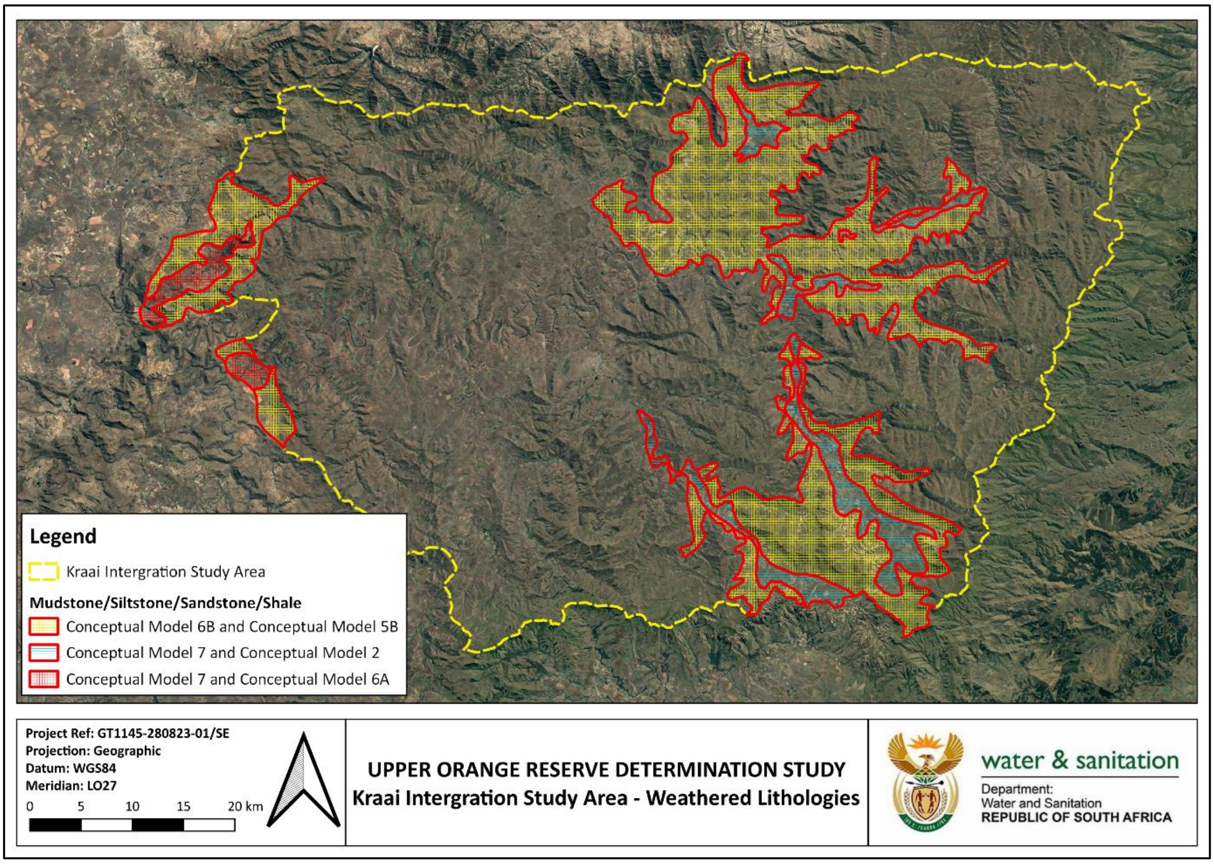


Figure 13-15: Mapped groundwater-surface water interaction units for the sandstone/mudstone and siltstone lithologies in the Upper Kraai study area.

Similarly to the sandstone/mudstone and siltstone lithologies, the basalt lithological area was split into discrete interaction zones based on slope, elevation and soil type data. For the steeper and higher lying areas, the conceptual model presented in Figure 13-9A and Figure 13-9B represent the most probable groundwater-surface water interaction for streams. Additionally, the probability that wetlands found on these lithologies similarly interact according to the conceptual model presented in Figure 13-7B. However, very few surface water resources are mapped on these basalt lithologies given the high permeability of the soils and the relogith (Colvin *et al.* 2002). The lower lying areas are probably similar in their groundwater-surface water interaction models to the lower lying areas on the sandstone/mudstone and siltstone lithologies and probably interact as depicted in Figure 13-5 and Figure 13-7. However, the dependency of these surface water systems may differ.

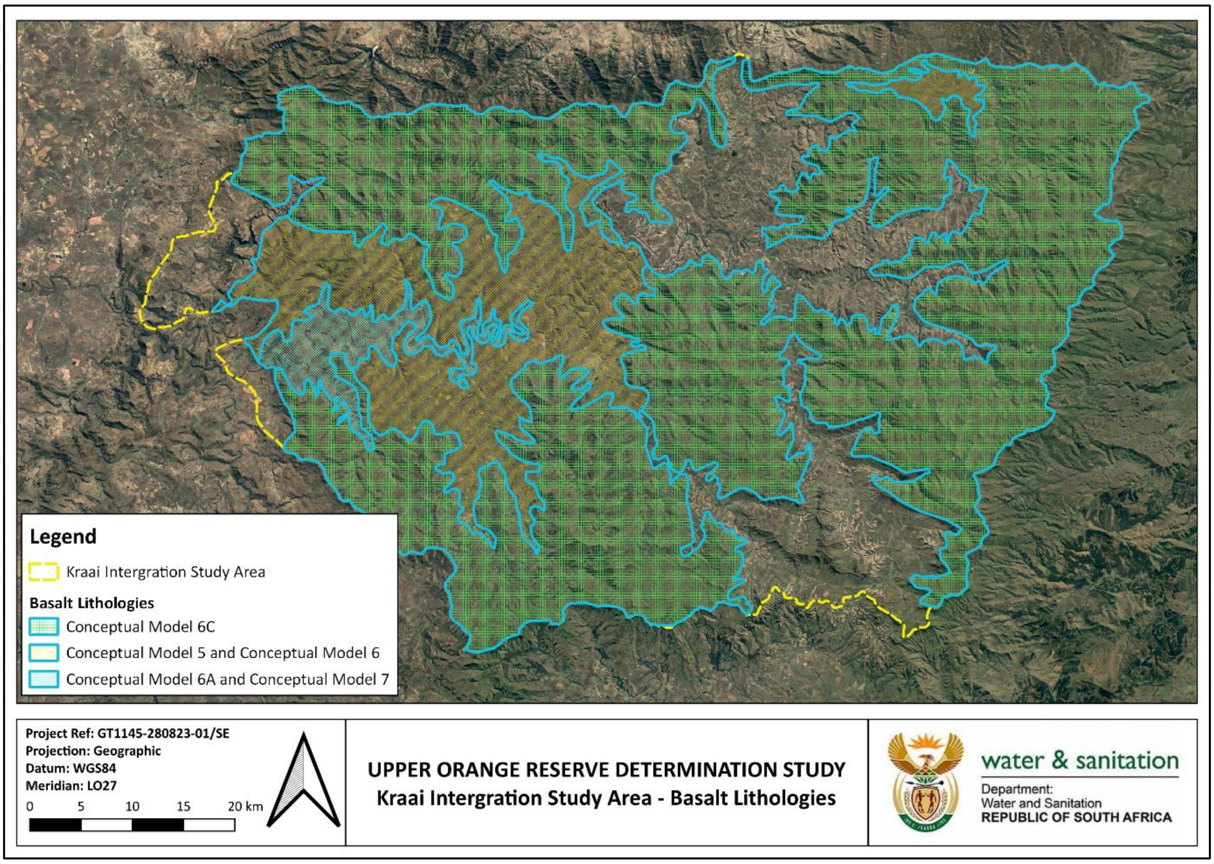


Figure 13-16: Mapped groundwater-surface water interaction units for the basalt lithologies in the Upper Kraai study area.

Step 4B: Split the remaining portions of the study area into preliminary surface water-surface water interaction areas based on the conceptual models presented in Winter et al. (1999) and Ollis et al. (2013).

Based on the consideration of the information presented above, split any remaining areas that have not been assigned a groundwater-surface water interaction type as having a surface water-surface water interaction. In addition, there may be areas that have been assigned a groundwater-surface water interaction type that also have a surface water-surface water interaction, and these areas should be mapped as well.

A single example of a surface water-surface water interaction in the Upper Kraai study area is presented in Figure 13-16. Extensive seep wetlands are located on the steeper east-west facing slopes and large channelled valley-bottom wetlands are located on the valley floor, often on either side of the Klein Wildebeesspruit and the Wildebeesspruit stream channels. As such, it is likely that the conceptual model presented in Figure 13-9 for the channelled valley-bottom wetland and seep wetland types apply here. As such, there is a high probability that the Klein Wildebeesspruit and the Wildebeesspruit streams are fed by water inputs from the seep wetlands and similarly, there is a high probability that the channelled valley-bottom wetlands are fed by seasonal overflow of the Klein Wildebeesspruit and Wildebeesspruit streams.

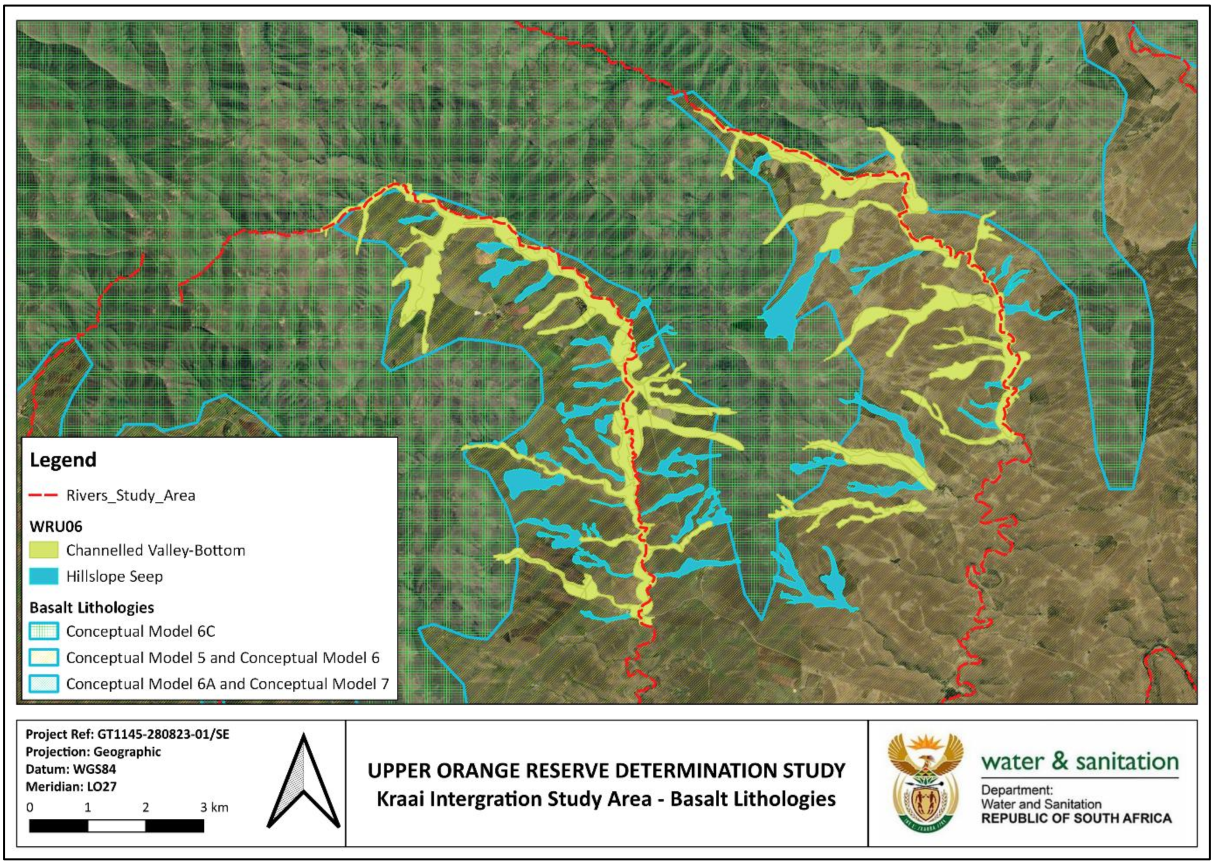


Figure 13-17: The mapped WRU 6 along with the low order streams of the Klein Wildebeesspruit and the Wildebeesspruit Rivers flowing through the WRU.

Step 5A: Infer groundwater dependency or groundwater recharge dependency (note that this step should only be undertaken for SW ecosystems that are dependent on GW, for all groundwater resources dependent on surface water resources proceed to Step 6B)

Consider the questions in Table 13-1 and answer the questions to the best of your knowledge given the data that has been considered in the preceding steps. The sequential questions can be used to infer groundwater dependency. This initial determination of groundwater dependency is based on a correlation with a number of factors including location, ecology and/or function of an ecosystem. This should be considered as the final step to highlighting those ecosystems that *have a high potential to be groundwater dependent.* Positive answers to the questions below do not provide any information about the nature of the dependencies or about the groundwater regime (i.e., timing of groundwater availability, volume of availability, location of surface expression etc.) needed to support the ecosystem. This process should be conducted for each area that interacts under a different conceptual model. Section 1 – 'General questions' should be filled out for all interaction areas regardless of the type of surface water resource that is anticipated. Depending on the type of surface water resource that one is assessing, answer Section 2.1 for all areas that contain streams and Section 2.2 for all areas that contain wetlands. For all areas that contain both wetlands and streams, it will be necessary to answer both Sections 2.1 and 2.2. More positive answers indicate a greater probability that there is groundwater dependency, and a higher number of negative answers indicate a lower probability of groundwater dependency. For all surface water systems that appear to be either entirely or partially dependent on groundwater, decide whether or not they are dependent on shallow/perched aquifers or on deeper aquifers.

Table 13-1: Inferring groundwater dependency. A worked example of the basalt lithologies shown Figure 13-17 is shown below

1. General questions for all groundwater dependent ecosystems (GDE)	**Yes**	**No**	**Unknown**
Is the ecosystem similar to another that is known to be groundwater dependent?	X		
Is the distribution of the ecosystem consistent with known areas of groundwater discharge?			X
Is the distribution of the ecosystem often confined to locations where groundwater is known or expected to be at a shallow depth? (Consider topography, boreholes, geology, alluvial setting of the system)	X		
Does the system withstand prolonged dry conditions without obvious signs of water stress?	X		
Does expert opinion indicate that the ecosystem is groundwater dependent?			X
2. GDE Specific Questions			
2.1. Base flow streams			
Is the stream perennial, and does streamflow increase consistently downstream during prolonged dry conditions? (Consider flow gauge data and proximal borehole data)	X		
Is the stream or sections of the stream known to be gaining; i.e., receiving water from groundwater discharge where surrounding groundwater levels are higher than the stream bed or there is groundwater up-welling?			X
Is the stream bed composed of course grained unconsolidated sediments such as sand or gravel? (Consider soil type data, geology and in-field observation)	X		
Is the aquatic invertebrate community within the surface water comprised predominantly of long lived, short range endemic species? (Consider SASS data/ infield observations)			X
Is the aquatic invertebrate community within the stream bed substrate composed of groundwater obligate (stygofauna) species?			X
2.2. Groundwater dependent wetlands			
Does the location of the wetlands suggest that they are likely to be groundwater dependent; e.g. permanent wetlands on coastal sand beds, seasonal wetlands along paleo-drainage lines, streams with consistent flow along flow path during extended dry periods? (Consider topography, slope, geology, depth to water table, flow gauges, local knowledge)		X	
Is the wetland associated with a spring or a seep? Groundwater discharge that is concentrated and occurs adjacent or in the wetland suggests groundwater may be an important source of water (Consider wetland type, landscape position, topography, slope, geology)	X		
Is there visible water in the wetlands (especially during prolonged dry periods) and do the wetlands lack surface inflow? (Consider wetland type, landscape position, topography, satellite imagery). Some permanent wetlands that lack distinct surface water inflows can be perched on hardpan soils and are isolated from groundwater.	X		
Is the vegetation, vertebrate or invertebrate community composed of species known to require permanent saturation in situations that are not obviously fed by surface water? (Consider vegetation type, satellite imagery, infield observations)			X
Is the wetland considered seasonal? Seasonal wetlands are unlikely to receive significant, season long inputs of groundwater and are likely to be maintained by surface water inputs. **Answering No to this question indicates and increased probability for groundwater dependency.**		X	

For the Upper Kraai study area, this process was undertaken for all areas where there were potentially groundwater dependent ecosystems. A worked example for the basalt lithologies shown in Figure 13-17 is presented in Table 13-1 above.

Step 5B: Infer direction of surface water dependency (note that this step should only be undertaken for surface water ecosystems that are dependent on other surface water ecosystems).

Consider the questions in Table 13-2 and answer the questions to the best of your knowledge given the data that has been considered in the preceding steps. The sequential questions can be used to infer dependency on other surface water ecosystems. This initial determination of surface water dependency is based on a correlation with a number of factors including location, ecology and/or function of an ecosystem. This should be considered as the final step to highlighting those ecosystems that *have a high potential to be surface water dependent.* Positive answers to the questions below do not provide any information about the nature of the dependencies or about the surface water regime (i.e., timing of surface water availability, volume of availability, quality of available water etc.) needed to support the ecosystem. This process should be conducted for each area that interacts under a different conceptual model. Only answer the questions relevant to the type of ecosystem that is deemed to be present in the mapped area (there may be multiple surface water ecosystems that are assessed per mapped surface water-surface water interaction area.

For the Upper Kraai study area, this process was undertaken for all areas where there were potentially surface water ecosystems that are either totally or partially dependent on water inputs from other surface water ecosystems. An example of the Klein Wildebeesspruit and Wildebeesspruit rivers is given below where there are multiple seep wetlands located in the catchment of the Klein Wildebeesspruit and Wildebeesspruit rivers which are thought to contribute in a significant way to the perenniality of the Klein Wildebeesspruit and Wildebeesspruit rivers. Additionally, multiple channelled valley-bottom wetlands were noted adjacent to the Klein Wildebeesspruit and Wildebeesspruit which are thought to be seasonally supported by flooding of the Klein Wildebeesspruit and Wildebeesspruit rivers. Additionally, it is probable that the valley-bottom wetlands are responsible for partially supporting the Klein Wildebeesspruit and Wildebeesspruit rivers during the dry season.

Table 13-2: Inferring surface water-surface water dependency. A worked example of the systems depicted in Figure 13-17 is included below.

1. Questions for Channelled Valley-Bottom and Floodplain Wetlands	**Yes**	**No**	**Unknown**
1.1 If the wetland were operating naturally, would the main source of water to the wetland be derived from the overbank flooding of the stream channel(s) running through/into the wetland? If "Yes" proceed to 1.3.	**X**		
1.2 If the answer to 1.1. is "No", is the predominant source of water derived from lateral seepage inputs? Proceed to 1.3.	**N/A**		
1.3 Is there evidence that overbank flooding still occurs periodically within the wetland? If "Yes", proceed to 1.5.		**X**	
1.4 If the answer to 1.3. is "No" is there evidence for why overbank flooding is no longer/less frequently occurring? Reasons might include inter alia: channel incision, extensive dam construction upstream, extensive flow diversions/abstraction in the catchment.	**X**		
1.5 Is there evidence that shows that water remains within the wetland areas adjacent to the stream channel(s) throughout the year? It is especially important to note this for the dry season when the streams might be low.	**X**		
2. Questions for Unchannelled Valley-Bottom Wetlands			
2.1 Is there a channel that flows into the wetland? i.e., is the wetland fed by a stream?	**N/A**		
2.2 Is there a channel that flows out of the wetland? i.e., does the wetland feed a stream?			
2.3 Are there significant lateral water inputs from seeps and/or springs?			
2.4 Is there evidence of water retention within the wetland particularly in the dry season?			
3. Questions for seasonal streams			
3.1 Is the stream located in an area where the MAP is >800mm?	**N/A**		
3.2 Is the stream a perennial stream?			
3.3 Of the total catchment area for the seasonal stream, is the proportion that is comprised of seepage and/or unchannelled valley bottom wetlands greater than 1% of the total catchment area?			
3.4 Is the stream located in a temperate or seasonal climate?			
4. Questions for perennial streams			
4.1 Is the stream located in an area where the MAP is >800mm?		**X**	
4.2 Is the stream a perennial stream?	**X**		
4.3 Of the total catchment area for the perennial stream, is the proportion that is comprised of seepage and/or unchannelled valley bottom wetlands greater than 1% of the total catchment area?	**X**		
4.4 Is the stream located in a temperate or seasonal climate?	**X**		

Step 6A: Categorise each delineated area from Step 4A to reflect inferences made in Step 5A and categorise the overall dependence of the groundwater or surface water ecosystem.

Using the decision tree in Figure 13-18, define the direction of dependency and the degree of dependency for each delineated area. Refine the mapping (where necessary) based on this delineation such that each mapped area is delineated based on a conceptual model of groundwater-surface water interaction and the degree and direction of dependency.

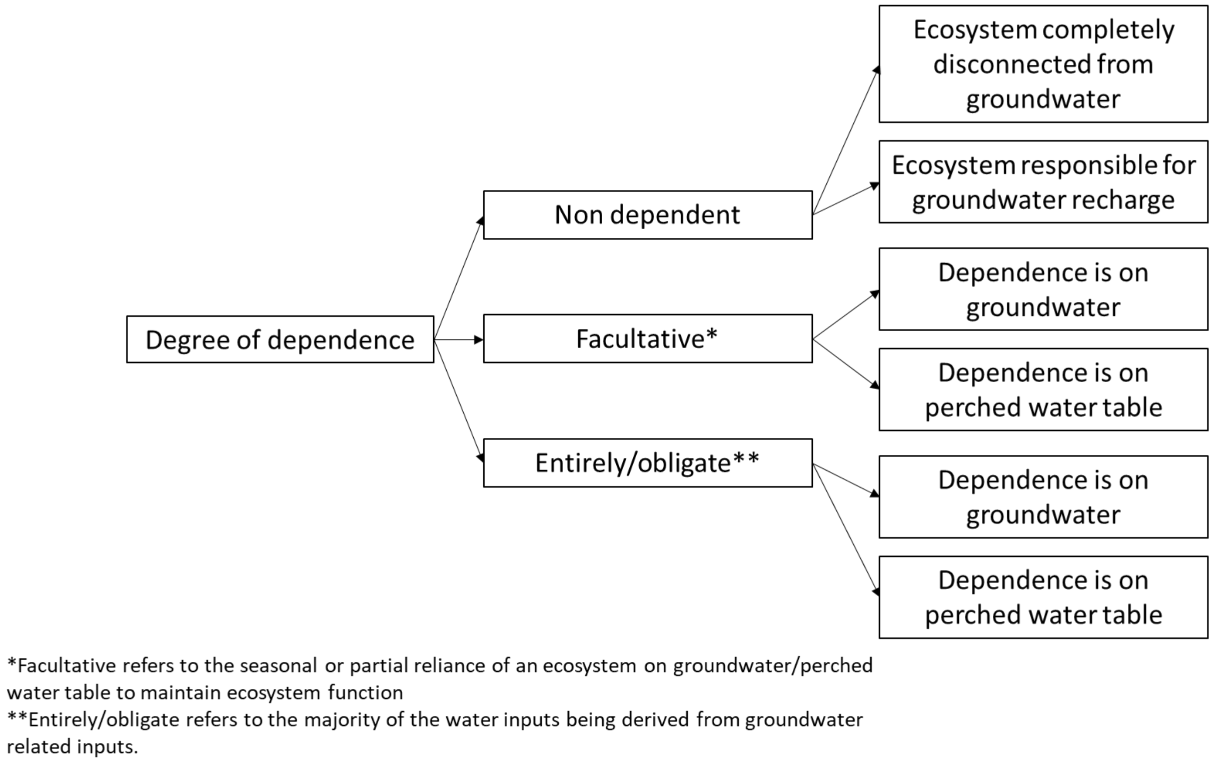
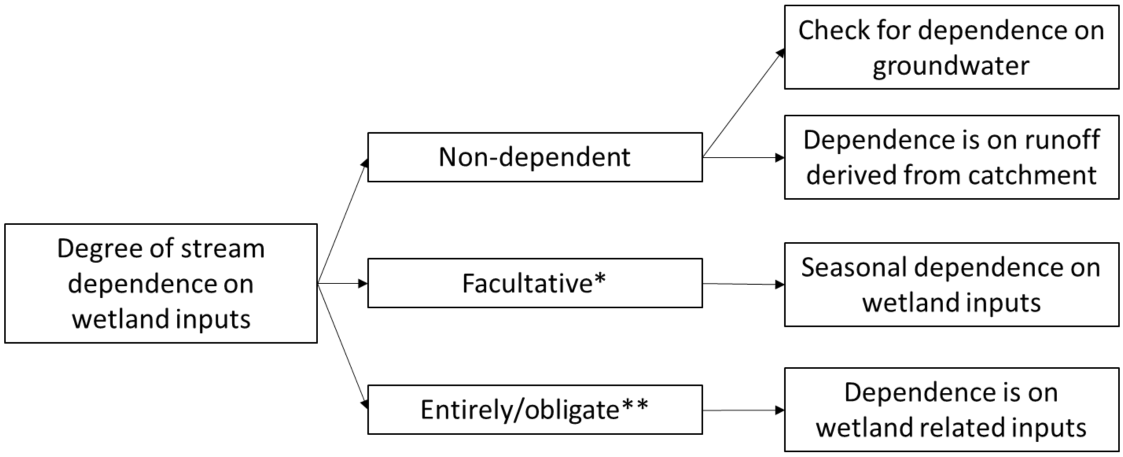


Figure 13-18: Decision tree used to categorise delineated interaction areas in terms of the degree and direction of dependence on groundwater or surface water ecosystems (adapted from Sigonyela et al., 2006).

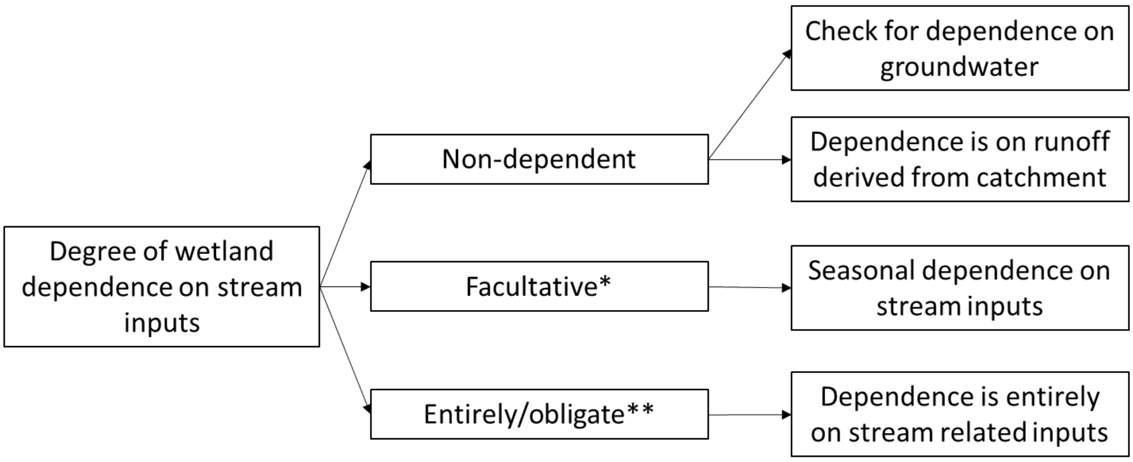
Step 6B: Categorise each delineated area from Step 4B to reflect inferences made in Step 5B and categorise the overall dependence of the surface water ecosystem on other surface water ecosystems.

Using the decision tree Figure 13-19 or Figure 13-20, define the direction and degree of dependency for each delineated area. Refine the mapping (where necessary) based on this delineation such that each mapped area is delineated based on a conceptual model of surface water-surface water interaction and the degree and direction of dependency.



*Facultative refers to the seasonal or partial reliance of an ecosystem on inputs from wetlands to maintain ecosystem function
**Entirely/obligate refers to the majority of the water inputs being derived from wetland related inputs.

Figure 13-19: Decision tree used to categorise streams in delineated interaction areas in terms of the degree and direction of dependence on wetland ecosystems (adapted from Sigonyela et al., 2006).



*Facultative refers to the seasonal or partial reliance of an ecosystem on inputs from wetlands to maintain ecosystem function
**Entirely/obligate refers to the majority of the water inputs being derived from wetland related inputs.

Figure 13-20: Decision tree used to categorise wetlands in delineated interaction areas in terms of the degree and direction of dependence on streams (adapted from Sigonyela et al., 2006).

Step 7: Update the preliminary mapping undertaken in Steps 6A and 6B to reflect the refined interaction model for the entire study area.

Further refine and update the spatial and attribute data of the GIS layer to indicate the probability of groundwater or surface water dependency.

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