DETERMINATION OF WATER RESOURCE CLASSES, RESERVE AND RESOURCE QUALITY OBJECTIVES STUDY FOR SECONDARY CATCHMENTS A5 – A9 WITHIN THE LIMPOPO WATER MANAGEMENT AREA (WMA 1) AND SECONDARY CATCHMENT B9 IN THE OLIFANTS WATER MANAGEMENT AREA (WMA 2)

EWR REPORT: RIVER ASSESSMENT

VOLUME 3 – ECOLOGICAL WATER REQUIREMENTS REPORT

FINAL DRAFT

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Cover page photo credit: View of the Luvuvhu River, Makuleke area. Photo from Lee Berger's Lanner Gorge expedition. 29 July 2007. Author Profberger at English Wikipedia

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03	WEM/WMA01&02/00/CON/RDM/0322	Delineation and Status Quo Report
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ACRONYMS

ACRONYM	DESCRIPTION
ASPT	Average Score per Taxon
BF	Base Flow Separated
BHN	Basic Human Needs
BN	Bayesian Network
DRIFT	Downstream Response to Instream Flow Transformation
Dry	Dry Season
DSS	Decision Support System
DWS	Department of Water and Sanitation
EC	Ecological Category
EFlows	Environmental Flows
EI	Ecological Importance
EIS	Ecological Importance and Sensitivity
ES	Ecological Sensitivity
EWR	Ecological Water Requirement
GSM	Gravel/Sand/Mud
GVA	Gross Value Added
GWSA	Groundwater Source Areas
IWMI	International Water Management Institute
KNP	Kruger National Park
LIMCOM	Limpopo Watercourse Commission
LoEs	Lines of Evidence
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
MIRAI	Macroinvertebrate Response Assessment Index
MSEZ	Musina-Makhado Special Economic Zone
NAT	Natural
nMAR	Naturalised Mean Annual Runoff
PES	Present Ecological Status
PO_4-P	Orthophosphate
PRS	Present day
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RQOs	Resource Quality Objectives
SA	South Africa

ACRONYM	DESCRIPTION
SASS	South African Scoring System
SC	Secondary Catchment
SnA	Southern Africa
SS	Synthetic Scenarios
SWA	Source Water Areas
SWSA	Strategic Water Source Areas
TIN	Total Inorganic Nitrogen
ToR	Terms of Reference
TPCs	Thresholds of Potential Concern
USAID	United States Agency for International Development
WMA	Water Management Area
WQ	Water Quality
WRC	Water Research Commission
WTW	Water Treatment works
WWTW	Waste Water Treatment Works

UNITS OF MEASUREMENT

%	percentage
m	meter
m^3/s	metres cubed per second
$m^3 \times 10^6$	Million cubic meters
Mm^3/a	Million cubic meters per annum
N/m^2	Newtons per square meter

ABBREVIATIONS

Q	Discharge

EXECUTIVE SUMMARY

The overall objective of the project is to classify and determine the Reserve and Resource Quality Objectives for all significant water resources in the secondary catchments (SCs) (A5-A9) of the Limpopo Water Management Area (WMA) and B9 in the Olifants WMA. The project study area spans six river catchments: Lephalala, Mogalakwena, Sand, Nzhelele and Luvuvhu in the Limpopo WMA and the Shingwedzi in the Olifants WMA.

The rivers included in the Environmental Water Requirement (EWR) assessment were:

- Lephalala River
- Rietfontein River
- Olifantspruit River
- Mogalakwena River
- Kolope River
- Sand River
- Nzhelele River
- Ṅwaneḓi River
- Mutshindudi River
- Latonyanda River
- Luvuvhu River
- Mutale River.

For the EWR assessment, the DRIFT EWR Model, hereafter referred to as DRIFT-Limpopo, was set up for 14 EWR sites (**Table E1**), i.e., one or more on each of the study rivers.

Table E1: Location and co-ordinates of the river EWR sites

No.	Node	River	EWR (DRIFT) Code	Quaternary Catchment	Latitude	Longitude
1	Riv11	Lephalala	1_Lephalala	A50B	23°59'11"S	28°24'20"E
2	Rvi1	Rietfontein	2_Rietfontein	A63C	22°34'06"S	28°37'31"E
3	Ri1	Olifantspruit	3_Olifantspruit	A61B	24°39'46"S	28°28'31"E
4	Ri5	Mogalakwena	4_Mogalakwena1	A62B	23°54'55"S	28°43'59"E
5	Ri14	Mogalakwena	5_Mogalakwena2	A63A	23°09'05"S	28°40'44"E
6	Riv32	Kolope	6_Kolope	A63E	22°13'50"S	29°14'56"E
7	Ri20	Sand	7_Sand	A71D	23°22'03"S	29°35'41"E
8	Ri27	Nzhelele	8_Nzhelele	A80G	22°28'52"S	30°15' 45"E
9	Ri28	Ṅwaneḓi	9_ Ṅwaneḓi	A80J	22°30'50"S	30°26'52"E
10	Riii6	Latonyanda	10_Latonyanda	A91D	23°02'51"S	30°13'54"E
11	Ri30	Mutshindudi	11_Mutshindudi	A91G	22°53'18"S	30°35'18"E
12	Ri32	Luvuvhu	12_Luvuvhu	A91H	22°45'42"S	30°53'41"E
13	Ri33	Mutale	13_Mutale1	A92B	22°40'26"S	30°42'11"E
14	Ri34	Mutale	14_Mutale2	A92D	22°26'17"S	31°04'39"E

The Present Ecological Status (PES) for each of the disciplines at each EWR site as well as the overall PES for each EWR site is given in **Table E2**.

Table E2: PES for each discipline at each EWR site and the overall PES of the EWR site

Discipline PES	EWR site													
	1_Lephalala	2_Rietfontein	3_Olifantspruit	4_Mogalakwena1	5_Mogalakwena2	6_Kolope	7_Sand	8_Nzhelele	9_N Ṅwaneḓi	10_Latonyanda	11_Mutshindudi	12_Luvuvhu	13_Mutale1	14_Mutale2
Hydrology	B	C	A	C	C/D	D	B	C/D	B/C	C	B	C	A	A
Geomorphology	C	C	C	C	D	D	C	C/D	D	C	C	D	C	C
Water quality	B	B/C	B	C	B/C	B/C	D	C	C	A/B	B/C	B	B	B
Vegetation	C	A/B	D	C/D	C	C	C	C	C	C/D	C	C	B/C	B
Invertebrates	B/C	B	B/C	C	C	B/C	C	C	C	B/C	C	B/C	C	C
Fish	D/E	A/B	C	C	A/B	D	C	B	B/C	B/C	C	C	C	C
PES (2022)	**C**	**B/C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**

Four scenarios were modelled in DRIFT-Limpopo:

- PES (2022), which used the climatic period of 1925-2021 with human influences such as water-resource developments, population and land use at 2022 levels.
- Reference, which used the climatic period of 1925-2021 with human influences such as water-resource developments, population and land use at *c.* 1900 levels.
- Future1, which overlaid planned 2050 water resource developments on PES (2022).
- Future2, which overlaid a dry future climate scenario on Future1.

DRIFT-Limpopo was calibrated against the PES (2022) and Reference scenarios. The Future1 and Future2 scenarios were then run through DRIFT-Limpopo to predict the effects of additional planned water-resource developments without and with a dry climate, respectively. The water-resource development plans differ between the catchments, and in some catchments there are no future water developments planned (**Table E3**) (DWS Technical Task Team meeting June 2023, pers.comm T. Nditwani 2023).

The factors considered in the Future1 scenario (**Table E4**) include increasing return flows from Waste Water Treatment Works (WWTW), raising existing dams or building new dams (increased storage), increasing releases from dams for domestic or agricultural supply, decreasing releases from dams because of increasing demands, increasing flows from inter-basin transfers, and increasing domestic, mining, industrial or agricultural water use (DWS Technical Task Team meeting June 2023, pers.comm T. Nditwani 2023).

Table E3: EWR sites where developments are planned

EWR site	Additional planned water-resource development
1_Lephalala	Yes
2_Rietfontein	No
3_Olifantspruit	No
4_Mogalakwena1	Yes
5_Mogalakwena2	Yes
6_Kolope	No
7_Sand	Yes
8_Nzhelele	Yes
9_ Ṅwanedi	Yes
10_Latonyanda	No
11_Mutshindudi	Yes
12_Luvuvhu	Yes
13_Mutale1	Yes
14_Mutale2	Yes

Table E4: Factors relevant for the Future1 scenario

EWR site	Increased return flows	New dam storage/ Increased dam storage	Incoming inter-basin transfers	Transfers of return flows out of catchment	Increased water use
1_Lephalala					X
4_Mogalakwena1	X				
5_Mogalakwena2	X				
7_Sand	X		X		X
8_Nzhelele		X			X
9_Ṅwanedi					X
11_Mutshindudi		X			X
12_Luvuvhu	X			X	X
13_Mutale1		X			X
14_Mutale2		X			

The Ecological Importance and Sensitivity (EIS) of all the sites was **MODERATE** but despite this, taking into account the other site-specific factors discussed, Recommended Ecological Categories (RECs) of one-half category higher are recommended at four of the sites along with suggestions to better manage the non-flow related causes of the PES as follows:

- 1_Lephalala: PES = C, aim for a REC of a B/C category by clearing the exotic plants and re-stocking indigenous fish.
- 2_Rietfontein: maintain the PES = REC = a B/C category.

- 3_Olifantspruit: PES = C, aim for a REC of a B/C category by clearing exotic plants and curtail further future water use to support inflows into the Nyl River for the Nyl River floodplain.
- 4_Mogalakwena1: maintain the PES = REC = a C category.
- 5_Mogalakwena2: maintain the PES = REC = a C category.
- 6_Kolope: PES = C, aim for a REC of a B/C category by continuing the efforts to curb bank instability (gabion dams) and monitor the re-establishment of the riparian vegetation.
- 7_Sand: maintain the PES = REC = a C category.
- 8_Nzhelele: maintain the PES = REC = a C category.
- 9_Ṅwanedi: maintain the PES = REC = a C category.
- 10_Latonyanda: maintain the PES = REC = a C category.
- 11_Mutshindudi: maintain the PES = REC = a C category, which will require removing the exotic plants and in particular *Mimosa pigra* that has the potential to travel downstream and grow on the Luvuvhu River Floodplain.
- 12_Luvuvhu: PES = C, aim for a REC of a B/C category by better managing nutrients in WWTW, sand mining, and clearing the exotic plants.
- 13_Mutale1: maintain the PES = REC = a C category.
- 14_Mutale2: maintain the PES = REC = a C category.

The outcomes of the scenario analyses were used to guide the options for EWRs (**Table E5**):

- For the four rivers where no additional water-resource developments are planned under the Future1 scenario, and where there are no regulating structures upstream, the PES (2022) flow regime was used as EWRs.
- For the six rivers where additional water-resource developments are included in Future1 but the expected Ecological Status is either the same or better than the present state, the PES (2022) and Future1 flow regimes were used as EWRs for the REC; PES (2022) flows for pre-development and Future1 flows for post-development.
- For the four rivers where additional water-resource developments are included in Future1 and the expected Ecological Status under Future1 is poorer than PES, Synthetic Scenarios (SS) were created to allow for development and predict a better Ecological Status than Future1. The PES (2022) flow regime is given as EWRs for pre-development with two options for post-development: the Future1 and Synthetic Scenario flow regimes.

The Synthetic Scenarios explored the effects of increasing baseflow in the dry season (mostly) to test whether the predicted Ecological Status could be improved. The increases were unrelated to the planned developments and were designed to test whether it was possible to improve the ecological outcome of the flow scenario to be better than that predicted by Future1, the water resource developments as planned. This was done to offer an alternative to the planned developments with a view to maintain better ecological conditions at the EWR sites.

Table E5: RECs and outcomes for the PES (2022), Future1 and Synthetic Scenario flow regimes at each EWR site (Mod = moderate)

Future development	EWR site	PES	EIS	REC	Future1	Future2	Synthetic Scenario		Management actions* recommended?
Yes / No					Outcome of scenario flow regime				Yes / No
No	2_Rietfontein	B/C	Mod	B/C	B/C	B/C			No
	3_Olifantspruit	C	Mod	B/C	C	C/D			Yes
	6_Kolope	C	Mod	B/C	C	C/D			Yes
	10_Latonyanda	C	Mod	C	C	C			No
Yes	1_Lephala	C	Mod	B/C	C	C/D			Yes
	4_Mogalakwena1	C	Mod	C	B/C	B/C			No
	5_Mogalakwena2	C	Mod	C	C	C			No
	7_Sand	C	Mod	C	B/C	B/C			No
	11_Mutshindudi	C	Mod	C	C	C/D			Yes
	12_Luvuvhu	C	Mod	B/C	C	C/D			Yes
	8_Nzhelele	C	Mod	C	D	D/E	SS1	C/D	No
	9_Ṅwanedi	C	Mod	C	D	D/E	SS1	C/D	No
	13_Mutale1	C	Mod	C	C/D	D	SS2	C	No
	14_Mutale2	C	Mod	C	C/D	D	SS1	C	No

** Management actions were recommended for EWR sites where the REC was one half category higher than the PES where non-flow related actions could improve the PES. For example, at 1_Lephalala the PES was brought down by the presence of exotic plants and few indigenous fish. The management actions recommended were to clear the exotic plants and to re-stock indigenous fish.*

A summary of ecological water requirements for the 14 assessed river sites are provided in (**Table E6**) with:

- Basic statistics for the naturalised (reference) flows, viz:
    - Naturalised Mean Annual Runoff (nMAR)
- The EWR and its components for maintenance of the REC as volumes and percentages of naturalized, viz.:
    - Maintenance lowflows
    - Drought lowflows
    - Maintenance highflows, which are floods that occur at least once a year, *viz*.: within-year flood events
- Total monthly volume (maintenance lowflows and highflows)
- Magnitude, duration and timing of within-year floods.

Table E6: Summary of Ecological Water Requirements

Future development? Yes / No	EWR site	EIS	REC	Scenario	Ecological category	Management actions? Yes / No	Ecological Water Requirements nMAR MCM	Low MCM	% nMAR	High MCM	% nMAR	Total MCM	% nMAR
Yes	1_Lephala	Moderate	B/C	PES (2022)	C	Yes	66.217	37.824	57.1	7.872	11.9	45.696	69
				Future1				35.825	54.1	7.773	11.7	43.557	65.8
No	2_Rietfontein	Moderate	B/C	PES (2022)	B/C	No	0.181	0.057	31.7	0.010	5.3	0.067	40
	3_Olifantspruit	Moderate	B/C	PES (2022)	C	Yes	7.815	3.385	43.3	2.616	33.5	6.002	76.8
Yes	4_Mogalakwena1	Moderate	C	PES (2022)	C	No	130.390	26.120	20.0	6.368	4.9	32.488	24.9
				Future1	B/C			29.828	22.9	7.985	6.1	37.792	29
	5_Mogalakwena2	Moderate	C	PES (2022)	C	No	188.946	39.096	20.7	4.343	2.3	43.439	23
				Future1				39.671	21	4.755	2.5	44.516	23.6
No	6_Kolope	Moderate	B/C	PES (2022)	C	Yes	1.998	0.349	17.5	0.017	0.9	0.366	18.3
Yes	7_Sand	Moderate	C	PES (2022)	C	No	23.125	4.125	17.9	1.421	6.1	5.546	24
				Future1	B/C			22.276	96.3	6.674	28.9	28.95	125.2
	8_Nzhelele	Moderate	C	PES (2022)	C	No	98.42	41.595	42.3	8.662	8.8	50.257	51.1
				Future1	D			24.584	25	4.951	5	29.535	30
				Synthetic Scenario1	C/D			27.482	27.9	4.902	5	32.383	32.9
	9_Ṅwaneḓi	Moderate	C	PES (2022)	C	No	32.578	11.872	36.4	4.42	13.6	16.292	50
				Future1	D			8.517	26.1	3.453	10.6	11.97	36.7
				Synthetic Scenario1	C/D			9.087	27.9	3.432	10.5	12.52	38.4
No	10_Latonyanda	Moderate	C	PES (2022)	C	No	23.206	13.507	58.6	3.2	13.7	16.785	72.3
Yes	11_Mutshindudi	Moderate	C	PES (2022)	C	Yes	56.420	24.108	42.7	16.703	29.605	40.811	72.335
				Future1				20.591	36.5	12.5	22.2	33.091	58.7
	12_Luvuvhu	Moderate	B/C	PES (2022)	C	Yes	388.014	114.146	29.4	37.773	9.7	151.92	39.1
				Future1				87.104	22.5	29.547	7.6	116.651	30.1
	13_Mutale1	Moderate	C	PES (2022)	C	No	121.822	56.109	46.1	31.487	25.8	87.596	71.9
				Future1	C/D			38.751	31.8	26.933	22.1	65.684	53.9
				Synthetic Scenario2	C			40.716	33.4	27.445	22.5	68.161	56
	14_Mutale2	Moderate	C	PES (2022)	C	No	153.098	67.063	43.8	36.702	24	103.765	67.8
				Future1	C/D			49.569	32.4	32	20.9	81.565	53.3
				Synthetic Scenario1	C			51.662	33.8	31.964	20.9	83.626	54.6

The rivers in the study area are part of the transboundary Limpopo River Basin, which is shared by South Africa, Botswana, Zimbabwe and Mozambique and falls under the ambit of the Limpopo Watercourse Commission (LIMCOM). An EWR assessment (O'Brien *et al*. 2022) was recently completed on the watercourse and the results from this study are outlined below.

There are five LIMCOM study sites that are all situated at the junction of these rivers in South Africa with the Limpopo River:

- The lower Lephalala River (site code LEPH-A50H-SEEKO)
- The lower Mogalakwena River (MOGA-A63D-LIMPK)
- The lower Sand River (SAND-A71K-R508B)
- The lower Luvuvhu River (LUVU-A91K-OUTPO)
- The Shingwedzi River (SHIN-B90H-POACH).

The overall PES of the LIMCOM sites was determined by combining scores for invertebrates, fish and vegetation and are provided in **Table E7** below**.**

Table E7: Summary of PES and REC for the LIMCOM study sites

E-Flow site	River	Invertebrates		Fish		Vegetation		Overall	
		PES	REC	PES	REC	PES	REC	PES	REC
LEPH-A50H-SEEKO	Lephalala River	C/D	C	D	C	C	C	C	C
MOGA-A36D-LIMPK	Mogalakwena River	D	D	D	D	C	C	C	C
SAND-A71K-R508B	Sand River	C	C	C/D	C	B/C	C	C	C
LUVU-A91K-OUTPO	Luvuvhu River	C	C	C	C	B	C	C	C
SHIN-B90H-POACH	Shingwedzi River	B/C	C	D	C	B	C	C	B/C

The EWRs for the LIMCOM sites are summarised in **Table E8**.

Table E8: Summary of EWRs for the LIMCOM study sites

Rivers	E-Flow site	nMAR ($10^6 m^3$)	%Drought	%Baseflows	%Floods	%Total
Lephalala River	LEPH-A50H-SEEKO	142	8.79	18.09	21.02	39.11
Mogalakwena River	MOGA-A36D-LIMPK	243	13.98	19.24	17.82	37.06
Sand River	SAND-A71K-R508B	74	0	9.02	23.41	32.43
Luvuvhu River	LUVU-A91K-OUTPO	560	12.29	24.1	15.97	40.06
Shingwedzi River	SHIN-B90H-POACH	87	0.93	15.57	16.34	31.91

For the WRCS, EWR information is required at a wider resolution so that the consequences of water resource developments, and other relevant scenarios, can be understood up- and downstream of the EWR sites, and on significant tributaries. The 14 EWRs from the DRIFT assessment (this study) and the 5 from the LIMCOM study (O'Brien *et al.* 2022) will go forward into the WRCS process. There are 75 nodes identified in the study area and 19 of these are where detailed EWRs have been determined. There are therefore 56 nodes that need EWRs for the WRCS process. For this purpose, the biophysical and hydrological characteristics of the rivers at the 75 nodes will be compared and the rivers will be grouped by similarity. Those with characteristics that are similar to a nearby EWR site will use the same EWR configuration as the EWR site. This may be a site on the same main-stem river or on a tributary with similar characteristics. The others will be generated using the Revised Desktop model (Birkhead et al. 2019).

A water balance will be undertaken that links all the nodes with one another in a downstream direction, so that the consequences of changes in flow on the PES of the rivers can be considered from upstream to downstream, and in the incremental tributaries. The water balance using the EWR data for 75 nodes will be reported on in the Ecological Sustainable Baseline Configuration Report (DWS 2024, Report WEM/WMA01&02/00/CON/RDM/0224).

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1 INTRODUCTION

1.1 Background

The Department of Water and Sanitation (DWS), Chief Directorate: Water Ecosystems Management initiated a three-year study for the Determination of Water Resource Classes, Reserve and Resource Quality Objectives for Secondary Catchments (SC) A5-A9 within the Limpopo Water Management Area (WMA) and SC B9 in the Olifants WMA.

The suite of Resource Directed Measures tools being implemented in these catchments aims to promote sustainable utilisation of the water resources to meet the ecological, social and economic needs of the communities dependent on them.

1.2 Objectives of the study

The overall objective of the study is to classify and determine the Reserve and Resource Quality Objectives (RQOs) for all significant water resources in SCs A5-A9 in the Limpopo WMA and SC B9 in the Olifants WMA.

The Scope of Work as stipulated in the Terms of Reference calls for:

- Implementation of the Water Resources Classification System as required in Regulation 810 in Government Gazette 33541, by classifying all significant water resources in the Limpopo WMA (SCs A5-A9) and Olifants WMA (SC B9).
- Determination of the water quantity and quality components of the groundwater and surface water (rivers and wetlands) Reserve[1].
- Determination of the RQOs using the DWS 'Procedures to Determine and Implement Resource Quality Objectives' (DWAF 2011).

The determination of the water quantity and quality components of the Ecological Reserve comprises a series of steps including Eco-Categorisation, which is the process of determining the Present Ecological Status (PES) of the groundwater and surface water (rivers and wetlands), taking into consideration the Ecological Importance and Sensitivity (EIS) of the water resources to derive a Recommended Ecological Category (REC) for which the Ecological Water Requirements (EWR) are determined. The EWR[2] is needed to support different levels of ecological health (habitat and biota) in the rivers and wetlands (Adams *et al.* 2016). Before the final EWR can be set for the determined REC, the selected development scenarios must be assessed to determine what the risk of each scenario is on meeting the REC and its associated requirements. The most feasible scenario will be selected based on providing optimum sustainable water use, but without compromising the ecological infrastructure (health providing the goods and services). This value presented as the Ecological Category is taken through to the Water Resource Classification process. It is during this phase where closer attention is given to the social and economic requirements related to water use and the future management of the

[1] The Basic Human Needs are provided in the Main EWR report.

[2] The quality, quantity and timing of flow to support ecosystem function (Adams *et al*. 2016).

studied water resources. Stakeholders participate in this process by using the risks identified when evaluating the implication of existing and planned water-resource developments on the water available for the rivers and wetlands (ecological health) and the associated predicted impacts on the selected REC. **Table** 1-1 provides the generic descriptions of the ecological condition expressed by the Ecological Category. In the WRCS, one EWR and its associated ecological category will be chosen for a river reach. This becomes the Ecological Reserve.

Table 1-1 Definitions of the ecological categories (Kleynhans 1996)

ECOLOGICAL CATEGORY	GENERIC DESCRIPTION OF ECOLOGICAL CONDITIONS	SCORE (%)
A	Unmodified/natural. Close to natural or close to predevelopment conditions within the natural variability of the system drivers: hydrology, physico-chemical and geomorphology. The habitat template and biological components can be considered close to natural or to pre-development conditions. The resilience of the system has not been compromised.	>92-100
A/B	The system and its components are in a close to natural condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a B category.	>88-≤92
B	Largely natural with few modifications. A small change in the attributes of natural habitats and biota may have taken place in terms of frequencies of occurrence and abundance. Ecosystem functions and resilience are essentially unchanged.	>82-≤88
B/C	Close to largely natural most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a C category.	>78-≤82
C	Moderately modified. Loss and change of natural habitat and biota have occurred in terms of frequencies of occurrence and abundance. Basic ecosystem functions are still predominantly unchanged. The resilience of the system to recover from human impacts has not been lost and it is ability to recover to a moderately modified condition following disturbance has been maintained.	>62-≤78
C/D	The system is in a close to moderately modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a D category.	>58-≤62
D	Largely modified. A large change or loss of natural habitat, biota and basic ecosystem functions have occurred. The resilience of the system to sustain this category has not been compromised and the ability to deliver Ecosystem Services has been maintained.	>42-≤58
D/E	The system is in a close to largely modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of an E category. The resilience of the system is often under severe stress and may be lost permanently if adverse impacts continue.	>38-≤42
E	Seriously modified. The change in the natural habitat template, biota and basic ecosystem functions are extensive. Only resilient biota may survive, and it is highly likely that invasive and problem (pest) species may dominate. The resilience of the system is severely compromised as is the capacity to provide Ecosystem Services. However, geomorphological conditions are largely intact but extensive restoration may be required to improve the system's hydrology and physico-chemical conditions.	20-≤38
F	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete change of the natural habitat template, biota, and basic ecosystem functions. Ecosystem Services have largely been lost This is likely to include severe catchment changes as well as hydrological, physico-chemical, and geomorphological changes. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible. Restoration of the system to a synthetic but sustainable condition acceptable for human purposes and to limit downstream impacts is the only option.	<20

1.3 Study area

The study area encompasses the Limpopo WMA SC A5 – A9 and the Olifants WMA SC B9 (**Figure** 1-1). The area spans six river catchments: Lephalala, Mogalakwena, Sand, Nzhelele and Luvuvhu rivers in the Limpopo WMA and the Shingwedzi River in the Olifants WMA.

There are a number of important conservation areas (**Figure** 1-1) in the study area. The Shingwedzi and the Luvuvhu Rivers flow into the Kruger National Park. The lower Luvuvhu River flows through the Luvuvhu River Floodplain that is part of the Makuleke wetland complex, a Ramsar site along the

Limpopo River. There are a number of other nature reserves near the Kruger National Park: the Thengwe Nature Reserve and the Mphaphuli Protected Environment is situated between the Mutale and Luvuvhu Rivers; the Ṅwaneḓi Nature Reserve on the Ṅwaneḓi River and the Philip Herd Nature Reserve on the Nzhelele River. The Kolope River flows through the Mapungubwe National Park into the Limpopo River and the Wonderkop Nature Reserve is situated along the lower Mogalakwena River with the Doorndraai Nature Reserve in its upper catchment. The Lephalala River flows through the Lephalala Nature Reserve and there is another Ramsar site on the upper Nyl River, the Nylsvley Nature Reserve.

Fourteen EWR sites were selected on the main rivers flowing into the Limpopo River as follows and shown in **Figure** 1-1:

- Upper Lephalala River (site code 1_Lephalala)
- Rietfontein River (2_Rietfontein)
- Olifantspruit River (3_Olifantspruit)
- Upper Mogalakwena River (4_Mogalakwena1)
- Lower Mogalakwena River (5_Mogalakwena2)
- Kolope River (6_Kolope)
- Upper Sand River (7_Sand)
- Nzhelele River (8_Nzhelele)
- Ṅwaneḓi River (9_Ṅwaneḓi)
- Latonyanda River (10_Latonyanda)
- Mutshindudi River (11_Mutshindudi)
- Luvuvhu River (12_Luvuvhu)
- Upper Mutale River (13_Mutale1)
- Lower Mutale River (14_Mutale2).

The rivers in the Limpopo WMA are part of the transboundary Limpopo River Basin, which is shared by South Africa, Botswana, Zimbabwe and Mozambique. The mainstem Limpopo River is a transboundary watercourse that falls under the ambit of the Limpopo River Commission (LIMCOM) and its four member states that recently completed an EWR assessment (O'Brien et al. 2022). There are five LIMCOM EWR study sites (**Figure** 1-1) in South Africa that are all situated at the junction of these rivers in South Africa with the Limpopo River:

- The lower Lephalala River (site code LEPH-A50H-SEEKO).
- The lower Mogalakwena River (MOGA-A63D-LIMPK).
- The lower Sand River (SAND-A71K-R508B).
- The lower Luvuvhu River (LUVU-A91K-OUTPO).
- The Shingwedzi River (SHIN-B90H-POACH).

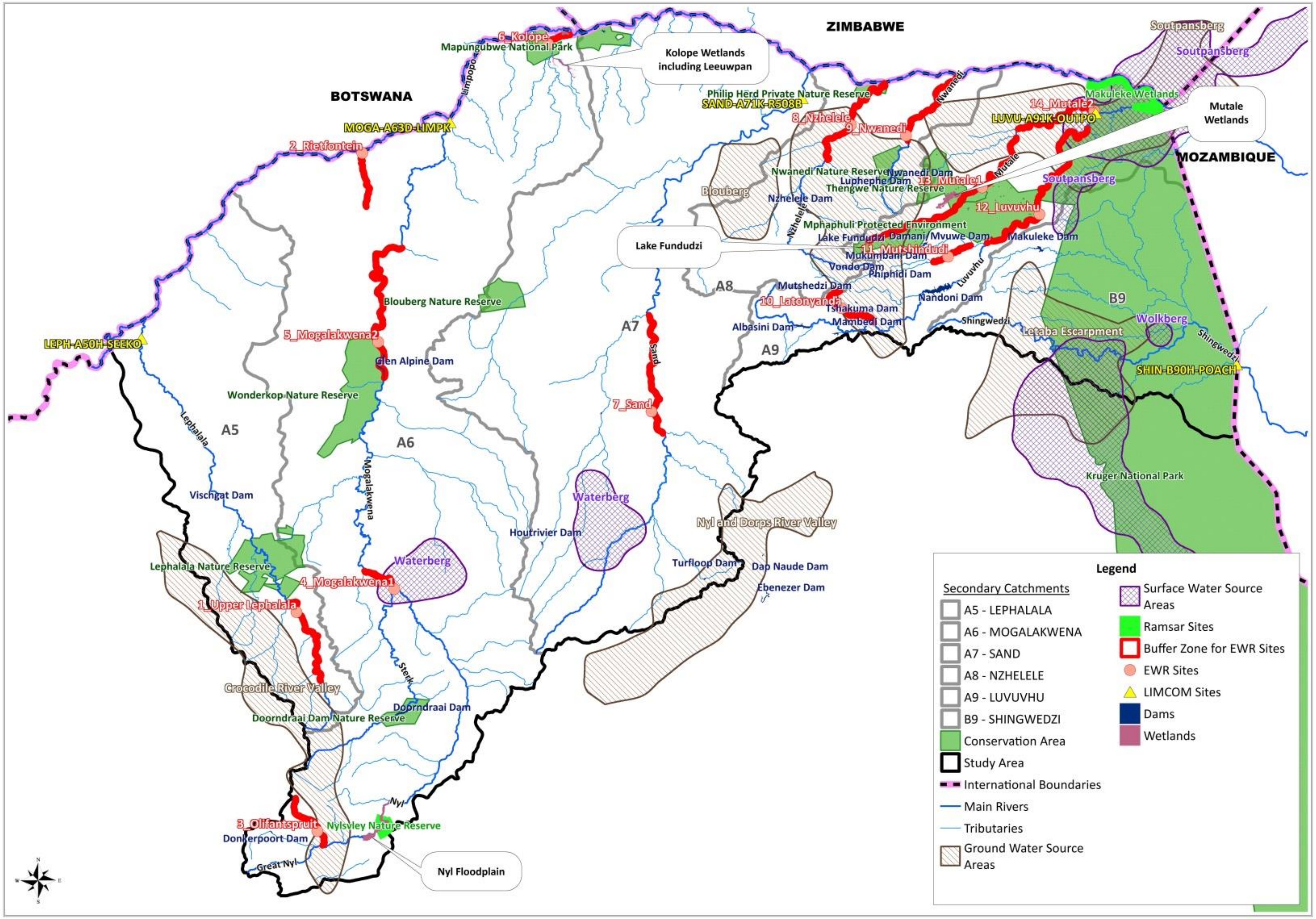


Figure 1-1 Map of the study area

1.4 The LIMCOM study

There are eight reports from the LIMCOM EWR study of the Limpopo River basin:

- E-Flows for the Limpopo River Basin – Inception Report (Dickens and O'Brien 2020)
- E-Flows for the Limpopo River Basin – Basin Description (Dickens *et al.* 2020a)
- E-Flows for the Limpopo River Basin – From Vision to Management (Dickens *et al.* 2020b)
- E-Flows for the Limpopo River Basin – Specialist Literature and Data Review (Dickens et al. 2022a)
- E-Flows for the Limpopo River Basin – Drivers of Ecosystem Change (Dickens *et al.* 2022b)
- E-Flows for the Limpopo River Basin – Ecological Responses to Change (O'Brien *et al.* 2022a)
- E-Flows for the Limpopo River Basin – Environmental Flow Determination for the Limpopo Basin (O'Brien *et al.* 2022b)
- Risk of Altered Flows to the ecosystem services of the Limpopo Basin (O'Brien *et al.* 2022c).

The Limpopo River basin study is ongoing (as at February 2024) having just entered a new phase of work in three concurrent projects:

- To harmonise the EWRs for the Limpopo River basin, which will include making use of the EWRs that were determined for the rivers in South Africa as part of this project.
- To connect and interact with various stakeholders extensively.
- To define and analyse scenarios of possible future outcomes that are likely to influence freshwater ecosystems of the Limpopo River basin.

The EWRs from South Africa will become part of the project to harmonise EWRs for the Limpopo River basin and the outcomes of scenario analyses from this EWR assessment and the WRCS process will also be considered in the analysis of LIMCOM scenarios. Likewise, the existing EWRs from the first LIMCOM project (O'Brien *et al.* 2022b) will be used in the analysis of scenarios during the WRCS process, along with those determined in this project for the two Ramsar wetlands and the rivers in this report.

The Eco-Categorisation of the five LIMCOM EWR sites and the EWRs determined are summarised in **Section 8**. The executive summary that explains the methods used (O'Brien *et al.* 2022b) is provided in **Appendix A** with permission from USAID and IWMI.

1.5 Contents of the EWR Reports - Rivers

This report is the EWR Report – Rivers (Volume 3): Ecological Water Requirements and outlines step 4 & 5 (EWR quantification and scenario analysis) of the generic procedure for the determination of the Ecological Reserve **(Figure** 1-2).

It is one of three volumes dealing with river assessment in the study:

- EWR Report – Rivers (Volume 1): Eco-Categorisation Report.
- EWR Report – Rivers (Volume 2): Data Collection and Analysis Report.
- **EWR Report – Rivers (Volume 3): Ecological Water Requirements Report.**

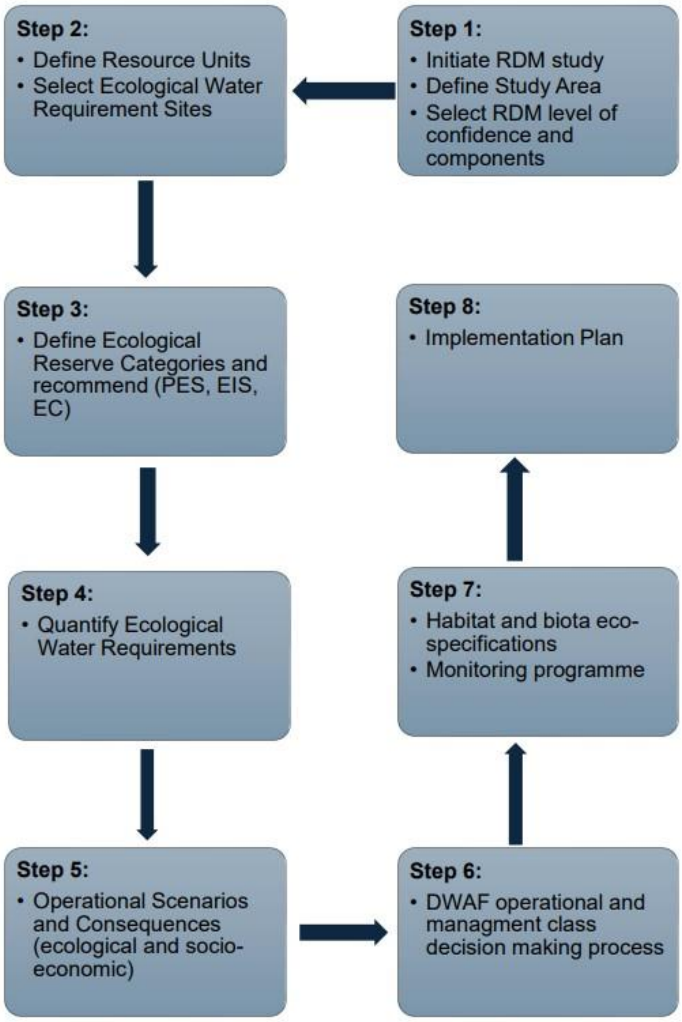


Figure 1-2: Generic steps to determine the Ecological Reserve

1.5.1 Eco-Categorisation Report (Volume 1)

In the Eco-Categorisation Report (Volume 1) there is a chapter for each river that describes the PES of each EWR site and compares it to the reference conditions expected, along with the sources of the information used to describe both the PES and the reference conditions. The causes and sources of the PES are given and trends in the PES considered. The overall ratings given for the EIS of the biota and habitats are given and notes provided for the reasoning behind the scores. The approach followed in Resource Directed Measures (RDM) is that if the EIS is high or very high, the ecological aim should be to improve the condition of the river. However, the causes related to the particular PES should also be considered to determine if improvement is realistic and attainable. This relates to whether the problems in the catchment can be addressed and mitigated. If the EIS evaluated is moderate or low, the ecological aim should be to maintain the river in its PES (Kleynhans and Louw 2007). The PES, EIS and REC are summarised at the end of each chapter for each EWR site.

1.5.2 Data Collection and Analysis Report (Volume 2)

In the **Data Collection and Analysis Report (Volume 2)** the details of the work done for each of the river components assessed are described:

- **Section 2** Hydrology
  - **Section 2.1** Describes the prevailing climate
  - **Section 2.2** Describes the water supply infrastructure
  - **Section 2.3** Describes the hydrological models used and extension of the time series'
  - **Section 2.4** Describes the hydrological time series' that were generated for the scenarios
  - **Section 2.5** Describes how an ecological category was derived for hydrological state
- **Section 3** Hydraulics
  - **Section 3.1** Describes the considerations given to selecting study sites
  - **Section 3.2** Describes the methods used to collect the hydraulic data
  - **Section 3.3** Describes the analysis and modelling of the hydraulic data
  - **Section 3.4** Provides the outputs from the hydraulic modelling, the inputs for the DRIFT model, for each of the EWR sites.
- **Section 4** Ecological Importance and Sensitivity. There is a sub-section for each EWR site that provides the ratings given to the vegetation, invertebrates and fish, and their habitat, that was used to derive the EIS for each site. A description of other factors considered to inform whether mitigation can practically be achieved and is warranted for each site is discussed. The other factors considered were: the current day flow, the location of the EWR site in relation to important conservation areas, Source Water Areas (SWA) and high priority wetlands.
- **Sections 5 – 10** (for water quality, geomorphology, riparian vegetation, aquatic macroinvertebrates, fish and socio-economics respectively) describe the EWR sites from the perspective of each river component; summarise the information used to determine the PES; describe the characteristics of the variables, habitat types and biota selected to represent the river ecosystem in the DRIFT model, and the reasons why these were selected; describe the status and trends in the different variables from 1900 to present, and; provide Ecological Specifications, Thresholds of Potential Concern (TPCs) and recommendations for monitoring.

1.5.3 Ecological Water Requirements Report (Volume 3)

In this report:

- **Section 2** summarises the steps and outcomes of the Eco-Categorisation for the 14 river sites; the PES (2022), EIS and decisions made for the REC.
- **Section 3** is an overview of DRIFT-Limpopo, including the indicators chosen to represent each of the main disciplines studied.
- **Section 4** describes the current and future water requirements and resource developments of the catchments.
- **Section 5** describes the scenarios that were assessed.
- **Section 6** summarises the ecosystem and social outcomes for the scenarios assessed.
- **Section 7** summarises the EWRs generated from DRIFT-Limpopo.
- **Section 8** summarises the outcomes of the LIMCOM study; PES, REC and EWRs.

1.6 EWR assessment method

The seven-step DRIFT process (**Figure** 1-3) (King *et al*. 2003; Joubert *et al*; **Section 3**) was used to organise three main kinds of eco-social information for the study rivers: (i) existing data; (ii) relevant data in the international scientific literature and project reports, and; (iii) expert opinion from the experienced expert team of river scientists (**Appendix B**). This knowledge base was then used to:

- select the main drivers and responders that represent the rivers
- assess the **ecological condition** of the rivers and describe this as the PES (2022)
- set up the database (or model) called DRIFT-Limpopo that will be used to run scenarios that will predict the outcomes of the future water resource developments
- predict the overall **ecological condition** of the river ecosystem under each scenario.

DRIFT-Limpopo was set up for 14 EWR sites (**Section 3**) and used to predict the outcome of the planned water resource developments on the PES of the EWR sites and whether this puts the sites at risk of not meeting their RECs. These scenarios were site specific for the reach that each EWR site represented; taken to be between any significant upstream and downstream incremental tributaries that would change the flow of water and sediment (see **Section 2.1**).

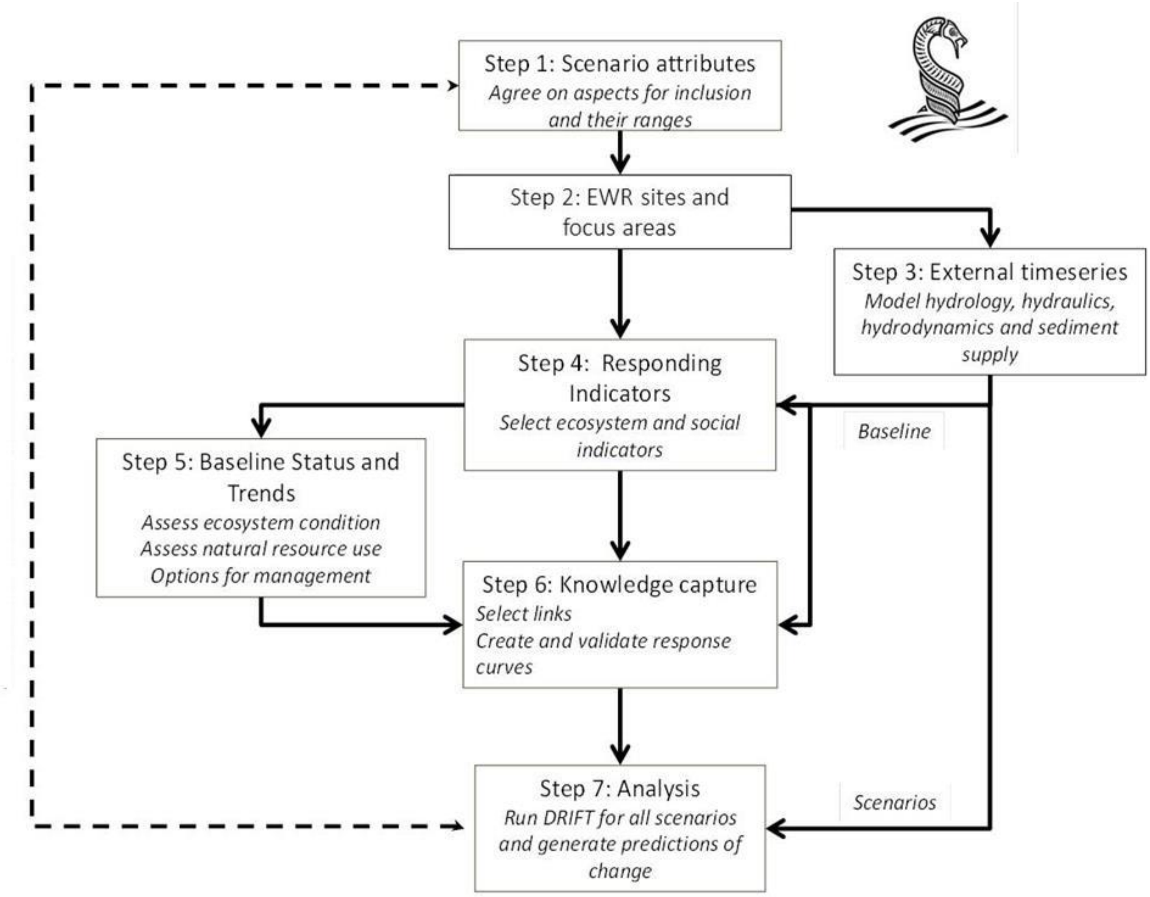


Figure 1-3 The seven-step DRIFT process

2 EWR SITES, ZONES AND ECOCATEGORISATION

2.1 EWR sites and zones

EWRs were determined at 14 EWR sites (**Table** 2-1), i.e., one or more on each of the study rivers.

Table 2-1: Location and co-ordinates of the river EWR sites

No.	Node	River	EWR (Drift) Code	Quaternary Catchment	Latitude	Longitude
1	Riv11	Lephalala	1_Lephalala	A50B	23°59'11"S	28°24'20"E
2	Rvi1	Rietfontein	2_Rietfontein	A63C	22°34'06"S	28°37'31"E
3	Ri1	Olifantspruit	3_Olifantspruit	A61B	24°39'46"S	28°28'31"E
4	Ri5	Mogalakwena	4_Mogalakwena1	A62B	23°54'55"S	28°43'59"E
5	Ri14	Mogalakwena	5_Mogalakwena2	A63A	23°09'05"S	28°40'44"E
6	Riv32	Kolope	6_Kolope	A63E	22°13'50"S	29°14'56"E
7	Ri20	Sand	7_Sand	A71D	23°22'03"S	29°35'41"E
8	Ri27	Nzhelele	8_Nzhelele	A80G	22°28'52"S	30°15' 45"E
9	Ri28	Ṅwanedi	9_Ṅwanedi	A80J	22°30'50"S	30°26'52"E
10	Riii6	Latonyanda	10_Latonyanda	A91D	23°02'51"S	30°13'54"E
11	Ri30	Mutshindudi	11_Mutshindudi	A91G	22°53'18"S	30°35'18"E
12	Ri32	Luvuvhu	12_Luvuvhu	A91H	22°45'42"S	30°53'41"E
13	Ri33	Mutale	13_Mutale1	A92B	22°40'26"S	30°42'11"E
14	Ri34	Mutale	14_Mutale2	A92D	22°26'17"S	31°04'39"E

Each EWR site represents an EWR zone (**Figure** 1-1), which extends up- and downstream to the confluence with the nearest tributary (DWS 2015). The EWR zones associated with each EWR site are:

- 1_Lephalala, downstream of the Rietbokvleispruit River to the Melk River.
- 2_Rietfontein, from source to the Limpopo River.
- 3_Olifantspruit, from source to the Nyl River.
- 4_Mogalakwena1, downstream of the Sterk River to the Mokemole River.
- 5_Mogalakwena2, downstream of the Seepabana River to the Leokeng River.
- 6_Kolope, downstream of Leeupan to the Maloutswa River.
- 7_Sand, downstream of the Dwars River to the Hout River.
- 8_Nzhelele, downstream of the Tshishiru River to the Limpopo River.
- 9_Ṅwanedi, downstream of Cross Dam to the Limpopo River.
- 10_Latonyanda, from source to the Luvuvhu River.
- 11_Mutshindudi, downstream of the Tshinane River to the Mbwedi River.
- 12_Luvuvhu, downstream of the Mutshindudi River to the Matsaringwe River.
- 13_Mutale1, downstream of Lake Fundudzi to the Mbodi River.
- 14_Mutale2, downstream of the Tshipise River to the Luvuvhu River.

2.2 Eco-Categorisation

2.2.1 Present Ecological Status (PES 2022)

The Present Ecological Status (PES 2022) for the disciplines representing the river ecosystem at each EWR site are given in **Table** 2-2, and the definitions of the categories are given in **Table** 1-1. Each discipline was given an equal weight in determining the PES.

Detail on the individual assessments is provided in:

- **EWR Report – Rivers (Volume 1): Eco-Categorisation**
- **EWR Report – Rivers (Volume 2): Data Collection and Analysis.**

Overall, the study rivers were in fair ecological condition. Thirteen of the 14 sites had an overall PES of a C, and the 14th site 2_Rietfontein was in a B/C category (**Table** 2-2).

Table 2-2: PES (2022) of all river components and the EWR sites overall

Discipline PES	EWR site													
	1_Lephalala	2_Rietfontein	3_Olifantspruit	4_Mogalakwena1	5_Mogalakwena2	6_Kolope	7_Sand	8_Nzhelele	9_N Ṅwaneḓi	10_Latonyanda	11_Mutshindudi	12_Luvuvhu	13_Mutale1	14_Mutale2
Hydrology	B	C	A	C	C/D	D	B	C/D	B/C	C	B	C	A	A
Geomorphology	C	C	C	C	D	D	C	C/D	D	C	C	D	C	C
Water quality	B	B/C	B	C	B/C	B/C	D	C	C	A/B	B/C	B	B	B
Vegetation	C	A/B	D	C/D	C	C	C	C	C	C/D	C	C	B/C	B
Invertebrates[3]	B/C	B	B/C	C	C	B/C	C	C	C	B/C	C	B/C	C	C
Fish[4]	D/E	A/B	C	C	A/B	D	C	B	B/C	B/C	C	C	C	C
PES (2022)	**C**	**B/C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**

The PES of most of the components were in a C category or higher (**Table** 2-2), except for:

- D/E for fish at 1_Lephalala
- D for riparian vegetation at 3_Olifantspruit
- C/D for riparian vegetation at 4_Mogalakwena
- D for geomorphology at 5_Mogalakwena
- D for geomorphology and fish at 6_Kolope

[3] 'There were no invertebrate data collected at the non-perennial sites (2_Rietfontein, 6_Kolope, 7_Sand) because they were dry. However, to acknowledge that there would be invertebrates in these rivers a PES score for these sites for this discipline was made based on specialist opinion and discussions during the workshop held in July and September 2023. The PES estimates are low confidence.'

[4] 'There were no fish data collected at the non-perennial sites (6_Kolope, 7_Sand) because they were dry. However, to acknowledge that there would be fish in these rivers a PES score for these sites for this discipline was made based on specialist opinion and discussions during the workshop held in July and September 2023. The PES estimates are low confidence.'

- D for water quality at 7_Sand
- C/D for geomorphology at 8_Nzhelele
- D for geomorphology at 9_Ṅwaneḓi
- C/D for riparian vegetation at 10_Latonyanda
- D for geomorphology at 12_Luvuvhu.

2.2.2 Ecological Importance and Sensitivity

The Ecological Importance of a river is an expression of its importance to the maintenance of biological diversity and ecological functioning on local and wider scales. Ecological Sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred, called resilience (Kleynhans and Louw 2007).

The EIS was assessed using the DWS ratings for riparian, invertebrate and fish biota and instream habitats using the scoring system shown in **Table** 2-3. Detail on the EIS assessments is given in **EWR Report – Rivers (Volume 2): Data Collection and Analysis.**

Table 2-3: Determinants rated to determine EIS

Ecological Importance and Sensitivity Determinants (Kleynhans and Louw 2007)
BIOTA (RIPARIAN & INSTREAM)
Rare & endangered (range: 4=very high - 0 = none)
Unique (endemic, isolated, etc.) (range: 4=very high - 0 = none)
Intolerant (flow & flow related water quality) (range: 4=very high - 0 = none)
Species/taxon richness (range: 4=very high - 1=low/marginal)
RIPARIAN & INSTREAM HABITATS
Diversity of types (4=Very high - 1=marginal/low)
Refugia (4=Very high - 1=marginal/low)
Sensitivity to flow changes (4=Very high - 1=marginal/low)
Sensitivity to flow related water quality changes (4=Very high - 1=marginal/low)
Migration route/corridor (instream & riparian, range: 4=very high - 0 = none)
Importance of conservation & natural areas (range, 4=very high - 0=very low)

The EIS rating per discipline at each site and for the EWR site overall is given in **Table** 2-4**.**

Table 2-4: EIS rating for each biological discipline and overall for the EWR site (H = High, M = Moderate; L = Low)

Discipline EIS	EWR site													
	1_Lephalala	2_Rietfontein	3_Olifantspruit	4_Mogalakwena1	5_Mogalakwena2	6_Kolope	7_Sand	8_Nzhelele	9_N Ṅwanedi	10_Latonyanda	11_Mutshindudi	12_Luvuvhu	13_Mutale1	14_Mutale2
Vegetation	M	L	L	L	M	L	L	M	L	L	M	L	H	M
Invertebrates	M		M	M	M			H	M	M	H	M	M	H
Fish	H	L	H	H	H	M	M	H	M	H	H	H	H	H
OVERALL EIS RATING (MEDIAN)	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**

Once the scores are assessed, further consideration is given to other factors that help to inform whether mitigation can be practically achieved and is warranted. The other factors considered were:

- The current day flow (Mean Annual Runoff, MAR) as a percentage of the naturalised (reference) MAR (**Table** 2-5).
- The location of the EWR site in relation to (Figure 1-1):
    - Important conservation areas, nature reserves and National Parks
    - Strategic Water Source Areas (SWSA)
    - Groundwater Source Areas (GWSA)
    - High Priority wetlands and Ramsar sites in particular.

Table 2-5: Hydrological metrics at EWR sites

Metrics	1_Lephalala	2_Rietfontein	3_Olifantspruit	4_Mogalakwena	5_Mogalakwena	6_Kolope	7_Sand	8_Nzhelele	9_Ṅwanedi	10_Latonyanda	11_Mutshindudi	12_Luvuvhu	13_Mutale	14_Mutale
Naturalised (MCM)	67.6	0.2	8.1	73.4	193.3	2.1	27.4	99.7	33.5	64.3	127.9	398.5	149.7	154.9
Current (MCM)	56.2	0.1	7.6	53.9	114.3	1.1	23.5	59.6	26.6	47.6	105.5	247.8	138.6	143.6
%nMAR	83	76	94	74	59	51	86	60	80	74	82	62	93	93
Flow Category	B	C	A	C	C/D	D	B	C/D	B/C	C	B	C	A	A

2.2.3 Recommended Ecological Category

The approach followed in Resource Directed Measures studies is if the EIS is high or very high, the ecological aim should be to improve the condition of the river. However, the causes related to the particular PES should also be considered to determine if improvement is realistic and attainable. This relates to whether the problems in the catchment can be addressed and mitigated. If the EIS evaluated is moderate or low, the ecological aim should be to maintain the river in its PES (Kleynhans and Louw 2007).

Within the Ecological Reserve context, Ecological Categories A to D can be recommended as future states (REC), depending on the EIS and PES. Ecological Categories E and F are regarded as ecologically unacceptable, and remediation is needed (Kleynhans and Louw 2007).
The REC put forward for each EWR site are given in **Table** 2-6**.**

Table 2-6: PES, EIS and REC for EWR sites

Discipline	EWR site													
	1_Lephalala	2_Rietfontein	3_Olifantspruit	4_Mogalakwena1	5_Mogalakwena2	6_Kolope	7_Sand	8_Nzhelele	9_Ṅwanedi	10_Latonyanda	11_Mutshindudi	12_Luvuvhu	13_Mutale1	14_Mutale2
PES (2022)	C	B/C	C	C	C	C	C	C	C	C	C	C	C	C
EIS	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod
REC	B/C	B/C	B/C	C	C	B/C	C	C	C	C	C	B/C	C	C

The EIS of all the sites was MODERATE but despite this, taking into account the other site-specific factors discussed, RECs of one-half category higher are recommended at four of the sites along with suggestions to better manage the non-flow related causes of the PES as follows:

- 1_Lephalala: PES = C, aim for a REC of a B/C category by clearing the exotic plants and re-stocking indigenous fish.
- 2_Rietfontein: maintain the PES = REC = a B/C category.
- 3_Olifantspruit: PES = C, aim for a REC of a B/C category by clearing exotic plants and curtail further future water use to support inflows into the Nyl River for the Nyl River floodplain.
- 4_Mogalakwena1: maintain the PES = REC = a C category.
- 5_Mogalakwena2: maintain the PES = REC = a C category.
- 6_Kolope: PES = C, aim for a REC of a B/C category by continuing the efforts to curb bank instability (gabion dams) and monitor the re-establishment of the riparian vegetation.
- 7_Sand: maintain the PES = REC = a C category.
- 8_Nzhelele: maintain the PES = REC = a C category.
- 9_Ṅwanedi: maintain the PES = REC = a C category.
- 10_Latonyanda: maintain the PES = REC = a C category.

- 11_Mutshindudi: maintain the PES = REC = a C category, which will require removing the exotic plants and in particular *Mimosa pigra* that has the potential to travel downstream and grow on the Luvuvhu River Floodplain.
- 12_Luvuvhu: PES = C, aim for a REC of a B/C category by better managing nutrients in WWTW, sand mining, and clearing the exotic plants.
- 13_Mutale1: maintain the PES = REC = a C category.
- 14_Mutale2: maintain the PES = REC = a C category.

3 OVERVIEW OF DRIFT-LIMPOPO

DRIFT-Limpopo is a model and database of eco-social information and knowledge used to predict potential changes to the study rivers because of human pressures, such as amongst others water-resource developments, plant harvesting, mining and agricultural practices.

3.1 Modules

DRIFT-Limpopo comprises three modules **(Figure** 3-1): Setup, Knowledge Capture, and Analysis.

These three modules, with all their components, are presented within the cream block at the bottom of **Figure** 3-1. The elements that provide input to and outputs from these are indicated in the area above the cream block.

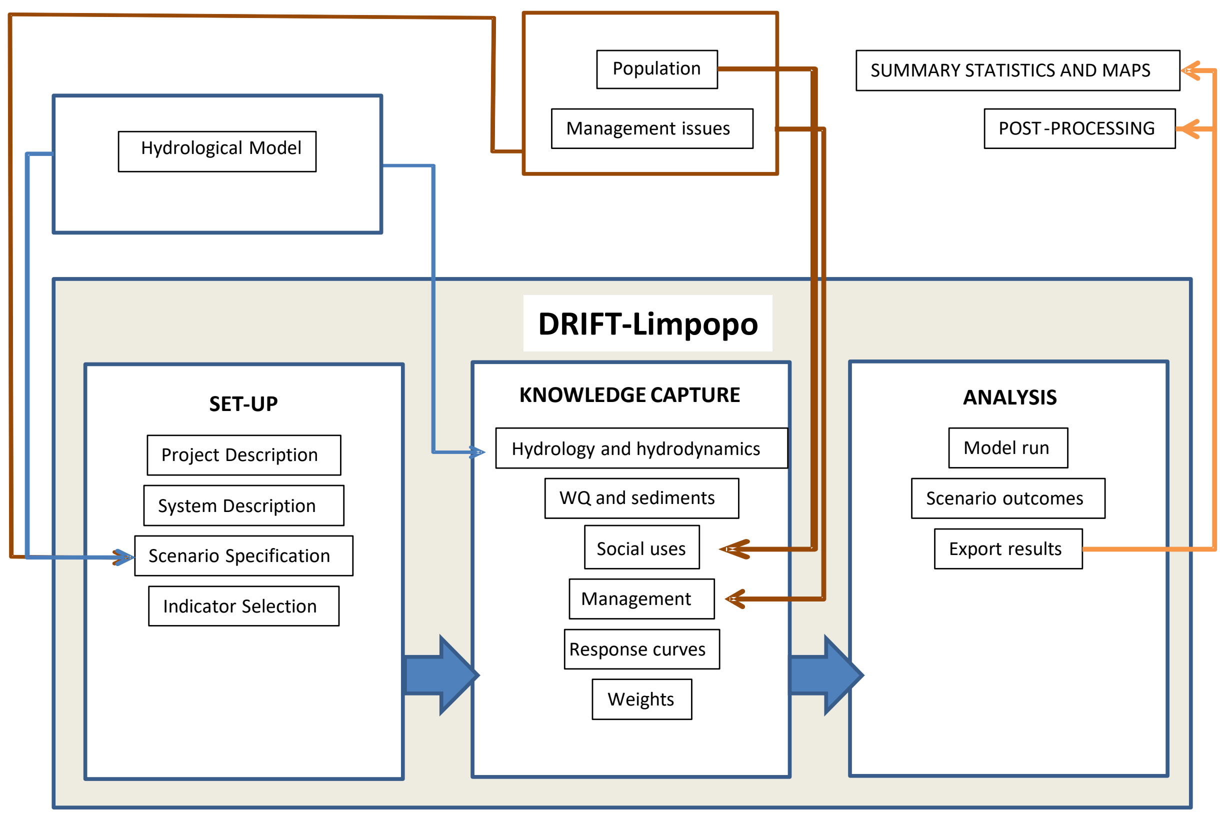


Figure 3-1: Arrangement of modules in DRIFT-Limpopo (light-brown shading) and inputs/ outputs from/ to external models/ data sources

The first two modules deal with the setup, population and calibration of the flow-eco-social relationships that are used to predict the ecosystem response to potential development /management actions. The third module is used to generate results once the first two modules have been configured, and to export the output data detailing the predictions for the configurations under consideration to MS Excel for post-processing and reporting.

3.2 Representative reaches and sites

DRIFT-Limpopo focuses on the EWR sites/zones described in **Section 2**. The designated EWR sites in each zone were the focus for all data collection/collation, hydrological/hydraulic modelling, selection of drivers (Hydrology, hydraulics, habitat and water quality) and responders (riparian vegetation, aquatic macroinvertebrates and fish), and reporting.

3.3 Disciplines

The hydrology for the study rivers is described in **Section 5.1**, and the hydrological and hydraulic modelling are described in the **EWR Report – Rivers (Volume 2): Data Collection and Analysis.**

In DRIFT-Limpopo, the river ecosystems are represented by six disciplines:

- Geomorphology
- Water quality
- Vegetation
- Macroinvertebrates
- Fish
- Social use.

The supporting information gathered and data collected for the disciplines and the indicators selected to represent them are provided in the **EWR Report – Rivers (Volume 2): Data Collection and Analysis.**

3.4 Hydro-biological flow seasons

DRIFT uses four hydro-biological flow seasons:

- **Dry Season** (Dry). Flows are much less than the annual average and there is relatively little *natural* flow variability from day to day.
- **Transition Season 1** (T1). A time of transition between the end of the Dry Season and the start of the Flood Season. Flows increase but not necessarily rapidly. A number of spates or 'freshets' might typically signify a number of false starts to the Flood Season, with flows receding again after each one.
- **Flood/Wet Season** (Flood). This is initially characterized by a number of periods of accelerated rates of increasing flow until the annual peak discharge is reached. There may be a number of pulses in this process but overall there is a clear **single flood-pulse hydrograph**.
- **Transition Season 2** (T2). A second transition season between the end of the Flood Season and the start of the Dry Season, during which time the rate of flow recession remains higher than in the Dry Season. In some years there may be late but relatively minor spate events etc. (freshets).

3.5 Indicators and links

The discipline-specific representatives of the river ecosystems and the links between driving and responding indicators derived by the river EWR team are described in the **EWR Report – Rivers (Volume 2): Data Collection and Analysis.** The hydrological and hydraulic data for the drivers were generated outside of the DRIFT-Limpopo (**Section 3.5.1**). Others are internal eco-social indicators (**Section 3.5.2**) whose predicted changes are provided through response curves in DRIFT-Limpopo.

3.5.1 Hydrology input data and indicators

DRIFT-Limpopo used modelled hydrology as the main (driving) input data.

All the time-series use the same period: 1925-2021. Once imported into DRIFT-Limpopo, the time-series' were summarized into **ecologically relevant 'driver' indicators**, reported as annual values or as values for one or more of four hydro-biological flow seasons (**Section 3.4; Table** 3-1):

- Dry Season (Dry).
- Transition Season 1 (T1)
- Flood/Wet Season (Flood)
- Transition Season 2 (T2).

The indicators created using these time-series' and the seasons for which they were calculated are provided in **Table** 3-1.

The first sets of data produced for each EWR zone were the PES (2022) and naturalised scenarios against which the DRIFT-Limpopo was calibrated:

- PES (2022), which used the climatic period of 1925-2021 with human influences such as water-resource developments, population and land use at 2022 levels.
- Reference, which used the climatic period of 1925-2021 with human influences such as water-resource developments, population and land use at C 1900 levels.

Thereafter, simulated time-series over the same period were produced for the scenarios (**Section 4**), and relative change linked to the scenarios is reported relative to PES (2022).

3.5.2 Internal eco-social indicators

Eco-social indicators are a set of indicators that represent the riverine ecosystem and resources used by humans that are reliant on the ecosystem and human pressures on those resources. They are deemed to be sensitive to a change in the driver indicators in **Table** 3-1 by changing in one of the following ways:

- abundance/size, e.g., fish
- extent (area), e.g., cover of riparian tree community on upper dry bank
- concentration, e.g., sediments and nutrients.

Table 3-1: DRIFT-Limpopo hydrology and hydraulic input data and indicators

Discipline	Season	Indicator	Units
Hydrology	Annual	Mean annual runoff	m^3/s
		Zero flow days per year	days
		Days continuous depth > 5 cm	
		Days continuous depth > 10 cm	
	Dry Season	Onset	calendar week
		Duration	days
		Minimum 5-day discharge	m^3/s
		Average daily volume	$m^3 \times 10^6$
	Transition Season 1	Average daily volume	
		Duration	days
	Flood/Wet Season	Onset	hydrological week
		Duration	days
		Maximum 5-day discharge	m^3/s
		Maximum instantaneous discharge	
		Maximum 5-day baseflow discharge	
		Average daily volume	$m^3 \times 10^6$
		Volume	
	Transition Season 2	Average daily volume	
		Duration	days
River hydraulics (for all seasons above, at one or two selected cross-sections at each EWR site)		Average shear stress	N/m^2
		Minimum (of average) depth	m
		Maximum (of average) depth	
		Minimum (of average) velocity	m/s
		Average (of maximum) velocity	
		Maximum (of average) velocity	
		Average fast very shallow flow	% cross-section
		Average fast shallow flow	
		Average fast deep flow	
		Average slow deep flow	
		Average slow very shallow flow	
		Average slow shallow flow	
		Average slow deep flow	

Indicator selection in each discipline took due consideration of the relevance for the other disciplines. For instance, the geomorphological indicator 'pool depth' was selected because pools are an important habitat for fish, and are subject to scour or infilling with sand or silt. The indicators, the reasons for their selection and the driving links are discussed in greater detail in the **EWR Report – Rivers (Volume 2): Data Collection and Analysis**.

The value of an indicator may change with scenarios, and in doing so, drive other indicators to change. For instance, responders to one driver (e.g., pool depth declining as sediment loads increase) can become drivers themselves (e.g., change in pool depth affects some fish species), thus driving further change (e.g., reduction in fish catch, this has a knock-on effect for birds for instance as well). The simplified linkages between disciplines are shown in **Figure** 3-2 thus mask the suite of driver-response links used in the analyses (see **EWR Report – Rivers (Volume 2): Data Collection and Analysis**). Each line in **Figure** 3-2 represents a response curve drawn by the specialists and housed in the DRIFT-Limpopo; along with a motivation for its shape. For instance, at EWR site 10_Latonyanda there were 234 response curves. There were similar numbers of response curves for the other EWR sites.

The DRIFT-Limpopo database thus forms a knowledge base set up by the EWR specialists using existing knowledge and understanding about the functioning of the aquatic ecosystems. In this study the database was interrogated to analyse a suite of EWR scenarios, but it is also available to test other scenarios as part of future studies or planning initiatives.

The full list of drivers and responders used for each discipline is provided in **Table** 3-2. These were selected because of their importance in the functioning of the ecosystem and also, in the case of the fauna, because they represent wider groups of species and/or species of particular conservation concern. A description of each indicator in **Table** 3-2, the reasons for its selection, its links and explanations/supporting references for the response curves for the river are presented in the **EWR Report – Rivers (Volume 2): Data Collection and Analysis**.

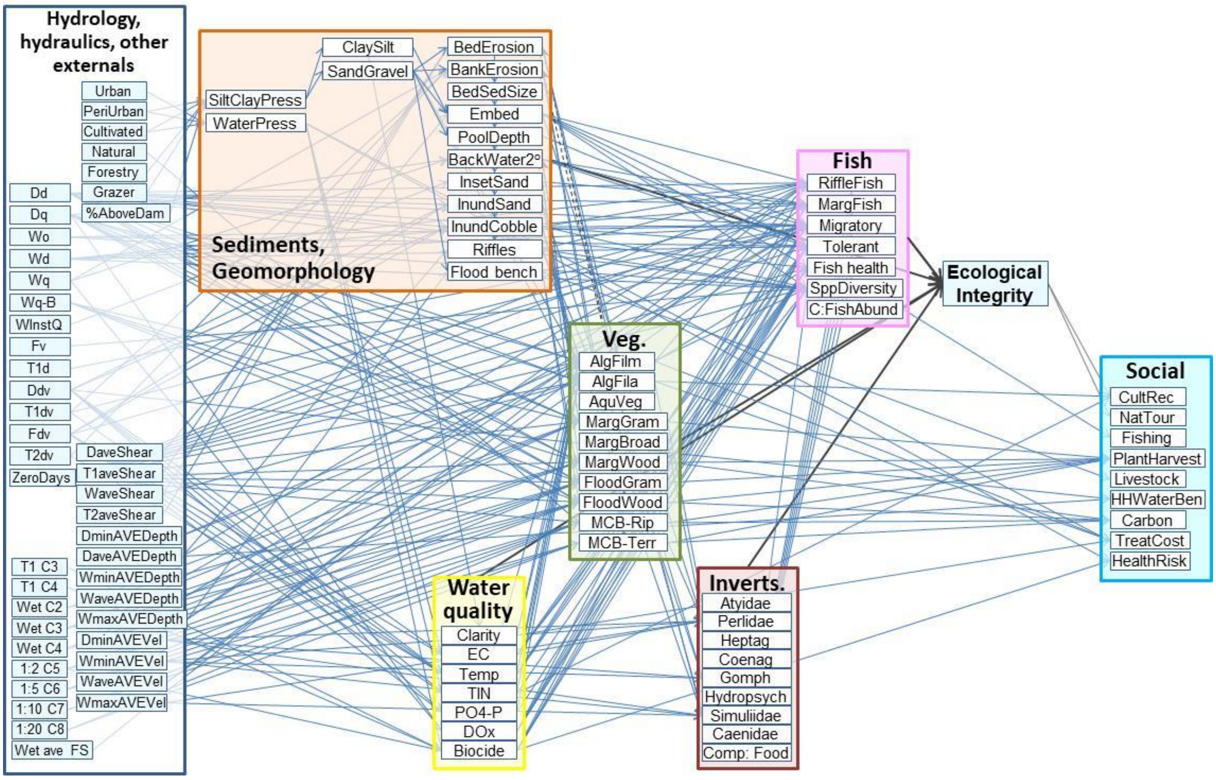


Figure 3-2: Discipline-level assessment framework for EWR sites in DRIFT-Limpopo. Each line is represented by a response curve

Table 3-2: DRIFT-Limpopo eco-social indicators

Indicators	EWR site													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discipline: Water quality														
Water clarity														
Electrical conductivity														
Water temperature														
Total inorganic nitrogen (TIN)														
Orthophosphate (PO_4-P)														
Dissolved oxygen														
Biocides														
Discipline: Geomorphology														
Clay silt FPOM supply														
Sand gravel supply														
Bed erosion														
Bank erosion														
Bed sediment size														
Embeddedness														
Pool depth														
Backwaters and secondary channels														
Inset bench and sand bars														
Inundated sandy habitat														
Inundated cobble habitat														
Riffles														
Flood benches														
Discipline: Vegetation														
Algal biofilms														
Filamentous algae														
Aquatic vegetation														
Marginal zone graminoids (grass like plants)														
Marginal zone broadleaf plants														
Marginal zone woody vegetation														
Flood bench graminoids														
Flood bench woody vegetation														
Macrochannel bank riparian trees														
Macrochannel bank terrestrial woody plants														
Discipline: Aquatic macroinvertebrates														
Atyidae (shrimps)														
Perlidae (stone files)														
Heptageniidae (flat-head mayflies)														
Coenograionidae (sprites and blues)														
Gomphidae (club-tailed dragonflies)														
Hydropsychidae (caddisflies)														
Simulidae (blackflies)														
Caenidae (cainflies)														
Composite[5]: Invertebrate food for fish														
Discipline: Fish														
Rocky riffle fish														
Quiet vegetated water fish														
Migratory fish														

[5] The sum of the invertebrate responders when grouped together, to create a driver for fish food.

Indicators	EWR site													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tolerant species														
Fish health														
Species diversity														
Composite: fish abundance[6]														
Discipline: Social														
Recreation, cultural value														
Nature tourism value														
Fisheries value														
Plant resource value														
Household water benefits														
Subsistence livestock grazing														
Carbon retention value														
Water treatment costs														
Health risk														
Discipline: Pressures														
Pressures affecting sediment supply														
Pressures affecting sand gravel and cobble														
Pressures affecting water quality														

3.6 Response curves

Response curves are housed in DRIFT-Limpopo and depict the relationship between an eco-social indicator and a driving variable (e.g., discharge).

A response curve for the relationship between erosion and the maximum discharge in the wet season is shown in **Figure** 3-3.

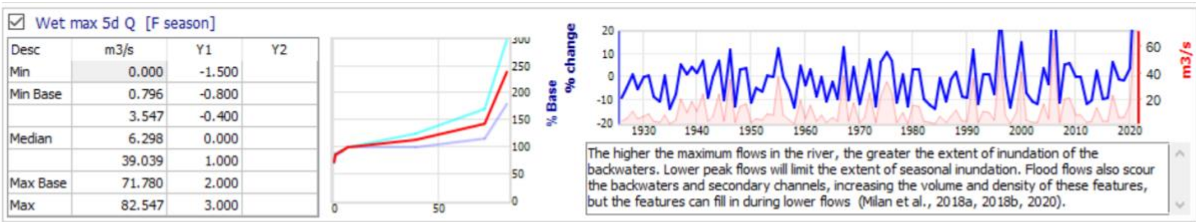


Figure 3-3: A snap-shot from DRIFT-Limpopo showing one of the geomorphology response curves and explanations for backwaters and secondary channels at 1_Lephalala

In **Figure** 3-3, the red line in the first graph is the mean response, and the light blue and darker blue lines represent the uncertainty (upper and lower limits). In the second graph (time-series), the solid pink series shows the annual values for the linked indicator, e.g., maximum discharge in the wet season. The blue lines in these time-series graphs show the modelled annual response of backwaters and secondary channels to the PES (2022) variations for the linked indicator only, i.e., excluding any responses to other drivers. These variations are around the mean PES (2022) values of 100% for the indicator.

[6] The sum of the abundance of rocky riffle, quiet vegetated water, migratory and tolerant fish.

The units on the x-axis depend on the driving indicator under consideration. For instance, for the maximum discharge in the wet season (**Figure** 3-3), these are in m^3/s. The y-axis may refer to abundance as in **Figure** 3-3, but also to other measures such as concentration or area, depending on the indicator. Response curves were constructed using severity ratings (**Table** 3-3).

Table 3-3: DRIFT severity ratings and their associated gains and losses – a negative score means a loss in abundance relative to PES (2022), a positive means a gain

Severity rating	Severity	% abundance change
5	Critically severe	501 % gain to ∞ up to pest proportions
4	Severe	251-500 % gain
3	Moderate	68-250 % gain
2	Low	26-67 % gain
1	Negligible	1-25 % gain
0	None	no change
-1	Negligible	80-100 % retained
-2	Low	60-79 % retained
-3	Moderate	40-59 % retained
-4	Severe	20-39 % retained
-5	Critically severe	0-19 % retained includes local extinction

Each response curve is accompanied by an explanation of its importance and the relationship it depicts. For the example in **Figure** 3-3, the explanation for the backwaters and secondary channels response curve reads as follows: "*The higher the maximum flows in the river, the greater the extent of inundation of the backwaters. Lower peak flows will limit the extent of seasonal inundation. Flood flows also scour the backwaters and secondary channels, increasing the volume and density of these features, but the features can fill in during lower flows (Milan et al. 2018a, 2018b, 2020)".*

The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations refer to conditions that are unlikely to occur under any of the water-resource development scenarios but are needed for completion of the response curves. In addition, each response curve assumes that all other driving indicators are at PES (2022).

The response curves are used to evaluate scenarios by taking the value of the flow indicator for any one scenario and reading off the resultant values for the eco-social indicators from their respective response curves. For each year of the hydrological record, and for each eco-social indicator, the severity rating corresponding to the value of a driving indicator is read off its Response Curve and converted to a percentage change. The severity ratings for each driving indicator are then combined to produce an overall change in abundance for each season, which provide an indication of how abundance, area or concentration of an indicator is expected to change under the given flow conditions over time, relative to the changes that would have been expected under PES (2022) conditions.

3.7 Major assumptions and limitations

Predicting the effect of changes in flow, sediment and human pressures on rivers is difficult because the actual trajectory and magnitude of the change is dependent on so many other variables, such as climate, politics, road networks, economics and regulations. Thus, several assumptions and limitations apply to DRIFT-Limpopo:

- The modelled time-series of flow and other drivers of ecosystem condition approximate the actual conditions in the river over the period of record, and for the development levels selected. Should this not be the case, then the PES (2022) for the scenarios would be different to that used and so the scenario predictions, which are relative to this PES (2022), could also change. For instance, if the PES (2022) hydrological time-series was changed, then the scenario predictions would change.
- Capturing the complexity of the system is confounded by the paucity of data. This is a universal problem, as by their nature human interactions with ecosystems are complex. Complete certainty of the present and possible future characteristics of the ecosystems is not realistic. However, it is essential to proceed cautiously, and aid decision-making using best available information. The alternative is that development and management decisions are made without consideration of the consequences for the supporting ecosystems, eventually making management of sustainability impossible. Data paucity was addressed in DRIFT-Limpopo by accessing as much available knowledge as possible within the constraints of the ToR using general scientific understanding; international scientific literature; local wisdom and insights from people who have worked in the rivers of the region. This information was captured in a structured process that is transparent, with the inputs and outputs checked at every step. The response curves (and the reasoning used to construct them) are available for scrutiny within DRIFT-Limpopo. They can (and should be) updated as new information becomes available and new insights gained.

These inherent uncertainties mean that attention should be directed toward trends in the sequence of scenarios and the position of scenarios relative to each other, rather than towards absolute values.

4 CURRENT AND FUTURE WATER REQUIREMENTS AND RESOURCE DEVELOPMENTS OF THE CATCHMENTS

4.1 Overview

This chapter provides an overview of the current and future water requirements and associated water resource development in each secondary catchment within the study area, which informed the development of the Future Scenarios.

The date for assessing the current water requirements was set at 2020. The extent of water abstraction to meet the current water requirements and the return flows from the wastewater treatment works were based on the Green Drop assessments undertaken in 2021/22.

4.2 Lephalala River Catchment

4.2.1 Current water requirements and existing water resource infrastructure

The existing water resources infrastructure in the Lephalala River catchment is shown in **Figure** 4-1 and **Table** 4-1. As illustrated in the figure and table:

- The EWR site is located in the upper Lephalala catchment. The significant water use in the catchment is irrigation agriculture from the farm dams in the tributaries of the Lephalala River. These farm dams are situated downstream of the EWR and will not impact the immediate reach downstream of the EWR.
- Further downstream are rural communities that abstract water from run-of-river and groundwater for consumptive purposes.
- The following can be noted from **Table** 4-1:
    - The most significant water requirement in the Lephalala catchment is irrigation agriculture. Since this is not supplied from regulated sources, the assurance of supply for agriculture is very low. Some, if not most, of the agriculture is considered opportunistic irrigation.
    - Livestock farming is the second largest water requirement, with domestic water requirements dependent on run-of-river abstraction.

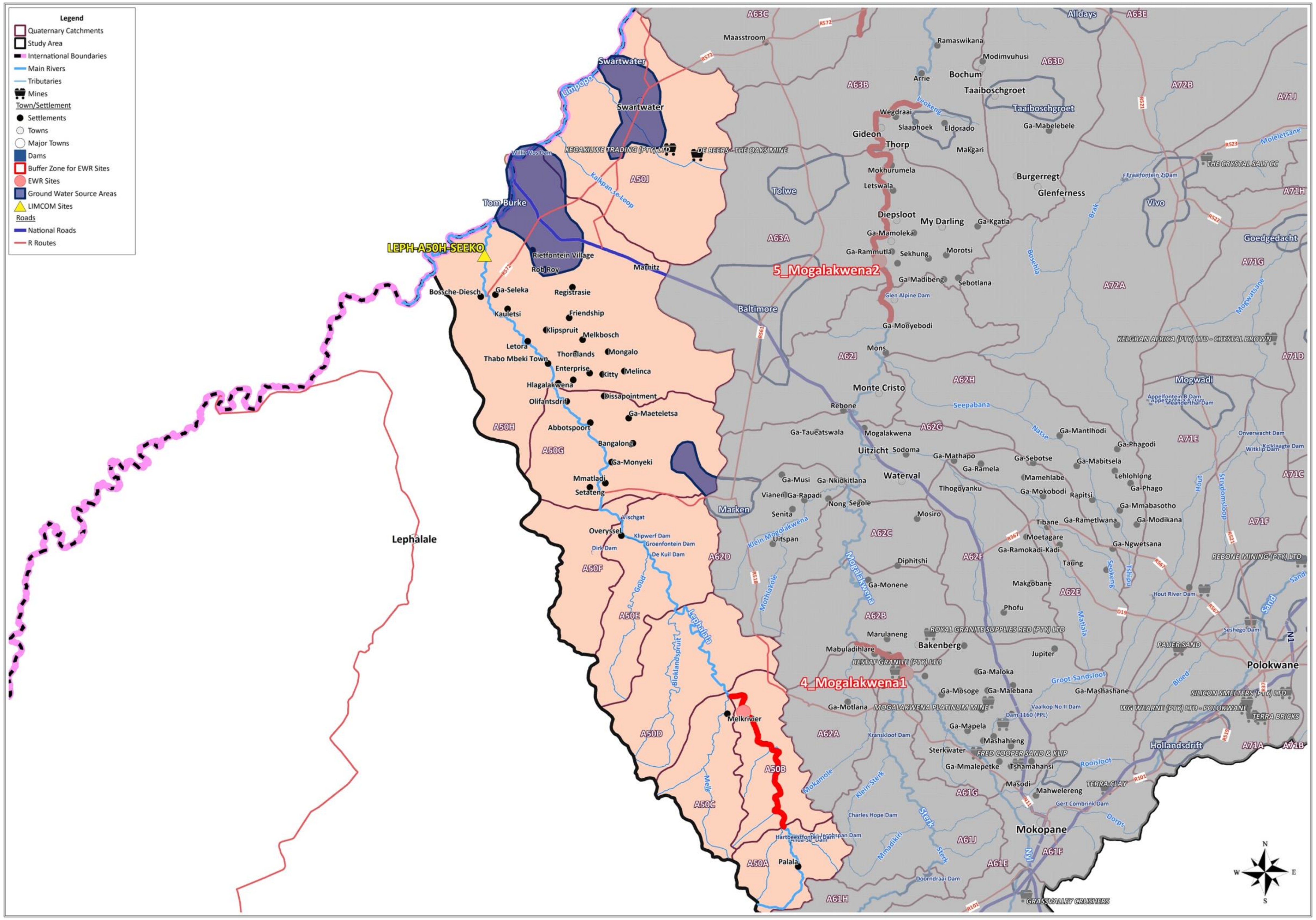


Figure 4-1: Lephalala River Catchment – Existing Water Resources

Table 4-1: Current water requirements and sources of supply in the Lephalala, Mogalakwena and Sand River catchments

Catchment	EWR Site	Current Water User - 2020		River System	Current Abstraction (million m^3/a)	Quaternary Catchment	Water Transfers		
		Username	Source				From which resource	million m^3/a	Water Use Point
Lephalala	Riv 11	Modimole							
		Irrigation Agriculture	Visgacth Dam / Farm Dams	Palala River	42.91	A50 E			
		Domestic	Groundwater Aquifer	Lephalala River	1.36	A50G			
		Livestock	Lephalala	Lephalala River	2.39	A50 A & B			
		Domestic	Run-of-River abstraction	Lephalala River	1.46	A50E			
		Sub-Total Water Abstractions (million m^3/a)			48.12			-	
Mogalakwena	Ri 1	Modimole Town	Donkerpoort Dam	Little Nyl	2.19	A61A			
			Groundwater Aquifer	Groundwater	0.44	A61A	Roodeplaat Dam	1.83	A61A
		Irrigation	Groundwater Aquifer	Groundwater		A61A			
		Sub-Total Water Abstractions (million m^3/a)			2.63			1.83	
	Ri 5	Mookgophong Town	Welgevonden Dam	Sterk River	1.86	A61H			
			Nyl River Wellfield	Groundwater					
		Mokopane Town & surrounds	Doorndraai Dam	Sterk River	6.21	A61F			
		Legends Golf Course	Doorndraai Dam	Sterk River	0.27	A61J			
		Irrigation agriculture	Doorndraai Dam	Sterk River	4.26	A61J			
		Mines	Doorndraai Dam	Sterk River	1.74	A61D			
		Mines - Mogalakwena Platinum Mine	Return Flows	Sand River catchment	8.90	A61G			
		Sub-Total Water Abstractions (million m^3/a)			14.34			-	
	Ri 14	Irrigation agriculture - Glen Alpine Dam	Glen Alpine Dam	Mogalakwena	7.30	A63A			
		Water Losses	Glen Alpine Dam	Mogalakwena	5.48	A63 A			
		Irrigation agriculture	Groundwater	Groundwater	43.20	A63B			
		Domestic	Glen Alpine Dam	Mogalakwena	3.34	A63B			
		Livestock	Mogalakwena	Mogalakwena	3.50				
		Sub-Total Water Abstractions (million m^3/a)			59.32	-	-	-	

Catchment	EWR Site	Current Water User - 2020		River System	Current Abstraction (million m^3/a)	Quaternary Catchment	Water Transfers		
		Username	Source				From which resource	million m^3/a	Water Use Point
Sand River	Ri20	Polokwane - Domestic & Industrial	Seshego Dam	Bloed River	3.66	A71A			
			Chuenespoort Dam				Dap Naude Dam	6.53	A71A
		Moletjie - Domestic & Industrial	Mashashane Dam	Hout River	0.37	A71E			
			Houtrivier Dam	Hout River	0.47	A71E	Flag Boshielo Dam	9.42	A71A
			Molepo Dam		0.76		Ebenezer Dam	16.20	A71A
		Silicon Smelters Mine			15.10	A71A			
		Irrigation agriculture	Sand River Aquifer	Groundwater	126.80	A71G / A72A			
		Makhado Town					Albasini Dam / Nandoni Dam Transfer Scheme	3.58	A71 H
		Musina Town	Limpopo River - aquifer	Limpopo	6.57	A71K			
		Sinthumule / Kutama RWS	Groundwater Aquifer	Sand River catchment	0.94				
		Sub-Total Water Abstractions (million m^3/a)			154.67	-	-	35.73	-

4.2.2 Return flow analysis

The wastewater treatment in the Lephalala catchment (see **Table** 4-2) is an oxidation pond that evaporates the final water into the atmosphere. This does not contribute to the flows downstream of the EWR site.

Return flow from irrigation agriculture is located downstream of the EWR site and will not contribute to the flows at the EWR site.

4.2.3 Water Requirements Forecast and Proposed Development Options

With the growth in population and economic activities in the Lephalala catchment, it is envisaged that the domestic and non-domestic water requirements will increase over the planning period to 2050 (**Table** 4-3**)**. The development of groundwater and increased run-of-river abstraction will meet future water requirements.

No significant proposed developments are envisaged in the catchment. Irrigation agriculture is not likely to grow and no water resource infrastructure is planned for this purpose.

With the envisaged growth in domestic water consumption, the return flows from the wastewater treatment works were considered in the Future scenarios.

4.3 Mogalakwena River Catchment

4.3.1 Current water requirements and existing water resource infrastructure

Water users in the Mogalakwena catchment include domestic users, industries, irrigation agriculture and mining (see **Table** 4-1).

Dams in the catchment include the Doorndraai Dam in the Sterk River and the Glen Alpine Dam in the lower Mogalakwena River. These are multipurpose dams. Several farm dams supply irrigation agriculture. The local water resources cannot meet the current water requirements and there is a transfer scheme from Roodeplaat Dam to supplement the water resources of Modimolle and the surrounding communities. There is also a transfer of return flows from Polokwane WwTWs to supply water to the platinum mines in the Mogalakwena catchment, as illustrated in **Figure** 4-2**.**

Water abstraction will impact the three EWR sites in the Mogalakwena catchment for use. The hydrological modelling considered the raw water abstractions upstream of each EWR site, as illustrated in **Table** 4-1 above.

Table 4-2: Return Flow Analysis in the Lephalala, Mogalakwena and Sand River catchments

Catchment	EWR Site	Current Water User - 2020		River System	Return Flow					Notes
		User Name	Source		Wastewater Treatment Plant	Design Capacity (Ml/d)	Current Utilisation	Current Return Flow (million m^3/a)	Resource Discharged into	
Upper Lephalala	Riv 11	Modimole								
		Irrigation Agriculture	Visgath Dam / Farm Dams	Palala River						
		Domestic	Groundwater Aquifer	Lephalala River						
		Livestock	Lephalala	Lephalala River	Zongesien WWTW	0.5	120%	0.22	None = Waste Stabilisation Pond	
		Domestic	Run-of-River abstraction	Lephalala River						
		Sub-Total Water Abstractions (million m^3/a)				0.5		0.22		
Mogalakwena	Ri 1	Modimole Town	Donkerpoort Dam	Little Nyl	Modimolle	6.50		2.04		Although the abstraction is upstream, it affects the tributary contribution downstream of the EWR site
			Groundwater Aquifer	Groundwater						
		Irrigation	Groundwater Aquifer	Groundwater						
		Sub-Total Water Abstractions (million m^3/a)				6.5		2.04		
	Ri 5	Mookgophong Town	Welgevonden Dam	Sterk River	Mokgophong WWTW	2	0%			No return flow - irrigation or effluent
			Nyl River Wellfield	Groundwater						
		Mokopane Town & surrounds	Doorndraai Dam	Sterk River						
		Legends Golf Course	Doorndraai Dam	Sterk River						
		Irrigation agriculture	Doorndraai Dam	Sterk River						
		Mines	Doorndraai Dam	Sterk River						
		Mines - Mogalakwena Platinum Mine	Return Flows	Sand River catchment						
		Sub-Total Water Abstractions (million m^3/a)				2		-		
	Ri 14									
		Irrigation agriculture - Glen Alpine Dam	Glen Alpine Dam	Mogalakwena	Mokopane WWTW	9	89%	2.92	Mogalakwena River	
		Water Losses	Glen Alpine Dam	Mogalakwena	Rebone WWTW	0.5		0.35	Mogalakwena River	
		Irrigation agriculture	Groundwater	Groundwater	Mosodi WWTW	1.5		1.32	Mogalakwena River	
		Domestic	Glen Alpine Dam	Mogalakwena						
		Livestock	Mogalakwena	Mogalakwena						
		Sub-Total Water Abstractions (million m^3/a)				11.00		4.59		
Sand River	Ri20	Polokwane - Domestic & Industrial	Seshego Dam	Bloed River	Polokwane WWTW	32	97%	11.33		Return Flows recharging the groundwater
			Chuenespoort Dam							
		Moletjie - Domestic & Industrial	Mashashane Dam	Hout River						
			Houtrivier Dam	Hout River	Seshego WWTW	7.8	71%	2.02		Return Flows recharging the groundwater
			Molepo Dam							
		Silicon Smelters Mine								The plant has been restarted
		Irrigation agriculture	Sand River Aquifer	Groundwater	Makhado WWTW	13.91		5.08	Listhovhu River	Most irrigation is downstream of Polokwane Town - Mainly in the tributaries of Hout & Brak
		Makhado Town			Rietvlei WWTW	5	80%	1.46	Listhovhu River	
		Musina Town	Limpopo River - aquifer	Limpopo	Musina WWTW	2		0.69	Sand River	
		Sinthumule / Kutama RWS	Groundwater Aquifer	Sand River catchment						
		Sub-Total Water Abstractions (million m^3/a)				60.71		20.58	-	

Table 4-3: Water Requirement Projections for the Lephalala, Mogalakwena and Sand River catchments

Catchment	EWR Site	Current Water User - 2020		River System	Current Abstraction (million m³/a)	Quaternary Catchment	Water Requirements Projections				
		User Name	Source				2025	2035	2040	2045	2050
Upper Lephalala	Riv 11	Modimole									
		Irrigation Agriculture	VisgacthDam / Farm Dams	Palala River	42.91	A50 E	42.91	42.91	42.91	42.91	42.91
		Domestic	Groundwater Aquifer	Lephalala River	1.36	A50G	1.48	1.74	1.89	2.05	2.22
		Livestock	Lephalala	Lephalala River	2.39	A50 A & B	2.39	2.39	2.39	2.39	2.39
		Domestic	Run-of-River abstraction	Lephalala River	1.46	A50E	1.55	1.76	1.87	1.99	2.12
		Sub-Total Water Abstractions (million m³/a)			48.12						
Mogalakwena	Ri 1	Modimole Town	Donkerpoort Dam	Little Nyl	2.19	A61A	4.20	4.65	4.90	5.18	5.50
			Groundwater Aquifer	Groundwater	0.44	A61A	0.48	0.59	0.65	0.72	0.79
		Irrigation	Groundwater Aquifer	Groundwater		A61A					
		Sub-Total Water Abstractions (million m³/a)			2.63		4.69	5.24	5.55	5.90	6.29
	Ri 5	Mookgophong Town	Welgevonden Dam	Sterk River	0.73	A61H	0.81	1.00	1.11	1.23	1.36
			Nyl River Wellfield	Groundwater	1.42	A61H	1.58	1.94	2.16	2.39	2.66
		Mokopane Town & surrounds	Doorndraai Dam	Sterk River	6.21	A61F	6.94	8.67	9.69	10.83	12.11
		Legends Golf Course	Doorndraai Dam	Sterk River	0.27	A61J	0.27	0.27	0.27	0.27	0.27
		Irrigation agriculture	Doorndraai Dam	Sterk River	4.26	A61J	4.26	4.26	4.26	4.26	4.26
		Mines	Doorndraai Dam	Sterk River	1.74	A61D	1.74	1.74	1.74	1.74	1.74
		Mines - Mogalakwena Platinum Mine	Return Flows	Sand River catchment	8.90	A61G	9.66	11.38	12.35	13.40	14.54
		Sub-Total Water Abstractions (million m³/a)			23.53		25.26	29.26	31.57	34.12	36.93
	Ri 14	Irrigation agriculture - Glen Alpine Dam	Glen Alpine Dam	Mogalakwena	7.30	A63A	7.30	7.30	7.30	7.30	7.30
		Water Losses	Glen Alpine Dam	Mogalakwena	5.48	A63 A	5.48	5.48	5.48	5.48	5.48
		Irrigation agriculture	Groundwater	Groundwater	43.20	A63B	43.20	43.20	43.20	43.20	43.20
		Domestic	Glen Alpine Dam	Mogalakwena	3.34	A63B	3.60	4.18	4.50	4.85	5.22
		Livestock	Mogalakwena	Mogalakwena	3.50		3.50	3.50	3.50	3.50	3.50
		Sub-Total Water Abstractions (million m³/a)			59.32	-					
Sand River	Ri20	Polokwane - Domestic & Industrial	Seshego Dam	Bloed River	3.66	A71A	37.63	51.57	60.36	70.66	82.71
			Chuenespoort Dam								
		Moletjie - Domestic & Industrial	Mashashane Dam	Hout River	0.37	A71E	0.43	0.59	0.69	0.81	0.95
			Houtrivier Dam	Hout River	0.47	A71E	0.50	0.55	0.58	0.61	0.64
			Molepo Dam		0.76		0.80	0.89	0.94	0.99	1.04
		Silicon Smelters Mine			15.10	A71A					
		Irrigation agriculture	Sand River Aquifer	Groundwater	126.80	A71G / A72A	126.80	126.80	126.80	126.80	126.80
		Makhado Town					4.08	5.30	6.04	6.88	7.84
		Musina Town	Limpopo River - aquifer	Limpopo	6.57	A71K	7.86	11.25	13.45	16.09	19.25
		Sinthumule / Kutama RWS	Groundwater Aquifer	Sand River catchment	0.94	A71H	1.12	1.61	1.93	2.30	2.76
		Waterpoort Water Supply									
		Sub-Total Water Abstractions (million m³/a)			154.67	-					

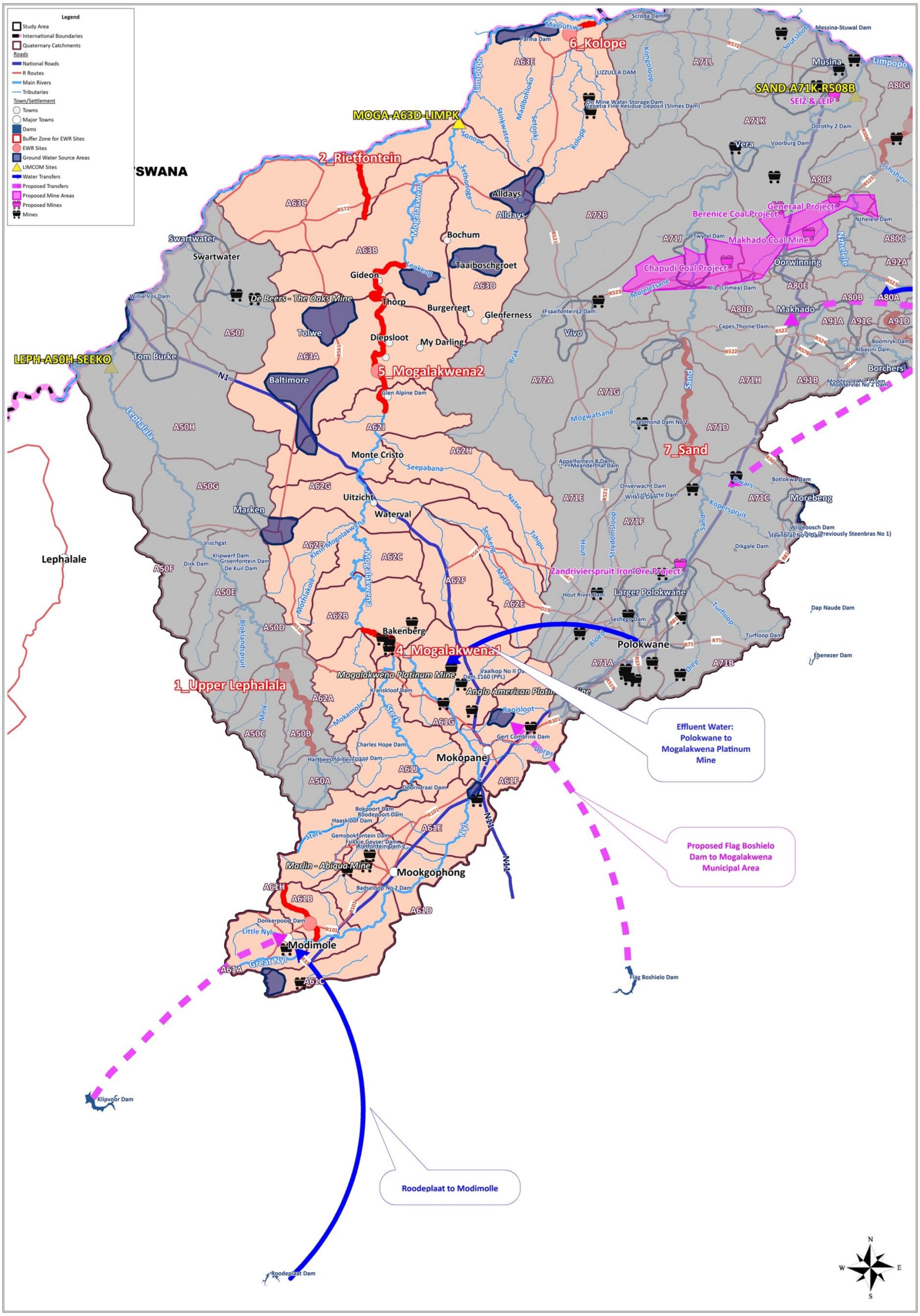


Figure 4-2: Mogalakwena River catchment demands and existing water resource infrastructure

4.3.2 Return Flow Analysis

There are several WWTWs in the Mogalakwena River catchment whose discharge points are upstream of the EWR sites. These were factored in the hydrological modelling of the system to determine the flows at each EWR site (see **Table** 4-2 above).

The irrigation return flows were also factored in the hydrological modelling of the systems.

4.3.3 Water Requirements Forecast and Proposed Development Options

Growth in the domestic, industries and mining water requirements is indicated in **Table** 4-3 above.

There is limited capacity to develop the local resources to meet these growing demands. Therefore, additional transfers from Flag Boshielo Dam and potentially from Klipvoor Dam into the Mogalakwena catchment are planned as indicated in **Figure** 4-2 above. There will also be increased return flows from the WWTWs into the catchment. It is anticipated that some of these return flows will be used.

The growth in water requirements that affect the EWR sites (**Table** 4-3**)** has been factored into future scenarios.

4.4 Sand River Catchment

4.4.1 Current water requirements and existing water resource infrastructure

The provincial city of the Limpopo Province, Polokwane, is in the upper Sand River catchment (see **Figure** 4-3 below). Significant developments have occurred in the Sand River catchment, including urban and rural communities, irrigation agriculture, and mining activities in the lower Sand River catchment. These are dependent on the water resources of the Sand River catchment.

The surface water resources of the Sand catchment are minimal. Although there are significant groundwater aquifers that are used for both irrigation agriculture and domestic water use, additional water is transferred from the neighbouring catchment to augment the limited water resources of the Sand catchment. As illustrated in **Figure** 4-3, there are two primary transfer schemes, one from the Letaba catchment and the second from the Olifants catchment. The water allocations for transfer from these two catchments into the upper Sand catchment are indicated in **Table** 4-1 above. Irrigation agriculture accounts for nearly 82% of the current water requirements. This is mainly from groundwater and some from return flows from the WWTWs.

The EWR site is downstream of Polokwane town and is affected by the return flows discharged into the Sand River. Some return flows are transferred to the Mogalakwena catchment for mine water use and at Mooketsi for irrigation in the Letaba catchment by ZZ2.

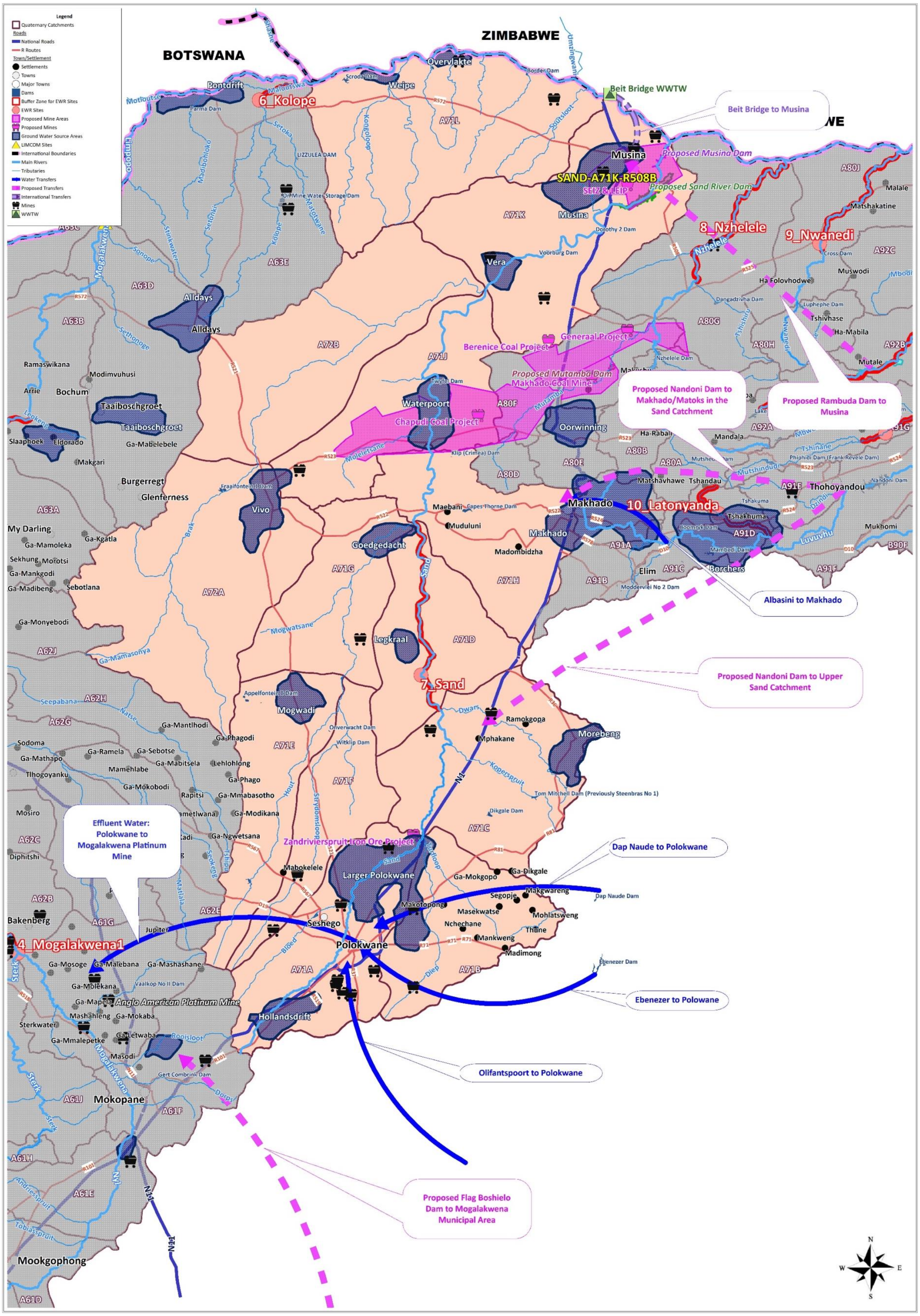


Figure 4-3: Sand River Catchment – Demands and Existing Water Resource Infrastructure

4.4.2 Return Flow Analysis

There are several WWTWs, as indicated in **Table** 4-2 above. These return flows were factored into the hydrological modelling of the flows going past the EWR site. With most irrigation dependent on groundwater downstream of the site, the return flows from irrigation agriculture are not likely to impact the flows at the EWR site.

4.4.3 Water Requirements Forecast and Proposed Development Options

The growth of the town of Polokwane and the planned Musina-Makhado Special Economic Zone (MSEZ) development will significantly impact the water requirements of the Sand River catchment. In addition, depending on the market conditions, there are plans to open new coal mines in the Sand / Nzhelele watershed, as indicated in **Figure** 4-3 above.

To meet these growing needs of the Sand catchment, the following water resource developments are envisaged in the medium to long term:

- There are plans to transfer water from the Luvuvhu River catchment to meet the growing water requirements of the upper Sand River catchment.
- There are programmes to reduce water loss by undertaking AC pipe replacement in Polokwane. This will impact the return flows flowing downstream into the Sand River catchment.
- Potential dam sites were identified in the lower Sand River catchment to supply the gazetted Musina SEZ south site. These are the Sand River Dam and Musina Dam (see **Figure** 4-4 below), which will be pumped water storage dams with water pumped from the Limpopo River to supplement the Sand River flows.

The impact of the additional flows was then modelled in the hydrological analysis to determine the flows at each EWR site affected by the additional water resource developments in the catchment.

4.5 Nzhelele River Catchment

4.5.1 Current water requirements and existing water resource infrastructure

The Nzhelele River catchment is dominated by irrigation agriculture supplied by the Nzhelele Dam. This is the only dam in the catchment (see **Figure** 4-4 below). The domestic water use in the catchment is not significant, as illustrated in **Table** 4-4 below. It only accounts for 20.3% of the current water use at the different levels of assurance of supply.

It is essential to note the following:

- The yield of the Nzhelele Dam has been fully allocated, and the required level of assurance supply has been overallocated. Therefore, the level of assurance of supply for irrigation water use has dropped.
- There are much higher releases to meet the irrigation demands because of the canal conveyance water losses. With the EWR site downstream of the releases, any changes to the current water use and operating practices will impact the flows at the EWR site.

4.5.2 Return Flow Analysis

The existing WwTWs in the Nzhelele River catchment are mainly oxidation ponds, which do not discharge into the downstream river reaches, but the final water evaporates into the atmosphere. This is illustrated in **Table** 4-5 below.

The return flows from the irrigation agriculture water were included in the hydrological modelling of the Nzhelele River catchment.

4.5.3 Water Requirements Forecast and Proposed Development Options

Because of the limited capacity of the existing water resources of the Nzhelele River catchment, growth in water requirements for irrigation agriculture would not be possible. Irrigation agriculture is therefore not expected to grow. The raw water abstraction for irrigation agriculture would increase up to its authorised allocation.

It is envisaged that there will be growth in the future water requirements of the domestic and industrial sectors. This is because of plans to develop the coal mines, namely Makhado and Generaal Project coalfields. These developments will require augmentation of the water resources in the catchments.

The proposed development and management options to meet the water requirements in the domestic, industrial and coal mining projects in the catchment include the following:

- The development of a dam in the Mutamba River, a tributary of the Nzhelele River. The dam will provide an additional storage capacity of 5 million m^3. This will provide water for the mining activities of the proposed coal mining developments.
- Implement an irrigation water management plan to reduce the high canal conveyance losses. This will then be transferred for use in coal mining activities. This will reduce the return flows from the irrigation agriculture to the downstream EWR site in the Nzhelele River catchment.

The impact of the reduced contribution of the proposed Mutamba Dam to the run-off into the Nzhelele River catchment was modelled to determine the flow regime at the EWR site in the Future scenario.

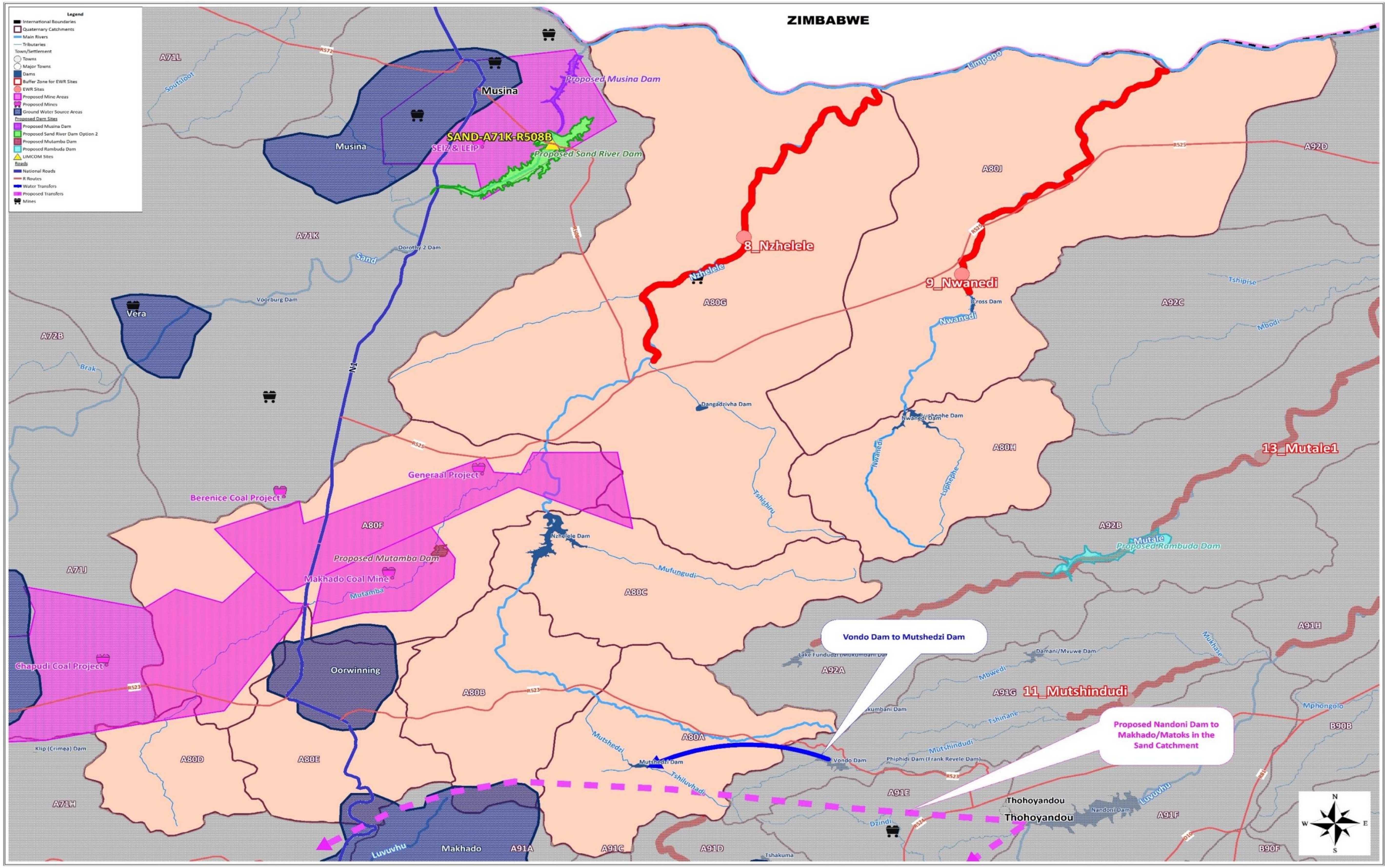


Figure 4-4: Nzhelele River Catchment – Demands and Existing Water Resource Infrastructure

Table 4-4: Current Water Requirements of the Nzhelele, Nwanedi, Mutale, Luvuvhu and Shingwedzi

Catchment	EWR Site	Current Water User -2020		River System	Current Abstraction	Quaternary Catchment	Water Transfers in		
		Username	Source		(million m^3/a)		From which resource	million m^3/a	Water Use Point
Nzhelele	Ri 27	Nzhelele Domestic Water Supply -VDM	Nzhelele Dam	Nzhelele River	2.56				
		Mutshedzi Water Supply Scheme	Mutshedzi Dam	Mutshedzi River	4.32				
		Nzhelele Irrigation Board	Nzhelele Dam	Nzhelele River	29.10				
		Tshipise Holiday Resort	Nzhelele Dam	Nzhelele River	0.50				
		Sub-Total Water Abstractions (million m^3/a)			36.48	-	-	-	-
Ṅwanedi	Ri28	Ṅwaneḓi Irrigation Scheme	Ṅwaneḓi Dam	Ṅwaneḓi River	5.31				
		Cross Dam Irrigation Scheme	Cross Dam	Ṅwaneḓi River					
		Luphephe RWS	Ṅwaneḓi Dam	Ṅwaneḓi River	1.14				
		Masisi RWS	Ṅwaneḓi Dam	Ṅwaneḓi River					
		Sub-Total Water Abstractions (million m^3/a)			6.45	-	-	-	-
Mutale	Ri33, Ri34	Mutale RWS	Mutale River	Mutale River	0.62				
		Mukumbani Tea Estate	Mukumbani Dam	Mutale River	6.83				
		Sub-Total Water Abstractions (million m^3/a)			7.45	-	-	-	-
Luvuvhu	Riii6, Ri30, Ri32	Luvuvhu Irrigation Scheme	Albasini Dam	Luvuvhu River	18.25				
		Makhado LM	Various	Luvuvhu River	8.57				
		Thulamela	Various - Nandoni	Luvuvhu River	34.13				
		Sub-Total Water Abstractions (million m^3/a)			68.40	-	-	-	-
Shingwedzi		Collins Chabane LM							
		Collins Chabane LM	Various WTW	Luvuvhu River	7.50				
		Sub-Total Water Abstractions (million m^3/a)			7.50	-	-	-	-

Table 4-5: Water Requirements Projections for the Nzhelele, Nwanedi, Mutale, Luvuvhu and Shingwedzi

Catchment	EWR Site	Current Water User - PES (2022)		River System	Current Abstraction	Quaternary Catchment	Water Requirements Projections				
		Username	Source		(million m³/a)		2025	2035	2040	2045	2050
Nzhelele	Ri 27	Nzhelele Domestic Water Supply -VDM	Nzhelele Dam	Nzhelele River	2.56	A80G	2.83	3.49	3.87	4.30	4.77
		Mutshedzi Water Supply Scheme	Mutshedzi Dam	Mutshedzi River	4.32	A80A	4.72	5.61	6.12	6.67	7.28
		Nzhelele Irrigation Board	Nzhelele Dam	Nzhelele River	29.10	A80G	29.10	29.10	29.10	29.10	29.10
		Makhado Coal Mine	Nzhelele Dam /Mutamba Proposed Dam	Mutamba River	-	A80F	0.37	0.64	1.28	1.28	1.92
		Sub-Total Water Abstractions (million m³/a)			35.98	-					
Nwanedi	Ri28	Ṅwanedi Irrigation Scheme	Ṅwanedi Dam	Nwanedi River	5.31	A80J	5.31	5.31	5.31	5.31	5.31
		Cross Dam Irrigation Scheme	Cross Dam	Nwanedi River							
		Luphephe RWS	Ṅwanedi Dam	Nwanedi River	1.14	A80H	1.22	1.39	1.49	1.59	1.70
		Masisi RWS	Ṅwanedi Dam	Nwanedi River	0.46	A80J	0.49	0.56	0.60	0.64	0.69
		Sub-Total Water Abstractions (million m³/a)			6.91	-	7.02	7.27	7.40	7.55	7.70
Mutale	Ri33, Ri34	Mutale RWS	Mutale River	Mutalle River	0.62		0.66	0.76	0.81	0.87	0.93
		Mukumbani Tea Estate	Mukumbani Dam	Mutalle River	6.83		6.83	6.83	6.83	6.83	6.83
		Sub-Total Water Abstractions (million m³/a)			7.45	-	7.49	7.58	7.64	7.69	7.75
Luvuvhu	Riii6, Ri30, Ri32	Luvuvhu Irrigation Scheme	Albasini Dam	Luvuvhu River	18.25		18.25	18.25	18.25	18.25	18.25
		Thulamela	Various - Nandoni	Luvuvhu River	34.13		38.33	48.36	54.31	61.00	68.51
		Collins Chabane LM	Various WTW	Luvuvhu River	7.50		8.42	10.63	11.93	13.40	15.06
		Sub-Total Water Abstractions (million m³/a)			67.33	-					
Shingwedzi		Collins Chabane LM									
		Collins Chabane LM	Various WTW	Luvuvhu River	7.50		8.42	10.63	11.93	13.40	15.06
		Sub-Total Water Abstractions (million m³/a)			7.50	-					

4.6 Mutale / Luvuvhu River Catchment

4.6.1 Current water requirements and existing water resource infrastructure

The Nandoni and Vondo Dams are situated in the Luvuvhu River catchment and provide the domestic and irrigation agriculture water requirements. Several smaller dams also provide domestic water requirements.

As indicated in **Table** 4-4 above:

- The irrigation allocation for the Mukumbani Tea estate was considered in the current water requirements, although the current abstraction is much less than the total allocation for the scheme.
- The Luvuvhu Irrigation Scheme, with releases from Albasini Dam, is the largest water user, with a total water allocation of 18.25 million m^3/a for irrigation.

The current water requirements in the Mutale and Luvuvhu River catchments are upstream of the EWR sites and will impact the flows at the sites.

Water transfers from the Nandoni Dam to Makhado are made to supplement the area's groundwater resources for domestic and industrial water use in the town. This was indicated in the Sand River catchment as a demand.

4.6.2 Return Flow Analysis

The principal return flows in the Mutale and Luvuvhu River catchments are from the conventional wastewater treatment works, which discharge into the rivers upstream of the EWR sites, contributing to the flows past these sites. These include the Thohoyandou WWTW, which has a treatment capacity of 12 Ml/d. Its current utilisation is 80% of the plant capacity, meaning 3.5 million m^3/a is discharged into the Luvuvhu River system.

4.6.3 Water Requirements Forecast and Proposed Development Options

The water requirements for the domestic and industrial water users in the Mutale and Luvuvhu River catchments are envisaged to increase as the population and service levels improve (see **Table** 4-5).

Significant water resource development is planned for the Mutale River catchment to meet these future water requirements. There is also the potential for the raising of the Vondo Dam. Additional groundwater to augment the surface water resource is planned to supply the future water requirements, particularly in the outlying rural communities. The proposed dam in the Mutale River, known as the Rambuda Dam (see **Figure** 4-5 below), will have an excess yield to supply some of the water for the proposed Musina-Makhado Special Economic Zone, south site in Musina.

According to the Directorate of Water Use, there is a water use licence application that requires the transfer of approximately 5 million m^3/a from Nandoni Dam to augment the water resources of Giyani town and the surrounding communities. There are, therefore, plans for an interbasin transfer from the Luvuvhu River catchment to the Middle Letaba River system.

Water use developments affecting EWR sites have been modelled for future scenarios.

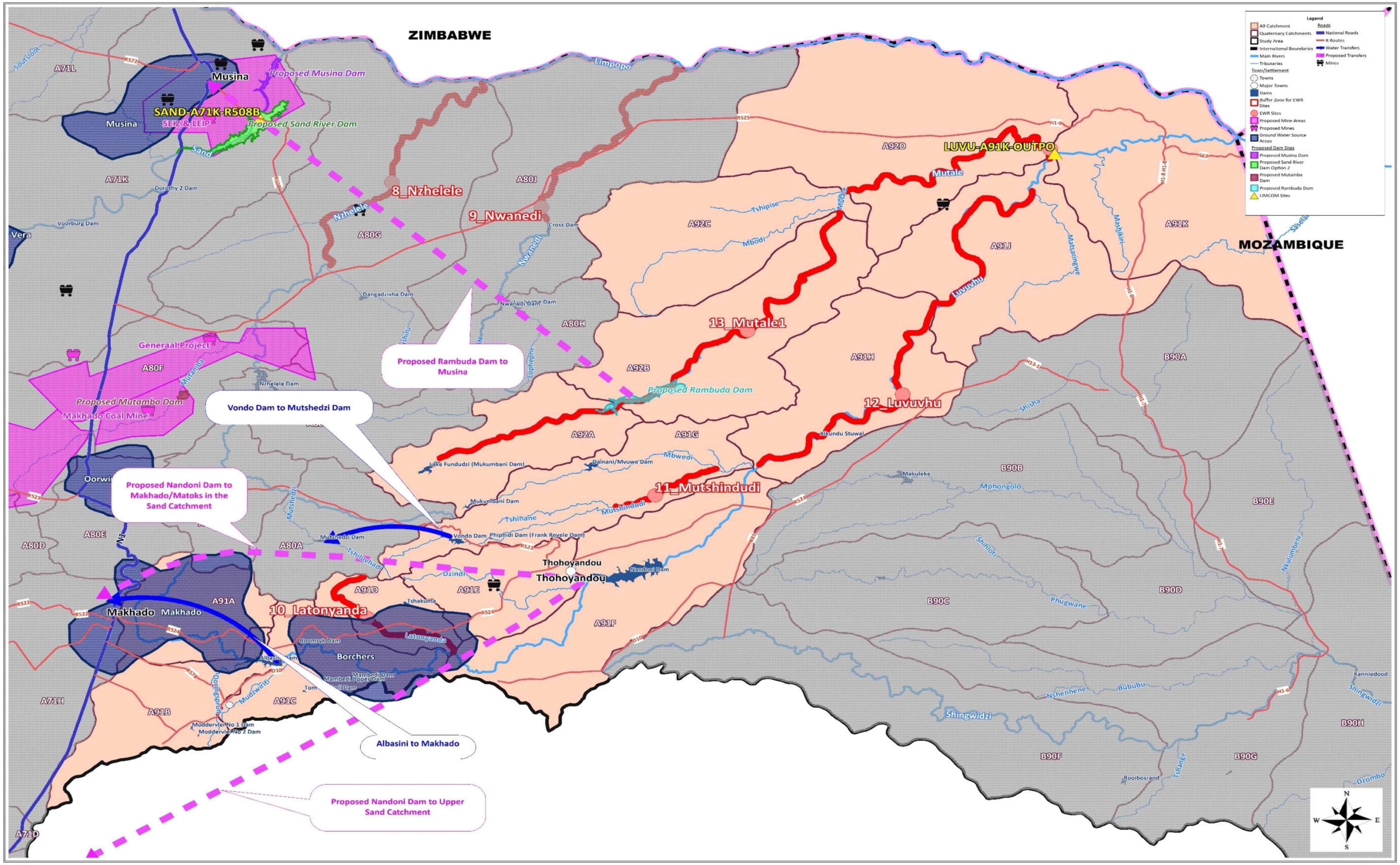


Figure 4-5: Mutale / Luvuvhu River Catchments – Demands and Existing and Potential Water Resources Infrastructure

4.7 Shingwedzi River Catchment

4.7.1 Current water requirements and existing water resource infrastructure

The current water requirements of the Shingwedzi River catchment are dominated by domestic and small industries with ecotourism being another user in the catchment. Although there are water requirements for agriculture, this is mainly for subsistence agriculture in the catchment.

The main dam in the catchment is the Makuleke Dam, which is in the Mphongolo River, a tributary of the Shingwedzi River (see **Figure** 4-6 below).

4.7.2 Return Flow Analysis

There are minimal return flows from the wastewater treatment works. This is because most treatment works are oxidation ponds that do not discharge the final effluent into the rivers.

4.7.3 Water Requirements Forecast and Proposed Development Options

The future water requirements of the domestic, small industries and ecotourism are envisaged to increase as the population of the Shingwedzi River catchment increases. This is illustrated in **Table** 4-5 above.

No significant developments are expected in the Shingwedzi catchment because of its pristine nature, particularly downstream from Makuleke Dam. The future water requirements will be met from the conjunctive use of groundwater and surface water resources, which are upstream of the LIMCOM EWR site located at the border with the Kruger National Park.

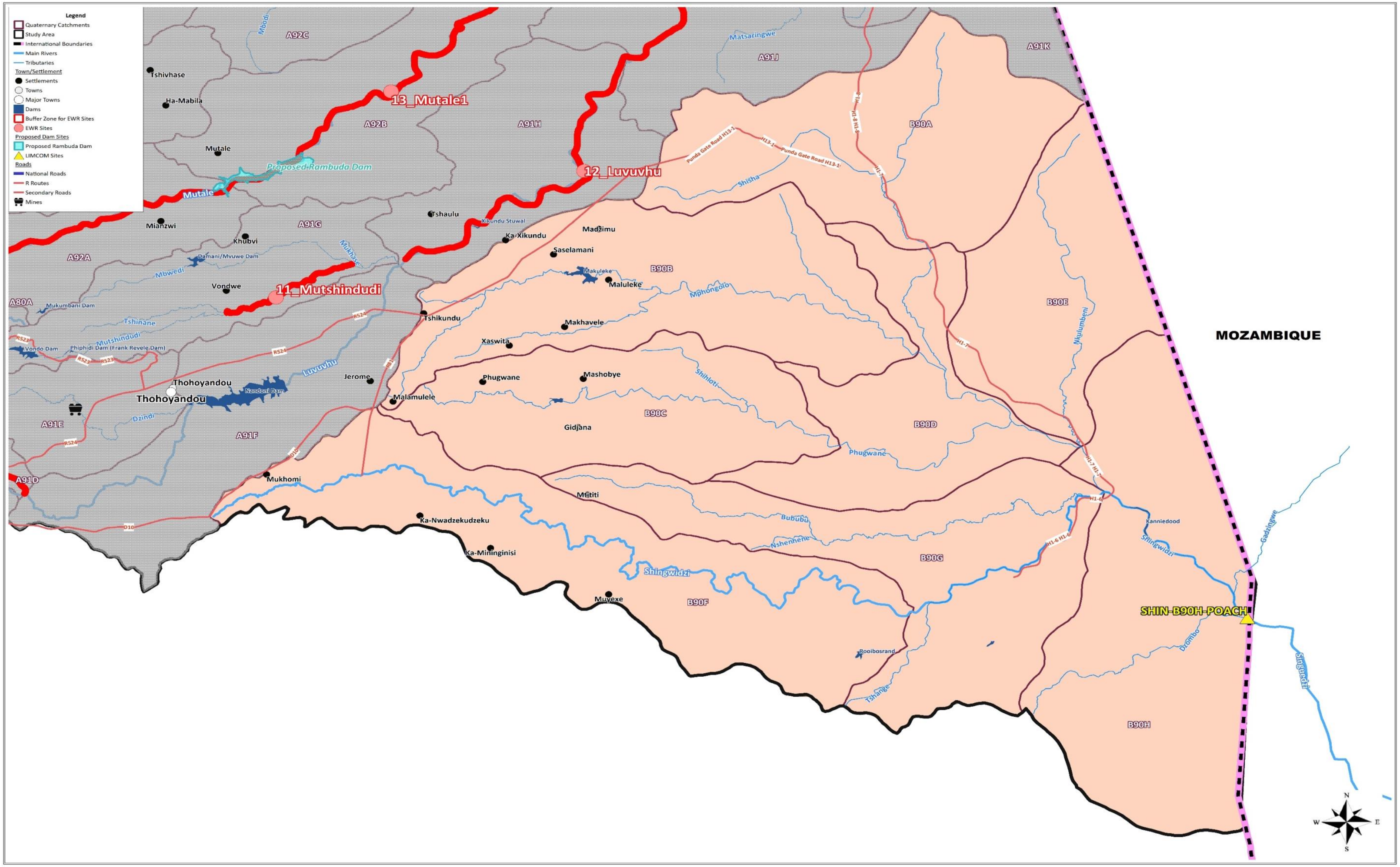


Figure 4-6: Shingwedzi River Catchment – Demands and Existing and Potential Water Resource Infrastructure

5 DESCRIPTION OF THE SCENARIOS

Four scenarios were assessed using DRIFT-Limpopo:

- **PES** (2022), which used the climatic period of 1925-2021 with human influences such as water-resource developments, population and land use at 2022 levels.
- **Reference**, which used the climatic period of 1925-2021 with human influences such as water-resource developments, population and land use at *c*. 1900 levels.
- **Future1**, which overlaid 2050 water resource developments on PES (2022).
- **Future2**, which overlaid a dry future climate scenario onto Future1.

DRIFT-Limpopo was calibrated against the PES (2022) and Reference scenarios. The Future1 and Future2 scenarios were then run through the DRIFT-Limpopo to predict the effects of additional planned water-resource developments without and with a dry climate, respectively. The water-resource development plans differ between the basins, and in some basins there are no future water developments planned (**Table** 5-1) (DWS Technical Task Team meeting June 2023, pers.comm T. Nditwani 2023).

Table 5-1: EWR sites where Future1 developments are planned

EWR site	Future Use
1_Lephalala	X
2_Rietfontein	
3_Olifantspruit	
4_Mogalakwena1	X
5_Mogalakwena2	X
6_Kolope	
7_Sand	X
8_Nzhelele	X
9_Ṅwaneḓi	X
10_Latonyanda	
11_Mutshindudi	X
12_Luvuvhu	X
13_Mutale1	X
14_Mutale2	X

The factors considered in the **Future1** scenario (**Table** 5-2) include increasing return flows from Waste Water Treatment Works (WWTW), raising existing dams or building new dams (increased storage), increasing releases from dams for domestic or agricultural supply, decreasing releases from dams because of increasing demands, increasing flows from inter-basin transfers, and increasing domestic, mining, industrial or agricultural water use (DWS Technical Task Team meeting June 2023, pers.comm T. Nditwani 2023).

Since the locations of the different developments planned vary, the consequences on the modelled flow regimes for the Future1 scenario were not the same (**Table** 5-3). At the following EWR sites:

- 1_Lephalala, a 5% increase in water use and no increase in return flows throughout the year is planned.

- 4_Mogalakwena1, return flows increase dry season low flows significantly and wet season flows are relatively unaffected.

Table 5-2: Factors relevant for the Future1 scenario

EWR site	Increased return flows	New dam storage/ Increased dam storage	Incoming inter-basin transfers	Transfers of return flows out of catchment	Increased water use
1_Lephalala					X
4_Mogalakwena1	X				
5_Mogalakwena2	X				
7_Sand	X		X		X
8_Nzhelele		X			X
9_Ṅwaneḓi					X
11_Mutshindudi		X			X
12_Luvuvhu	X			X	X
13_Mutale1		X			X
14_Mutale2		X			

Table 5-3 Monthly flow volumes (Mm³) in the PES (2022) and Future1 scenarios

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
	1_Lephalala												
Reference	0.99	2.03	4.81	8.54	12.81	12.44	8.81	5.98	4.29	2.85	1.63	1.03	66.22
PES (2022)	0.47	1.16	3.2	6.39	11.24	11.4	8.24	5.52	3.62	2.12	0.92	0.52	54.8
Future1	0.47	1.1	2.98	5.92	10.64	10.87	7.8	5.25	3.43	1.97	0.88	0.51	51.8
Future2	0.3	0.7	3.1	6.5	8.9	7.9	5.4	3.6	2.2	1.2	0.5	0.4	40.7
	4_Mogalakwena												
Reference	2.7981	9.62	15.2	26.7	31.9	15.1	8.46	5.04	3.79	3.46	3.1	2.76	2.7981
PES (2022)	0.4545	4.03	8.11	16	23.8	9.68	4.54	1.96	1.18	1.05	0.79	0.6	0.4545
Future1	1.0072	3.83	7.76	15.6	23.2	9.83	4.92	2.52	1.77	1.64	1.38	1.2	1.0072
Future2	0.6231	1.94	9.06	8.87	7.64	2.72	1.82	1.17	0.98	0.93	0.83	0.75	0.6231
	5_Mogalakwena												
Reference	3.57	13.59	18.22	35.22	52.71	26.71	15.52	9.07	5.99	5	4.18	3.48	193.27
PES (2022)	0.6	6.29	8.42	20.18	42.04	18.75	9.68	4.21	1.85	1.33	0.6	0.35	114.3
Future1	0.69	5.9	7.91	19.85	41.24	18.64	9.79	4.44	2.12	1.59	0.78	0.44	113.4
Future2	0.47	2.44	9.05	10.14	13.49	5.14	3.57	1.6	0.59	0.48	0.23	0.21	47.4
	7_Sand												
Reference	0.28	1.00	1.52	7.00	12.12	4.53	0.58	0.18	0.09	0.07	0.04	0.03	27.45
PES (2022)	0.29	0.47	0.74	5.32	10.57	3.85	0.55	0.34	0.36	0.37	0.32	0.3	23.48
Future1	2.64	2.82	3.09	7.67	12.92	6.2	2.9	2.69	2.71	2.72	2.67	2.65	51.68
Future2	2.6	2.7	3.51	5.2	6.42	2.85	2.8	2.65	2.69	2.71	2.65	2.64	39.42
	8_Nzhelele												
Reference	1.94	2.16	3.99	14.55	25.45	18.86	11.34	7.28	5.27	3.93	2.86	2.1	99.73
PES (2022)	0.69	0.6	1.27	8.81	18.54	13.02	6.99	3.58	2.42	1.95	1.1	0.64	59.6
Future1	0.5	0.49	1.06	7.89	17.53	11.7	6.39	3.01	2.03	1.6	0.88	0.48	53.56
Future2	0.19	0.2	1.41	4.39	8.45	3.98	1.94	0.74	0.5	0.64	0.36	0.15	22.95
	9_Ṅwanedi												
Reference	1.22	1.58	2.77	5.89	8.06	5	2.59	1.77	1.37	1.17	1.07	0.99	33.47
PES (2022)	0.38	0.58	1.32	4.06	6.47	3.96	1.7	1.06	0.76	0.62	0.52	0.43	21.87

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Future1	0.34	0.54	1.26	3.96	6.4	3.9	1.65	1.01	0.71	0.57	0.47	0.39	21.21
Future2	0.13	0.23	1.58	2.8	3.64	1.76	0.85	0.56	0.42	0.35	0.28	0.23	12.84
	11_Mutshindudi												
Reference	1.15	2.49	6.06	9.72	12.6	10.4	5.18	2.62	1.73	1.39	1.14	1.03	1.15
PES (2022)	0.74	1.43	4.18	8.16	11.5	9.36	4.37	1.97	1.31	1.06	0.88	0.75	0.74
Future1	0.7	1.18	2.92	5.48	8.91	7.97	3.71	1.87	1.29	1.06	0.87	0.74	0.7
Future2	0.46	0.79	3.14	5.01	6	4.55	1.98	1.21	0.87	0.74	0.61	0.52	0.46
	12_Luvuvhu												
Reference	9.21	14.53	30.39	61.94	92.59	78.99	40.74	21.61	15.83	12.85	10.73	9.12	398.52
PES (2022)	1.6	4.35	15.92	44.68	75.56	60.9	25.76	8.19	4.41	2.87	1.96	1.56	247.8
Future1	1.3	3	10.23	29.78	61.68	51.44	21.06	6.27	3.52	2.44	1.87	1.43	194
Future2	0.58	1.82	11.41	22.51	33.6	22.14	7.14	2.99	1.79	1.39	1.03	0.76	107.17
	13_Mutale1												
Reference	2.89	5.8	12.13	22.51	31.19	24.12	11.86	4.52	2.52	2.3	1.89	1.87	2.89
PES (2022)	2.23	4.99	11.12	21.24	29.76	22.83	10.9	3.83	1.93	1.7	1.29	1.32	2.23
Future1	0.62	2.14	7.58	18.49	27.65	20.59	8.91	2.18	0.73	0.48	0.4	0.37	0.62
Future2	0.13	0.8	7.79	16.37	19.26	11.36	4.18	0.86	0.19	0.18	0.16	0.11	0.13
	14_Mutale2												
Reference	3.24	6.91	15.51	29.34	42.25	29.78	13.23	4.99	2.86	2.6	2.14	2.09	154.95
PES (2022)	2.54	6.03	14.4	27.92	40.66	28.39	12.22	4.26	2.23	1.97	1.51	1.51	143.6
Future1	0.8	3.03	10.7	25.08	38.48	26.05	10.14	2.55	0.99	0.7	0.58	0.53	119.6
Future2	0.23	1.35	12.23	21.8	25.7	13.86	4.7	1.08	0.34	0.32	0.28	0.21	82.1

- 5_Mogalakwena2, return flows increase inflows into, and releases made from, Glen Alpine Dam in the dry season. Dry season low flows are higher and wet season high flows slightly lower because of increased water use from Glen Alpine that increases storage capacity.
- 7_Sand, there are large transfers from Seshego Dam into the Sand catchment via the Bloed River for Polokwane, which in turn increases return flows, some of which are taken up by irrigators. The remaining return flows create large elevated dry and wet season flows.
- 8_Nzhelele, increased water use and no increase in return flows result in a general reduction in flow throughout the year.
- 9_Ṅwanedi, increased water use and no increase in return flows result in a general reduction in flow throughout the year but less so than at 8_Nzhelele.
- 11_Mutshindudi, raising of Vondo Dam and increased water use from the dam result in a significant reduction in wet season flows. Low flows in the dry season remain unchanged as agricultural releases from Vondo Dam can still be met.
- 12_Luvuvhu, wet season flows are reduced because of increased demand from Nandoni Dam, which results in fewer wet season spills and lower dry season flows because Nandoni cannot meet all the required releases.
- 13_Mutale1 and 14_Mutale2, the building of Rambuda Dam on the Mutale River results in major reductions all year round due to increased demand from the river.

5.1 Ecologically-relevant flow indicators in DRIFT-Limpopo

Median values for the ecologically-relevant flow indicators are provided in **Table** 5-4. The values for the PES (2022) and Future1 scenarios are the same at 2_Rietfontein, 3_Olifantspruit, 6_Kolope and 10_Latonyanda because there are no developments planned (**Table** 5-1).

The ecologically-relevant flow indicators that best described the differences between scenarios are Mean Annual Runoff (MAR), discharge (Q) and volumes in the wet and dry seasons, duration and onset of the wet and dry seasons, the number of zero flow days and of flow days at depths >= 5 and 10 cm. The flow regime of the Reference scenario is wetter than PES (2022) at all sites except for at 3_Olifantspruit, 13_Mutale1 and 14_Mutale2 where PES (2022) and Reference are similar (**Table** 5-4**).** The flows at 4_Mogalakwena1, 5_Mogalakwena2 and 7_Sand are wetter in the Future1 scenario when compared to PES (2022) and drier at 1_Lephalala, 8_Nzhelele, 9_Ṅwanedi̭, 11_Mutshindudi, 12_Luvuvhu, 13_Mutale1 and 14_Mutale2. The flow regime of the Future2 scenario is wetter at the non-perennial river 7_Sand and drier at all the other sites.

Table 5-4: Ecologically-relevant flow indicators in DRIFT-Limpopo (median values)

	Scenario			
EWR site	**PES (2022)**	**Reference**	**Future1**	**Future2**
1_Lephalala				
Mean annual runoff (m^3/s)	1.2	1.6	1.1	0.8
Dry onset (calendar week)	22.0	18.0	22.0	14.0
Dry duration (days)	215.0	202.5	215.5	255.5
Dry minimum 5-day Q (m^3/s)	0.03	0.09	0.03	0.02
Wet onset (hydrological week)	16.0	12.0	15.5	15.5
Wet duration (days)	102.5	127.0	100.0	70.0
Wet maximum 5-day Q (m^3/s)	6.3	8.0	5.5	4.0
Wet maximum instantaneous 5-day Q (m^3/s)	8.6	10.7	7.7	5.6
Wet maximum 5-day Q-Baseflow (m^3/s)	2.57	3.51	2.28	1.75
Wet season volume ($m^3 \times 10^6$)	20.78	30.68	19.16	10.22
Dry average daily volume ($m^3 \times 10^6$)	0.034	0.056	0.034	0.029
T1 average daily volume ($m^3 \times 10^6$)	0.090	0.088	0.082	0.080
Wet average daily volume ($m^3 \times 10^6$)	0.235	0.272	0.221	0.169
T2 average daily volume ($m^3 \times 10^6$)	0.106	0.109	0.102	0.097
T1 duration (days)	15.50	16.50	16.00	15.50
Zero days per year (days)	2.26	1.98	2.26	2.26
(max)Continuous days>=5 cm deep (days)	327.50	353.50	327.50	327.50
(max)Continuous days>=10 cm deep (days)	302.50	322.00	301.50	289.50
2_Rietfontein				
Mean annual runoff (m^3/s)	0.0004	0.0009	0.0004	0.0003
Dry onset (calendar week)	17.00	14.00	15.00	16.00
Dry duration (days)	255.00	270.00	259.00	268.00
Dry minimum 5-day Q (m^3/s)	0.0000	0.0000	0.0000	0.0000
Wet onset (hydrological week)	15.00	15.00	15.00	15.00
Wet duration (days)	61.50	59.00	60.00	60.00
Wet maximum 5-day Q (m^3/s)	0.0074	0.0128	0.0074	0.0042
Wet maximum instantaneous 5-day Q (m^3/s)	0.0115	0.0145	0.0115	0.0035
Wet maximum 5-day Q-Baseflow (m^3/s)	0.0036	0.0038	0.0036	0.0020
Wet season volume ($m^3 \times 10^6$)	0.0050	0.0122	0.0050	0.0016
Dry average daily volume ($m^3 \times 10^6$)	0.0000	0.0000	0.0000	0.0000
T1 average daily volume ($m^3 \times 10^6$)	0.0001	0.0001	0.0002	0.0001
Wet average daily volume ($m^3 \times 10^6$)	0.0004	0.0005	0.0004	0.0003
T2 average daily volume ($m^3 \times 10^6$)	0.0000	0.0001	0.0000	0.0000
T1 duration (days)	24.00	18.00	20.50	31.00
Zero days per year (days)	328.56	319.52	327.46	340.28
(max)Continuous days>=5 cm deep (days)	364.00	364.00	364.00	364.00
(max)Continuous days>=10 cm deep (days)	4.00	8.00	4.00	0.00
3_Olifantspruit				
Mean annual runoff (m^3/s)	0.16	0.17	0.16	0.09
Dry onset (calendar week)	13.00	13.00	13.00	10.00
Dry duration (days)	256.50	242.00	256.50	295.50
Dry minimum 5-day Q (m^3/s)	0.002	0.004	0.002	0.000
Wet onset (hydrological week)	10.00	9.00	10.00	10.00
Wet duration (days)	73.50	82.00	73.50	37.00

	Scenario			
EWR site	**PES (2022)**	**Reference**	**Future1**	**Future2**
Wet maximum 5-day Q (m^3/s)	1.65	1.82	1.65	0.76
Wet maximum instantaneous 5-day Q (m^3/s)	3.36	3.54	3.36	1.10
Wet maximum 5-day Q-Baseflow (m^3/s)	0.36	0.38	0.36	0.26
Wet season volume (m^3 x 10^6)	2.33	2.75	2.33	0.76
Dry average daily volume (m^3 x 10^6)	0.00	0.01	0.00	0.00
T1 average daily volume (m^3 x 10^6)	0.01	0.01	0.01	0.01
Wet average daily volume (m^3 x 10^6)	0.03	0.04	0.03	0.03
T2 average daily volume (m^3 x 10^6)	0.01	0.01	0.01	0.01
T1 duration (days)	20.00	28.00	20.00	19.50
Zero days per year (days)	10.15	8.67	10.15	17.90
(max)Continuous days>=5 cm deep (days)	329.50	329.50	329.50	319.00
(max)Continuous days>=10 cm deep (days)	179.50	186.00	179.50	119.00
4_Mogalakwena1				
Mean annual runoff (m^3/s)	0.47	2.28	0.67	0.26
Dry onset (calendar week)	18.00	17.00	16.50	12.00
Dry duration (days)	245.00	225.00	271.50	293.50
Dry minimum 5-day Q (m^3/s)	0.00	0.04	0.01	0.00
Wet onset (hydrological week)	15.00	5.00	11.00	11.00
Wet duration (days)	72.00	124.00	30.00	7.00
Wet maximum 5-day Q (m^3/s)	3.80	23.87	4.99	1.25
Wet maximum instantaneous 5-day Q (m^3/s)	4.48	43.95	9.22	1.75
Wet maximum 5-day Q-Baseflow (m^3/s)	0.98	2.87	1.04	0.37
Wet season volume (m^3 x 10^6)	1.53	33.33	4.50	0.41
Dry average daily volume (m^3 x 10^6)	0.02	0.11	0.04	0.02
T1 average daily volume (m^3 x 10^6)	0.08	0.16	0.09	0.04
Wet average daily volume (m^3 x 10^6)	0.18	0.37	0.21	0.07
T2 average daily volume (m^3 x 10^6)	0.06	0.09	0.08	0.07
T1 duration (days)	30.50	4.00	20.50	31.00
Zero days per year (days)	132.54	3.32	3.59	4.67
(max)Continuous days>=5 cm deep (days)	180.50	290.50	265.00	241.50
(max)Continuous days>=10 cm deep (days)	148.00	262.00	200.50	183.00
5_Mogalakwena2				
Mean annual runoff (m^3/s)	0.6	3.3	0.6	0.1
Dry onset (calendar week)	18.0	17.0	18.0	18.0
Dry duration (days)	233.5	211.0	231.5	222.5
Dry minimum 5-day Q (m^3/s)	0.0000	0.0477	0.0000	0.0010
Wet onset (hydrological week)	15.0	5.0	15.0	15.0
Wet duration (days)	90.0	127.0	90.0	90.0
Wet maximum 5-day Q (m^3/s)	2.9	30.3	2.9	0.7
Wet maximum instantaneous 5-day Q (m^3/s)	2.7	52.1	3.0	0.9
Wet maximum 5-day Q-Baseflow (m^3/s)	0.65	3.71	1.31	0.42
Wet season volume (m^3 x 10^6)	1.39	59.37	1.58	1.36
Dry average daily volume (m^3 x 10^6)	0.02	0.15	0.02	0.01
T1 average daily volume (m^3 x 10^6)	0.10	0.22	0.09	0.01
Wet average daily volume (m^3 x 10^6)	0.2	0.6	0.2	0.0
T2 average daily volume (m^3 x 10^6)	0.0	0.1	0.1	0.0
T1 duration (days)	31.0	4.5	31.0	31.0
Zero days per year (days)	27.0	4.0	27.0	27.0
(max)Continuous days>=5 cm deep (days)	203.00	295.00	203.00	203.00
(max)Continuous days>=10 cm deep (days)	169.00	260.00	169.00	106.00
6_Kolope				
Mean annual runoff (m^3/s)	0.00	0.01	0.00	0.00
Dry onset (calendar week)	22.00	14.00	22.00	22.00
Dry duration (days)	254.50	265.00	254.50	215.00
Dry minimum 5-day Q (m^3/s)	0.00	0.00	0.00	0.00
Wet onset (hydrological week)	19.00	19.00	19.00	19.00
Wet duration (days)	89.00	64.50	89.00	89.00
Wet maximum 5-day Q (m^3/s)	0.02	0.08	0.02	0.00
Wet maximum instantaneous 5-day Q (m^3/s)	0.01	0.10	0.01	0.00
Wet maximum 5-day Q-Baseflow (m^3/s)	0.00	0.03	0.00	0.00
Wet season volume (m^3 x 10^6)	0.00	0.05	0.00	0.00
Dry average daily volume (m^3 x 10^6)	0.00	0.00	0.00	0.00

	Scenario			
EWR site	**PES (2022)**	**Reference**	**Future1**	**Future2**
T1 average daily volume (m^3 x 10^6)	0.00	0.00	0.00	0.00
Wet average daily volume (m^3 x 10^6)	0.00	0.00	0.00	0.00
T2 average daily volume (m^3 x 10^6)	0.00	0.00	0.00	0.00
T1 duration (days)	29.50	18.50	29.50	31.00
Zero days per year (days)	324.375	228.812	324.375	337.781
(max)Continuous days>=5 cm deep (days)	4.00	44.00	4.00	0.00
(max)Continuous days>=10 cm deep (days)	0.00	5.00	0.00	0.00
7_Sand				
Mean annual runoff (m^3/s)	0.147	0.207	1.040	1.024
Dry onset (calendar week)	8.000	9.000	10.000	10.500
Dry duration (days)	286.000	289.500	268.500	272.500
Dry minimum 5-day Q (m^3/s)	0.006	0.000	0.048	0.043
Wet onset (hydrological week)	15.000	11.000	9.000	9.000
Wet duration (days)	7.500	28.500	80.500	81.500
Wet maximum 5-day Q (m^3/s)	1.944	4.706	6.533	5.692
Wet maximum instantaneous 5-day Q (m^3/s)	4.155	10.126	17.832	15.731
Wet maximum 5-day Q-Baseflow (m^3/s)	0.195	0.398	0.877	0.848
Wet season volume (m^3 x 10^6)	0.606	3.184	11.513	9.765
Dry average daily volume (m^3 x 10^6)	0.010	0.006	0.085	0.083
T1 average daily volume (m^3 x 10^6)	0.013	0.042	0.051	0.050
Wet average daily volume (m^3 x 10^6)	0.063	0.112	0.118	0.111
T2 average daily volume (m^3 x 10^6)	0.010	0.013	0.029	0.027
T1 duration (days)	33.500	11.500	7.000	7.000
Zero days per year (days)	5.385	31.261	3.589	3.589
(max)Continuous days>=5 cm deep (days)	62.000	31.000	212.000	195.000
(max)Continuous days>=10 cm deep (days)	5.000	13.000	183.000	183.000
8_Nzhelele				
Mean annual runoff (m^3/s)	1.0	1.8	0.3	0.1
Dry onset (calendar week)	17.5	23.0	22.0	22.0
Dry duration (days)	231.5	184.0	237.0	240.5
Dry minimum 5-day Q (m^3/s)	0.2	0.3	0.0	0.0
Wet onset (hydrological week)	16.0	13.5	15.0	15.0
Wet duration (days)	53.5	137.0	117.0	120.0
Wet maximum 5-day Q (m^3/s)	4.7	8.8	2.9	1.1
Wet maximum instantaneous 5-day Q (m^3/s)	7.3	12.8	3.5	1.4
Wet maximum 5-day Q-Baseflow (m^3/s)	1.0	2.6	0.5	1.1
Wet season volume (m^3 x 10^6)	7.5	30.4	1.4	0.5
Dry average daily volume (m^3 x 10^6)	0.1	0.1	0.0	0.0
T1 average daily volume (m^3 x 10^6)	0.1	0.1	0.1	0.1
Wet average daily volume (m^3 x 10^6)	0.2	0.3	0.2	0.1
T2 average daily volume (m^3 x 10^6)	0.1	0.1	0.1	0.0
T1 duration (days)	16.5	19.5	13.0	31.0
Zero days per year (days)	0.0	0.0	60.6	178.3
(max)Continuous days>=5 cm deep (days)	364.0	364.0	273.0	92.0
(max)Continuous days>=10 cm deep (days)	364.0	364.0	273.0	85.0
9_Ṅwanedi				
Mean annual runoff (m^3/s)	0.6	0.8	0.4	0.2
Dry onset (calendar week)	15.0	17.0	18.0	17.0
Dry duration (days)	259.0	224.5	247.5	253.0
Dry minimum 5-day Q (m^3/s)	0.1	0.2	0.0	0.0
Wet onset (hydrological week)	12.0	8.0	17.0	17.0
Wet duration (days)	75.5	119.5	59.5	68.0
Wet maximum 5-day Q (m^3/s)	2.8	3.7	1.2	0.7
Wet maximum instantaneous 5-day Q (m^3/s)	4.2	5.4	1.2	0.7
Wet maximum 5-day Q-Baseflow (m^3/s)	0.6	0.9	0.5	0.3
Wet season volume (m^3 x 10^6)	5.8	12.4	0.7	0.4
Dry average daily volume (m^3 x 10^6)	0.0	0.0	0.0	0.0
T1 average daily volume (m^3 x 10^6)	0.0	0.0	0.0	0.0
Wet average daily volume (m^3 x 10^6)	0.1	0.1	0.1	0.0
T2 average daily volume (m^3 x 10^6)	0.0	0.0	0.0	0.0
T1 duration (days)	17.5	7.0	31.0	26.5
Zero days per year (days)	0.0	0.0	50.0	90.0

	Scenario			
EWR site	**PES (2022)**	**Reference**	**Future1**	**Future2**
(max)Continuous days>=5 cm deep (days)	364.0	364.0	243.5	218.0
(max)Continuous days>=10 cm deep (days)	297.0	364.0	234.0	174.0
10_Latonyanda				
Mean annual runoff (m^3/s)	0.47	0.63	0.47	0.34
Dry onset (calendar week)	18.00	20.00	18.00	15.00
Dry duration (days)	202.00	183.50	202.00	246.50
Dry minimum 5-day Q (m^3/s)	0.10	0.13	0.10	0.07
Wet onset (hydrological week)	14.50	11.00	14.50	14.50
Wet duration (days)	111.50	135.00	111.50	63.50
Wet maximum 5-day Q (m^3/s)	2.01	2.97	2.01	1.63
Wet maximum instantaneous 5-day Q (m^3/s)	2.86	4.28	2.86	2.13
Wet maximum 5-day Q-Baseflow (m^3/s)	1.02	1.38	1.02	0.72
Wet season volume ($m^3 \times 10^6$)	9.66	14.49	9.66	5.02
Dry average daily volume ($m^3 \times 10^6$)	0.02	0.02	0.02	0.02
T1 average daily volume ($m^3 \times 10^6$)	0.02	0.03	0.02	0.02
Wet average daily volume ($m^3 \times 10^6$)	0.08	0.10	0.08	0.08
T2 average daily volume ($m^3 \times 10^6$)	0.04	0.04	0.04	0.04
T1 duration (days)	33.00	31.50	33.00	29.00
Zero days per year (days)	0.00	0.00	0.00	0.00
(max)Continuous days>=5 cm deep (days)	364.00	364.00	364.00	364.00
(max)Continuous days>=10 cm deep (days)	250.50	303.50	250.50	213.50
11_Mutshindudi				
Mean annual runoff (m^3/s)	1.01	1.33	0.69	0.49
Dry onset (calendar week)	14.00	15.00	15.00	12.50
Dry duration (days)	232.50	209.50	232.50	275.00
Dry minimum 5-day Q (m^3/s)	0.16	0.22	0.16	0.10
Wet onset (hydrological week)	15.00	11.00	16.50	16.50
Wet duration (days)	86.50	111.00	55.50	14.50
Wet maximum 5-day Q (m^3/s)	5.11	6.60	2.69	1.88
Wet maximum instantaneous 5-day Q (m^3/s)	6.78	11.63	3.81	2.23
Wet maximum 5-day Q-Baseflow (m^3/s)	1.60	2.25	0.87	0.65
Wet season volume ($m^3 \times 10^6$)	18.59	28.96	8.50	1.15
Dry average daily volume ($m^3 \times 10^6$)	0.04	0.05	0.04	0.03
T1 average daily volume ($m^3 \times 10^6$)	0.04	0.06	0.05	0.05
Wet average daily volume ($m^3 \times 10^6$)	0.23	0.27	0.16	0.13
T2 average daily volume ($m^3 \times 10^6$)	0.09	0.10	0.08	0.06
T1 duration (days)	38.50	27.00	45.00	31.00
Zero days per year (days)	0.00	0.00	0.00	0.00
(max)Continuous days>=5 cm deep (days)	364.00	364.00	364.00	364.00
(max)Continuous days>=10 cm deep (days)	364.00	364.00	364.00	334.00
12_Luvuvhu				
Mean annual runoff (m^3/s)	4.48	9.03	2.40	1.19
Dry onset (calendar week)	15.50	25.50	15.00	15.00
Dry duration (days)	258.00	158.50	262.50	283.00
Dry minimum 5-day Q (m^3/s)	0.17	1.68	0.16	0.06
Wet onset (hydrological week)	15.00	7.00	16.50	16.50
Wet duration (days)	81.00	201.00	51.00	47.00
Wet maximum 5-day Q (m^3/s)	37.35	63.45	17.32	9.10
Wet maximum instantaneous 5-day Q (m^3/s)	54.39	95.95	28.58	10.20
Wet maximum 5-day Q-Baseflow (m^3/s)	10.10	15.82	4.45	2.61
Wet season volume ($m^3 \times 10^6$)	80.02	211.75	21.01	4.50
Dry average daily volume ($m^3 \times 10^6$)	0.11	0.32	0.09	0.06
T1 average daily volume ($m^3 \times 10^6$)	0.28	0.38	0.24	0.25
Wet average daily volume ($m^3 \times 10^6$)	1.29	1.25	0.79	0.47
T2 average daily volume ($m^3 \times 10^6$)	0.36	0.42	0.27	0.19
T1 duration (days)	17.00	7.00	17.00	17.00
Zero days per year (days)	0.00	0.00	0.00	0.00
(max)Continuous days>=5 cm deep (days)	364.00	364.00	364.00	364.00
(max)Continuous days>=10 cm deep (days)	334.00	364.00	324.00	284.50

	Scenario			
EWR site	**PES (2022)**	**Reference**	**Future1**	**Future2**
13_Mutale1				
Mean annual runoff (m^3/s)	2.80	3.13	2.07	1.27
Dry onset (calendar week)	15.00	15.50	15.00	14.00
Dry duration (days)	211.00	204.50	242.50	265.50
Dry minimum 5-day Q (m^3/s)	0.18	0.32	0.03	0.02
Wet onset (hydrological week)	10.00	9.00	15.00	15.00
Wet duration (days)	120.00	125.50	90.00	60.50
Wet maximum 5-day Q (m^3/s)	20.39	21.62	16.00	11.88
Wet maximum instantaneous 5-day Q (m^3/s)	22.83	24.69	18.80	13.27
Wet maximum 5-day Q-Baseflow (m^3/s)	4.73	5.19	3.84	2.70
Wet season volume ($m^3 \times 10^6$)	64.05	71.14	36.66	19.72
Dry average daily volume ($m^3 \times 10^6$)	0.06	0.08	0.02	0.02
T1 average daily volume ($m^3 \times 10^6$)	0.15	0.14	0.17	0.17
Wet average daily volume ($m^3 \times 10^6$)	0.57	0.62	0.58	0.49
T2 average daily volume ($m^3 \times 10^6$)	0.19	0.19	0.15	0.12
T1 duration (days)	20.50	19.50	11.00	13.00
Zero days per year (days)	0.00	0.00	0.00	0.00
(max)Continuous days>=5 cm deep (days)	364.00	364.00	364.00	364.00
(max)Continuous days>=10 cm deep (days)	364.00	364.00	335.00	301.00
14_Mutale2				
Mean annual runoff (m^3/s)	3.12	3.44	2.32	1.55
Dry onset (calendar week)	15.00	15.00	15.00	14.00
Dry duration (days)	231.50	220.50	260.00	272.50
Dry minimum 5-day Q (m^3/s)	0.21	0.35	0.05	0.02
Wet onset (hydrological week)	11.00	10.00	15.00	15.00
Wet duration (days)	88.00	96.50	74.50	61.50
Wet maximum 5-day Q (m^3/s)	23.37	25.31	19.15	12.75
Wet maximum instantaneous 5-day Q (m^3/s)	32.43	33.60	28.34	16.38
Wet maximum 5-day Q-Baseflow (m^3/s)	5.51	5.74	4.92	3.23
Wet season volume ($m^3 \times 10^6$)	55.60	62.55	42.23	18.67
Dry average daily volume ($m^3 \times 10^6$)	0.08	0.10	0.04	0.03
T1 average daily volume ($m^3 \times 10^6$)	0.24	0.23	0.32	0.31
Wet average daily volume ($m^3 \times 10^6$)	0.70	0.69	0.74	0.55
T2 average daily volume ($m^3 \times 10^6$)	0.22	0.23	0.17	0.14
T1 duration (days)	17.00	16.00	5.00	11.00
Zero days per year (days)	0.00	0.00	0.00	0.00
(max)Continuous days>=5 cm deep (days)	364.00	364.00	364.00	364.00
(max)Continuous days>=10 cm deep (days)	364.00	364.00	230.00	150.50

5.2 Presentation of the results of the scenario analysis

The results for the scenarios are presented in terms of the predicted implications relative to PES (2022), and include, as appropriate:

- Individual discipline integrity
- Overall ecosystem integrity.

5.2.1 Overall Ecosystem Integrity

The overall Ecosystem Integrity is a measure of the expected condition or health of the river ecosystem based on the expected condition of the disciplines representing the river ecosystem (**Table** 1-1).

Ecosystem Integrity is predicted for each site/scenario as a measure of how far the scenarios would move the condition of the ecosystem from **reference conditions**. It is calculated as a function of the values for the individual ecosystem indicators:

- Discipline Integrity, is a weighted average of its individual indicators. In some disciplines, indicators were weighted slightly differently at different sites. For example, where sandy habitats were less of an important feature of the river, these might have been down weighted. In addition, for geomorphological integrity, erosion was excluded as it is a driver rather than an outcome.
- The overall Ecosystem integrity is a weighted average of the Discipline Integrity scores (geomorphology, riparian vegetation, macroinvertebrates and fish).

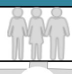
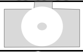
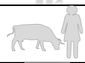
5.2.2 Social-use

River-related social-use indicators included in the scenario assesment are:

- intangible contributions that affect quality of life, either individually or collectively, such as recreational, cultural and spiritual links to a river (**Section 5.2.1**);
- tangible contributions such as access and availabilty of water for domestic use, fishing, plant harvesting, recession farming, livestock grazing, contribution to tourism and carbon sequestration;
- changes in health risks due to water-borne or water-associated diseases (e.g. bilharzia);
- changes in water treatment costs (e.g. due to algae or pollution).
- overall social well-being as a weighted average of all the individual indicators.

A subset of these indicators is provided in the summary tables (**Table** 5-5).

Table 5-5: Icons for social use

Recreation, culture value	Icon
Overall social well-being	
Nature tourism value	
Fisheries value	
Plant resource value	
Domestic and livestock watering	
Carbon retention value	

The social-use icons are reported as percentage increases or decreases in value relative to the PES (2022) using the colours in Table 5-6**.**. The PES (2022) social conditions, population size and household densities are different at different sites, so the results relative to the PES (2022) are not comparable across EWR zones since the population size and household densities differ.

Table 5-6: Definitions of colours used to report change in the social-use icons

Colour	Change relative to PES (2022)
	Marked increase/improvement >+40%)
	Increase/improvement (+20 to +40%)
	Slight increase/improvement (+5 to +20%)
	Little or no change (-5 to +5%)
	Slight decrease/deterioration (-5 to –20%)
	Decrease/deterioration (-20 to -40%)
	Marked decrease/deterioration (<-40%) (a greater than 40% decrease)

6 ECOSYSTEM AND SOCIAL OUTCOMES

6.1 Predicted changes in overall Ecological Integrity

The ecological categories predicted under the three scenarios without improved management are provided in **Table** 6-1.

Table 6-1: The ecological categories predicted under the PES (2022), Future1 and Future2 flow scenarios, without improved management

Future development? Yes / No	EWR site	PES (2022)	Future1	Future2
Yes	1_Lephalala	C	C	C/D
No	2_Rietfontein	B/C	B/C	B/C
No	3_Olifantspruit	C	C	C/D
Yes	4_Mogalakwena1	C	B/C	C
Yes	5_Mogalakwena2	C	C	C
No	6_Kolope	C	C	C/D
Yes	7_Sand	C	B/C	B/C
Yes	8_Nzhelele	C	D	D/E
Yes	9_Ṅwanedi	C	D	D/E
No	10_Latonyanda	C	C	C
Yes	11_Mutshindudi	C	C	C/D
Yes	12_Luvuvhu	C	C	C/D
Yes	13_Mutale1	C	C/D	D
Yes	14_Mutale2	C	C/D	D

Under the PES (2022), the rivers are in fair to good ecological condition. The ecological category is a C at 13 of the 14 sites, and at 2_Rietfontein it is a B/C category.

Under Future1 (future development, **Table** 6-1):

- There were no changes predicted to the ecological categories at 2_Rietfontein, 3_Olifantsfontein, 6_Kolope and 10_Latonyanda because there are no planned water-resource developments modelled for these sites, i.e., PES (2022) and Future1 have identical flow regimes.
- There were no changes predicted to the ecological categories at 1_Lephalala, 5_Mogalakwena2, 11_Mutshindudi and 12_Luvuvhu because the changes in the flow regime were insufficient to illicit an ecological response.
- The ecological category was expected to be higher than PES (2022) at two sites as a result of higher dry and wet season low flows:
  - 4_Mogalakwena1 improved from a C to a B category
  - 7_Sand improved from a C to a B/C category.
- The ecological category was expected to be lower than PES (2022) at four sites as a result of reduced flows:
  - 8_Nzhelele and 9_Ṅwanedi dropped from a C to a D category
  - 13_Mutale1 and 14_Mutale2 dropped from a C to a C/D category.

Under Future2 (climate change, **Table** 6-1):

- There were no changes predicted to the ecological categories at 2_Rietfontein, 4_Mogalakwena1, 5_Mogalakwena2, and 10_Latonyanda because the changes in the flow regime were insufficient to illicit an ecological response.
- The ecological category was expected to be higher than PES (2022) at 7_Sand as a result of higher dry and wet season low flows:
  - 7_Sand improved from a C to a B/C category.
- The ecological category was expected to be lower than PES (2022) at nine sites as a result of reduced flows:
  - 1_Lephalala, 3_Olifantspruit, 6_Kolope, 11_Mutshinududi and 12 Luvuvhu dropped from a C to a C/D category
  - 8_Nzhelele and 9_Ṅwaneḓi dropped from a C to a D/E category
  - 13_Mutale1 and 14_Mutale2 dropped from a C to a D category.

6.2 Drivers of predicted ecological condition

6.2.1 Future1 scenario (future development)

The discipline specific ecological conditions associated with PES (2022) and Future1 scenarios are presented in **Table** 6-2.

Table 6-2: PES (2022) and Future1 predicted discipline-specific ecological conditions (EC = Ecological Category, G = Geomorphology, WQ = Water Quality, V = Vegetation, I = Macroinvertebrates, F = Fish)

	PES							Future1					
	EC	G	WQ	V	I[7]	F[8]		EC	G	WQ	V	I	F
1_Lephalala	C	C	B	C	B/C	D/E		C	C	B	C	B/C	D/E
2_Rietfontein	B/C	C	B/C	A/B	B	A/B		B/C	C	B/C	A/B	B	A/B
3_Olifantspruit	C	C	B	D	B/C	C		C	C	B	D	B	C
4_Mogalakwena1	C	C	C	C/D	C	C		B/C	C	C	B	B/C	A
5_Mogalakwena2	C	D	B/C	C	C	A/B		C	D	B/C	B/C	C	A
6_Kolope	C	D	B/C	C	B/C	D		C	D	B/C	C	B/C	D
7_Sand	C	C	D	C	C	C		B/C	C	D	A/B	A/B	A/B
8_Nzhelele	C	C/D	C	C	C	B		D	D	C	D/E	D	E
9_Ṅwaneḓi	C	D	C	C	C	B/C		D	D	C	D	C/D	D/E
10_Latonyanda	C	C	A/B	C/D	B/C	B/C		C	C	A/B	C/D	B/C	B/C
11_Mutshindudi	C	C	B/C	C	C	C		C	C	B/C	C/D	C	C/D
12_Luvuvhu	C	D	B	C	B/C	C		C	D	B	C/D	C	C/D
13_Mutale1	C	C	B	B/C	C	C		C/D	C/D	B/C	C/D	D	D/E
14_Mutale2	C	C	B	B	C	C		C/D	C/D	B/C	C/D	C/D	D

[7] There were no invertebrate data collected at the non-perennial sites (2_Rietfontein, 6_Kolope, 7_Sand) because they were dry. However, to acknowledge that there would be invertebrates in these rivers a PES score for these sites for this discipline was made based on specialist opinion and discussions during the workshop held in July and September 2023. The PES estimates are low confidence.'

[8] There were no fish data collected at the non-perennial sites (6_Kolope, 7_Sand) because they were dry. However, to acknowledge that there would be fish in these rivers a PES score for these sites for this discipline was made based on specialist opinion and discussions during the workshop held in July and September 2023. The PES estimates are low confidence.

Sites where the overall ecosystem category did not change relative to PES (2022) under Future1 are not discussed further.

6.2.1.1 Predicted improvements in ecological category

The predicted improvement at 4_Mogalakwena1 (C to a B/C category) is in response to increased dry season flows. These are expected to reduce embeddedness, increase pool depth and inundate more sandy and rocky habitat. The resultant improvement in habitat conditions is expected to lead to increased abundance of riparian plants, invertebrates and fish.

The predicted improvement at 7_Sand (C to a B/C category) is in response to increased abundance of riparian plants, invertebrates and fish in response to higher dry and wet season flows relative to PES (2022).

6.2.1.2 Predicted declines in ecological category

The predicted decline at 8_Nzhelele and 9_Ṅwaneḓi (C to a D) is in response to significantly lower flows year round relative to PES (2022). These are expected to increase embeddedness and reduce habitat area and quality for riparian vegetation, invertebrates and fish.

The predicted decline at 13_Mutale1 and 14_Mutale2 (C to a C/D) is also in response to significantly lower flows year round. At these sites, the implications are expected to include increased embeddedness; lower pool depths; smaller backwaters and secondary channels, and; less inundated sandy and rocky habitat. The reduce habitat area and quality are expected to have negative repercussions for riparian vegetation, invertebrates and fish.

6.2.2 Future2 scenario (climate change)

The discipline specific ecological conditions associated with PES (2022) and Future2 scenarios are presented in **Table** 6-3.

Table 6-3: PES (2022) and Future2 predicted discipline-specific ecological conditions (EC = Ecological Category, G = Geomorphology, WQ = Water Quality, V = Vegetation, I = Macroinvertebrates, F = Fish)

	PES							Future2					
	EC	G	WQ	V	I[9]	F[10]		EC	G	WQ	V	I	F
1_Lephalala	C	C	B	C	B/C	D/E		C/D	C/D	B	C/D	C	E
2_Rietfontein	B/C	C	B/C	A/B	B	A/B		B/C	C	B/C	B	B	A/B
3_Olifantspruit	C	C	B	D	B/C	C		C/D	C/D	B	E	B/C	D
4_Mogalakwena1	C	C	C	C/D	C	C		C	C	C	C	C	B/C
5_Mogalakwena2	C	D	B/C	C	C	A/B		C	D	B/C	C	C	B/C
6_Kolope	C	D	B/C	C	B/C	D		C/D	D	B/C	C	B/C	D
7_Sand	C	C	D	C	C	C		B/C	C	D	A/B	A/B	A/B
8_Nzhelele	C	C/D	C	C	C	B		D/E	D	C/D	E/F	D/E	F
9_Ṅwanedi	C	D	C	C	C	B/C		D/E	D	C	E	D	E/F
10_Latonyanda	C	C	A/B	C/D	B/C	B/C		C	C	A/B	D	C	C/D
11_Mutshindudi	C	C	B/C	C	C	C		C/D	C/D	B/C	C/D	C/D	D
12_Luvuvhu	C	D	B	C	B/C	C		C/D	D	B	D	C	D/E
13_Mutale1	C	C	B	B/C	C	C		D	C/D	B/C	D	D	E
14_Mutale2	C	C	B	B	C	C		D	C/D	B/C	D	C/D	D/E

Sites where the overall ecological category did not change relative to PES (2022) under Future2 are not discussed further.

6.2.2.1 Predicted improvements in ecological category

The predicted improvements at 7_Sand (C to a B/C category) is in response to increased abundance of riparian plants, invertebrates and fish in response to higher dry and wet season flows relative to PES (2022).

6.2.2.2 Predicted decline in ecological category

The predicted declines in ecological category are all in response to a significant reduction in flows all year round relative to PES (2022).

At 1_Lephalala and 3_Olifantspruit (C to a C/D category) this is expected to lead to smaller secondary channels and backwaters and less inundated sand, cobble and riffle habitat. The reductions in area and quality of habitat are expected to have negative repercussions for riparian vegetation and fish.

[9] There were no invertebrate data collected at the non-perennial sites (2_Rietfontein, 6_Kolope, 7_Sand) because they were dry. However, to acknowledge that there would be invertebrates in these rivers a PES score for these sites for this discipline was made based on specialist opinion and discussions during the workshop held in July and September 2023. The PES estimates are low confidence.

[10] There were no invertebrate data collected at the non-perennial sites (2_Rietfontein, 6_Kolope, 7_Sand) because they were dry. However, to acknowledge that there would be invertebrates in these rivers a PES score for these sites for this discipline was made based on specialist opinion and discussions during the workshop held in July and September 2023. The PES estimates are low confidence.

At 8_Nzhelele and 9_Ṅwanedi (C to a D/E category) and 11_Mutshindudi and 12_Luvuvhu (C to a C/D category) this is expected to increase embeddedness and reduce habitat area and quality for riparian vegetation, invertebrates and fish.

At 13_Mutale1 and 14_Mutale2 (C to a D category) predicted responses include increased embeddedness; lower pool depths; smaller backwaters and secondary channels, and; less inundated sandy and rocky habitat. The reduced habitat area and quality are expected to have negative repercussions for riparian vegetation, invertebrates and fish.

6.3 Social use and economic value

6.3.1 Future1 scenario

The discipline specific social use and ecosystem value associated with PES (2022) and Future1 scenarios are presented in **Figure** 6-1**.**

There were no changes predicted to the overall social wellbeing at any of the sites because most predictions were for slight improvements or declines. Sites where no changes in any discipline were predicted relative to PES (2022) under Future1 are not discussed further.

6.3.1.1 Predicted improvements in social use and ecosystem value

The predicted improvements in carbon storage value at 4_Mogalakwena1, 5_Mogalakwena2 and 7_Sand are in response to increased dry season flows that are expected to increase the abundance of riparian vegetation at these sites (**Section 6.2.1.1**). This is expected to improve plant resource value at 5_Mogalakwena2. The increased dry season flows are also expected to improve domestic livestock use at 4_Mogalakwena1.

6.3.1.2 Predicted decline in social use and ecosystem value

The predicted decline in social use and ecosystem value at 8_Nzhelele, 9_Ṅwanedi, 13_Mutale1 and 14_Mutale2 are all in response to a significant reduction in flows all year round. This is expected to reduce domestic livestock use. The predicted reduction in abundance of fish (**Section 6.2.1.2**) is expected to reduce the fisheries value and the predicted reduction in abundance of riparian vegetation to reduce carbon retention value and plant resource value.

6.3.2 Future2 scenario

The discipline specific social use and ecosystem value associated with PES (2022) and Future2 scenarios are presented in **Figure** 6-1.

There were no changes predicted to the overall social wellbeing at any of the sites because most predictions were for slight improvements or declines. Sites where no changes in any discipline were predicted relative to PES (2022) under Future2 are not discussed further.

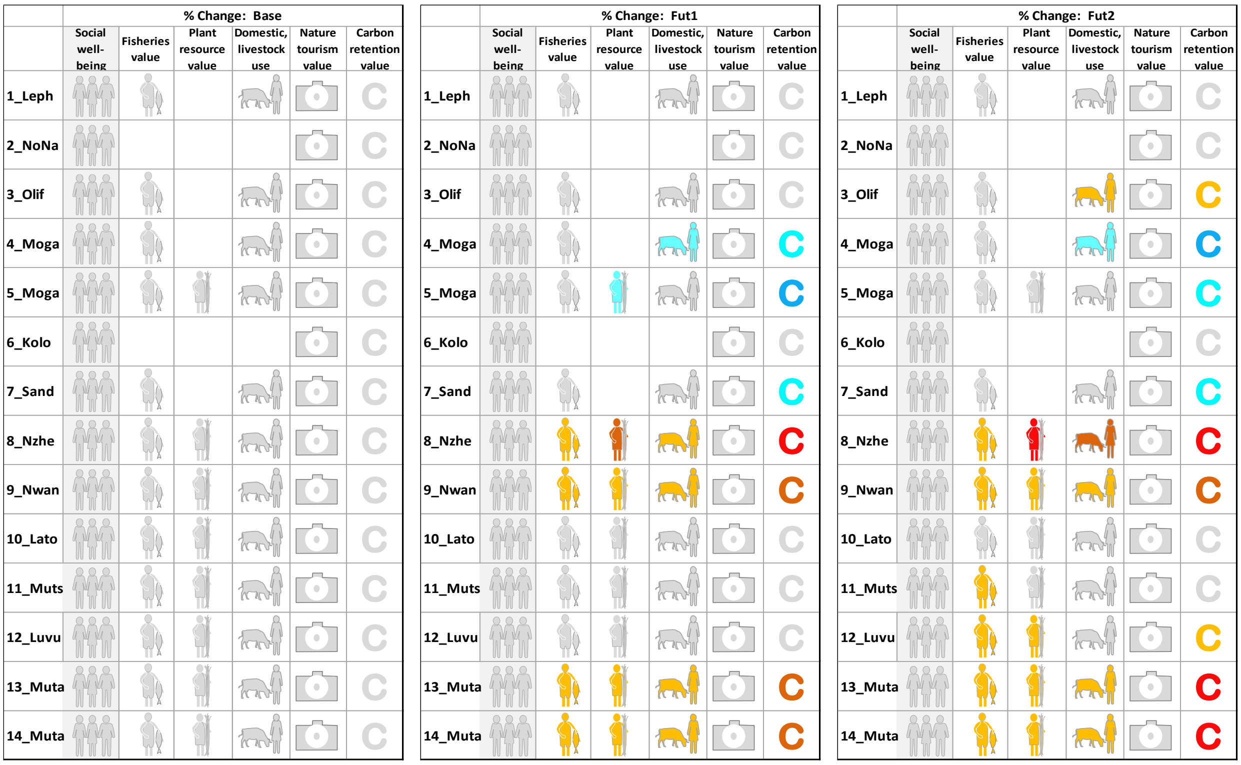


Figure 6-1 PES (2022), Future1 and Future2: Social use and ecosystem value predictions

6.3.2.1 Predicted improvements in social use and ecosystem value

The predicted improvements in carbon storage value at 4_Mogalakwena1, 5_Mogalakwena2 and 7_Sand are in response to increased dry season flows that are expected to increase the abundance of riparian vegetation at these sites (**Section 6.2.1.1**). The increased dry season flows are also expected to improve domestic livestock use at 4_Mogalakwena1.

6.3.2.2 Predicted decline in social use and ecosystem value

The predicted declines in social use and ecosystem value are all in response to a significant reduction in flows all year round relative to PES (2022).

Most of the declines predicted at 8_Nzhelele, 9_Ṅwanedi, 13_Mutale1 and 14_Mutale2 are the same as Future 1. The three exceptions are more severe declines in plant resource value and domestic livestock value at 8_Nzhelele and carbon retention value at 14_Mutale2.

Further declines are predicted in:

- domestic livestock value and at 3_Olifantspruit
- carbon retention value at 3_Olifantspruit and 12_Luvuvhu and plant resource value at 12_Luvuvhu in response to the predicted decline in the abundance of riparian vegetation (**Section 6.2.2.2**), and
- fisheries value at 11_Mutshindudi in response to the predicted decline in the abundance of fish (**Section 6.2.2.2**).

7 ECOLOGICAL WATER REQUIREMENTS

The outcomes of the scenario analyses (**Table** 7-1) were used to guide the options for EWRs.

Table 7-1 RECs and outcomes under PES (2022), Future1, Future2 and Synthetic Scenarios

Future development	EWR site	PES	EIS	REC	Future1	Future2	Synthetic Scenario		Management actions* recommended?
Yes / No					Outcome of scenario flow regime				Yes / No
No	2_Rietfontein	B/C	Mod	B/C	B/C	B/C			No
	3_Olifantspruit	C	Mod	B/C	C	C/D			Yes
	6_Kolope	C	Mod	B/C	C	C/D			Yes
	10_Latonyanda	C	Mod	C	C	C			No
Yes	1_Lephalala	C	Mod	B/C	C	C/D			Yes
	4_Mogalakwena1	C	Mod	C	B/C	B/C			No
	5_Mogalakwena2	C	Mod	C	C	C			No
	7_Sand	C	Mod	C	B/C	B/C			No
	11_Mutshindudi	C	Mod	C	C	C/D			Yes
	12_Luvuvhu	C	Mod	B/C	C	C/D			Yes
	8_Nzhelele	C	Mod	C	D	D/E	SS1	C/D	No
	9_Ṅwaneḓi	C	Mod	C	D	D/E	SS1	C/D	No
	13_Mutale1	C	Mod	C	C/D	D	SS2	C	No
	14_Mutale2	C	Mod	C	C/D	D	SS1	C	No

Where no developments were planned under the Future1 scenario (four sites), and there were no regulating structures upstream to regulate river flow (i.e. Future1 scenario's flow regime is the same as the PES (2022) scenario), PES (2022) flows are given as EWRs so that, all other factors remaining the same, PES (2022) conditions would be maintained under the Future1 scenario. The flows are predicted to:

- maintain a PES (2022) B/C category at 2_Rietfontein (**Section 7.2.2**).
- maintain the PES (2022) C category at 3_Olifantspruit (**Section 7.2.4**) and 6_Kolope (**Section 7.2.6**) and with suggested non-flow related mitigations improve to the REC of a B/C (see **Section 2.2.2**).
- maintain a PES (2022) C category at 10_Latonyanda (**Section 7.2.10**).

For six sites where developments are planned under the Future1 scenario and the expected Ecological Status was the same as PES (2022) or better, the PES (2022) and Future1 scenario flows are both provided as EWRs, the former for use prior to development and the latter for use once the developments are in place. These flows are predicted to:

- maintain a C category at 1_Lephalala prior to and after development (**Section 7.2.1**) and with suggested non-flow related mitigations (see **Section 2.2.2**) improve to the REC of a B/C category.
- maintain a C category at 4_Mogalakwena1 (**Section 7.2.4**) and 7_Sand (**Section 7.2.7**) prior to development, and improve to a B category at 4_Mogalakwena1 and a B/C at 7_Sand after development.
- maintain a C category at 5_Mogalakwena2 (**Section 7.2.5**).
- maintain a C category at 11_Mutshindudi (**Section 7.2.11**) prior to and after development along with the suggested non-flow related mitigations (see **Section 2.2.2**).

- maintain a C category at 12_Luvuvhu (**Section 7.2.12**) prior to and after development, and with suggested non-flow related mitigations improve to the REC of a B/C (see **Section 2.2.2**).

Where developments are planned under the Future1 scenario and the expected Ecological Status under Future1 was poorer than PES (2022), the PES (2022) and Future1 flows are both provided as EWRs, the former for use prior to development and the latter as *an option* for use once the developments are in place. These flows are predicted to:

- maintain a C category at 8_Nzhelele (**Section 7.2.8**) and 9_Ṅwaneḓi (**Section 7.2.9**) prior to development and result in a D category after development.
- maintain a C category at 13_Mutale1 (**Section 7.2.13**) and 14_Mutale2 (**Section 7.2.14**) prior to development and result in a C/D category after development.

7.1 Synthetic scenarios

Since the expected Ecological Status under Future1 at 8_Nzhelele, 9_Ṅwaneḓi, 13_Mutale1 and 14_Mutale2 was close to, or at, the lower limit acceptable for sustainability (a D category), Synthetic Scenarios (SS) were created to explore other options that allow for development with less severe consequences for the overall Ecological Status of the rivers. These are described in **Section 7.1**.

Three scenarios were developed, progressively increasing the low flows with restrictions (e.g. if the resulting flows were higher than PES (2022) then Future1 flows were retained (**Figure** 7-1).

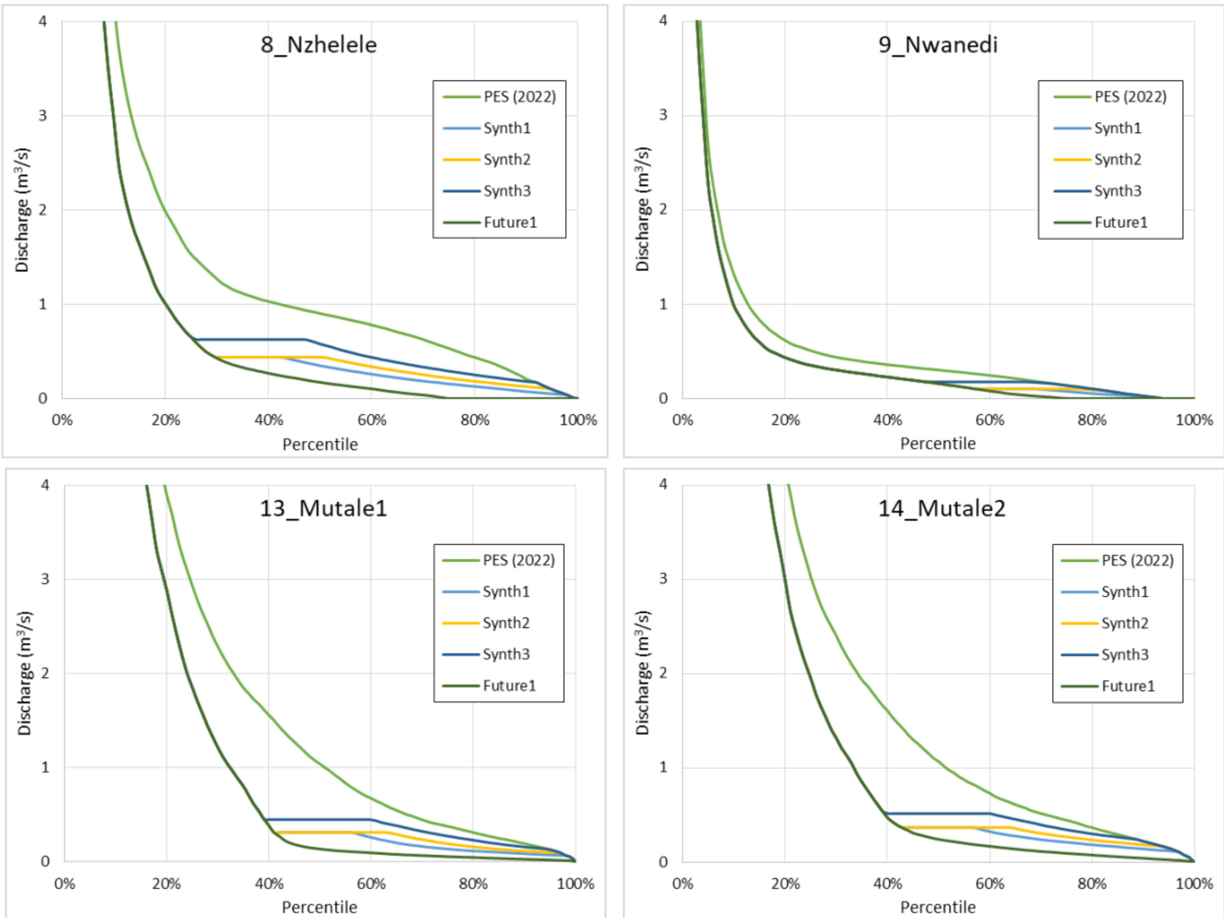


Figure 7-1 Flow duration curve for PES (2022), Future1 and Synthetic Scenarios 1, 2 and 3

The three Synthetic Scenarios were developed using the following rules:

- Synthetic Scenario 1 (Synth1): low flows lower than the 30th percentile of Future1 were restored to PES (2022). No changes were made to floods.
- Synthetic Scenario 2 (Synth2): low flows lower than the 40th percentile of Future1 were restored to PES (2022). No changes were made to floods.
- Synthetic Scenario 3 (Synth3): low flows lower than the 50th percentile of Future1 were restored to PES (2022). No changes were made to floods.

Synth1 is the driest scenario and Synth2 and Synth3 are steadily wetter. The Synthetic Scenarios explored scenarios by *increasing low flows (mostly) in the dry season* to see whether the expected Ecological Status could be improved. The increases were unrelated to the planned developments.

All three scenarios increased the Ecological Status expected under the Future1 flow scenario of the Nzhelele and Ṅwanedi Rivers from a D to C/D category (**Figure** 7-2). Increases higher than those of Synth1 (i.e. Synth2 and Synth3) did not improve the overall Ecological Status above that of Synth1. Increases higher than Synth1 are probably also unrealistic given planned developments. The driest of the three (SS1) was therefore selected as an alternate option for the EWR that has slightly more flow than Future1 and results in an improvement overall to a C/D category.

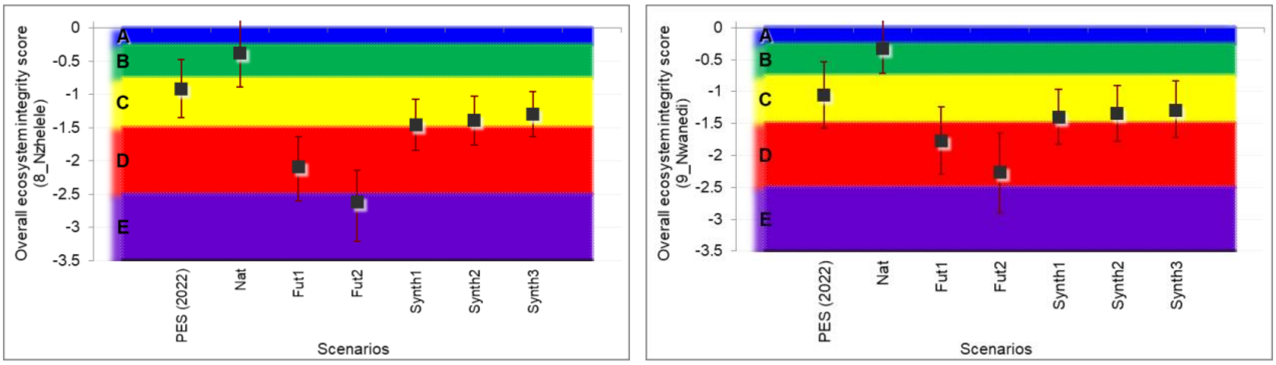


Figure 7-2 Changes predicted in Ecological Status at 8_Nzhelele (L) and 9_Ṅwanedi (R)

For 13_Mutale1 the increased flows under Synth1 were insufficient, but those of Synth2 improved the overall condition from a C/D to a C category and was selected as an alternate option for the EWRs having slightly more flow than Future1 (**Figure** 7-3).

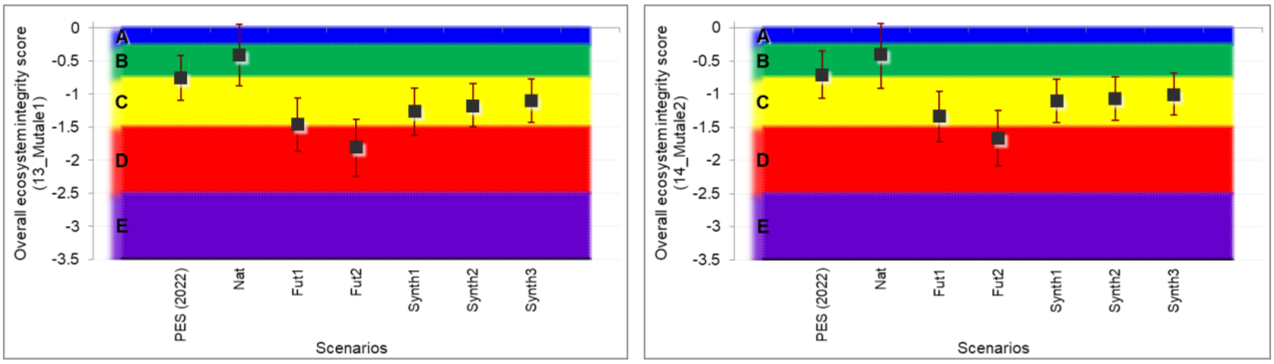


Figure 7-3 Changes predicted in Ecological Status at 13_Mutale1 (L) and 14_Mutale2 (R)

The improvement in low flows at 4_Mogalakwena1, 5_Mogalakwena2, 8_Nzhelele and 9_Ṅwaneḓi of Synthetic Scenario 1 or 2 over Future1 are shown relative to the PES (2022) scenario in **Figure** 7-4.

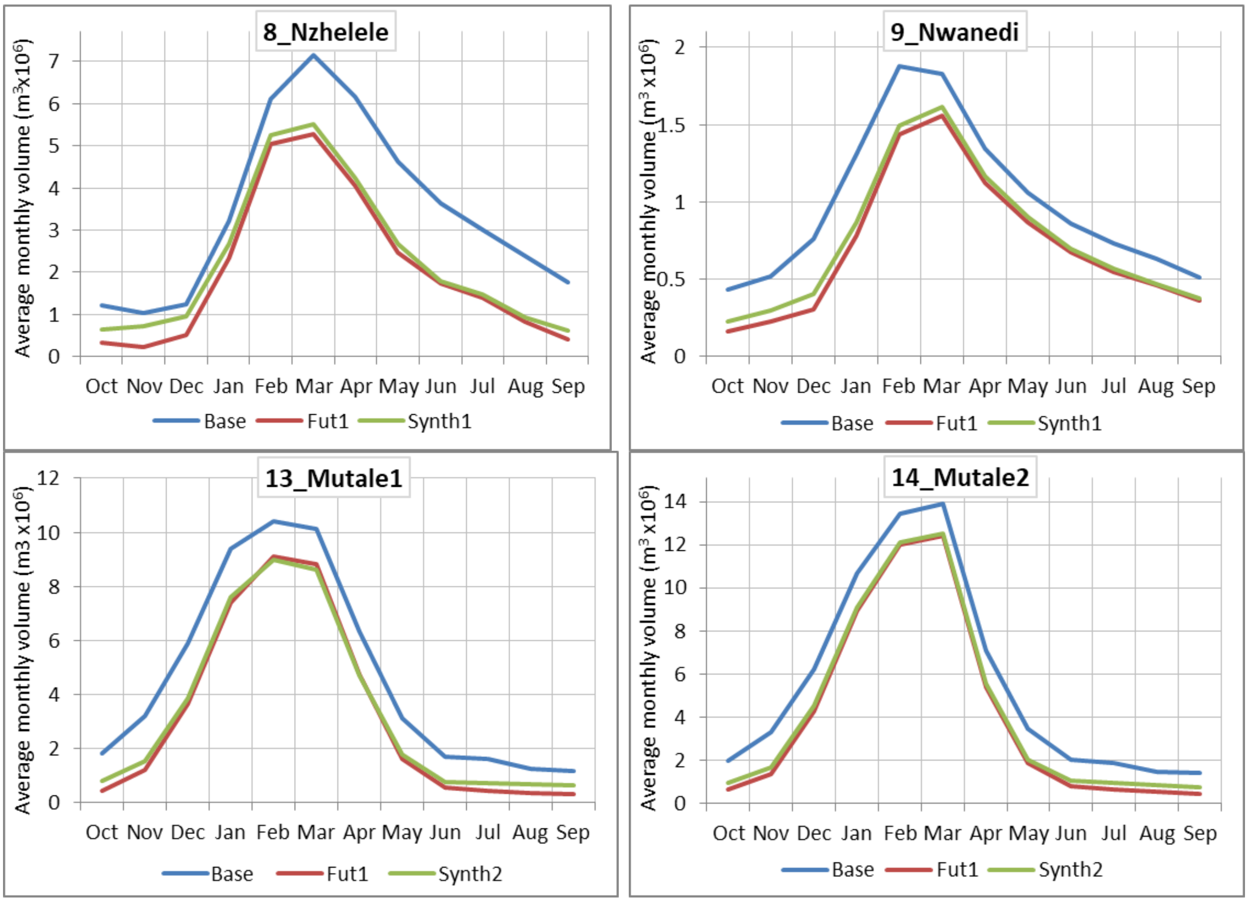


Figure 7-4 Average monthly low flows for PES (2022), Future1 and Synthetic Scenarios 1 or 2

7.2 EWR summary tables

Sections 7.2.1 to 7.2.14 are the standard DWS EWR summary tables for each of the 14 study sites, which comprise:

- Basic statistics for the naturalised (Reference) flows, viz:
  - Naturalised Mean Annual Runoff (nMAR)
- The EWR and its components for maintenance of the Ecological Category as volumes and percentages of naturalized, viz.:
  - Maintenance low flows
  - Drought low flows
  - Maintenance high flows, which are floods that occur at least once a year, *viz*.: within-year flood events
- Total monthly volume (maintenance low flows and high flows)
- Magnitude, duration and timing of within-year floods.

7.2.1 1_Lephalala

The REC is a **B/C** category, which is one half category higher than PES (2022) and will require improved management to achieve the higher category (**Section 2.2.3**).

EWR tables are provided for maintenance of:

- PES (2022) = C **(Table** 7-2), prior to development, with improved management = B/C
- Future1 = C **(Table** 7-3), after development, with improved management = B/C.

Table 7-2 EWRs to maintain a C category at 1_Lephalala (PES 2022 flow scenario)

nMAR	66.22	MCM			
S.Dev.	3.462				
CV	0.052				
Q75	0.2025				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	45.696	69.009			
Maint. Lowflows	37.824	57.121			
Drought Lowflows	16.663	25.164			
Maint. Highflows	7.872	11.887			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.994	0.419	0.325	0.050	0.469
Nov	2.032	0.775	0.509	0.277	1.052
Dec	4.813	1.833	1.073	0.970	2.804
Jan	8.536	3.380	1.741	1.550	4.930
Feb	12.814	6.007	2.530	1.356	7.362
Mar	12.445	7.550	2.987	1.410	8.960
Apr	8.808	6.342	2.372	1.208	7.550
May	5.981	4.807	1.823	0.604	5.411
Jun	4.291	3.314	1.364	0.295	3.609
Jul	2.848	2.000	0.974	0.117	2.117
Aug	1.628	0.905	0.584	0.010	0.915
Sep	1.027	0.492	0.381	0.023	0.516
Total	66.22	37.82	16.66	7.87	45.70

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.00	1.80	3.50	6.20
Ave duration (days)	4	6	8	11
Number	2	3	3	2
Oct				
Nov				
Dec	1			
Jan	1	1		
Feb		1	1	
Mar				1
Apr				1
May		1	1	
Jun			1	
Jul				
Aug				
Sep				
Vol (10^6m^3)	0.51	2.04	4.34	6.29
% PES (2022) MAR	0.93	3.72	7.91	11.48

Table 7-3 EWRs to maintain a C category at 1_Lephalala (Future1 flow scenario)

nMAR	66.217	MCM			
S.Dev.	3.462				
CV	0.052				
Q75	0.2025				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	43.557	65.779			
Maint. Lowflows	35.825	54.102			
Drought Lowflows	16.663	25.164			
Maint. Highflows	7.733	11.678			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.994	0.420	0.325	0.050	0.470
Nov	2.032	0.749	0.509	0.272	1.021
Dec	4.813	1.723	1.073	0.924	2.646
Jan	8.536	3.142	1.741	1.524	4.666
Feb	12.814	5.659	2.530	1.377	7.036
Mar	12.445	7.186	2.987	1.417	8.604
Apr	8.808	6.018	2.372	1.154	7.171
May	5.981	4.565	1.823	0.583	5.147
Jun	4.291	3.132	1.364	0.295	3.427
Jul	2.848	1.869	0.974	0.106	1.975
Aug	1.628	0.870	0.584	0.009	0.879
Sep	1.027	0.491	0.381	0.023	0.514
Total	66.22	35.82	16.66	7.73	43.56

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.00	1.80	3.50	6.20
Ave duration (days)	4	6	8	10
Number	3	3	3	2
Oct	1			
Nov	1			
Dec	1	1		
Jan			1	
Feb				1
Mar			1	1
Apr		1	1	
May		1		
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	0.77	2.04	4.34	6.29
% PES (2022) MAR	1.40	3.72	7.91	11.48

7.2.2 2_Rietfontein

The REC is a **B/C** category, which is the same as PES (2022). There are no developments planned.

An EWR table is provided for maintenance of:

- PES (2022) = B/C (**Table** 7-4).

Table 7-4 EWRs to maintain a B/C category at 2_Rietfontein (PES 2022 flow scenario)

nMAR	0.181	MCM			
S.Dev.	0.020				
CV	0.109				
Q75	0				
Ecological Category	B/C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	0.067	36.961			
Maint. Lowflows	0.057	31.650			
Drought Lowflows	0.030	16.576			
Maint. Highflows	0.010	5.311			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.000	0.000	0.000	0.000	0.000
Nov	0.004	0.001	0.001	0.000	0.001
Dec	0.014	0.004	0.002	0.002	0.006
Jan	0.042	0.011	0.007	0.002	0.013
Feb	0.074	0.019	0.010	0.003	0.022
Mar	0.037	0.019	0.008	0.002	0.021
Apr	0.009	0.002	0.001	0.000	0.002
May	0.001	0.001	0.000	0.000	0.001
Jun	0.000	0.000	0.000	0.000	0.000
Jul	0.000	0.000	0.000	0.000	0.000
Aug	0.000	0.000	0.000	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000
Total	0.18	0.06	0.03	0.01	0.07

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*			
Flood Class	Class1 or 2	Class3	Class4
Ave peak discharge (m^3/s)	0.10	0.10	0.10
Ave duration (days)	5	8	9
Number	1	1	1
Oct			
Nov			
Dec	1		
Jan		1	
Feb			1
Mar			
Apr			
May			
Jun			
Jul			
Aug			
Sep			
Vol ($10^6 m^3$)	0.002	0.008	0.013
% PES (2022) MAR	1.136	5.682	9.092

7.2.3 3_Olifantspruit

The REC is a **B/C** category, which is one half category higher than PES (2022) and will require improved management to achieve the higher category (**Section 2.2.3**). There are no developments planned.

An EWR table is provided for maintenance of:

- PES (2022) = C (**Table** 7-5), with improved management = B/C.

Table 7-5 EWRs to maintain a C category at 3_Olifantspruit (PES 2022 flow scenario)

nMAR	7.815	MCM			
S.Dev.	0.784				
CV	0.100				
Q75	0.0111				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	6.002	76.792			
Maint. Lowflows	3.385	43.318			
Drought Lowflows	1.513	19.354			
Maint. Highflows	2.616	33.474			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		HighFlows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.147	0.089	0.059	0.012	0.101
Nov	0.605	0.259	0.130	0.215	0.475
Dec	1.171	0.399	0.194	0.485	0.884
Jan	1.407	0.494	0.222	0.570	1.064
Feb	1.641	0.578	0.235	0.588	1.166
Mar	1.355	0.549	0.219	0.475	1.024
Apr	0.686	0.392	0.158	0.237	0.629
May	0.297	0.229	0.096	0.032	0.261
Jun	0.154	0.132	0.058	0.001	0.133
Jul	0.125	0.103	0.049	0.001	0.103
Aug	0.116	0.087	0.046	0.000	0.087
Sep	0.111	0.075	0.048	0.000	0.075
Total	7.82	3.39	1.51	2.62	6.00

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.60	0.90	1.70	3.40
Ave duration (days)	3	4	7	8
Number	2	2	1	1
Oct				
Nov	1			
Dec		1		
Jan			1	
Feb				1
Mar		1		
Apr	1			
May				
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	0.142	0.339	0.485	0.916
% PES (2022) MAR	1.943	4.629	6.616	12.501

7.2.4 4_Mogalakwena1

The REC is a C category, which is the same as PES (2022).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-6), prior to development
- Future1 = B/C (**Table** 7-7), after development.

Table 7-6 EWRs to maintain a C category at 4_Mogalakwena1 (PES 2022 flow scenario)

nMAR	130.390	MCM			
S.Dev.	13.312				
CV	0.102				
Q75	0.1884				
Ecological Category	**C**				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	32.488	24.916			
Maint. Lowflows	26.120	20.032			
Drought Lowflows	20.943	16.062			
Maint. Highflows	6.368	4.884			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	2.813	0.273	0.663	0.154	0.427
Nov	9.298	0.999	1.134	0.409	1.408
Dec	15.403	2.503	2.170	1.007	3.510
Jan	24.935	4.283	3.116	1.135	5.419
Feb	35.499	6.628	3.828	1.019	7.647
Mar	15.991	5.248	3.061	0.992	6.240
Apr	8.245	1.928	1.612	0.697	2.625
May	5.017	1.337	1.308	0.334	1.671
Jun	3.793	0.935	1.079	0.198	1.133
Jul	3.486	0.868	1.113	0.157	1.024
Aug	3.126	0.659	0.970	0.135	0.794
Sep	2.784	0.458	0.890	0.132	0.590
Total	2.813	0.273	0.663	0.154	0.427

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.30	2.50	4.60	9.20
Ave duration (days)	5	5	6	7
Number	2	2	2	1
Oct				
Nov	1			
Dec		1		
Jan			1	
Feb				1
Mar			1	
Apr		1		
May	1			
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	0.688	1.232	2.427	2.488
% PES (2022) MAR	0.921	1.649	3.248	3.329

Table 7-7 EWRs to maintain a B/C category at 4_Mogalakwena1 (Future1 flow scenario)

nMAR	130.390	MCM			
S.Dev.	13.312				
CV	0.102				
Q75	0.1884				
Ecological Category	**B/C**				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	37.792	28.984			
Maint. Lowflows	29.828	22.876			
Drought Lowflows	20.943	16.062			
Maint. Highflows	7.965	6.108			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	2.813	0.667	0.663	0.349	0.990
Nov	9.298	1.201	1.134	2.596	1.841
Dec	15.403	2.564	2.170	5.373	3.675
Jan	24.935	4.342	3.116	9.660	5.683
Feb	35.499	6.667	3.828	20.127	7.802
Mar	15.991	5.389	3.061	5.421	6.498
Apr	8.245	2.296	1.612	2.407	3.115
May	5.017	1.792	1.308	0.685	2.255
Jun	3.793	1.405	1.079	0.361	1.739
Jul	3.486	1.373	1.113	0.279	1.623
Aug	3.126	1.164	0.970	0.234	1.374
Sep	2.784	0.967	0.890	0.243	1.199
Total	130.39	29.83	20.94	47.74	37.79

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.30	2.50	4.60	9.20
Ave duration (days)	4	6	6	6
Number	4	3	3	1
Oct				
Nov	1			
Dec	1	1		
Jan	1		1	
Feb				1
Mar		1	1	
Apr		1		
May	1			
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	1.376	1.848	2.427	2.488
% PES (2022) MAR	1.841	2.473	3.248	3.329

7.2.5 5_Mogalakwena2

The REC is a **C** category, which is the same as PES (2022).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-8), prior to development
- Future1 = C (**Table** 7-9), after development.

Table 7-8 EWRs to maintain a C category at 5_Mogalakwena (PES 2022 flow scenario)

nMAR	188.946	MCM			
S.Dev.	15.804				
CV	0.084				
Q75	0.2848				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	43.439	22.990			
Maint. Lowflows	39.096	20.692			
Drought Lowflows	26.707	14.135			
Maint. Highflows	4.343	2.299			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.417	0.487	0.741	0.107	0.594
Nov	13.305	2.120	1.020	0.135	2.255
Dec	18.652	2.557	1.951	0.313	2.870
Jan	31.569	3.906	3.485	0.758	4.663
Feb	52.951	10.470	4.785	0.495	10.965
Mar	26.374	9.273	4.619	0.606	9.879
Apr	15.229	4.486	2.522	0.658	5.143
May	8.955	2.496	2.082	0.629	3.125
Jun	5.898	1.351	1.632	0.367	1.717
Jul	4.964	1.104	1.552	0.183	1.287
Aug	4.168	0.546	1.266	0.057	0.603
Sep	3.464	0.300	1.054	0.038	0.338
Total	188.95	39.10	26.71	4.34	43.44

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.20	2.20	4.00	7.00
Ave duration (days)	4	5	5	9
Number	2	2	2	1
Oct				
Nov				
Dec				
Jan	1			
Feb				1
Mar			1	
Apr			1	
May	1	1		
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	0.477	0.538	2.155	2.811
% PES (2022) MAR	0.431	0.487	1.949	2.542

Table 7-9 EWRs to maintain a C category at 5_Mogalakwena (Future1 flow scenario)

nMAR	188.946	MCM			
S.Dev.	15.804				
CV	0.084				
Q75	0.2848				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	44.516	23.560			
Maint. Lowflows	39.761	21.043			
Drought Lowflows	26.707	14.135			
Maint. Highflows	4.755	2.517			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.417	0.575	0.741	0.110	0.685
Nov	13.305	2.014	1.020	0.145	2.160
Dec	18.652	2.355	1.951	0.379	2.734
Jan	31.569	3.891	3.485	0.853	4.744
Feb	52.951	10.445	4.785	0.528	10.973
Mar	26.374	9.252	4.619	0.608	9.860
Apr	15.229	4.604	2.522	0.703	5.308
May	8.955	2.676	2.082	0.656	3.332
Jun	5.898	1.553	1.632	0.415	1.968
Jul	4.964	1.309	1.552	0.230	1.539
Aug	4.168	0.704	1.266	0.079	0.783
Sep	3.464	0.383	1.054	0.049	0.432
Total	188.95	39.76	26.71	4.76	44.52

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.20	2.20	4.00	7.00
Ave duration (days)	12	7	7	8
Number	2	2	2	1
Oct				
Nov				
Dec				
Jan	1			
Feb				1
Mar			1	
Apr			1	
May	1	1		
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	0.612	1.454	2.294	2.026
% PES (2022) MAR	0.553	1.315	2.075	1.833

7.2.6 6_Kolope

The REC is a **B/C** category, which is one half category higher than PES (2022) and will require improved management to achieve the higher category (**Section 2.2.3**). There are no developments planned.

An EWR table is provided for maintenance of:

- PES (2022) = C (**Table** 7-10), with improved management = B/C.

Table 7-10 EWRs to maintain a C category at 6_Kolope (PES 2022 flow scenario)

nMAR	1.998	MCM			
S.Dev.	0.153				
CV	0.077				
Q75	0.0003				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	0.366	18.314			
Maint. Lowflows	0.349	17.457			
Drought Lowflows	0.305	15.274			
Maint. Highflows	0.017	0.857			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.002	0.000	0.000	0.000	0.000
Nov	0.038	0.001	0.004	0.001	0.002
Dec	0.146	0.008	0.021	0.005	0.013
Jan	0.460	0.038	0.072	0.004	0.042
Feb	0.817	0.141	0.107	0.003	0.144
Mar	0.390	0.143	0.075	0.004	0.147
Apr	0.119	0.015	0.016	0.001	0.016
May	0.016	0.002	0.005	0.000	0.002
Jun	0.004	0.000	0.002	0.000	0.000
Jul	0.004	0.000	0.001	0.000	0.000
Aug	0.002	0.000	0.001	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000
Total	2.00	0.35	0.31	0.02	0.37

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.010	0.020	0.034	0.055
Ave duration (days)	6	7	10	10
Number	1	1	1	1
Oct				
Nov				
Dec	1			
Jan		1		
Feb			1	
Mar				1
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	0.003	0.007	0.016	0.024
% PES (2022) MAR	0.265	0.677	1.515	2.297

7.2.7 7_Sand

The REC is a **C** category, which is the same as PES (2022).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-11), prior to development
- Future1 = B/C (**Table** 7-12), after development.

Table 7-11 EWRs to maintain a high C category at 7_Sand (PES 2022 flow scenario)

nMAR	23.125	MCM			
S.Dev.	8.540				
CV	0.369				
Q75	0.0095				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	5.546	23.981			
Maint. Lowflows	4.125	17.838			
Drought Lowflows	1.581	6.837			
Maint. Highflows	1.421	6.143			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.180	0.230	0.059	0.023	0.253
Nov	0.983	0.212	0.175	0.112	0.324
Dec	1.554	0.231	0.201	0.226	0.457
Jan	7.024	0.581	0.361	0.361	0.943
Feb	11.348	0.669	0.377	0.364	1.033
Mar	1.078	0.230	0.143	0.173	0.403
Apr	0.567	0.344	0.110	0.101	0.445
May	0.169	0.315	0.064	0.018	0.333
Jun	0.087	0.356	0.036	0.004	0.360
Jul	0.067	0.361	0.028	0.012	0.373
Aug	0.039	0.317	0.016	0.002	0.319
Sep	0.031	0.279	0.011	0.023	0.302
Total	23.13	4.13	1.58	1.42	5.55

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.80	1.20	2.20	4.10
Ave duration (days)	7	3	3	7
Number	1	1	1	1
Oct				
Nov				
Dec	1			
Jan				1
Feb			1	
Mar		1		
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	0.251	0.151	0.273	0.518
% PES (2022) MAR	1.293	0.776	1.404	2.665

Table 7-12 EWRs to maintain a B/C category at 7_Sand (Future1 flow scenario)

nMAR	23.125	MCM			
S.Dev.	8.540				
CV	0.369				
Q75	0.0095				
Ecological Category	B/C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	28.950	125.188			
Maint. Lowflows	22.276	96.329			
Drought Lowflows	1.581	6.837			
Maint. Highflows	6.674	28.860			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.180	2.117	0.059	0.300	2.417
Nov	0.983	1.311	0.175	0.776	2.087
Dec	1.554	1.112	0.201	0.847	1.959
Jan	7.024	1.375	0.361	0.745	2.120
Feb	11.348	1.844	0.377	0.883	2.727
Mar	1.078	1.430	0.143	0.759	2.189
Apr	0.567	1.778	0.110	0.671	2.450
May	0.169	2.179	0.064	0.369	2.548
Jun	0.087	2.300	0.036	0.382	2.682
Jul	0.067	2.186	0.028	0.454	2.640
Aug	0.039	2.352	0.016	0.301	2.653
Sep	0.031	2.290	0.011	0.187	2.478
Total	23.13	22.28	1.58	6.67	28.95

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.80	1.20	2.20	4.10
Ave duration (days)	4	6	7	6
Number	1	10	4	2
Oct		1		
Nov			1	
Dec			1	
Jan	1	1		
Feb		1		1
Mar		1		1
Apr		1	1	
May		1	1	
Jun		1		
Jul		1		
Aug		1		
Sep		1		
Vol ($10^6 m^3$)	0.251	1.507	1.090	1.035
% PES (2022) MAR	1.293	7.758	5.614	5.331

7.2.8 8_Nzhelele

The REC is a **C** category, which is the same as PES (2022).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-13), prior to development
- Future1 = D (**Table** 7-14), after development
- Synthetic Scenario 1 = C/D (**Table** 7-15), after development.

Table 7-13 EWRs to maintain a C category at 8_Nzhelele (PES 2022 flow scenario)

nMAR	98.420	MCM			
S.Dev.	7.494				
CV	0.076				
Q75	0.2467				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	50.257	51.063			
Maint. Lowflows	41.595	42.263			
Drought Lowflows	22.504	22.865			
Maint. Highflows	8.662	8.801			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.719	1.212	0.626	0.328	1.539
Nov	2.083	1.023	0.603	0.455	1.478
Dec	4.001	1.252	0.998	0.788	2.039
Jan	14.739	3.229	2.323	1.080	4.309
Feb	25.980	6.116	3.542	1.220	7.336
Mar	18.102	7.159	3.919	1.476	8.635
Apr	10.976	6.174	3.048	1.453	7.627
May	6.986	4.635	2.387	0.490	5.124
Jun	5.158	3.641	1.779	0.481	4.122
Jul	3.835	3.012	1.395	0.345	3.358
Aug	2.794	2.381	1.076	0.201	2.582
Sep	2.047	1.762	0.809	0.345	2.107
Total	98.42	41.59	22.50	8.66	50.26

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.00	1.60	3.10	5.80
Ave duration (days)	9	13	13	14
Number	5	5	2	1
Oct	1			
Nov	1			
Dec	1			
Jan		1	1	
Feb		1		
Mar				1
Apr			1	
May		1		
Jun		1		
Jul		1		
Aug	1			
Sep	1			
Vol ($10^6 m^3$)	2.66	5.05	3.61	3.15
% PES (2022) MAR	3.50	6.66	4.76	4.15

Table 7-14 EWRs to maintain a D category at 8_Nzhelele (Future1 flow scenario)

nMAR	98.420 MCM				
S.Dev.	7.494				
CV	0.076				
Q75	0.2467				
Ecological Category	D				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	29.535	30.010			
Maint. Lowflows	24.584	24.979			
Drought Lowflows	22.504	22.865			
Maint. Highflows	4.951	5.030			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.719	0.317	0.626	0.106	0.422
Nov	2.083	0.222	0.603	0.193	0.415
Dec	4.001	0.499	0.998	0.478	0.978
Jan	14.739	2.343	2.323	0.755	3.098
Feb	25.980	5.049	3.542	0.865	5.914
Mar	18.102	5.276	3.919	0.879	6.155
Apr	10.976	4.042	3.048	1.050	5.092
May	6.986	2.470	2.387	0.245	2.715
Jun	5.158	1.731	1.779	0.177	1.908
Jul	3.835	1.401	1.395	0.122	1.523
Aug	2.794	0.818	1.076	0.040	0.857
Sep	2.047	0.417	0.809	0.040	0.457
Total	98.42	24.58	22.50	4.95	29.54

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.00	1.60	3.10	5.80
Ave duration (days)	9	13	13	14
Number	2	2	1	1
Oct				
Nov				
Dec	1			
Jan	1			
Feb		1		
Mar			1	
Apr				1
May		1		
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	1.06	2.02	1.80	3.15
% PES (2022) MAR	1.40	2.66	2.38	4.15

Table 7-15 EWRs to maintain a C/D category at 8_Nzhelele (Synthetic scenario 1)

nMAR	98.420	MCM			
S.Dev.	7.494				
CV	0.076				
Q75	0.2467				
Ecological Category	C/D				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	32.383	32.903			
Maint. Lowflows	27.482	27.923			
Drought Lowflows	22.504	22.865			
Maint. Highflows	4.902	4.980			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.719	0.641	0.626	0.099	0.740
Nov	2.083	0.720	0.603	0.190	0.910
Dec	4.001	0.950	0.998	0.464	1.414
Jan	14.739	2.676	2.323	0.733	3.409
Feb	25.980	5.261	3.542	0.860	6.121
Mar	18.102	5.514	3.919	0.879	6.393
Apr	10.976	4.224	3.048	1.045	5.269
May	6.986	2.685	2.387	0.253	2.938
Jun	5.158	1.786	1.779	0.177	1.962
Jul	3.835	1.484	1.395	0.122	1.606
Aug	2.794	0.935	1.076	0.040	0.974
Sep	2.047	0.607	0.809	0.040	0.648
Total	98.42	27.48	22.50	4.90	32.38

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	1.00	1.60	3.10	5.80
Ave duration (days)	9	13	13	14
Number	2	1	1	1
Oct				
Nov				
Dec				
Jan	1			
Feb		1		
Mar			1	
Apr				1
May	1			
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	1.06	1.01	1.80	3.15
% PES (2022) MAR	1.40	1.33	2.38	4.15

7.2.9 9_Ṅwaneḓi

The REC is a **C** category, which is the same as PES (2022).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-16), prior to development
- Future1 = D (**Table** 7-17), after development
- Synthetic Scenario 1 = C/D (**Table** 7-18), after development.

Table 7-16 EWRs to maintain a C category at 9_Ṅwaneḓi (PES 2022)

nMAR	32.578	MCM			
S.Dev.	2.567				
CV	0.079				
Q75	0.067				
Ecological Category	C				
	MCM	% nMAR			
Total EWR	16.292	50.011	Excludes floods with return period ≥1:2 years.		
Maint. Lowflows	11.872	36.443			
Drought Lowflows	6.837	20.988			
Maint. Highflows	4.420	13.568			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.154	0.437	0.383	0.195	0.632
Nov	1.573	0.517	0.408	0.314	0.831
Dec	2.832	0.763	0.518	0.513	1.275
Jan	5.632	1.307	0.739	0.829	2.136
Feb	8.012	1.877	0.904	0.998	2.875
Mar	4.674	1.830	0.906	0.866	2.697
Apr	2.455	1.344	0.683	0.468	1.811
May	1.706	1.063	0.582	0.117	1.180
Jun	1.343	0.860	0.480	0.043	0.903
Jul	1.157	0.730	0.432	0.024	0.754
Aug	1.061	0.630	0.412	0.017	0.647
Sep	0.979	0.515	0.391	0.036	0.551
Total	32.58	11.87	6.84	4.42	16.29

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.60	1.00	1.90	3.70
Ave duration (days)	9	10	16	16
Number	3	2	2	1
Oct				
Nov	1			
Dec		1		
Jan			1	
Feb				1
Mar		1	1	
Apr	1			
May	1			
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	0.81	0.90	2.29	1.98
% PES (2022) MAR	3.12	3.47	8.84	7.65

Table 7-17 EWRs to maintain a D category at 9_Ṅwaneḓi (Future1 flow scenario)

nMAR	32.578	MCM			
S.Dev.	2.567				
CV	0.079				
Q75	0.0671				
Ecological Category	D				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	11.970	36.742			
Maint. Lowflows	8.517	26.142			
Drought Lowflows	6.837	20.988			
Maint. Highflows	3.453	10.599			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.154	0.165	0.383	0.154	0.319
Nov	1.573	0.227	0.408	0.170	0.397
Dec	2.832	0.309	0.518	0.242	0.551
Jan	5.632	0.786	0.739	0.565	1.351
Feb	8.012	1.434	0.904	0.868	2.302
Mar	4.674	1.558	0.906	0.908	2.466
Apr	2.455	1.121	0.683	0.411	1.532
May	1.706	0.871	0.582	0.089	0.960
Jun	1.343	0.673	0.480	0.020	0.693
Jul	1.157	0.548	0.432	0.010	0.559
Aug	1.061	0.460	0.412	0.003	0.463
Sep	0.979	0.365	0.391	0.013	0.378
Total	32.58	8.52	6.84	3.45	11.97

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.60	1.00	1.90	3.70
Ave duration (days)	11	11	13	17
Number	1	2	1	1
Oct				
Nov				
Dec	1			
Jan				1
Feb			1	
Mar		1		
Apr		1		
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	0.27	0.90	1.14	1.98
% PES (2022) MAR	1.04	3.47	4.42	7.65

Table 7-18 EWRs to maintain a C/D category at 9_Ṅwaneḓi (Synthetic Scenario 1)

nMAR	32.578	MCM			
S.Dev.	2.567				
CV	0.079				
Q75	0.067				
Ecological Category	C/D				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	12.520	38.430			
Maint. Lowflows	9.087	27.894			
Drought Lowflows	6.837	20.988			
Maint. Highflows	3.432	10.536			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.154	0.228	0.383	0.154	0.382
Nov	1.573	0.298	0.408	0.168	0.467
Dec	2.832	0.405	0.518	0.242	0.647
Jan	5.632	0.870	0.739	0.561	1.431
Feb	8.012	1.492	0.904	0.863	2.355
Mar	4.674	1.617	0.906	0.903	2.520
Apr	2.455	1.165	0.683	0.408	1.573
May	1.706	0.904	0.582	0.088	0.992
Jun	1.343	0.698	0.480	0.020	0.718
Jul	1.157	0.566	0.432	0.010	0.576
Aug	1.061	0.471	0.412	0.003	0.474
Sep	0.979	0.374	0.391	0.013	0.386
Total	32.58	9.09	6.84	3.43	12.52

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.60	1.00	1.90	3.70
Ave duration (days)	11	11	13	17
Number	1	2	1	1
Oct				
Nov				
Dec	1			
Jan				1
Feb			1	
Mar		1		
Apr		1		
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	0.27	0.90	1.14	1.98
% PES (2022) MAR	1.04	3.47	4.42	7.65

7.2.10 10_Latonyanda

The REC is a **C** category, which is the same as PES (2022). There are no developments planned.

An EWR table is provided for maintenance of:

- PES (2022) = C (**Table** 7-19).

Table 7-19 EWRs to maintain a C category at 10_Latonyanda (PES 2022 flow scenario)

nMAR	23.206	MCM			
S.Dev.	0.963				
CV	0.042				
Q75	0.064				
Ecological Category	**C**				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	16.785	72.328			
Maint. Lowflows	13.597	58.590			
Drought Lowflows	6.986	30.104			
Maint. Highflows	3.188	13.738			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	0.543	0.384	0.216	0.035	0.418
Nov	0.803	0.431	0.269	0.127	0.558
Dec	1.498	0.690	0.438	0.344	1.034
Jan	3.286	1.504	0.898	0.722	2.226
Feb	5.004	2.259	1.229	0.769	3.028
Mar	4.783	2.645	1.370	0.616	3.261
Apr	2.980	1.989	0.948	0.444	2.433
May	1.491	1.206	0.536	0.060	1.266
Jun	0.975	0.862	0.358	0.026	0.887
Jul	0.739	0.674	0.280	0.017	0.691
Aug	0.603	0.535	0.237	0.010	0.544
Sep	0.503	0.419	0.207	0.018	0.438
Total	23.21	13.60	6.99	3.19	16.78

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.30	0.60	1.10	1.80
Ave duration (days)	5	6	9	11
Number	4	4	3	1
Oct				
Nov	1			
Dec	1	1		
Jan	1	1	1	
Feb				1
Mar		1	1	
Apr		1	1	
May	1			
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	0.35	0.77	1.37	0.85
% PES (2022) MAR	1.94	4.30	7.61	4.75

7.2.11 11_Mutshindudi

The REC is a **C** category, wich is the same as PES (2022) and will require improved management to maintain the PES (**Section 2.2.3**).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-20), prior to development, with improved management = C.
- Future1 = C (**Table** 7-21), after development, with improved management = C.

Table 7-20 EWRs to maintain a C category at 11_Mutshindudi (PES 2022 flow scenario)

nMAR	56.420	MCM			
S.Dev.	3.444				
CV	0.061				
Q75	0.135				
Ecological Category	C				
	MCM	% MAR	Excludes floods with return period ≥1:2 years.		
Total EWR	40.811	72.335			
Maint. Lowflows	24.108	42.730			
Drought Lowflows	11.736	20.802			
Maint. Highflows	16.703	29.605			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.154	0.664	0.421	0.078	0.742
Nov	2.528	0.967	0.688	0.436	1.403
Dec	6.135	2.094	1.267	1.827	3.921
Jan	9.959	3.638	1.847	3.433	7.070
Feb	13.104	4.140	1.803	4.931	9.071
Mar	10.550	4.494	1.897	3.825	8.320
Apr	5.171	2.662	1.178	1.711	4.373
May	2.593	1.633	0.776	0.324	1.958
Jun	1.707	1.213	0.569	0.082	1.295
Jul	1.374	1.035	0.491	0.015	1.050
Aug	1.125	0.853	0.413	0.016	0.870
Sep	1.020	0.714	0.387	0.025	0.739
Total	56.42	24.11	11.74	16.70	40.81

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.80	1.80	3.80	6.90
Ave duration (days)	7	12	17	18
Number	5	2	1	1
Oct				
Nov	1			
Dec		1		
Jan	1	1		
Feb				1
Mar			1	
Apr	1			
May	1			
Jun	1			
Jul				
Aug				
Sep				
Vol (10^6m^3)	1.65	1.91	2.83	4.05
% PES (2022) MAR	3.54	4.08	6.07	8.67

Table 7-21 EWRs to maintain a C category at 11_Mutshindudi (Future1 flow scenario)

nMAR	56.420	MCM			
S.Dev.	3.444				
CV	0.061				
Q75	0.135				
Ecological Category	C				
	MCM	% MAR	Excludes floods with return period ≥1:2 years.		
Total EWR	33.091	58.650			
Maint. Lowflows	20.591	36.495			
Drought Lowflows	11.736	20.802			
Maint. Highflows	12.500	22.155			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	1.154	0.666	0.421	0.033	0.700
Nov	2.528	0.873	0.688	0.317	1.190
Dec	6.135	1.596	1.267	1.144	2.741
Jan	9.959	2.597	1.847	2.327	4.923
Feb	13.104	3.186	1.803	3.766	6.952
Mar	10.550	3.820	1.897	3.291	7.111
Apr	5.171	2.393	1.178	1.308	3.701
May	2.593	1.598	0.776	0.252	1.850
Jun	1.707	1.241	0.569	0.037	1.278
Jul	1.374	1.043	0.491	0.005	1.048
Aug	1.125	0.858	0.413	0.007	0.864
Sep	1.020	0.719	0.387	0.014	0.733
Total	56.42	20.59	11.74	12.50	33.09

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	0.80	1.80	3.80	6.90
Ave duration (days)	10	14	18	18
Number	2	2	1	1
Oct				
Nov	1			
Dec		1		
Jan			1	
Feb				1
Mar		1		
Apr	1			
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	0.66	1.91	2.83	4.05
% PES (2022) MAR	1.42	4.08	6.07	8.67

7.2.12 12_Luvuvhu

The REC is a **B/C** category, which is one half category higher than PES (2022) and will require improved management to achieve the higher category (**Section 2.2.3**).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-22), prior to development, with improved management = B/C.
- Future1 = C (**Table** 7-23), after development, with improved management = B/C.

Table 7-22 EWRs to maintain a C category at 12_Luvuvhu (PES 2022 flow scenario)

nMAR	388.014	MCM			
S.Dev.	22.810				
CV	0.059				
Q75	0.905				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	151.920	39.153			
Maint. Lowflows	114.146	29.418			
Drought Lowflows	92.115	23.740			
Maint. Highflows	37.773	9.735			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	9.253	1.441	3.625	0.169	1.610
Nov	14.455	2.622	4.419	1.095	3.718
Dec	30.646	7.833	7.423	4.808	12.641
Jan	60.397	15.474	10.840	7.867	23.340
Feb	92.187	25.241	13.731	9.055	34.296
Mar	74.955	28.602	15.832	8.316	36.917
Apr	37.623	16.085	10.752	5.574	21.658
May	20.738	6.640	7.113	0.732	7.372
Jun	15.321	3.964	5.587	0.090	4.055
Jul	12.726	2.787	4.823	0.038	2.825
Aug	10.651	1.938	4.195	0.007	1.944
Sep	9.063	1.520	3.776	0.023	1.543
Total	388.01	114.15	92.12	0.169	151.92

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	5.20	9.70	20.80	37.40
Ave duration (days)	6	10	10	11
Number	2	2	1	1
Oct				
Nov				
Dec	1			
Jan	1	1		
Feb			1	
Mar				1
Apr		1		
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	3.72	9.88	8.32	16.91
% PES (2022) MAR	1.56	4.13	3.48	7.07

Table 7-23 EWRs to maintain a C category at 12_Luvuvhu (Future1 flow scenario)

nMAR	388.014 MCM				
S.Dev.	22.810				
CV	0.059				
Q75	0.905				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	116.651	30.064			
Maint. Lowflows	87.104	22.449			
Drought Lowflows	92.115	23.740			
Maint. Highflows	29.547	7.615			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	9.253	1.228	3.625	0.070	1.298
Nov	14.455	2.092	4.419	0.747	2.839
Dec	30.646	5.298	7.423	3.271	8.568
Jan	60.397	10.373	10.840	5.818	16.191
Feb	92.187	18.789	13.731	7.058	25.846
Mar	74.955	22.721	15.832	7.851	30.572
Apr	37.623	12.820	10.752	4.198	17.017
May	20.738	5.042	7.113	0.418	5.460
Jun	15.321	3.130	5.587	0.052	3.182
Jul	12.726	2.383	4.823	0.032	2.415
Aug	10.651	1.842	4.195	0.010	1.852
Sep	9.063	1.389	3.776	0.023	1.412
Total	388.01	87.10	92.12	29.55	116.65

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	5.20	9.70	20.80	37.40
Ave duration (days)	8	14	9	12
Number	1	1	1	1
Oct				
Nov				
Dec	1			
Jan		1		
Feb			1	
Mar				1
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	1.86	4.94	8.32	16.91
% PES (2022) MAR	0.78	2.06	3.48	7.07

7.2.13 13_Mutale1

The REC is a **C** category, which is the same as PES (2022).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-24), prior to development.
- Future1 = C/D (**Table** 7-25), after development.
- Synthetic Scenario 2 = C (**Table** 7-26), after development.

Table 7-24 EWRs to maintain a C category at 13_Mutale1 (PES 2022)

nMAR	121.822 MCM				
S.Dev.	7.536				
CV	0.062				
Q75	0.315				
Ecological Category	C				
	MCM	% MAR	Excludes floods with return period ≥1:2 years.		
Total EWR	87.596	71.905			
Maint. Lowflows	56.109	46.058			
Drought Lowflows	26.295	21.585			
Maint. Highflows	31.487	25.847			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	2.908	1.828	1.059	0.415	2.243
Nov	5.668	3.207	1.695	1.472	4.679
Dec	12.037	5.888	2.877	4.181	10.069
Jan	22.649	9.399	4.294	5.897	15.296
Feb	31.766	10.421	4.464	7.925	18.346
Mar	23.447	10.140	4.505	7.593	17.733
Apr	10.662	6.325	2.745	3.299	9.624
May	4.208	3.143	1.440	0.360	3.503
Jun	2.376	1.720	0.872	0.061	1.781
Jul	2.323	1.608	0.856	0.104	1.712
Aug	1.911	1.258	0.752	0.043	1.301
Sep	1.868	1.173	0.735	0.137	1.310
Total	121.82	56.11	26.30	31.49	87.60

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	2.60	5.10	9.80	19.00
Ave duration (days)	7	13	15	18
Number	4	2	2	1
Oct				
Nov	1			
Dec	1	1		
Jan			1	
Feb				1
Mar	1		1	
Apr	1	1		
May				
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	4.16	6.81	11.46	11.67
% PES (2022) MAR	3.73	6.11	10.28	10.47

Table 7-25 EWRs to maintain a C/D category at 13_Mutale1 (Future1 flow scenario)

nMAR	121.822	MCM			
S.Dev.	7.536				
CV	0.062				
Q75	0.315				
Ecological Category	**C/D**				
	MCM	% MAR	Excludes floods with return period ≥1:2 years.		
Total EWR	65.684	53.918			
Maint. Lowflows	38.751	31.809			
Drought Lowflows	26.295	21.585			
Maint. Highflows	26.933	22.108			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	2.908	0.448	1.059	0.189	0.637
Nov	5.668	1.224	1.695	0.636	1.860
Dec	12.037	3.641	2.877	3.076	6.717
Jan	22.649	7.400	4.294	5.372	12.772
Feb	31.766	9.110	4.464	7.500	16.610
Mar	23.447	8.824	4.505	6.888	15.713
Apr	10.662	4.743	2.745	2.900	7.643
May	4.208	1.639	1.440	0.240	1.879
Jun	2.376	0.576	0.872	0.015	0.591
Jul	2.323	0.457	0.856	0.026	0.483
Aug	1.911	0.373	0.752	0.031	0.404
Sep	1.868	0.315	0.735	0.061	0.376
Total	121.82	38.75	26.30	26.93	65.68

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	2.60	5.10	9.80	19.00
Ave duration (days)	7	15	15	20
Number	2	2	1	1
Oct				
Nov				
Dec	1			
Jan		1	1	
Feb				1
Mar		1		
Apr	1			
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	2.08	6.81	5.73	11.67
% PES (2022) MAR	1.87	6.11	5.14	10.47

Table 7-26 EWRs to maintain a C category at 13_Mutale1 (Synthetic scenario 2)

nMAR	121.822	MCM			
S.Dev.	7.536				
CV	0.062				
Q75	0.31501				
Ecological Category	**C**				
	MCM	% MAR	Excludes floods with return period ≥1:2 years.		
Total EWR	68.161	55.951			
Maint. Lowflows	40.716	33.423			
Drought Lowflows	26.295	21.585			
Maint. Highflows	27.445	22.528			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.196	0.986	1.185	0.203	1.189
Nov	2.908	0.808	1.059	0.167	0.975
Dec	5.668	1.522	1.695	0.671	2.194
Jan	12.037	3.875	2.877	3.028	6.903
Feb	22.649	7.584	4.294	5.342	12.926
Mar	31.766	8.969	4.464	7.625	16.594
Apr	23.447	8.602	4.505	7.178	15.780
May	10.662	4.729	2.745	3.016	7.745
Jun	4.208	1.795	1.440	0.249	2.044
Jul	2.376	0.752	0.872	0.054	0.806
Aug	2.323	0.742	0.856	0.031	0.774
Sep	1.911	0.701	0.752	0.031	0.732
Total	1.868	0.636	0.735	0.051	0.687

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	2.60	5.10	9.80	19.00
Ave duration (days)	8	15	13	19
Number	2	2	1	1
Oct				
Nov				
Dec	1			
Jan		1	1	
Feb				1
Mar		1		
Apr	1			
May				
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	2.08	6.81	5.73	11.67
% PES (2022) MAR	1.87	6.11	5.14	10.47

7.2.14 14_Mutale2

The REC is a **C** category, which is the same as PES (2022).

EWR tables are provided for maintenance of:

- PES (2022) = C (**Table** 7-27), prior to development.
- Future1 = C/D (**Table** 7-28), after development.
- Synthetic Scenario 2 = C (**Table** 7-29), after development.

Table 7-27 EWRs to maintain a C category at 14_Mutale2 (PES 2022)

nMAR	153.098	MCM			
S.Dev.	11.962				
CV	0.078				
Q75	0.333				
Ecological Category	C				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	103.765	67.777			
Maint. Lowflows	67.063	43.804			
Drought Lowflows	30.071	19.642			
Maint. Highflows	36.702	23.973			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.198	2.001	1.098	0.501	2.501
Nov	6.784	3.347	1.714	1.662	5.010
Dec	15.623	6.257	3.016	5.061	11.318
Jan	29.488	10.677	4.827	7.505	18.182
Feb	42.607	13.442	5.587	9.146	22.588
Mar	29.026	13.943	5.758	8.277	22.220
Apr	12.075	7.119	2.901	3.763	10.882
May	4.691	3.467	1.529	0.483	3.950
Jun	2.711	2.035	1.008	0.051	2.086
Jul	2.627	1.903	0.960	0.083	1.986
Aug	2.166	1.467	0.844	0.059	1.526
Sep	2.100	1.404	0.828	0.111	1.515
Total	153.10	67.06	30.07	36.70	103.76

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	3.50	7.40	14.90	27.70
Ave duration (days)	7	13	10	18
Number	3	2	2	1
Oct				
Nov	1			
Dec	1	1		
Jan		1	1	
Feb				1
Mar			1	
Apr	1			
May				
Jun				
Jul				
Aug				
Sep				
Vol (10^6m^3)	5.05	11.31	14.24	13.09
% PES (2022) MAR	3.70	8.28	10.42	9.58

Table 7-28 EWRs to maintain a C/D category at 14_Mutale2 (Future1 flow scenario)

nMAR	153.098	MCM			
S.Dev.	11.962				
CV	0.078				
Q75	0.3328				
Ecological Category	**C/D**				
	MCM	% nMAR	Excludes floods with return period ≥1:2 years.		
Total EWR	81.565	53.277			
Maint. Lowflows	49.569	32.378			
Drought Lowflows	30.071	19.642			
Maint. Highflows	31.996	20.899			
Monthly Distributions (MCM)					
	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.198	0.641	1.098	0.184	0.824
Nov	6.784	1.368	1.714	1.053	2.421
Dec	15.623	4.309	3.016	3.616	7.924
Jan	29.488	8.940	4.827	6.693	15.633
Feb	42.607	12.033	5.587	8.831	20.865
Mar	29.026	12.431	5.758	7.707	20.137
Apr	12.075	5.445	2.901	3.385	8.830
May	4.691	1.872	1.529	0.383	2.255
Jun	2.711	0.827	1.008	0.017	0.844
Jul	2.627	0.681	0.960	0.021	0.702
Aug	2.166	0.550	0.844	0.040	0.590
Sep	2.100	0.474	0.828	0.066	0.540
Total	153.10	49.57	30.07	32.00	81.57

Within year floods (excludes floods with a return period of ≥1:2 years) *Flood can occur in the month before or after the month indicated*				
Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	3.50	7.40	14.90	27.70
Ave duration (days)	13	12	13	18
Number	1	2	1	1
Oct				
Nov	1			
Dec		1		
Jan			1	
Feb				1
Mar		1		
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	1.26	7.54	7.12	13.09
% PES (2022) MAR	0.92	5.52	5.21	9.58

Table 7-29 EWRs to maintain a C category at 14_Mutale2 (Synthetic scenario 1)

nMAR	153.098	MCM
S.Dev.	11.962	
CV	0.078	
Q75	0.333	
Ecological Category	C	
	MCM	% nMAR
Total EWR	83.626	54.623
Maint. Lowflows	51.662	33.745
Drought Lowflows	30.071	19.642
Maint. Highflows	31.964	20.878

Excludes floods with return period ≥1:2 years.

Monthly Distributions (MCM)

	Natural	Modified Flows (EWR)			
		Lowflows		Highflows	Total EWR
Month	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.198	0.894	1.098	0.184	1.077
Nov	6.784	1.642	1.714	1.052	2.694
Dec	15.623	4.514	3.016	3.597	8.111
Jan	29.488	9.070	4.827	6.686	15.756
Feb	42.607	12.114	5.587	8.832	20.946
Mar	29.026	12.526	5.758	7.701	20.227
Apr	12.075	5.542	2.901	3.385	8.927
May	4.691	2.000	1.529	0.383	2.383
Jun	2.711	0.989	1.008	0.017	1.006
Jul	2.627	0.888	0.960	0.021	0.909
Aug	2.166	0.780	0.844	0.040	0.820
Sep	2.100	0.703	0.828	0.066	0.769
Total	153.10	51.66	30.07	31.96	83.63

Within year floods (excludes floods with a return period of ≥1:2 years)
Flood can occur in the month before or after the month indicated

Flood Class	Class1	Class2	Class3	Class4
Ave peak discharge (m^3/s)	3.50	7.40	14.90	27.70
Ave duration (days)	13	12	12	18
Number	1	2	1	1
Oct				
Nov	1			
Dec		1		
Jan			1	
Feb				1
Mar		1		
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Vol ($10^6 m^3$)	1.26	7.54	7.12	13.09
% PES (2022) MAR	0.92	5.52	5.21	9.58

7.3 Summary

The EWRs for all the study sites are summarised in **Table** 7-30. The data provided are:

- Whether future developments are planned or not
- The Ecological Importance and Sensitivity (EIS)
- The Recommended Ecological Category (REC)
- The scenario from which the EWRs were derived
- The Ecological Category maintained by the relevant scenario
- Whether additional non-flow related mitigation measures are advised to maintain the REC
- The natural Mean Annual Runoff (nMAR) in units of Million Cubic Metres (MCM)
- The maintenance **low flow** requirements in units of MCM and as a percentage of nMAR
- The maintenance **high flow** requirements in units of MCM and as a percentage of nMAR
- The **total maintenance flow** requirements in units of MCM and as a percentage of nMAR.

Table 7-30 Summary of Ecological Water Requirements

Future development? Yes / No	EWR site	EIS	REC	Scenario	Ecological category	Management actions? Yes / No	Ecological Water Requirements nMAR MCM	Low MCM	% nMAR	High MCM	% nMAR	Total MCM	% nMAR
Yes	1_Lephala	Moderate	B/C	PES (2022)	C	Yes	66.217	37.824	57.1	7.872	11.9	45.696	69
				Future1				35.825	54.1	7.773	11.7	43.557	65.8
No	2_Rietfontein	Moderate	B/C	PES (2022)	B/C	No	0.181	0.057	31.7	0.010	5.3	0.067	40
	3_Olifantspruit	Moderate	B/C	PES (2022)	C	Yes	7.815	3.385	43.3	2.616	33.5	6.002	76.8
Yes	4_Mogalakwena1	Moderate	C	PES (2022)	C	No	130.390	26.120	20.0	6.368	4.9	32.488	24.9
				Future1	B/C			29.828	22.9	7.985	6.1	37.792	29
	5_Mogalakwena2	Moderate	C	PES (2022)	C	No	188.946	39.096	20.7	4.343	2.3	43.439	23
				Future1				39.671	21	4.755	2.5	44.516	23.6
No	6_Kolope	Moderate	B/C	PES (2022)	C	Yes	1.998	0.349	17.5	0.017	0.9	0.366	18.3
Yes	7_Sand	Moderate	C	PES (2022)	C	No	23.125	4.125	17.9	1.421	6.1	5.546	24
				Future1	B/C			22.276	96.3	6.674	28.9	28.95	125.2
	8_Nzhelele	Moderate	C	PES (2022)	C	No	98.42	41.595	42.3	8.662	8.8	50.257	51.1
				Future1	D			24.584	25	4.951	5	29.535	30
				Synthetic Scenario1	C/D			27.482	27.9	4.902	5	32.383	32.9
	9_Ṅwaneḓi	Moderate	C	PES (2022)	C	No	32.578	11.872	36.4	4.42	13.6	16.292	50
				Future1	D			8.517	26.1	3.453	10.6	11.97	36.7
				Synthetic Scenario1	C/D			9.087	27.9	3.432	10.5	12.52	38.4
No	10_Latonyanda	Moderate	C	PES (2022)	C	No	23.206	13.507	58.6	3.2	13.7	16.785	72.3
Yes	11_Mutshindudi	Moderate	C	PES (2022)	C	Yes	56.420	24.108	42.7	16.703	29.605	40.811	72.335
				Future1				20.591	36.5	12.5	22.2	33.091	58.7
	12_Luvuvhu	Moderate	B/C	PES (2022)	C	Yes	388.014	114.146	29.4	37.773	9.7	151.92	39.1
				Future1				87.104	22.5	29.547	7.6	116.651	30.1
	13_Mutale1	Moderate	C	PES (2022)	C	No	121.822	56.109	46.1	31.487	25.8	87.596	71.9
				Future1	C/D			38.751	31.8	26.933	22.1	65.684	53.9
				Synthetic Scenario2	C			40.716	33.4	27.445	22.5	68.161	56
	14_Mutale2	Moderate		PES (2022)	C	No	153.098	67.063	43.8	36.702	24	103.765	67.8
				Future1	C/D			49.569	32.4	32	20.9	81.565	53.3
				Synthetic Scenario1	C			51.662	33.8	31.964	20.9	83.626	54.6

8 LIMCOM STUDY SUMMARY OF ECO-CATEGORISATION AND EWRS

There are eight reports from the LIMCOM EWR study of the Limpopo River basin:

- E-Flows[11] for the Limpopo River Basin – Inception Report (Dickens and O'Brien 2020)
- E-Flows for the Limpopo River Basin – Basin Description (Dickens *et al.* 2020a)
- E-Flows for the Limpopo River Basin – From Vision to Management (Dickens *et al.* 2020b)
- E-Flows for the Limpopo River Basin – Specialist Literature and Data Review (Dickens *et al.* 2022a)
- E-Flows for the Limpopo River Basin – Drivers of Ecosystem Change (Dickens *et al.* 2022b)
- E-Flows for the Limpopo River Basin – Ecological Responses to Change (O'Brien *et al.* 2022a)
- E-Flows for the Limpopo River Basin – Environmental Flow Determination for the Limpopo Basin (O'Brien *et al.* 2022b)
- Risk of Altered Flows to the ecosystem services of the Limpopo Basin (O'Brien *et al.* 2022c).

The executive summary that explains the methods used (O'Brien *et al.* 2022b) is provided in **Appendix A** with permission from USAID and IWMI.

The Limpopo River basin study is ongoing (as at February 2024) having just entered a new phase of work in three concurrent projects:

- To harmonise the EWRs for the Limpopo River basin, which will include making use of the EWRs determined for the rivers in South Africa (**Section 7**).
- To connect and interact with various stakeholders extensively.
- To define and analyse scenarios of possible future outcomes that are likely to influence freshwater ecosystems of the Limpopo River basin.

The EWRs from South Africa will become part of the project to harmonise EWRs for the Limpopo River basin and the outcomes of scenario analyses from this EWR assessment and the WRCS process will also be considered in the analysis of LIMCOM scenarios. Likewise, the existing EWRs from the first LIMCOM project (O'Brien *et al.* 2022b) will be used in the analysis of scenarios during the WRCS process, along with those determined in this project for the two Ramsar wetlands and the rivers in this report.

The LIMCOM study provides EWRs for 18 river sites in the Limpopo River basin, five of these were in South Africa: the Lephalala, Mogalakwena, Sand, Luvuvhu and Shingwedzi Rivers. All these five sites are located at the downstream end of the river basins just upstream of their confluences with the Limpopo River (**Figure** 1-1**).**

A summary of EWR related information that will be taken forward into the WRCS is taken from the LIMCOM report series (**Section 1.4**), with permission from USAID and IWMI.

[11] In the LIMCOM study the term E-flows is used in place of EWRs

8.1 Lephalala River site LEPH-A50H-SEEKO

The Lephalala River is naturally a perennial river and currently the river does not flow all year round (**Figure** 8-1). There is extensive irrigation in the upper and middle reaches with numerous small dams on the river and its tributaries.

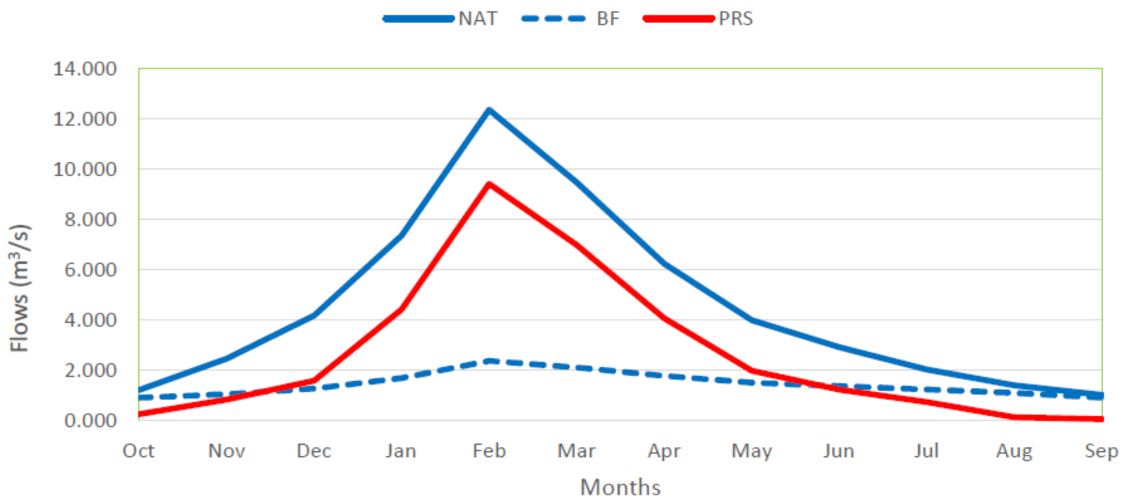


Figure 8-1: Mean monthly hydrology (discharge: Mean monthly hydrology (discharge m^3/s) representing the natural (NAT), present day (PRS) and base flow separated (BF)) for the Lephalala River (LEPH-A50H-SEEKO)

The current and historical water quality data were compared. The total dissolved solids and electrical conductivity were higher than the historical maximums and the inorganic phosphate levels were higher than the average levels.

The EWR site is situated in the lowlands (**Table** 8-1) along a sandy reach immediately downstream of a steep bedrock section with a weir and bridge. It has a single channel with inset benches, flood benches and a high floodplain/terrace (**Figure** 8-2). The bed consists mostly of fine gravel and coarse sand. Narrow elongated medium gravel bars form in the channel and provide anchor to reeds. The banks are composed of fine sand and silt, with recent medium grained sand deposits on the flood benches. There is evidence of recent high flows with extensive sand deposits and flood debris on flood prone areas. Shallow sandy pools are likely at low flow, with deeper pools associated with bedrock sections. The observed flow was mostly a glide type due to the largely uniform bed structure. Flood debris surveyed in at 6.8m. Some bank erosion is evident around exposed tree roots on near vertical banks and associated with the recent floods.

Table 8-1: Slope, geozone and discharge measured at LEPH-A50H-SEEKO

Site code	Latitude	Longitude	Date	Slope	Geozone	Discharge (m^3/s)
LEPH-A50H-SEEKO	-23.141278	27.885028	24/04/2021	0.00051	Lowland river	3.51

The Lephalala River, at this EWR site, was a single confined channel mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel (open and vegetated). Banks were dominated by tall trees and shrubs (some creeping shrubs), mostly riparian, but with some terrestrial and alien species, flood benches were mixed woody and non-woody and alluvial bars were dominated by non-woody grasses and sedges and some with linear reed beds. Alien vegetation was common, especially along unconsolidated alluvial deposits, but was mostly limited to annual weed species (Notably *Xanthium strumarium* and *Datura innoxia*). Dominant species included *Cynodon dactylon, Phragmites mauritianus, Panicum maximum, Combretum erythrophyllum, Vachellia gerardii, Ziziphus mucronata, Senegalia schweinfurthii, Faidherbia albida* and *Gymnosporia senegalensis*.

The site occurs along sub-quaternary A50H-00110. This sub-quaternary was assessed as a category D overall (largely modified; DWS 2014). Riparian zone continuity was largely modified and riparian zone modification was moderately modified. The majority of the impacts were flow related, both in terms of quantity and quality. The present ecological state was a PES score of 67.8% (category **C**, which is moderately modified from reference conditions). The most notable impacts on PES were reduced flows and floods that facilitate an increase in woody cover on the valley floor, notably *Faidherbia alba,* whose cohorts along the active channel suggest less frequent and smaller floods. There was some vegetation removal for roads, fence lines and the weir. Invasion by annual weeds was widespread and dense, especially on the valley bed. Benthic green algae in the channel suggested high nutrients but this could also be due to lower flows.

Flow conditions were visually rated as high, and the water colour was visually rated light to greenish brown. Instream habitat was rated as moderate to low, with boulders, cobble, and bedrock abundant downstream from the weir, but sand-mud and less often gravel dominant further downstream. Velocity-depth categories were well represented below the weir, but variety diminished further downstream. The marginal vegetation was dominated by reeds, with sedges and grasses present but very limited. Six sampling efforts were carried out in cobble, gravel, vegetation, and sand-mud-silt biotopes. Habitat heterogeneity for the site was high downstream of the weir, and homogenous further downstream. Overall habitat was rated to have moderate to low heterogeneity. The invertebrates were in a C/D category with a MIRAI score of 61%, meaning the community was moderately to largely impaired. Taxa diversity was low in 2021, with several expected taxa absent. Taxa rated as sensitive in SASS5 were present but not dominant. Flow sensitive taxa were dominant in cobble biotopes in-current.

Figure 8-2: (a) View of the channel from the right bank, (b) gravel from elongated gravel bars, (c) channel view from left bank, (d) recently deposited sediment from flood bench

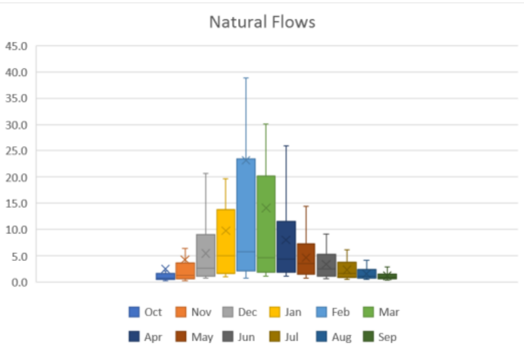
There was a high diversity of fish species, with 18 species present. The main problems affecting fish at this site was nutrient pollution that was evident by the dominance of primary producers (benthic algae). There was a high level of sediment on the channel bed from the commercial farms, over-grazing, dirt roads and urban areas. At the time of sampling, flow was high, the water slightly discoloured. There was good fish habitat immediately downstream of the weir and reduced habitat heterogeneity further downstream. Nutrient pollution causes a decline in biodiversity, through both a loss in species and through increased dominance of certain primary producers (Barker 2006; Cardinale 2011; Nie *et al.* 2018). Zinc was in a “poor” classification, which along with mercury, cadmium, copper, and lead are the most important heavy metal pollutants that affect the aquatic environment and health of fish (Authman et al. 2015).

The PES and REC for this site is a **C** category. The EWRs proposed for the site will return this naturally perennial river back into its perennial condition, although with reduced flows compared to its natural state (**Figure** 8-3). October represents the lowest observed flows in the hydrological record. The minimum EWR in October is 0.264 m^3/s.

Table 8-2: Summary of EWRs for a C category at LEPH-A50H-SEEKO

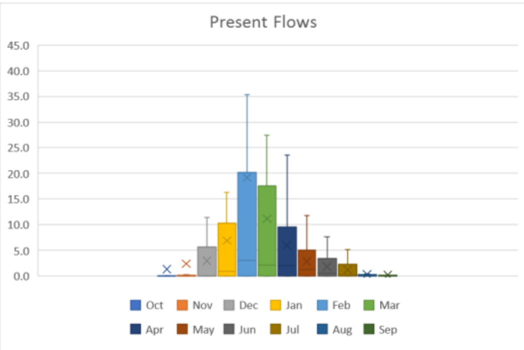
River	Site	nMAR (106m3)	%Drought	%Baseflows	%Floods	%Total
Lephalala	LEPH-A50H-SEEKO	142	8.79	18.09	21.02	39.11

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	24.9	25.8	20.6	38.2	136.3	60.6	27.5	14.4	9.1	6.1	4.2	3.1
1	5.2	21.1	15.4	32.8	114.7	58.0	26.0	11.3	8.8	5.7	3.8	2.9
5	2.2	6.4	12.8	19.7	38.9	30.0	18.4	8.8	6.6	4.6	3.0	2.2
10	1.9	4.4	11.1	14.9	25.1	22.7	12.2	7.9	5.7	4.0	2.5	1.7
15	1.4	3.0	7.0	12.6	21.7	17.5	10.9	6.6	4.9	3.4	2.2	1.4
20	1.2	2.4	5.2	11.9	15.1	14.5	8.8	5.8	4.4	3.1	1.8	1.3
30	1.1	1.8	4.5	8.6	11.0	8.9	7.1	4.5	3.1	2.2	1.5	1.1
40	0.9	1.4	3.7	7.7	7.2	6.2	5.1	4.1	2.7	1.9	1.2	1.0
50	0.8	1.2	2.7	5.0	5.7	4.7	4.4	3.5	2.5	1.7	1.1	0.8
60	0.7	1.1	2.2	3.9	4.9	4.0	3.4	2.8	2.0	1.4	1.0	0.8
70	0.6	1.0	1.7	2.8	3.3	2.8	2.9	2.2	1.6	1.2	1.0	0.7
80	0.5	0.8	1.3	2.0	2.6	2.1	2.4	1.9	1.4	1.1	0.8	0.6
85	0.5	0.7	1.2	1.8	2.4	2.0	2.1	1.7	1.3	0.9	0.7	0.6
90	0.4	0.6	1.0	1.4	1.8	1.9	1.8	1.3	1.1	0.8	0.7	0.6
95	0.4	0.5	0.9	1.2	1.5	1.5	1.4	0.9	0.8	0.7	0.6	0.5
99	0.3	0.3	0.8	1.0	1.1	1.3	1.2	0.7	0.6	0.5	0.5	0.4
99.9	0.3	0.3	0.8	0.9	0.8	1.1	1.1	0.7	0.6	0.5	0.4	0.4



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	19.1	21.9	16.3	33.5	116.0	50.7	23.7	11.7	7.6	5.1	1.9	1.8
1	3.2	14.2	11.5	27.8	104.8	49.9	23.6	9.1	6.7	4.9	1.4	1.4
5	0.1	4.0	9.1	16.3	35.3	27.5	15.7	7.3	5.2	2.9	1.0	0.1
10	0.0	0.3	7.5	11.1	21.2	20.3	10.2	5.5	3.6	2.3	0.4	0.1
15	0.0	0.1	3.7	9.4	19.2	14.7	8.8	4.6	3.1	2.2	0.2	0.1
20	0.0	0.0	1.8	8.4	12.7	11.8	7.1	3.5	2.2	1.4	0.0	0.1
30	0.0	0.0	0.4	5.4	7.8	7.2	4.6	2.2	1.4	0.7	0.0	0.0
40	0.0	0.0	0.0	4.3	4.3	3.9	3.3	1.8	0.8	0.3	0.0	0.0
50	0.0	0.0	0.0	0.9	3.0	2.2	2.0	1.3	0.5	0.1	0.0	0.0
60	0.0	0.0	0.0	0.0	1.5	1.1	1.2	0.5	0.1	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.1	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

B



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	1.694	1.823	2.649	5.563	16.269	3.991	2.378	1.361	1.334	1.216	1.092	0.930
1	1.687	1.820	2.643	5.558	16.256	3.988	2.374	1.357	1.333	1.215	1.091	0.930
5	1.684	1.811	2.637	5.544	16.201	3.960	2.362	1.352	1.330	1.214	1.090	0.929
10	1.667	1.784	2.617	5.509	15.896	3.916	2.322	1.339	1.328	1.210	1.086	0.926
15	1.421	1.762	2.398	4.877	14.267	3.858	2.297	1.316	1.321	1.206	1.083	0.922
20	1.221	1.697	2.196	4.545	12.005	3.726	2.205	1.275	1.313	1.200	1.075	0.917
30	1.083	1.545	1.823	3.647	9.669	3.326	2.015	1.148	1.285	1.178	1.054	0.899
40	0.862	1.278	1.410	2.833	6.690	2.829	1.580	0.958	1.253	1.139	1.023	0.862
50	0.769	0.992	0.923	1.663	3.605	2.120	1.262	0.756	1.186	1.092	0.972	0.816
60	0.599	0.740	0.778	1.118	2.330	1.452	0.914	0.588	1.077	1.002	0.883	0.731
70	0.433	0.578	0.588	0.772	1.566	1.001	0.692	0.486	0.920	0.871	0.755	0.610
80	0.355	0.401	0.436	0.635	1.259	0.787	0.587	0.439	0.720	0.700	0.592	0.461
85	0.337	0.378	0.428	0.635	1.220	0.739	0.561	0.427	0.613	0.597	0.501	0.386
90	0.328	0.373	0.428	0.635	1.220	0.730	0.551	0.421	0.514	0.513	0.424	0.326
95	0.328	0.373	0.428	0.635	1.220	0.730	0.551	0.419	0.428	0.419	0.357	0.295
99	0.321	0.336	0.428	0.635	1.128	0.730	0.551	0.419	0.403	0.377	0.334	0.295
99.9	0.264	0.304	0.428	0.635	0.810	0.730	0.551	0.419	0.403	0.368	0.334	0.295

C

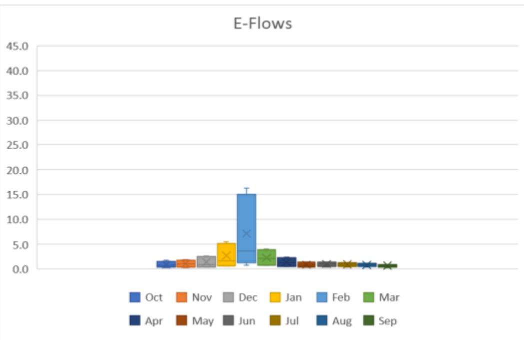


Figure 8-3: Exceedance tables and box and whisker charts for (A) natural, (B) present and (C) EWR scenario for the LEPH-A50H-SEEKO site. (The x in the box and whisker plots shows the mean value).

8.2 Mogalakwena River site MOGA-A36D-LIMPK

The Mogalakwena River is naturally a perennial river and currently flows all year round (**Figure** 8-4). Extensive irrigation occurs in the system from numerous small dams and a few larger dams, namely Doorndraai, Rooiwal and Glen Alpine Dams. The EWR site is situated upstream of the confluence with the Limpopo River (**Figure** 1-1). The Mogalakwena River and its floodplain supports fishing and farming services, and water is also used for household and small hold agriculture.

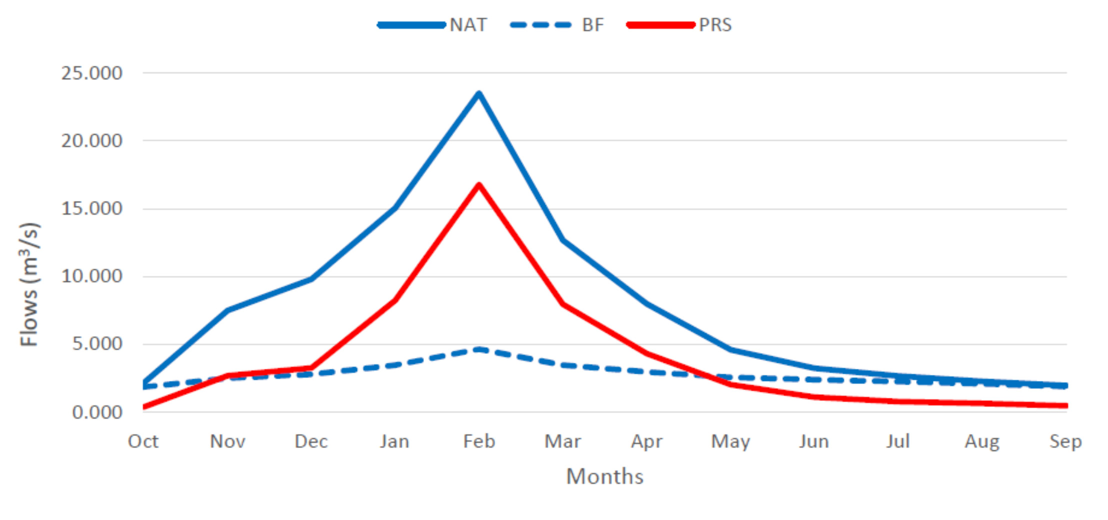


Figure 8-4: Mean monthly hydrology (discharge: Mean monthly hydrology (discharge m^3/s) representing the natural (NAT), present day (PRS) and base flow separated (BF)) for the Mogalakwena River (MOGA-A36D-LIMPK)

Water quality at the time of sampling showed elevated levels of nutrients, sulphates, sodium, magnesium, and calcium.

The EWR site is located in the lowlands (**Table** 8-3). The Mogalakwena is a mixed bed single channel with a wandering planform. The site is located downstream of a steep bedrock section with a weir on it. The river follows a pool riffle sequence when there is flow (no perceptible flow during field visit). Coarse sand and gravels dominate the relatively flat bed. Banks consist of fine sand and silt, with medium sand deposits on the left flood bench. The right flood bench has a gravel cover. There are low signs of siltation in the pools. The banks are poorly vegetated and eroding, with short sections of bank that is undercut. The banks are trampled by game.

Table 8-3: Slope, geozone and discharge measured at MOGA-A36D-LIMPK

Site code	Latitude	Longitude	Date	Slope	Geozone	Discharge (m^3/s)
MOGA-A36D-LIMPK	-22.473444	28.919500	26/04/2021	0.00011	Lowland river	0.0001

The Mogalakwena River at this site was a seasonal single confined channel mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel. Banks were dominated by tall trees and shrubs, clearly riparian, with a distinct treeline and require strongly seasonal flows or permanent pools. Riparian forest was dominated by *Schotia brachypetala, Ficus sycomorus, C. imberbe, Croton megalobotrys, F. albida, Philonoptera violacea* and *Colophospermum mopane*. The alluvial channel bed was dominated by open areas, linear stretches of reeds (*P. mauritianus*) and some tall shrub (notably *Nuxia oppositifolia*) stabilizing bank edges. The channel was dominated by filamentous green algae and sedges along the edge (*C. longus*). The site is known to host a population of Pel's fishing owl that nest in the riparian trees.

The site occurs along sub-quaternary A63D-00034. This sub-quaternary was assessed as a category C overall (moderately modified; DWS, 2014), but riparian zone continuity was only slightly modified, and riparian zone modification was moderately modified. The majority of the impacts were flow related. From 1955 to 2018 there has been an overall increase in woody vegetation cover although multiple changes are evident with some areas reducing woody cover. Tributaries show a noticeable increase in woody vegetation. The present state was a PES score of 76.4% (category **C**, which is moderately modified from reference conditions). The most notable impacts to PES were the reduction and regulation of flow. Many weirs occur along this reach with extensive irrigation. Bank and flood feature denudation from severe grazing and trampling pressure has led to erosion in some places. Some alien species are present but limited to annual weeds. Filamentous green algae suggest elevated nutrients.

Figure 8-5: (a) An upstream view of the sandy channel, (b) coarse sand on the channel bed, (c) eroding left bank, (d) gravel deposit on right flood bench

Flow was restricted to a trickle close to the weir wall, with no areas with any visible flow. The water colour was clear, with substrates at the site dominated by bedrock, cobble, gravel, and sand. Instream habitat was rated as low due to the lack of hydraulic biotope and flow-depth diversity. There was no marginal vegetation at the site, linked to recent bank scouring during high flows and the now absent flow. Eight sampling efforts were carried out in the trickle, in stones out of current, and in a sandy pool. Due to the limited flow and lack of marginal vegetation, habitat heterogeneity was rated low. Due to the shallowness of the trickle, the rocky substrates occupied a considerable volume of the area sampled. The invertebrates were in a D category, with a MIRAI score of 49%, meaning the community was rated as largely impaired. One flow sensitive taxon, Trichoptera: Hydropsychidae was surviving the available flow, but it is speculative whether it will complete its life cycle. Other expected flow sensitive taxa were all absent. No SASS-rated sensitive taxa were present.

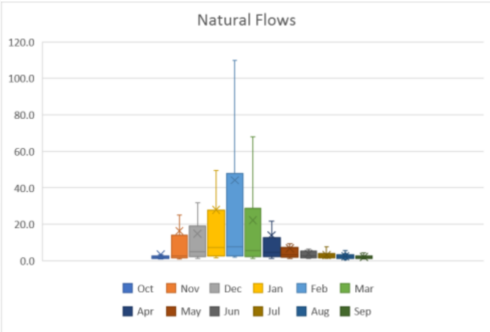
Chiloglanis paratus and *Labeo molybdinus* are moderately intolerant to no flow conditions and moderately intolerant to modified water quality (DWS 2014). They are substrate specialists and require mostly fast flows, however, *L. molybdinus* does prefer slow deep habitats (DWS 2014; Skelton 2001). The absence of these species was attributed to altered flows at MOGA-A36D-LIMPK. Nutrient pollution causes a decline in biodiversity, through both a loss in species and through increased dominance of certain primary producers (Barker 2006; Cardinale 2011; Nie *et al.* 2018). Zinc was in a “poor” classification, which along with mercury, cadmium, copper, and lead are the most important heavy metal pollutants that affect the aquatic environment and health of fish (Authman *et al.* 2015).

The PES and REC was a **C** category. The EWRs proposed for the site will return this naturally perennial river back into its perennial condition, although with reduced flows compared to its natural state **(Figure** 8-6). October represents the lowest observed flows in the hydrological record. The minimum EWR in October is 0.9 m^3/s.

Table 8-4: Summary of EWRs for a C category at MOGA-A36D-LIMPK

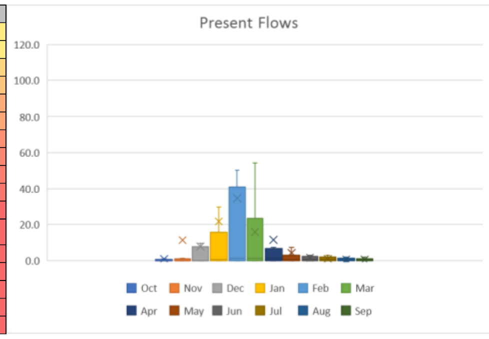
Site code	Latitude	Longitude	Date	Slope	Geozone	Discharge (m^3/s)
MOGA-A36D-LIMPK	-22.473444	28.919500	26/04/2021	0.00011	Lowland river	0.0001

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	21.6	130.3	65.2	176.7	284.5	148.5	84.9	33.1	10.7	7.6	5.4	4.3
1	8.6	64.6	63.0	118.1	177.1	68.0	58.8	25.3	10.7	7.1	4.7	3.7
5	3.2	25.0	31.8	49.5	109.7	42.7	21.6	9.4	6.1	4.6	3.7	3.1
10	2.8	17.2	22.1	31.4	57.2	33.5	13.9	7.4	5.2	4.0	3.3	2.8
15	2.6	10.8	16.1	24.3	38.5	24.0	11.6	7.1	5.0	3.9	3.2	2.7
20	2.4	6.8	13.2	20.5	26.0	15.8	9.9	6.2	4.2	3.4	2.9	2.5
30	2.2	3.9	9.9	14.1	15.3	10.8	7.6	4.8	3.7	3.0	2.5	2.3
40	2.1	3.2	6.2	10.6	9.6	7.0	6.5	3.8	3.2	2.8	2.4	2.0
50	1.8	2.7	5.1	7.2	7.5	5.5	4.6	3.2	2.7	2.4	2.1	1.8
60	1.6	2.5	3.9	5.3	5.7	4.6	3.7	2.8	2.6	2.2	1.9	1.7
70	1.5	2.2	3.2	3.4	4.1	3.9	3.1	2.3	2.0	1.9	1.7	1.5
80	1.3	1.9	2.5	3.0	3.1	2.6	2.4	2.0	1.8	1.6	1.5	1.3
85	1.2	1.7	2.1	2.6	2.7	2.5	2.2	1.8	1.7	1.5	1.4	1.3
90	1.1	1.6	2.0	2.4	2.5	2.2	2.1	1.8	1.6	1.4	1.4	1.2
95	1.0	1.3	1.7	2.0	2.1	1.9	1.8	1.6	1.5	1.3	1.2	1.1
99	1.0	1.0	1.3	1.7	1.8	1.6	1.6	1.4	1.3	1.2	1.1	1.1
99.9	1.0	0.9	1.3	1.6	1.7	1.4	1.3	1.2	1.2	1.2	1.1	1.0



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	9.6	123.2	53.0	176.0	222.3	113.4	81.4	28.7	8.4	3.2	2.0	2.0
1	3.6	62.1	42.5	115.5	152.8	54.3	73.1	24.9	6.9	3.1	1.9	1.9
5	1.1	4.1	19.1	29.9	107.6	35.4	16.7	7.3	3.0	2.6	1.8	1.5
10	0.8	1.3	9.7	18.4	50.1	30.2	7.3	3.7	2.5	2.2	1.6	1.3
15	0.7	1.0	5.5	13.0	31.9	16.6	6.0	2.6	2.2	1.6	1.3	1.0
20	0.6	0.8	2.9	8.7	14.1	11.4	4.0	1.9	1.7	1.4	1.2	0.9
30	0.3	0.4	1.4	5.9	5.6	5.2	2.7	1.5	1.2	1.0	0.9	0.5
40	0.1	0.3	0.5	2.0	3.2	2.4	1.9	1.3	1.0	0.8	0.7	0.4
50	0.0	0.1	0.1	0.8	1.4	1.5	1.4	0.8	0.7	0.6	0.5	0.3
60	0.0	0.0	0.0	0.3	0.8	0.9	0.9	0.5	0.4	0.2	0.3	0.2
70	0.0	0.0	0.0	0.0	0.3	0.3	0.5	0.3	0.2	0.1	0.1	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

B



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	2.615	5.204	3.948	8.081	29.894	3.657	2.564	2.270	2.267	2.145	1.989	1.823
1	2.607	5.188	3.946	8.070	29.846	3.646	2.560	2.267	2.266	2.144	1.986	1.819
5	2.597	5.175	3.933	8.053	29.819	3.642	2.555	2.260	2.256	2.137	1.982	1.815
10	2.573	5.130	3.861	7.824	27.746	3.605	2.535	2.237	2.233	2.119	1.955	1.788
15	2.537	5.037	3.669	7.275	25.557	3.564	2.505	2.219	2.220	2.099	1.944	1.776
20	2.423	4.873	3.435	6.726	22.940	3.485	2.443	2.163	2.157	2.056	1.893	1.733
30	2.188	3.866	2.882	5.420	15.286	3.230	2.284	2.004	2.044	1.921	1.782	1.601
40	1.953	3.210	2.266	4.300	9.554	2.658	2.046	1.709	1.842	1.724	1.634	1.420
50	1.616	2.674	1.735	2.824	6.611	2.295	1.767	1.581	1.620	1.530	1.443	1.234
60	1.303	2.057	1.358	2.042	4.258	1.809	1.518	1.390	1.422	1.360	1.275	1.071
70	1.104	1.498	1.132	1.546	2.850	1.481	1.359	1.274	1.291	1.253	1.163	0.972
80	1.011	1.233	1.041	1.350	2.284	1.325	1.284	1.219	1.223	1.198	1.106	0.925
85	0.989	1.176	1.030	1.350	2.212	1.291	1.266	1.206	1.204	1.182	1.090	0.914
90	0.978	1.161	1.030	1.350	2.212	1.283	1.258	1.199	1.194	1.174	1.082	0.908
95	0.978	1.161	1.030	1.350	2.134	1.283	1.258	1.197	1.188	1.169	1.077	0.906
99	0.976	1.013	1.030	1.350	1.763	1.283	1.256	1.194	1.186	1.165	1.074	0.906
99.9	0.958	0.903	1.030	1.350	1.740	1.283	1.237	1.175	1.181	1.155	1.065	0.906

C

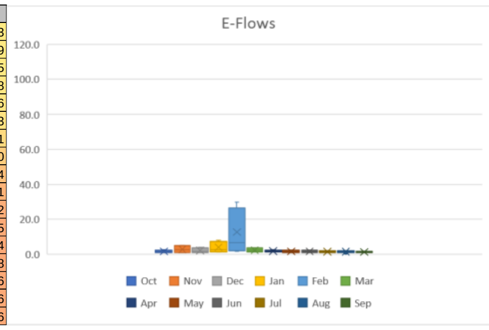


Figure 8-6: Exceedance tables and box and whisker charts for (A) natural, (B) present and (C) EWR scenario for the MOGA-A36D-LIMPK site. (The x in the box and whisker plots shows the mean value).

8.3 Sand River site SAND-A71K-R508B

The Sand River is naturally a seasonal river (**Figure** 8-7). There are a number of dams situated in the catchment for irrigation purposes; the Houtrivier, Turfloop, and Dikigale Dams. The EWR site is located upstream of the R508B road bridge from Musina to Tshipise, and downstream of Musina town (**Figure** 1-1). This is an important part of the catchment that supports the population from Musina for water provisioning, fishing and agriculture. Community members fish a number of species at this site which includes Tilapia, Carp and Tigerfish. Further downstream of this site, subsistence and commercial irrigation farming (tomatoes, beans) in downstream villages (Masisi) is common. Fresh produce shops around the Masisi village rely on groundwater (adverts for groundwater drilling). Cultural and spiritual ecosystem services were observed in this part of the catchment as burnt candles from these rituals were observed. This site is also used to harvest medicinal plants.

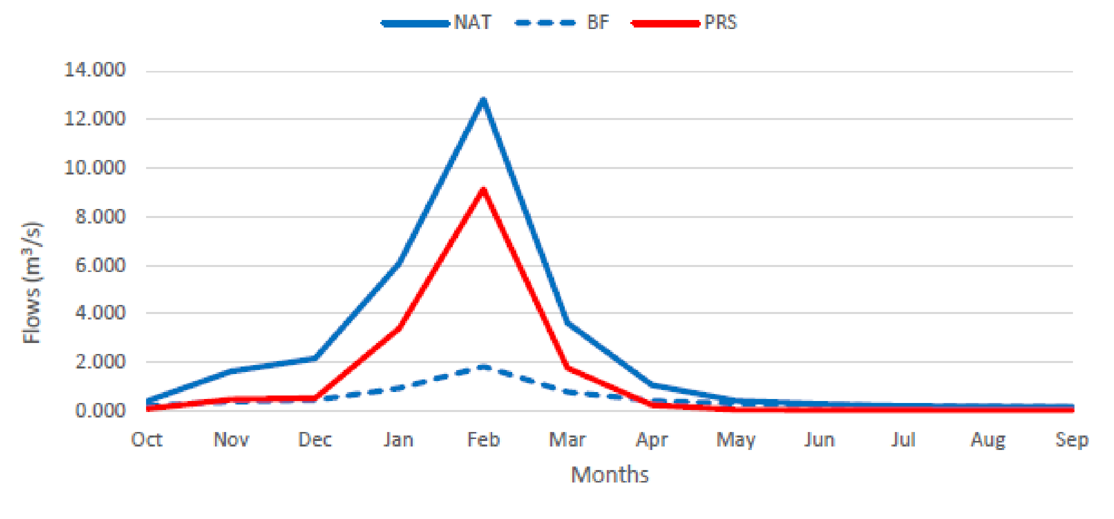


Figure 8-7: Mean monthly hydrology (discharge: Mean monthly hydrology (discharge m^3/s) representing the natural (NAT), present day (PRS) and base flow separated (BF)) for the Sand River (SAND-A71K-R508B)

Water quality at the time of sampling had elevated nutrients, chlorine, sulphates, sodium, potassium, and magnesium. Water temperature was high probably due to a shallow riverbed, with elevated pH and dissolved oxygen.

The EWR site was located in the lower foothills (**Table** 8-5). This section of the Sand River is a bedrock-controlled reach with a mixed load channel (**Figure** 8-8). The complex channel morphology is composed of a single wandering low-flow channel, with several high flow channels. Sand bars form small well vegetated islands between the high flow channels and a narrow flood bench is present along the left bank. Gravel bars form in the channel and on flood features in an otherwise coarse sand dominated channel. A recent flood level was surveyed at 1.6m above the thalweg elevation.

Table 8-5: Slope, geozone and discharge measured at SAND-A71K-R508B

Site code	Latitude	Longitude	Date	Slope	Geo Zone	Discharge (m^3/s)
SAND-A71K-R508B	-22.399278	30.099417	28/04/2021	0.0018	Lower foothills	0.01

The Sand River at this site was a single alluvial channel. Banks were gentle, merging into the upland and dominated by mostly terrestrial woody shrubs and trees (notably *V. tortilis*), but with some riparian indicators (*P. violacea, C. imberbe, S. brachypetala* and *F. sycomorus*). The macro-channel valley was undulating, with denuded alluvial high flow and flood channels, with dense vegetation on alluvial deposits, mainly sedges (*C. sexangularis*) and shrubs (*Pluchea dioscoridis*) but with some tree recruitment in places (*F. albida*). The active channel was narrow and with substrate covered by algae, lined by sedges and shrubs in places, otherwise open. The presence of *Cyperus sexangularis* near the active channel suggests the river is seasonal.

The site occurs along sub-quaternary A71K-00019. This sub-quaternary was assessed as a category **B** overall (Largely natural; DWS 2014), riparian zone continuity was only slightly modified, and riparian zone modification was also largely natural. The majority of the impacts were flow related (quantity). From 1937 to 1987 there was an increase in tree density and coverage and then a reduction to 2020 where tree cover and density was less than in 1937. The channel does however appear to be stable (**Figure** 8-8 below). The present state was a PES score of 78.3% (category B/C, which is slightly modified from reference conditions). The most notable impacts observed are vegetation removal for roads, fences, people and livestock access, and some invasion by alien plant species along the macrochannel valley, the majority were annual weeds.

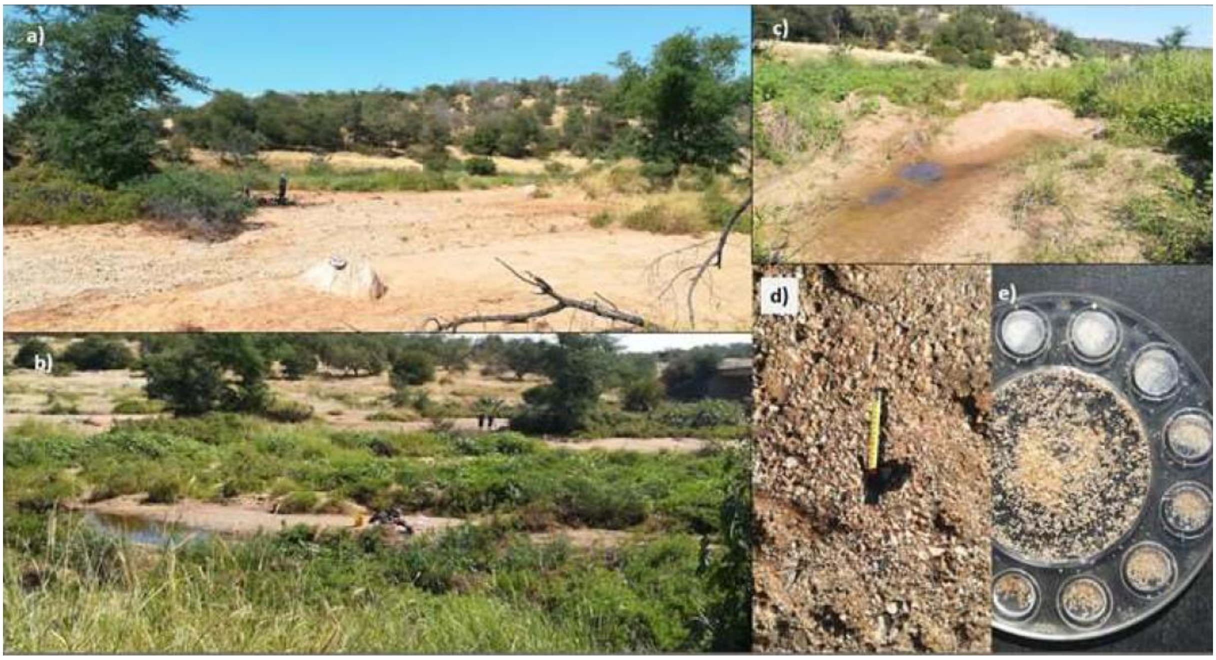


Figure 8-8: (a) View of left bank with gravel and sand bar in fore ground, (b) view from right bank, (c) high flow channel and vegetated sand bars, (d) gravel bar, (e) coarse sand from channel

Flow was visually rated as very low, predominantly shallow over sandy substrates. Water in the stream was categorised as warm, alkaline and subsaline. The water colour was clear to light brown, with cobbles limited, large boulders present, fine gravel to coarse sand dominant, and silt-mud-sand dominating slower flowing portions. Instream habitat was rated as low due to the lack of hydraulic biotope, and flow-depth diversity. Marginal vegetation was present but limited. Six sampling efforts were carried out across the narrow channel, mainly in the sand-gravel substrates. Cobbles were present but limited, with large boulder-bedrock and sand the dominant substrates. Only cobble-gravel-sand-mud substrates were sampled. Habitat heterogeneity was rated low. Habitat cover for invertebrates was relatively good where available but those habitats were limited. The invertebrates were in a C category, with a MIRAI score of 72%, meaning the community was moderately impaired. Taxa diversity was relatively low, with sensitive taxa mostly absent. Flow sensitive taxa were scarce and dominated by two Hydropsychidae species. Impaired conditions were attributed to limited instream habitat linked to subsaline conditions, with low flow-velocity habitat and substrate diversity.

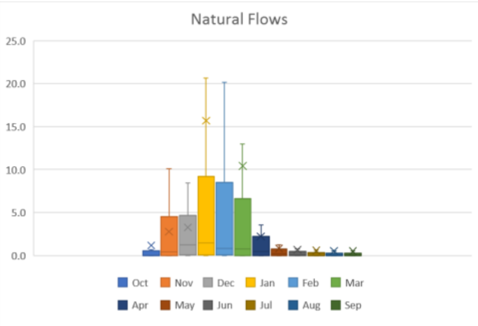
Chiloglanis paratus and *Labeo molybdinus* are moderately intolerant to no flow conditions and moderately intolerant to modified water quality (DWS 2014). They are substrate specialists and require mostly fast flows, however, *L. molybdinus* does prefer slow deep habitats (DWS 2014; Skelton 2001). The absence of these species are attributed to the absence of preferred habitat and altered water quality at SAND-A71K-R508B. *Labeobarbus marequensis, C. paratus, Labeo congoro, L.cylindricus, L. molybdinus, Micralestes acutidens* are fish expected in the Limpopo River Basin that are moderately intolerant to altered water quality (DWS 2014). These were not found at SAND-A71K-R508B because of compromised water quality from surrounding agricultural, industrial, urban and informal settlements that compromise the water quality.

The REC and PES was a **C** category. The EWRs proposed for this site are summarised in **Table** 8-6 and given in **Figure** 8-9.

Table 8-6: Summary of EWRs for a C category at SAND-A71K-R508B

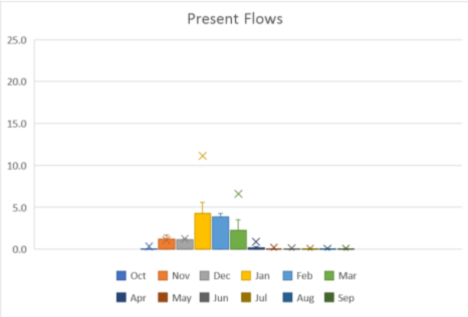
River	Site	nMAR ($10^6 m^3$)	%Drought	%Baseflows	%Floods	%Total
Sand	SAND-A71K-R508B	74	0	9.02	23.41	32.43

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	11.3	15.1	15.1	128.0	662.3	105.6	16.8	6.5	6.2	5.6	5.2	4.9
1	5.5	10.1	12.2	85.0	201.4	38.3	9.0	3.1	2.9	2.5	2.3	2.1
5	1.4	7.6	8.4	20.7	20.2	13.0	3.5	1.2	0.7	0.6	0.6	0.5
10	0.7	5.3	4.8	10.9	9.3	9.6	2.7	0.8	0.5	0.4	0.3	0.3
15	0.4	3.7	4.5	7.5	7.7	3.7	1.8	0.6	0.4	0.3	0.2	0.3
20	0.3	2.2	3.3	6.3	6.0	2.8	1.3	0.5	0.3	0.2	0.2	0.1
30	0.1	1.5	2.5	3.6	3.4	1.7	0.9	0.4	0.2	0.1	0.1	0.1
40	0.1	0.8	1.7	1.9	2.2	1.0	0.6	0.3	0.1	0.1	0.0	0.0
50	0.0	0.4	1.2	1.5	0.8	0.7	0.4	0.2	0.1	0.0	0.0	0.0
60	0.0	0.2	0.8	0.9	0.5	0.5	0.3	0.1	0.0	0.0	0.0	0.0
70	0.0	0.1	0.3	0.4	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
85	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	4.3	7.6	8.8	107.2	544.8	70.8	10.2	2.4	1.8	1.3	1.1	1.0
1	1.4	5.4	6.0	59.0	163.2	29.1	3.7	0.5	0.4	0.2	0.2	0.1
5	0.0	3.1	3.0	11.5	13.1	7.1	0.8	0.0	0.0	0.0	0.0	0.0
10	0.0	1.7	1.3	5.6	4.3	3.5	0.3	0.0	0.0	0.0	0.0	0.0
15	0.0	0.8	1.0	2.9	3.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.5	2.5	2.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.1	0.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

B



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	0.165	1.179	2.038	2.220	9.365	1.395	1.240	0.227	0.196	0.165	0.142	0.125
1	0.165	1.174	2.035	2.217	9.346	1.390	1.235	0.226	0.195	0.164	0.141	0.125
5	0.164	1.171	2.031	2.209	9.337	1.384	1.226	0.224	0.194	0.164	0.141	0.125
10	0.161	1.158	1.875	2.172	8.830	1.372	1.211	0.221	0.192	0.161	0.138	0.121
15	0.158	1.133	1.796	1.965	7.733	1.341	1.189	0.214	0.187	0.157	0.133	0.119
20	0.152	1.086	1.553	1.805	6.039	1.297	1.131	0.204	0.179	0.145	0.131	0.111
30	0.097	0.970	1.163	1.414	3.376	1.152	0.907	0.177	0.155	0.119	0.093	0.066
40	0.052	0.753	0.823	1.040	2.192	0.898	0.571	0.128	0.119	0.060	0.030	0.000
50	0.000	0.428	0.413	0.563	0.787	0.640	0.444	0.082	0.062	0.000	0.000	0.000
60	0.000	0.239	0.233	0.305	0.467	0.370	0.285	0.042	0.008	0.000	0.000	0.000
70	0.000	0.058	0.124	0.142	0.246	0.188	0.135	0.007	0.000	0.000	0.000	0.000
80	0.000	0.000	0.081	0.077	0.074	0.101	0.019	0.000	0.000	0.000	0.000	0.000
85	0.000	0.000	0.069	0.056	0.029	0.011	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99.9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

C

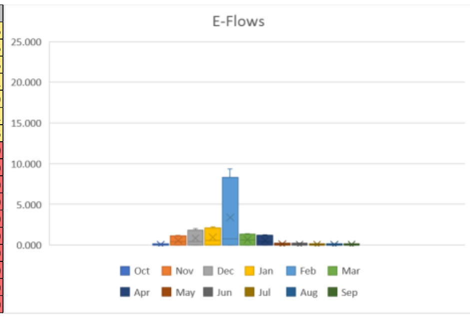


Figure 8-9: Exceedance tables and box and whisker charts for (A) natural, (B) present and (C) EWR scenario for the SAND-A71K-R508B site. (The x in the box and whisker plots shows the mean value).

8.4 Luvuvhu River SITE LUVU-A91K-OUTPO

The Luvuvhu River is naturally a perennial system and currently the river flows all year round **(Figure** 8-10). The EWR site is located on the Luvuvhu River in Kruger National Park below Outpost private lodge (**Figure** 1-1**)**. Water use includes afforestation in upper reaches, irrigation and domestic water use. There are a number of large dams in the catchment, including Albasini, Vondo and Nandoni Dams.

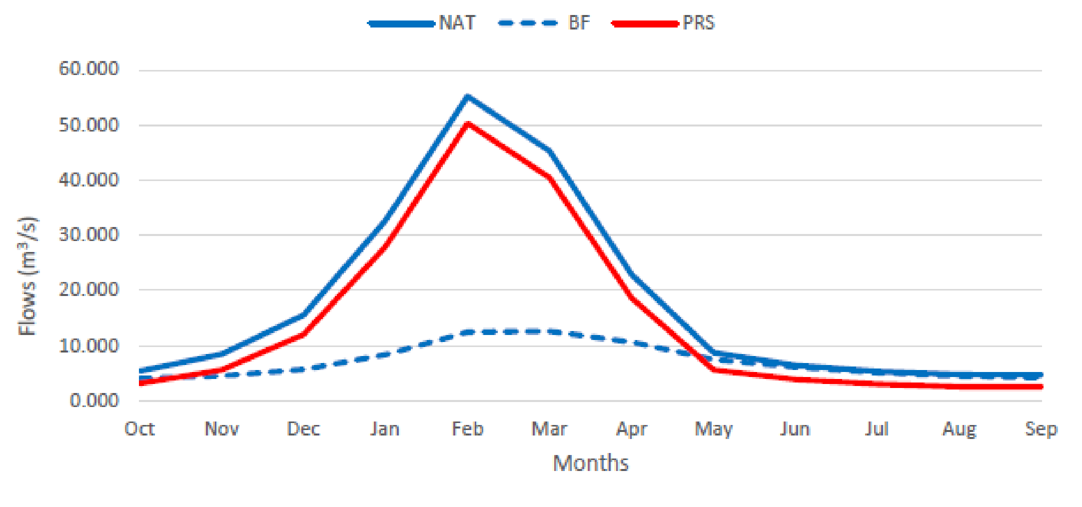


Figure 8-10: Mean monthly hydrology (discharge: Mean monthly hydrology (discharge m^3/s) representing the natural (NAT), present day (PRS) and base flow separated (BF)) for the Luvuvhu River (LUVU-A91K-OUTPO)

The current and historical water quality data were compared. The total dissolved solids, electrical conductivity and nutrients were all higher than the 50th percentile levels.

The EWR site is in the lower foothills (**Table** 8-7). This section of the Luvuvhu River is characterised by a pool riffle sequence with cobble and boulder sized material along the riffle. Sandy lee bars develop downstream of boulder high points. Small coarse sand and fine gravel deposits are found between the cobble and boulder high points in the slower flow of the riffle. The gravels and cobbles are moderately loose and mobile and were not embedded in sand or gravel. There was very low embeddedness and imbrication in the flowing water of the riffle and higher levels of imbrication and embeddedness out of the main flow zone. Bedrock is present along the left bank. The steep right bank is composed of loose medium to coarse sand and show erosion and deposition from the last flood. The pools are lined with sand and silt over cobble and gravel. Sandy inset benches develop and are covered by reeds.

Table 8-7: Slope, geozone and discharge measured at LUVU-A91K-OUTPO

Site code	Latitude	Longitude	Date	Slope	Geo Zone	Discharge (m^3/s)
LUVU-A91K-OUTPO	-22.444444	31.083444	29/04/2021	0.004	Lower foothills	17.43

The Luvuvhu River, at the site, was a single confined channel mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel (open and vegetated), and with an extensive gravel/cobble point bar downstream of the site. Looking upstream from the site the channel was single, bank full and with tall trees to the water's edge. Looking downstream the channel rounded a gravel/cobble point bar with some shrub (*P. dioscoridis*) and flood-damaged trees (*F. albida, Syzygium gerardii*). The marginal zone was either open unvegetated, woody (tall tree and shrub, notably *P. dioscoridis, S. gerardii, F. sycomorus, Breonadia salicina*) or lined by reeds, sedges and grasses, inundated at the time (P.*mauritianus, G. fruticosus, C. longus, C. dactylon*). The floodplain was mostly open sand with some cobble deposits, supporting younger trees, *C. imberbe* and *F. albida*, with tall trees at the edge (Figs, Nyala trees, Apple Leaf and Leadwoods). Banks were alluvial, mostly woody and steep with some open sandy areas.

The site occurs along sub-quaternary A91K-00039. This sub-quaternary was assessed as a category **B** overall (Largely natural; DWS 2014), riparian zone continuity was largely natural, and riparian zone modification was also largely natural. The majority of the impacts were flow related (quantity). Woody abundance and cover appears to be stable over the last 50 years (1964 to 2019). The present state has an overall PES score of 83.5% (category B, which is largely natural). The site is mostly natural in terms of riparian vegetation but with some presence of alien annual weeds.

Figure 8-11: (a) View from the left bank, (b) boulder and cobble along the edge of the slow riffle, (c) reeds growing on elongated boulder and riffle high points, (d) cobble and sand matrix out of current, (e) coarse sand trapped in between cobbles in riffle

Flow was visually rated as very high, with high availability of stable substrates restricted to deep areas during this high flow sampling event. Water in the stream was categorised as cool-warm alkaline freshwater. The water colour was clear to light brown, with cobbles-boulders the dominant habitat. Instream habitat was rated as high, and the inundation period of wadeable habitat unknown. Six sampling efforts were carried out limited to shallower flows in the channel. Boulders and cobbles were the dominant substrate, with a high variety of hydraulic biotopes, velocities and depth classes present, but not wadeable. Habitat heterogeneity at the site was high, but habitat sampled was rated moderate to high. Habitat cover (interstitial spaces) was considerable in the accessible fast flowing boulder-cobble biotopes. The invertebrates were in a C category with a MIRAI score of 63% in 2021. Taxa considered sensitive to water quality (e.g. Heptageneiidae, Tricorythidae, Philopotaamidae) dominated the community, as did those associated with moderate to fast flows. They are frequently encountered at the site during electrofishing (Robin Petersen 2018, Pers. Comm., 11 September 2021). SASS records presented less frequent encounters.

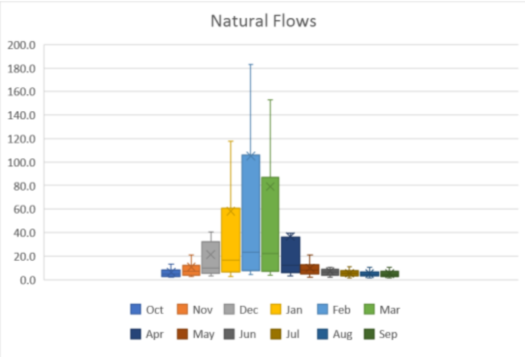
Nutrient pollution causes a decline in biodiversity, through both a loss in species and through increased dominance of certain primary producers (Barker 2006; Cardinale 2011; Nie et al. 2018). Zinc was in a “poor” classification LUVU-A91K-OUTPO, which along with mercury, cadmium, copper, and lead are the most important heavy metal pollutants that affect the aquatic environment and health of fish (Authman et al. 2015). At the LUVU-A91K-OUTPO site the ecological category of a C for fish was under estimated because of high flows which limited sampling effort and was not attributed to large modification of habitats. Sampling conditions were very high flow, with deeper fast flowing sections that were wadeable during low flow. Habitat heterogeneity was high with cobble-boulder substrates dominant and different velocity-depth classes. Matumi root wads were inaccessible due to high flow. The sampling time was limited.

The PES and REC was a **C** category. The EWRs proposed are summarised in **Table** 8-8. Sustained perenniality of this river (from the established EWRs **Figure** 8-12) will ensure that the ecosystem becomes sustainable, a recovery from present conditions and will help maintain the wellbeing of the Limpopo Basin ecosystem. This site occurs below a major dam that is able to maintain or on occasion augment the base flows of the river.

Table 8-8: Summary of EWRs for a C category at LUVU-A91K-OUTPO

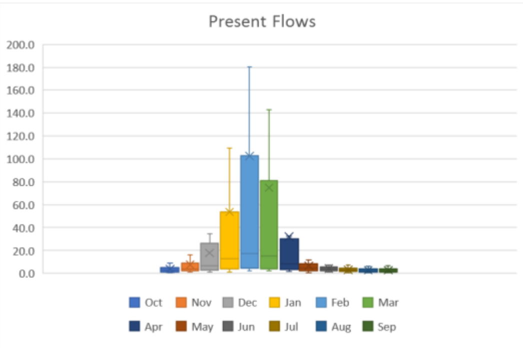
River	Site	nMAR ($10^6 m^3$)	%Drought	%Baseflows	%Floods	%Total
Luvuvhu	LUVU-A91K-OUTPO	560	12.29	24.1	15.97	40.06

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	20.4	38.1	82.8	331.4	775.9	493.0	190.9	31.6	16.6	10.9	10.3	10.3
1	13.0	30.1	74.1	258.2	357.9	306.7	138.4	21.0	16.2	10.1	9.2	9.7
5	9.2	21.3	40.5	117.6	183.0	152.8	100.7	16.7	10.6	9.0	7.8	8.2
10	8.5	12.9	34.2	67.9	124.1	92.8	39.3	13.8	9.3	7.9	6.9	7.3
15	7.6	11.4	30.2	53.6	88.2	81.3	33.1	11.8	8.3	7.0	6.3	6.5
20	7.2	10.3	23.4	39.2	79.1	67.7	25.5	11.0	7.9	6.6	6.1	6.2
30	6.2	9.1	16.7	30.2	59.0	47.1	17.3	9.8	7.3	6.1	5.5	5.4
40	5.3	7.5	11.3	20.7	32.2	26.6	14.4	9.2	6.8	5.4	4.8	4.9
50	5.0	6.8	9.7	16.6	23.2	22.2	12.3	8.0	6.3	5.1	4.5	4.3
60	4.5	6.2	8.3	13.0	16.3	11.2	10.4	6.9	5.5	4.6	4.0	4.0
70	3.5	5.4	6.9	10.3	12.1	9.7	8.3	6.1	4.7	4.2	3.8	3.4
80	3.1	4.7	6.2	7.6	9.1	7.6	6.9	5.1	4.3	3.6	3.2	3.0
85	2.9	4.1	5.6	6.9	8.5	7.2	6.4	4.8	4.1	3.4	3.1	2.9
90	2.7	3.6	5.1	6.4	7.0	6.6	5.9	4.5	3.7	3.3	2.9	2.7
95	2.5	3.3	3.4	5.1	5.9	5.7	5.1	3.8	3.3	2.8	2.7	2.4
99	2.0	2.7	3.0	3.3	4.0	4.6	3.8	2.6	2.4	1.9	2.2	1.9
99.9	2.0	2.7	3.0	2.8	4.0	3.9	3.2	2.0	2.3	1.6	1.6	1.6



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	16.9	32.6	78.0	328.8	785.5	485.5	184.2	27.5	11.6	7.6	6.1	7.0
1	9.3	22.3	66.8	250.5	357.7	305.1	129.2	17.2	11.1	6.7	6.1	6.6
5	5.9	16.2	34.5	109.3	180.3	143.2	91.8	11.8	7.2	5.4	4.5	4.7
10	5.5	9.8	29.5	61.7	122.1	86.7	32.4	8.5	5.9	4.8	4.0	4.2
15	4.6	7.8	23.7	45.1	83.4	75.6	27.8	7.8	5.1	4.2	3.6	3.9
20	4.2	7.2	19.4	31.6	70.0	60.1	20.1	7.3	4.8	3.8	3.4	3.4
30	3.6	6.0	12.6	23.2	54.9	42.0	13.5	6.1	4.5	3.3	3.0	3.0
40	2.9	4.6	8.3	15.6	27.4	22.6	10.2	5.8	4.0	3.1	2.5	2.6
50	2.8	4.2	6.5	13.0	17.6	15.4	8.2	4.8	3.7	2.8	2.4	2.3
60	2.4	3.4	5.1	9.2	11.1	8.6	7.1	4.2	3.1	2.5	2.1	2.1
70	1.8	3.1	4.3	6.1	8.3	6.4	5.2	3.6	2.7	2.2	1.9	1.7
80	1.6	2.5	3.4	4.8	5.8	4.6	4.1	3.0	2.3	2.0	1.6	1.4
85	1.5	2.3	3.2	4.0	5.2	4.2	3.8	2.7	2.2	1.7	1.5	1.3
90	1.2	1.9	2.8	3.7	4.1	3.7	3.4	2.5	2.0	1.7	1.4	1.2
95	1.0	1.6	1.8	2.7	3.4	3.3	2.8	2.1	1.6	1.3	1.2	1.0
99	0.8	1.3	1.5	1.6	2.2	2.7	2.0	1.3	1.2	0.8	0.9	0.7
99.9	0.7	1.2	1.4	1.5	2.1	2.1	1.6	0.8	1.1	0.7	0.6	0.6

B



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	9.991	7.267	13.476	16.331	35.511	16.907	10.136	6.519	6.340	5.838	5.381	5.134
1	9.956	7.250	13.469	16.324	35.468	16.889	10.119	6.510	6.334	5.823	5.368	5.125
5	9.246	7.232	13.453	16.310	35.425	16.872	10.105	6.506	6.302	5.803	5.352	5.106
10	8.486	7.123	13.218	16.221	35.141	16.813	10.065	6.487	6.242	5.737	5.305	5.035
15	7.598	7.058	12.794	15.872	33.250	16.750	9.993	6.462	6.132	5.614	5.209	4.923
20	7.213	6.888	12.120	15.433	31.504	16.664	9.872	6.396	5.975	5.414	5.045	4.787
30	6.243	6.340	11.147	14.758	28.405	16.381	9.541	6.294	5.267	4.884	4.558	4.259
40	5.324	5.337	9.910	13.880	24.698	15.805	9.072	6.063	4.383	3.908	3.878	3.537
50	4.992	4.426	8.737	13.056	21.157	15.018	8.171	5.707	3.640	3.198	3.121	2.860
60	3.775	3.412	6.573	10.990	14.887	11.152	6.873	5.104	2.811	2.469	2.426	2.230
70	2.833	2.728	4.772	8.871	10.019	9.659	5.338	4.239	2.262	2.007	1.967	1.847
80	2.389	2.403	3.049	3.345	5.363	6.873	3.946	3.187	1.978	1.772	1.729	1.667
85	2.280	2.331	2.659	3.345	4.310	4.383	3.386	2.626	1.904	1.709	1.659	1.623
90	2.234	2.315	2.659	3.345	4.310	3.588	3.118	2.229	1.860	1.672	1.630	1.601
95	2.234	2.315	2.659	3.345	4.310	3.588	3.118	2.008	1.834	1.648	1.609	1.592
99	2.022	2.315	2.659	3.262	4.045	3.588	3.118	1.999	1.828	1.632	1.597	1.590
99.9	2.013	2.315	2.659	2.830	4.025	3.588	3.118	1.920	1.828	1.588	1.537	1.576

C

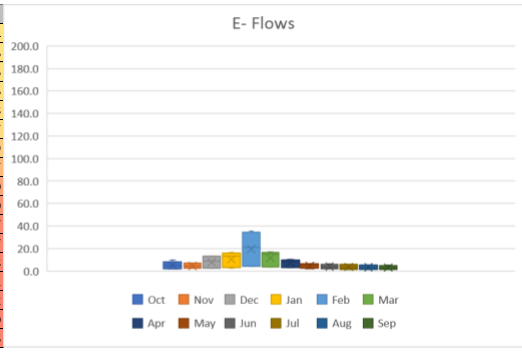


Figure 8-12: Exceedance tables and box and whisker charts for (A) natural, (B) present and (C) EWR scenario for the LUVU-A91K-OUTPO site. (The x in the box and whisker plots shows the mean value).

8.5 Shingwedzi River site SHIN-B90H-POACH

The Shingwedzi River is located in the Kruger National Park (KNP) at Poachers Corner (**Figure** 1-1**)**. The river is naturally seasonal to perennial in the upper reaches where the EWR site is located. The lower reaches (especially in Mozambique) are ephemeral with almost no flows year round and large floods during summer. Abstractions for irrigation and domestic water use occur outside the KNP with the Makuleke Dam the largest. Significant transmission losses and alluvial storage take place in the lower reaches of the river.

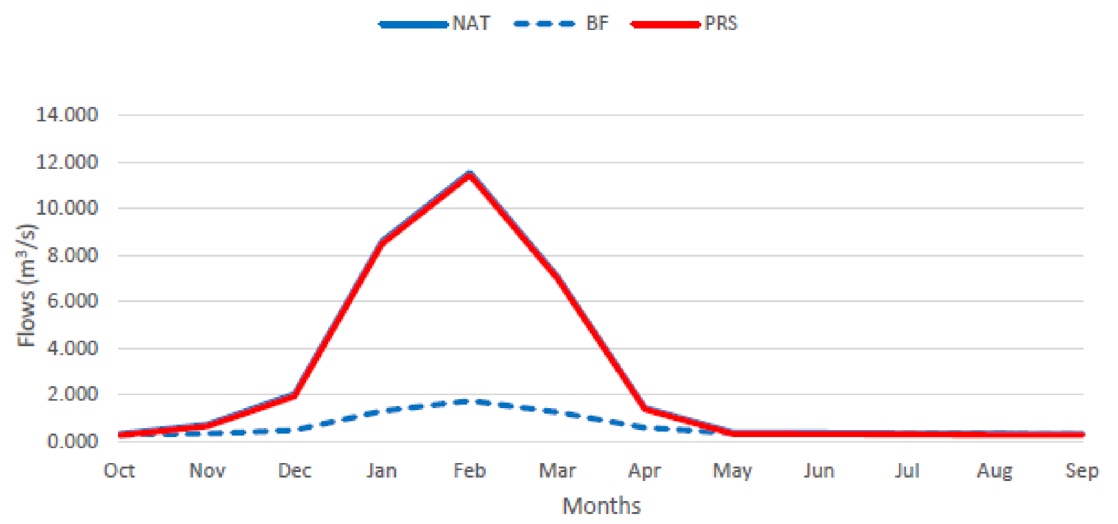


Figure 8-13: Mean monthly hydrology (discharge: Mean monthly hydrology (discharge m^3/s) representing the natural (NAT), present day (PRS) and base flow separated (BF)) for the Shingwedzi River (SHIN-B90H-POACH)

The current and historical water quality data were compared. All salt and nutrient levels were higher than the historical average but lower than the 75th percentile.

The Shingwedzi River is incised into the surrounding landscape with a very narrow floodplain. The EWR site is located in the lower foothills (**Table** 8-9). Pools form along the gentler gradients with wide shallow slow flowing water. Coarse sand and fine gravel dominate the bed material (**Figure** 8-14). The left bank is steep with good tree cover and composed of fine sand and silt. The right bank is composed of various levels of sand and gravel bars forming various flood levels.

Table 8-9: Slope, geozone and discharge measured at SHIN-B90H-POACH

Site code	Latitude	Longitude	Date	Slope	Geozone	Discharge (m^3/s)
SHIN-B90H-POACH	-23.221944	31.554917	01/05/2021	0.00011	Lower foothills	0.01

The Shingwedzi River, at the site, was mixed bedrock and alluvial and mostly with no marginal vegetation or scattered pockets of low shrub or sedge. Banks were well wooded in places, notably near or associated with deeper pools, possibly perennial pools. The mixed bedrock/gravel riffle areas supported a notable population of *Gomphocarpus fruticosus* but this area was also influenced by the confluence of a small tributary to the Shingwedzi. The extensive gravel flood bench was sparse, mostly unvegetated with some shrubs, notably *Gymnosporia senegalensis*, a species associated with seasonal or drier conditions. Pool edges supported the only marginal zone vegetation, mixed woody (*Nuxia oppositifolia, Vachellia xanthophloea, Phoenix reclinate* and *Hyphaene coriacea*) and non-woody, mostly *P. mauritianus and Cyperus sexangularis*. The macrochannel bank supported tall phreatophytic trees where pools persisted the longest or were perennial. Dominant species included *Spirostachys africana, P. violacea, C. imberbe and Diospyros mespiliformis*.

The site occurs along sub-quaternary B90H-00145. This sub quaternary was assessed as a category **B** overall (Largely natural; DWS 2014), riparian zone continuity was largely natural, and riparian zone modification was also largely natural. The majority of the impacts were flow related (quantity). From 1942 to 2016 in-channel pools seem to have expanded/deepened, but woody vegetation density and distribution appears stable along the main channel and has increased slightly along smaller tributaries. The present state has an overall PES score of 83.0% (category B, which is largely natural). The site is mostly natural in terms of riparian vegetation but with some presence of alien annual weeds, particularly where flood disturbance occurs.

Figure 8-14: (a) View from the right bank (gravel on the flood bench in the foreground, (b) well vegetated banks and sandy channel, (c) view of the sandy channel from the left bank, (d) sandy lee deposit behind bedrock core island

Flow was visually rated as low, with moderate habitat diversity. The water colour was light brown to clear, with sand-gravel substrates dominant. A rapid downstream from the bridge culverts provided some bedrock substrate in moderate to fast flows. The rest of the substrates in the channel was dominated by coarse sand-gravel. The water during the 2021 survey was categorised as cool, alkaline freshwater. Six sampling efforts were carried out, limited in terms of substrates, velocity classes and hydraulic biotopes. Habitat heterogeneity at the site was rated as moderate. Cover for aquatic invertebrates on the bedrock was very limited, but in the stones out of current effort, cover was moderate to high. The bulk of the riverbed was dominated with sand-gravel. Conditions in the Shingwedzi River at the sampling site was categorised as largely natural to moderately impaired, with a MIRAI score of 79% a B/C category. The Shingwedzi is annually restricted to subsurface flow regulated by groundwater inputs, while surface water is mostly restricted to isolated pools. Taxa expected based on historical data and available biotopes were mostly present in the 2021 sample.

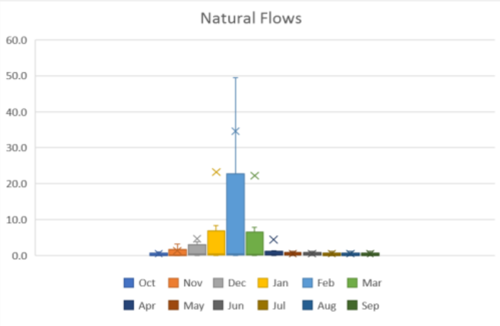
Nutrient pollution causes a decline in biodiversity, through both a loss in species and through increased dominance of certain primary producers (Barker 2006; Cardinale 2011; Nie *et al.* 2018). Zinc was in a “poor” classification SHIN-B90H-POACH, which along with mercury, cadmium, copper, and lead are the most important heavy metal pollutants that affect the aquatic environment and health of fish (Authman *et al.* 2015). O’Brien (2013) obtained the same ecological status for fish at SHIN-B90H-POACH=D. This implies that there was neither an improvement nor a worsening of the ecological status of the fish communities at these sites. Rivers that remain in Classes D and E have serious consequences on the resilience of the river systems, which threatens the health of fish communities (Evans *et al.* 2021). Sampling conditions were moderate to low flow, with pool habitats and flow over dominant. Stones biotopes sampled in the vicinity of the bridge, dominated by bedrock.

The PES and REC were a **C** category. The established EWR will allow the river to remain in its seasonal state, but with improved flows from present (**Table** 8-10**, Figure** 8-15).

Table 8-10: Summary of EWRs for a C category at SHIN-B90H-POACH

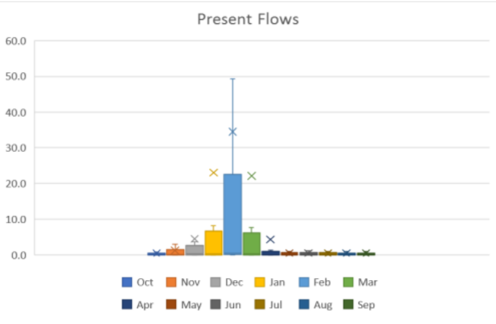
River	Site	nMAR ($10^6 m^3$)	%Drought	%Baseflows	%Floods	%Total
Shingwedzi	SHIN-B90H-POACH	87	0.93	15.57	16.34	31.91

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	2.5	7.2	33.9	170.4	347.3	213.5	46.3	2.1	2.0	1.9	1.9	1.8
1	1.7	6.3	27.1	152.0	135.1	125.6	19.9	2.1	2.0	1.9	1.8	1.7
5	1.0	3.1	7.8	51.5	49.5	20.9	3.9	1.2	1.2	1.2	1.1	1.1
10	0.7	2.1	3.9	8.4	35.0	7.9	1.4	0.9	0.8	0.8	0.8	0.7
15	0.6	1.3	2.0	5.4	10.5	5.0	1.1	0.7	0.7	0.7	0.7	0.7
20	0.5	0.9	1.4	3.0	5.6	2.3	0.8	0.6	0.6	0.5	0.5	0.5
30	0.3	0.4	0.9	1.4	2.1	1.1	0.6	0.4	0.4	0.3	0.3	0.3
40	0.2	0.3	0.7	0.9	0.9	0.5	0.4	0.3	0.3	0.3	0.2	0.2
50	0.2	0.2	0.5	0.5	0.5	0.3	0.3	0.2	0.2	0.2	0.2	0.2
60	0.1	0.1	0.3	0.3	0.4	0.2	0.2	0.2	0.2	0.1	0.1	0.1
70	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
80	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
85	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
90	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
95	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	2.1	7.0	33.7	170.2	347.1	213.4	46.1	1.9	1.9	1.8	1.7	1.6
1	1.5	6.1	26.9	151.8	134.9	125.4	19.8	1.9	1.9	1.7	1.6	1.5
5	0.8	2.9	7.5	51.3	49.2	20.7	3.7	1.1	1.1	1.0	1.0	0.9
10	0.6	1.9	3.7	8.2	34.8	7.7	1.3	0.7	0.7	0.7	0.6	0.6
15	0.5	1.1	1.8	5.1	10.3	4.8	0.9	0.6	0.6	0.6	0.5	0.5
20	0.4	0.8	1.2	2.7	5.4	2.1	0.6	0.5	0.5	0.5	0.4	0.4
30	0.2	0.4	0.8	1.2	1.9	0.9	0.5	0.3	0.3	0.3	0.3	0.2
40	0.2	0.3	0.6	0.7	0.7	0.5	0.3	0.2	0.2	0.2	0.2	0.2
50	0.1	0.2	0.4	0.4	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1
60	0.1	0.1	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1
70	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
80	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
85	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
90	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
95	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

B



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	0.346	0.378	0.484	4.726	7.781	3.021	0.623	0.422	0.431	0.414	0.389	0.371
1	0.345	0.377	0.484	4.722	7.764	3.013	0.621	0.422	0.431	0.413	0.388	0.371
5	0.345	0.377	0.483	4.705	7.751	2.998	0.619	0.421	0.430	0.412	0.387	0.369
10	0.343	0.375	0.481	4.297	7.688	2.964	0.615	0.417	0.426	0.409	0.383	0.366
15	0.342	0.372	0.478	4.161	6.863	2.911	0.612	0.414	0.421	0.403	0.379	0.362
20	0.338	0.368	0.475	2.961	5.613	2.263	0.604	0.408	0.414	0.396	0.373	0.354
30	0.287	0.355	0.465	1.449	2.102	1.120	0.556	0.381	0.370	0.347	0.325	0.309
40	0.224	0.305	0.442	0.874	0.889	0.530	0.413	0.276	0.255	0.254	0.243	0.239
50	0.161	0.208	0.409	0.504	0.545	0.336	0.258	0.205	0.204	0.190	0.179	0.162
60	0.127	0.135	0.344	0.306	0.352	0.213	0.201	0.168	0.158	0.149	0.146	0.143
70	0.101	0.120	0.183	0.228	0.242	0.157	0.147	0.134	0.131	0.119	0.111	0.091
80	0.082	0.076	0.081	0.149	0.156	0.116	0.104	0.089	0.086	0.074	0.060	0.048
85	0.052	0.039	0.029	0.125	0.152	0.112	0.063	0.054	0.055	0.054	0.044	0.034
90	0.024	0.029	0.029	0.093	0.123	0.097	0.035	0.035	0.041	0.039	0.033	0.028
95	0.024	0.029	0.029	0.069	0.080	0.084	0.035	0.025	0.029	0.029	0.026	0.025
99	0.024	0.027	0.028	0.040	0.040	0.037	0.034	0.024	0.025	0.025	0.024	0.025
99.9	0.023	0.027	0.026	0.031	0.030	0.031	0.031	0.023	0.023	0.023	0.023	0.023

C

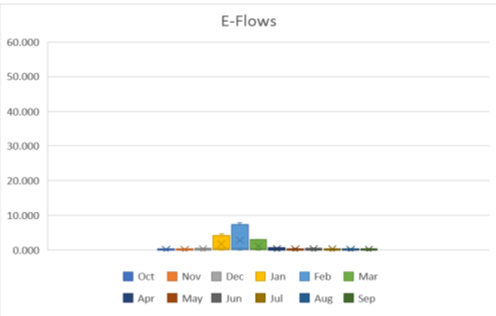


Figure 8-15: Exceedance tables and box and whisker charts for (A) natural, (B) present and (C) EWR scenario for the SHIN-B90H-POACH site. (The x in the box and whisker plots shows the mean value).

Summary of Eco-Categorisation

The PES of invertebrates, fish and vegetation were determined using the DWS PES models and are given in **Table** 8-11.

Table 8-11 PES and REC for invertebrates, fish and vegetation for the 5 LIMCOM study sites

E-Flow site	River	Invertebrates		Fish		Vegetation		Overall	
		PES	REC	PES	REC	PES	REC	PES	REC
LEPH-A50H-SEEKO	Lephalala River	C/D	C	D	C	C	C	C	C
MOGA-A36D-LIMPK	Mogalakwena River	D	D	D	D	C	C	C	C
SAND-A71K-R508B	Sand River	C	C	C/D	C	B/C	C	C	C
LUVU-A91K-OUTPO	Luvuvhu River	C	C	C	C	B	C	C	C
SHIN-B90H-POACH	Shingwedzi River	B/C	C	D	C	B	C	C	B/C

8.6 Ecological Water Requirements

The EWRs (**Table** 8-12) are provided in a similar format to that used by the DWS in Sections 0 to 8.6.4 and were taken directly from the **E-Flows for the Limpopo River Basin – Environmental Flow Determination for the Limpopo Basin Report** (O'Brien *et al.* 2022b), with permission from USAID and IWMI.

Table 8-12 Summary of EWRs for the 5 LIMCOM study sites

Rivers	E-Flow site	nMAR ($10^6 m^3$)	%Drought	%Baseflows	%Floods	%Total
Lephalala River	LEPH-A50H-SEEKO	142	8.79	18.09	21.02	39.11
Mogalakwena River	MOGA-A36D-LIMPK	243	13.98	19.24	17.82	37.06
Sand River	SAND-A71K-R508B	74	0	9.02	23.41	32.43
Luvuvhu River	LUVU-A91K-OUTPO	560	12.29	24.1	15.97	40.06
Shingwedzi River	SHIN-B90H-POACH	87	0.93	15.57	16.34	31.91

EWRs for LEPH-A50H-SEEKO

The EWRs for LEPH-A50H-SEEKO are given in **Table** 8-13. The EWRs are to maintain PES = REC of a C category.

Table 8-13 Summary of EWRs for LEPH-A50H-SEEKO

Annual Flows (Mill. cu. m or index values):

MAR	=	142.231
S.Dev.	=	117.15
CV	=	0.824
Q75	=	3.01
Q75/MMF	=	0.254
BFI Index	=	0.304
CV(JJA+JFM) Index	=	1.896
REC	=	**C**
Total EWRs	=	55.623 (39.11 %MAR)
Maint. Low flow	=	25.727 (18.09 %MAR)
Drought Low flow	=	12.503 (8.79 %MAR)
Maint. High flow	=	29.896 (21.02 %MAR)

Monthly Distributions (cu.m./s)
Distribution Type: Lowveld

Month	Natural flows			Modified flows (EWR)			
	Mean	SD	CV	Low flows		High flows	Total flows
				Maint.	Drought	Maint.	Maint.
Oct	1.212	2.791	0.859	0.568	0.258	0.612	1.18
Nov	2.457	4.062	0.638	0.644	0.301	0.632	1.276
Dec	4.174	3.985	0.356	0.726	0.359	0.612	1.338
Jan	7.356	7.019	0.356	0.911	0.444	1.758	2.669
Feb	12.476	20.697	0.686	1.277	0.615	5.756	7.033
Mar	9.47	11.779	0.464	1.104	0.533	1.758	2.862
Apr	6.237	5.516	0.341	0.98	0.476	0.632	1.612
May	3.986	2.641	0.247	0.844	0.413	0	0.844
Jun	2.916	1.909	0.253	0.807	0.397	0	0.807
Jul	2.023	1.254	0.231	0.727	0.359	0	0.727
Aug	1.392	0.776	0.208	0.661	0.329	0	0.661
Sep	1.019	0.53	0.2	0.577	0.291	0	0.577

8.6.1 EWRs for MOGA-A36D-LIMPK

The EWRs for MOGA-A36D-LIMPK are given in **Table** 8-14. The EWRs are to maintain PES = REC of a C category.

Table 8-14 Summary of EWRs for MOGA-A36D-LIMPK

Annual Flows (Mill. cu. m or index values):

MAR	=	242.551
S.Dev.	=	221.975
CV	=	0.915
Q75	=	5.26
Q75/MMF	=	0.26
BFI Index	=	0.341
CV(JJA+JFM) Index	=	2.143
REC	=	**C**
Total EWRs	=	89.884 (37.06 %MAR)
Maint. Low flow	=	46.671 (19.24 %MAR)
Drought Low flow	=	33.901 (13.98 %MAR)
Maint. High flow	=	43.214 (17.82 %MAR)

Monthly Distributions (cu.m./s)
Distribution Type: Lowveld

Month	Natural flows			Modified flows (EWR)			
	Mean	SD	CV	Low flows		High flows	Total flows
				Maint.	Drought	Maint.	Maint.
Oct	2.15	2.356	0.409	1.091	0.9	0.677	1.768
Nov	7.478	16.335	0.843	1.388	0.9	2.356	3.744
Dec	9.8	12.575	0.479	1.464	0.95	0.677	2.141
Jan	15.048	24.097	0.598	1.754	1.1	2.28	4.034
Feb	23.734	44.437	0.774	2.366	1.1	10.565	12.931
Mar	12.657	20.061	0.592	1.772	1.2	0.677	2.449
Apr	7.967	11.598	0.562	1.608	1.25	0	1.608
May	4.594	4.568	0.371	1.406	1.19	0	1.406
Jun	3.231	1.777	0.212	1.37	1.18	0	1.37
Jul	2.651	1.18	0.166	1.281	1.16	0	1.281
Aug	2.251	0.844	0.14	1.202	1.07	0	1.202
Sep	1.961	0.665	0.131	1.129	0.9	0	1.129

8.6.2 EWRs for SAND-A71K-R508B

The EWRs for SAND-A71K-R508B are given in **Table** 8-15. The EWRs are to maintain PES = REC of a C category.

Table 8-15 Summary of EWRs for SAND-A71K-R508B

Annual Flows (Mill. cu. m or index values):

MAR	=	74.191
S.Dev.	=	231.002
CV	=	3.114
Q75	=	0
Q75/MMF	=	0
BFI Index	=	0.192
CV(JJA+JFM) Index	=	7.399
REC	=	**C**
Total EWRs	=	24.061 (32.43 %MAR)
Maint. Low flow	=	6.689 (9.02 %MAR)
Drought Low flow	=	0 (0 %MAR)
Maint. High flow	=	17.372 (23.41 %MAR)

Monthly Distributions (cu.m./s)
Distribution Type : Lowveld

Month	Natural flows			Modified flows (EWRs)			
	Mean	SD	CV	Low flows		High flows	Total flows
				Maint.	Drought	Maint.	Maint.
Oct	0.39	1.418	1.357	0.104	0	0	0.104
Nov	1.618	2.735	0.652	0.163	0	0.72	0.883
Dec	2.147	2.754	0.479	0.188	0	0.697	0.885
Jan	6.078	17.105	1.051	0.372	0	0.697	1.069
Feb	12.955	76.681	2.447	0.72	0	3.324	4.044
Mar	3.614	12.492	1.291	0.32	0	0.697	1.017
Apr	1.06	2.201	0.801	0.195	0	0.72	0.915
May	0.405	0.857	0.789	0.141	0	0	0.141
Jun	0.262	0.757	1.114	0.119	0	0	0.119
Jul	0.199	0.675	1.266	0.099	0	0	0.099
Aug	0.167	0.623	1.393	0.086	0	0	0.086
Sep	0.158	0.596	1.451	0.078	0	0	0.078

8.6.3 EWRs for LUVU-A91K-OUTPO

The EWRs for LUVU-A91K-OUTPO are given in **Table** 8-16. The EWRs are to maintain PES = REC of a C category.

Table 8-16 Summary of EWRs for LUVU-A91K-OUTPO

Annual Flows (Mill. cu. m or index values):

MAR	=	559.847
S.Dev.	=	544.563
CV	=	0.973
Q75	=	12.62
Q75/MMF	=	0.271
BFI Index	=	0.32
CV(JJA+JFM) Index	=	1.993
REC	=	**C**
Total EWRs	=	224.297 (40.06 %MAR)
Maint. Low flow	=	134.904 (24.10 %MAR)
Drought Low flow	=	68.792 (12.29 %MAR)
Maint. High flow	=	89.393 (15.97 %MAR)

Monthly Distributions (cu.m./s)
Distribution Type: Lowveld

Month	Natural flows			Modified flows (EWRs)			
	Mean	SD	CV	Low flows		High flows	Total flows
				Maint.	Drought	Maint.	Maint.
Oct	5.363	2.72	0.189	3.07	1.79	3.948	7.018
Nov	8.402	5.878	0.27	3.363	2.13	1.54	4.903
Dec	15.559	14.613	0.351	3.786	2.22	3.948	7.734
Jan	32.726	49.397	0.564	5.018	2.74	5.439	10.457
Feb	55.759	99.984	0.741	7.075	2.94	12.866	19.941
Mar	45.31	70.986	0.585	6.315	2.96	5.439	11.754
Apr	22.865	32.278	0.545	5.113	2.92	1.54	6.653
May	8.66	4.446	0.192	4.042	1.98	0	4.042
Jun	6.414	2.555	0.154	3.837	1.8	0	3.837
Jul	5.301	1.902	0.134	3.492	1.61	0	3.492
Aug	4.717	1.659	0.131	3.257	1.58	0	3.257
Sep	4.711	1.879	0.154	3.184	1.57	0	3.184

8.6.4 EWRs for SHIN-B90H-POACH

The EWRs for SHIN-B90H-POACH are listed in **Table** 8-17. The EWRs are to maintain a REC of a B/C category.

Table 8-17 Summary of EWRs for the SHIN-B90H-POACH site

Annual Flows (Mill. cu. m or index values):

MAR	=	86.618
S.Dev.	=	200.484
CV	=	2.315
Q75	=	0.32
Q75/MMF	=	0.044
BFI Index	=	0.214
CV(JJA+JFM) Index	=	4.722
REC	=	**B/C**
Total EWRs	=	27.639 (31.91 %MAR)
Maint. Low flow	=	13.487 (15.57 %MAR)
Drought Low flow	=	0.806 (0.93 %MAR)
Maint. High flow	=	14.152 (16.34 %MAR)

Monthly Distributions (cu.m./s)
Distribution Type: Lowveld

Month	Natural flows			Modified flows (EWRs)			
	Mean	SD	CV	Low flows		High flows	Total flows
				Maint.	Drought	Maint.	Maint.
Oct	0.32	0.404	0.472	0.229	0.022	0	0.229
Nov	0.721	1.27	0.68	0.255	0.027	0	0.255
Dec	2.035	5.284	0.969	0.336	0.026	0	0.336
Jan	8.595	27.053	1.175	0.797	0.03	1.51	2.307
Feb	11.65	43.043	1.527	1.079	0.029	2.507	3.586
Mar	7.07	28.174	1.488	0.779	0.03	1.51	2.289
Apr	1.441	5.594	1.498	0.412	0.031	0	0.412
May	0.375	0.409	0.408	0.274	0.022	0	0.274
Jun	0.366	0.407	0.429	0.273	0.023	0	0.273
Jul	0.343	0.381	0.415	0.257	0.022	0	0.257
Aug	0.325	0.364	0.417	0.246	0.022	0	0.246
Sep	0.318	0.355	0.432	0.241	0.023	0	0.241

9 DATA TAKEN FORWARD INTO NEXT PHASE OF WORK

For the WRCS, EWR information is required at a wider resolution so that the consequences of water resource developments, and other relevant scenarios, can be understood up- and downstream of the EWR sites, and on significant tributaries. As such, a water balance will be undertaken that links all the nodes with one another in a downstream direction, so that the consequences of changes in flow on the PES of the rivers can be considered from upstream to downstream, and in the incremental tributaries. Most importantly, the WRCS analysis will provide the information necessary for the LIMCOM study to understand what the consequences are of water resource developments planned in South Africa on river flow into the Limpopo River. The outcomes of the WRCS analyses are provided in monetary terms by understanding the changes in flow and ecological condition through a socio-economic cost and benefit analysis.

The EWRs from the DRIFT assessment and the LIMCOM study (O'Brien *et al.* 2022) will go forward into the WRCS process. There are 75 nodes and 19 of these are where detailed EWRs have been determined; 14 from this study and the five from the LIMCOM study. There are therefore 56 nodes that need EWRs for the WRCS process. The biophysical and hydrological characteristics of the rivers at the 75 nodes will be compared and the rivers will be grouped by similarity. Those with characteristics that are similar to a nearby EWR site will use the same EWR configuration as the EWR site. This may be a site on the same main-stem river or on a tributary with similar characteristics. The others will be generated using the Revised Desktop model (Birkhead et al. 2019).

The water balance using the EWR data for 75 nodes will be reported on in the Ecological Sustainable Baseline Configuration Report (DWS 2024, Report WEM/WMA01&02/00/CON/RDM/0224).

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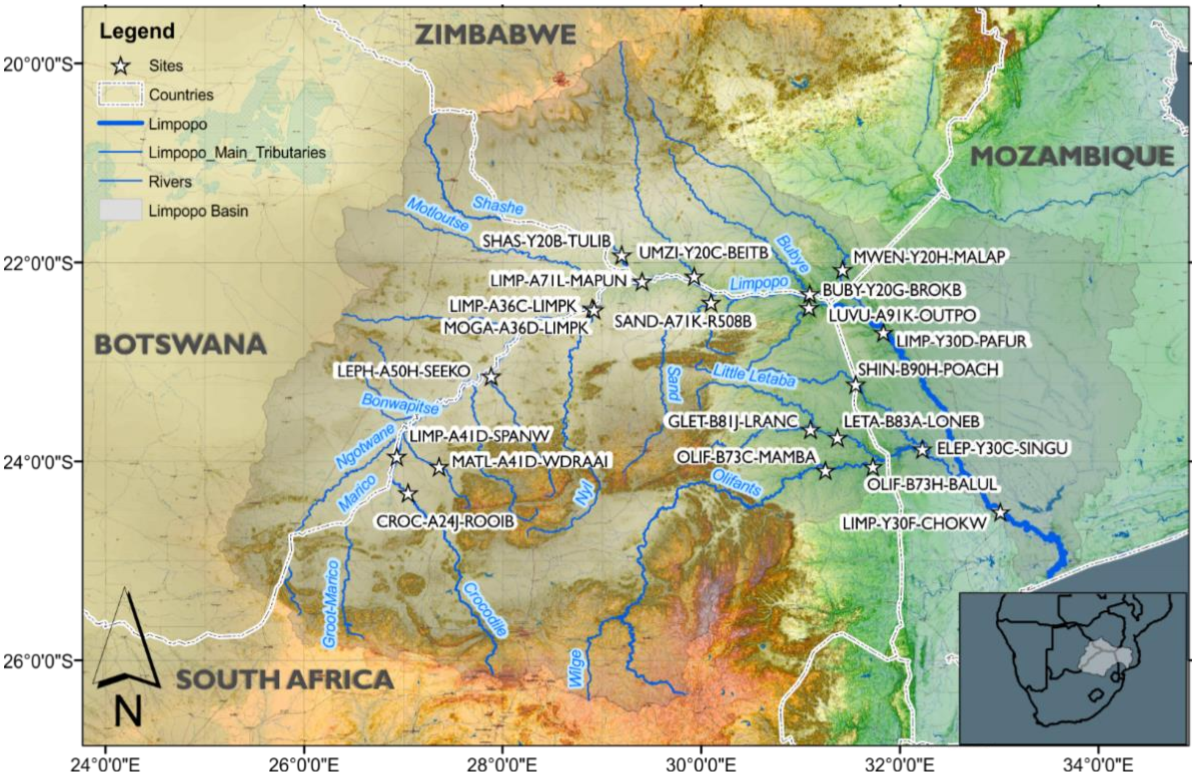
Appendix A. Executive Summary from the LIMCOM E-flows report (O'Brien et al. 2022b)

This executive summary was taken from the **E-Flows in the Limpopo River: E-flows report** (O'Brien *et al.* 2022b), with permission from USAID and IWMI. Cross-referencing was adjusted for compatibility in this EWR report. Readers interested in further details about the study are referred to the other reports listed for the Limpopo River E-flows project in **Section 1.4**.

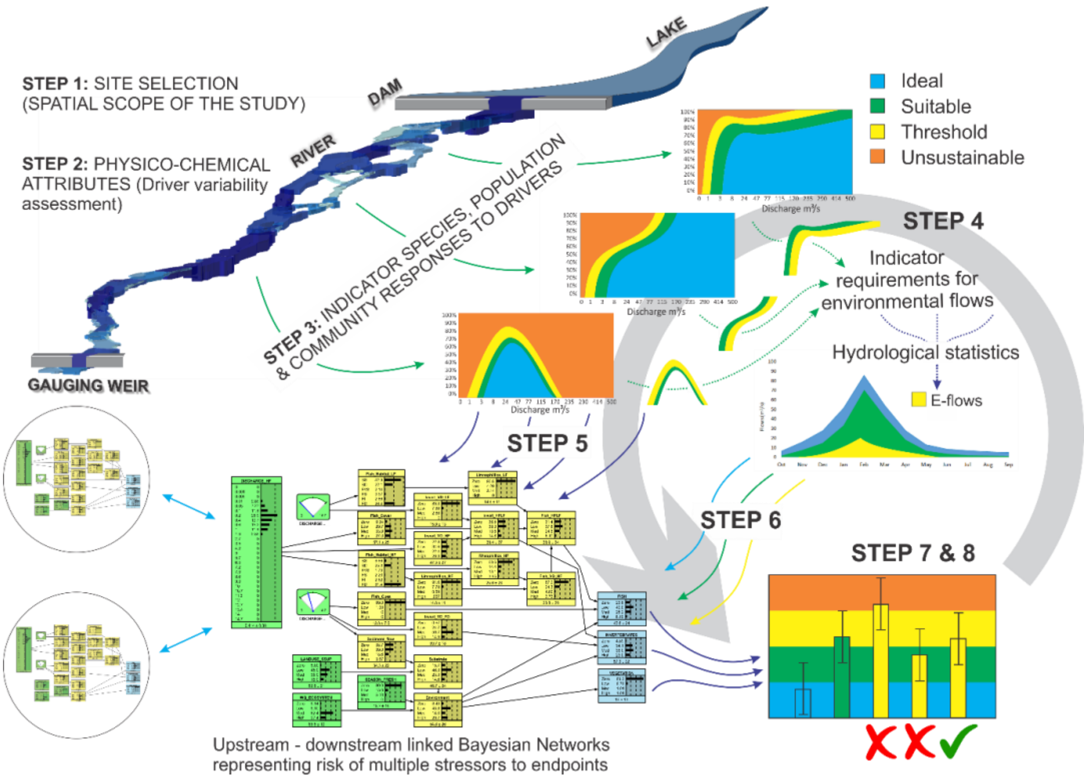
The E-flows report documents the culmination of the project to determine the E-flows for the Limpopo River Basin. In the process several documents were produced (see **Section 1.4**) that include a description of the water resources and other important issues in the basin as well as the vision that management has for the basin (Report 2); a comprehensive review of literature and existing data (Report 3); the results of field surveys that document the present ecological state of both the drivers of change (Report 4); and the ecological responses to change (Report 5). The E-flows report (Report 6) brings together all that information to describe the E-flows themselves, the relationship between river flows and the river ecosystem and details which flows are necessary to keep the ecosystem in its present condition or better at some sites. The E-flows report is followed by a supporting document (Report 7) that describes the risk of altered flows to the ecosystem services of the Limpopo Basin. The E-flows report has greater application for consideration of trade-offs in relation to the human use of the river.

A total of 18 sites were identified that would adequately represent the river reaches of the Limpopo Bain (**Appendix Figure 1**). These sites were selected for purely biophysical, practical and data reasons and not because of their political location, the preponderance of sites located in South Africa being entirely due to the greater number of tributaries in that region and the availability of existing data. E-flows were also determined for those generally non-flowing rivers in Botswana, but no sites were used. Note that the Changane tributary that enters the Limpopo just above the estuary was excluded because it was found, during the Monograph study, to be saline and could be characterised more as a wetland than a flowing river.

In this study, the PROBFLO holistic E-flow determination and framework approach (O'Brien *et al*. 2018, **Appendix Figure 2**), was implemented to establish E-flows for 15 sites on the Limpopo Basin, while the results from the three previously determined e-flow sites on the Letaba and Olifants River were reviewed, and E-flows for an additional 5 sites were inferred (Ngotwane, Bonwapitse, Lotsana, Motloutse and Bubye Rivers). PROBFLO combines Relative-Risk Modelling (RRM) and the use of Bayesian Networks (BN) in a BN-RRM approach to determine: (1) the flow requirements of selected indicator components of ecosystems, (2) evaluate the synergistic effects of E-flow scenarios to ensure they are suitable in a holistic context and (3) characterise and evaluate the relative risk of flow and non-flow stressors to social and ecological water resources on regional scales to contribute to water resource sustainability management. This report contains the first two components of the PROBFLO approach to determine holistic E-flows, while the third component is reported in Report 7: "*Risk of altered flows to the ecosystem services of the Limpopo Basin".*



Appendix Figure 1: River sites identified in the E-flow assessment for the Limpopo Basin. E-flows were also determined for the generally dry tributaries in Botswana but no specific sites were used.



Appendix Figure 2: The PROBFLO approach followed for the determination of E-flows for the Limpopo River.

Step 1 - In this study was to identify and select sites representative of the rivers reaches in the basin. These sites are located in the lower reaches of major systems to represent the effects of altered flows in the upstream catchment. The first step of the E-flow determination process is to identify a suitable reach of river, and associated ecosystems that can be used to determine the E-flows for a wider reach of the Limpopo River or an important tributary. Criteria for site selection for the collection of data are normally based on biophysical characteristics, however this was varied and included representativeness of the reach considered, access to the site for bio-physical surveys, existing data especially hydrological, and local and regional land use or resource development scenarios (as noted above, site selection was done only using ecological and practical considerations and ignored political boundaries). Data from all of these sites is needed so that flow-ecosystem and non-flow stressor and ecosystem relationships can be determined. At this stage the vision for each river reach in terms of its protection vs. use/development must be considered.

Step 2 - is where the physico-chemical drivers of the ecosystem are described and their role in support of E-flows and the resulting ecosystem considered for each reach of river.

Step 3 - a range of ecosystem lines of evidence (LoEs) are used in this step to consider how the “drivers” characterised in previous steps now interact with or affect “responder” components of ecosystems. Here teams identify species, populations and community indicators that represent the ecosystem and their preferences for the volume, timing, duration and frequencies of river flows. These relationships can also include timing and duration of flows to ensure that they are aligned to seasonal life-cycle activities of indicator species. These are the holistic flow-ecosystem relationships that characterise a sustainable ecosystem and are captured in the E-flow determination.

Step 4 – with this data and considering the vision for the resource, the flow-requirement information is provided. The hydrologist thus obtains indicator requirements pertaining to the volume, timing, duration and frequency of flows for each site associated with drought, base low and high flows, freshets and floods. These requirements for E-flows are based on isolated indicator requirements alone and still need to be considered in an integrated holistic context in step 5.

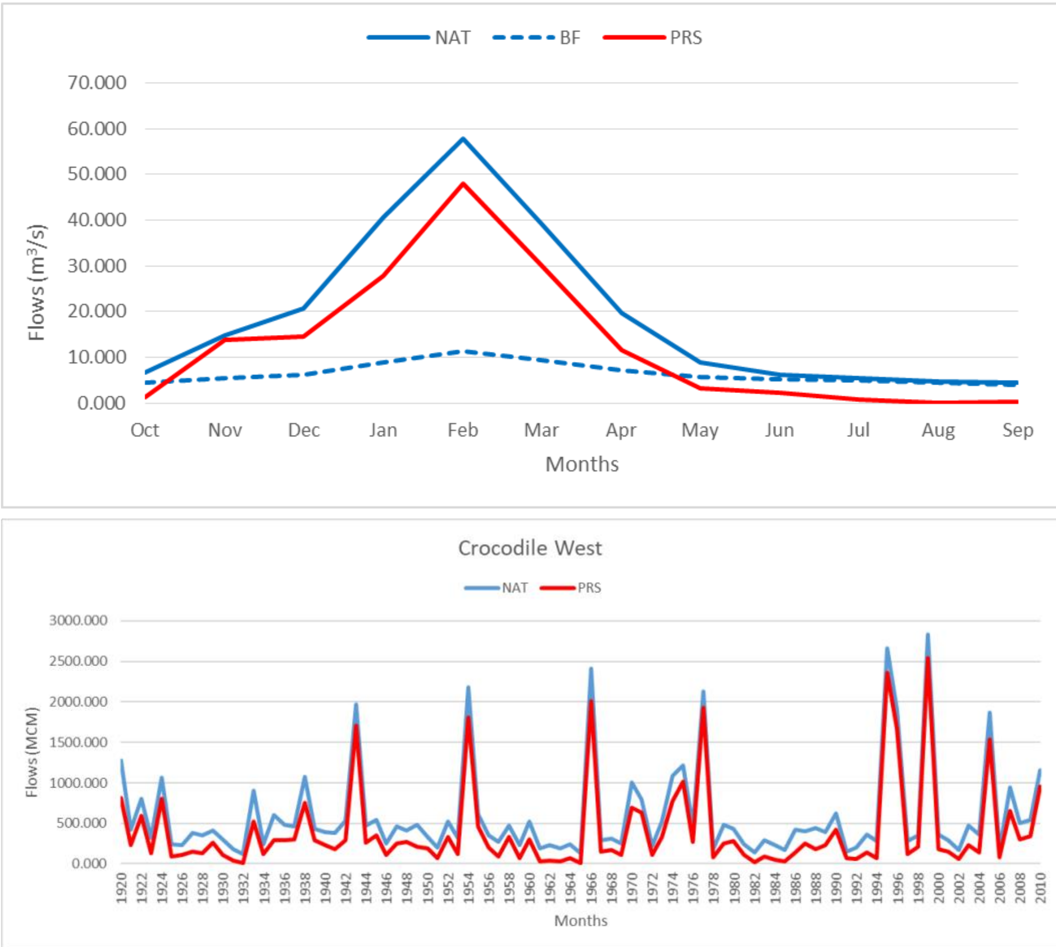
Step 5 - the knowledge of the socio-ecological system representing each reach of river, and links between sites to represent upstream and downstream relationships, is used to evaluate the integrated risk of the preliminary E-flow requirements, to ensure that they meet the integrated ecosystem requirements. This is achieved using Bayesian Network (BN) probabilistic modelling methods.

Step 6 - all the flow indicator components of the ecosystem used to establish preliminary E-flow requirements are integrated into the BN. The same rules or conditional probability tables (represented as stacked area graphs) are integrated into the model and combined to represent ecosystem components using additional conditional probability tables. BNs are applied to determine probable risk of multiple flow and non-flow stressors to model endpoints that represent the ecosystem in an acceptable condition. The relative risk of natural, present and preliminary (indicator based) E-flow scenarios are evaluated.

Step 7 - the integrated risk to the ecological endpoints is evaluated to ensure that not only are the indicator-based requirements determined, but requirements for the ecosystem in an integrated context are suitable to represent and balance the use and protection of the water resources.

Step 8 – the BN evaluation of risk of multiple stressors to the preliminary E-flows (from Step 6) are modelled resulting in E-flow requirements for the each site. This adaptive process can be applied through multiple iterations to result in a suitable “integrated, holistic” E-flow for each reach which is also integrated/synchronised between sites/reaches.

A detailed compilation of the physical drivers (Report 4: *Present Ecological State of the Limpopo River: Drivers of Ecosystem Change*) and the biological responses to these drivers (Report 5: *Present Ecological State of the Limpopo River: Ecological Responses to Change*) was used as input to the work that followed. An example of the hydrology, which is a key driver of ecosystem change, was used for each site is shown in **Appendix Figure 3**.



Appendix Figure 3: Example of site hydrology (above) – mean monthly hydrology (discharge m^3/s) representing the natural (NAT), present day (PS) and natural baseflow separated (BF) for the Crocodile River. (Below) mean monthly hydrology in million cubic metres per annum (MCM) for the flow record from 1920 to 2010 in the Crocodile River

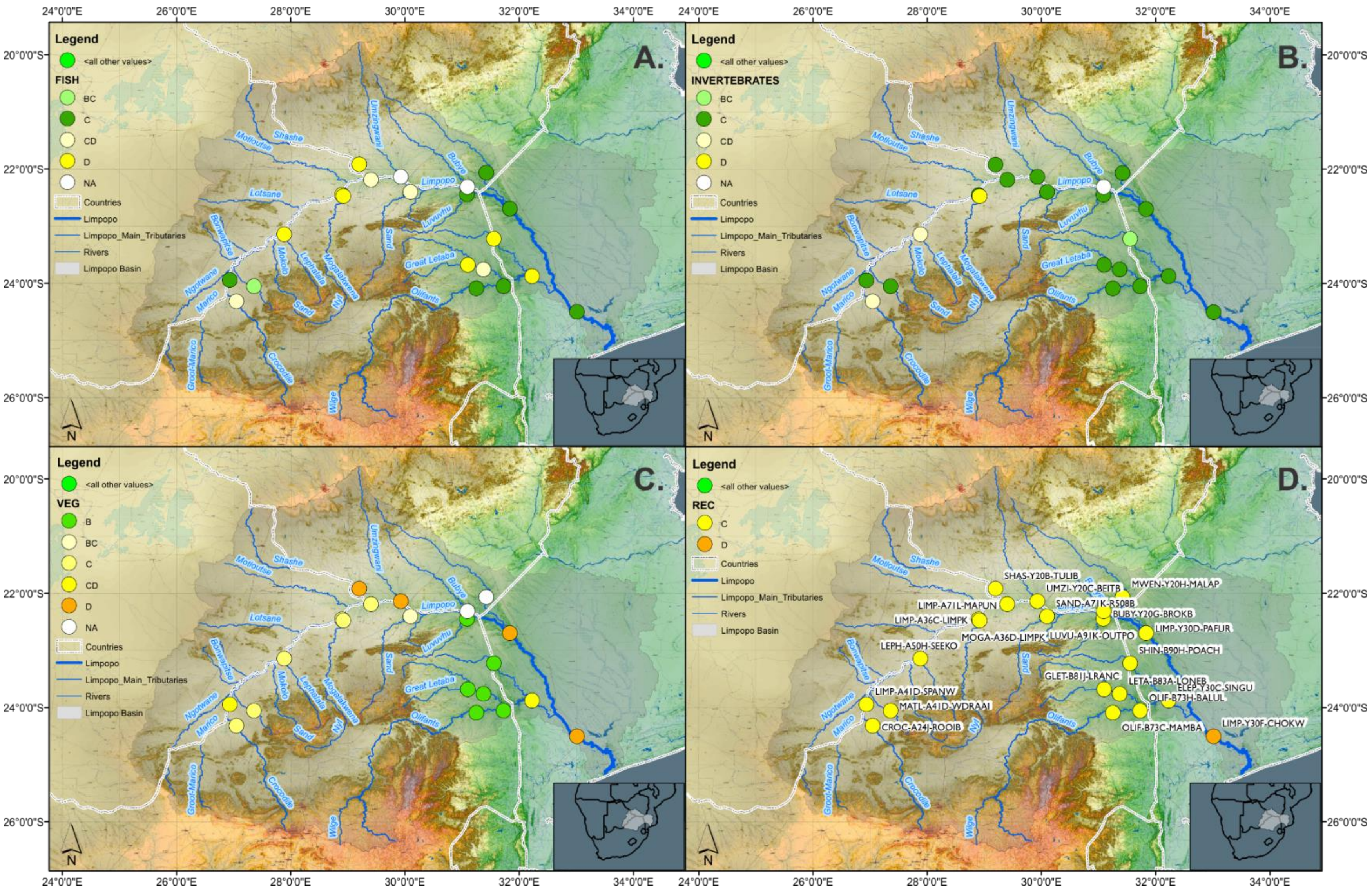
Following Step 2, which is the characterisation of the driver components (hydrology, water quality, geomorphology and hydraulics) for each site, fully described in Report 4: *Present Ecological State of the Limpopo River: Drivers of Ecosystem Change*, determination of the present ecological state of each ecological component (see **Appendix Figure 4**) was carried out during extensive field surveys and associated with existing literature, and detailed the indicator species, populations and communities identified to represent the ecosystem. This present ecological state data is used to determine the flows necessary to sustain the ecosystem in a pre-defined condition, the preliminary E-flow requirements. This is Step 3 of PROBFLO.

The biological status quo data and information that makes up **Appendix Figure 4** is presented in Report 5: *Present Ecological State of the Limpopo River: Ecological Responses to Change*. An example of the relationship between flow and habitat suitability for fish is shown in Appendix Figure 5.

A summary of the full process to make use of the biophysical data to determine first, the isolated indicator based E-flows, and then the holistic E-flows, as outlined in the 7 Step procedure, is not presented here. However, the final results are shown below in **Appendix Table 2**.

Using these relationships, Step 4 is to determine the preliminary e-flow requirements for each of the biological components, to ensure there is always sufficient water, in each month of the year, to satisfy the biota. An example where the data for the fish, invertebrates and vegetation are all catered for is shown in **Appendix Table 1** (flood requirements are then added to this, as shown in **Appendix Table 2**.

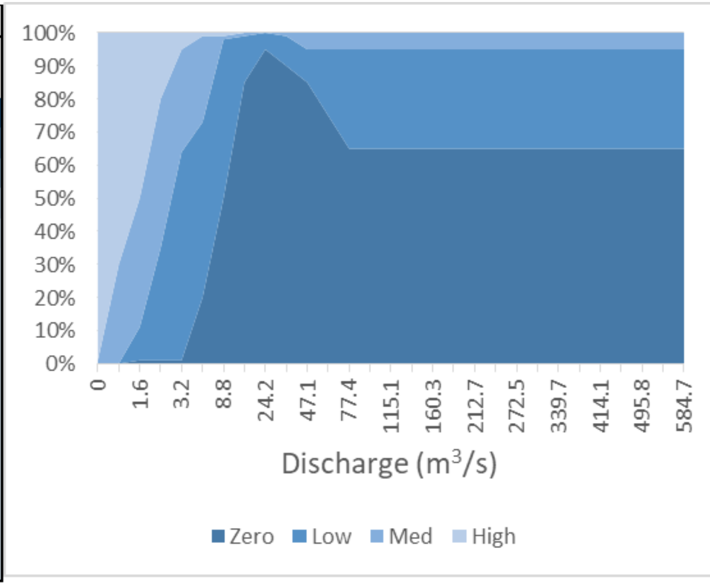
The E-flows to maintain the wellbeing of the rivers selected to represent the Limpopo basin have been determined to contribute to the sustainability of the ecosystem. These E-flows would maintain a suitable balance between the abstraction or alteration of the flow regime and the protection requirements. The E-flows established in the study include drought flows and baseflow and high flows for all of the sites, which has contributed to the determination of the portion of total flows (mean annual runoff) required to sustain the ecosystems. In addition, freshet and flood flows from all sites are provided to support holistic management of flows in the rivers of the basin. These requirements are all considerably more than what is presently being provided in the rivers of the basin suggesting that existing abstraction and or alteration of instream flows must be managed to meet these E-flow requirements.



Appendix Figure 4: Present Ecological State classification using A-F Eco-Categorisation range for fish (A), invertebrates (B) and vegetation (C). Ecological Category (D) representing the vision for the sustainable use and protection of water resources in the Limpopo Basin.

FISH_ECO_VD

m³/s	Zero	Low	Med	High
0	0	0	1	99
0.8	0	0	30	70
1.6	1	10	39	50
2.4	1	34	45	20
3.2	1	63	31	5
3.9	20	53	26	1
8.8	50	48	1	1
15.5	85	14	1	0
24.2	95	5	0	0
34.7	90	9	1	0
47.1	85	10	5	0
61.3	75	20	5	0
77.4	65	30	5	0
95.3	65	30	5	0
115.1	65	30	5	0
136.8	65	30	5	0



Appendix Figure 5: Flow-ecosystem relationship established in the study to represent the suitability of velocity-depth habitat characteristics for rehophillic indicator fish (*Labeo* spp.), associated with discharge based on hydraulic relationships between flows and velocity-depth habitats and species response data obtained in the study for the Limpopo River at LIMP-A41D-SPANW. Table represents relationships (left) which is graphically presented (right). Zero, low, moderate and high-risk ranks included.

Appendix Table 1: Integrated monthly average base flow discharge (m^3/s) requirements from the fish, invertebrates and vegetation indicator components for the CROC-A24J-ROOIB site.

Percentiles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
20	4.0	9.0	9.0	9.0	9.0	9.0	9.0	4.0	4.0	4.0	4.0	4.0
50			7.0	8.0	8.0	8.0	8.0	8.0				
80	2.4	3.2	3.2	3.2	3.2	3.2	3.2	2.4	2.4	2.4	2.4	2.4
99.9	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

Appendix Table 2: Summary of the E-flow statistics established in the study using indicator requirements for each site considered in the study. Note the E-flow requirements for the Groot Letaba River, Letaba River and the Olifants River have been extracted from formal gazettes and only tested in this study.

Rivers	E-flow site	nMAR ($10^6 m^3$)	%Drought	%Baseflows	%Floods	%Total
Crocodile River	CROC-A24J-ROOIB	596	9.48	25.73	9.37	35.09
Limpopo River	LIMP-A41D-SPANW	591	6.31	24.67	12.4	37.07
Matlabas River	MATL-A41D-WDRAAI	40	1.04	10.64	39.23	49.86
Lephalale River	LEPH-A50H-SEEKO	142	8.79	18.09	21.02	39.11
Limpopo River	LIMP-A36C-LIMPK	801	3.03	23.15	11.35	34.51
Mogalakwena River	MOGA-A36D-LIMPK	243	13.98	19.24	17.82	37.06
Shashe River	SHAS-Y20B-TULIB	687	0	5.33	11.96	17.29
Limpopo River	LIMP-A71L-MAPUN	1684	2.6	16.15	8.12*	24.27[#]
				>2000 m³/s (3-5year flood for >7 days).		
Umzingwani River	UMZI-Y20C-BEITB	438	0	4.74	15.5	20.23
Sand River	SAND-A71K-R508B	74	0	9.02	23.41	32.43
Luvuvhu River	LUVU-A91K-OUTPO	560	12.29	24.1	15.97	40.06
Mwenedzi River	MWEN-Y20H-MALAP	412				
Limpopo River	LIMP-Y30D-PAFUR	2792	1.16	10.46	1.63*	12.08[#]
				>2000 m³/s (3-5year flood for >7 days).		
Shingwedzi River	SHIN-B90H-POACH	87	0.93	15.57	16.34	31.91
Groot Letaba River	GLET-B81J-LRANC	441	***	***	***	42.53**
Letaba River	LETA-B83A-LONEB	642	***	***	***	***
Olifants River	OLIF-B73H-BALUL	1918	10.01	17.72	3.34	21.06
Elefantes River	ELEP-Y30C-SINGU	2552	5.52	15.65	3.56*	19.21[#]
				>500 m³/s (3-5year flood for >5 days).		
Limpopo River	LIMP-Y30F-CHOKW	5572	2.57	10.69	5.08*	15.77[#]
				>1600 m³/s (3-5year flood for >7 days).		

Importantly the E-flows proposed for nine of the sites considered return naturally perennial rivers back into their perennial conditions, although reduced flows compared to their natural states. While these reduced flows are significantly lower than natural states they are considerably greater than present flows and should result in considerable improvements to the wellbeing of the Limpopo River. The E-flows established also include some historically seasonal rivers that will remain in their seasonal state, but with improved flows from present. There are only four sites considered in the study which are presently in a perennial state and proposed to remain in this condition to maintain the wellbeing of the Limpopo Basin ecosystem. Sustained perenniality of these rivers will ensure that the ecosystem of these sites have the potential to become sustainable, a recovery from present conditions. The aim of this project was to provide the necessary evidence to determine holistic E-flows for increasing the resilience of communities and ecosystems in the Limpopo Basin to changes in streamflow resulting from basin activities and climate change. This report meets the first part of the aim and includes the E-flow requirements to maintain the ecosystems in a suitable condition. The socio-ecological implications of altered flows, and the benefits of establishing and meeting e-flows are included in the second final report titled: “Risk of altered flows to the ecosystem services of the Limpopo Basin”. The PROBFLO holistic e-flow determination approach which incorporates the use of the

RRM-BN risk assessment approach was successfully implemented in the study based on evidence obtained from historical published and grey literature, field surveys during the dry period of 2012 and the wet period of 2019. While the bio-physical data used to represent the relationships between flows and non-flow stressors and ecosystem components exists there is considerable uncertainty associated with the availability of quantitative data, rather than qualitative date for the assessment and repetitions which is my the risk framework established in this assessment should be considered to be an adaptive management tool that can learn from new information and improve risk projection confidence in the future. The E-flow determination process with E-flow results established in this report were used in a final relative risk assessment of multiple flow scenarios including natural, present, E-flows and a continued drought scenario, representing worst climate change possibilities for the region. The approach adopted to undertake this risk assessment and the findings are presented in the final "Risk of altered flows to the ecosystem services of the Limpopo Basin" report which follows this report. The final risk assessment report provides information on relative risk of multiple flow and non-flow stressors that are synergistically affecting the wellbeing of the ecological and social systems of the Limpopo River Basin and how trade-off decisions between use allocation and protection will affect the sustainability of these vulnerable resources.

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Appendix B. Rivers EWR Team

The members of the rivers EWR assessment team are listed in **B1**.

Table B1 The rivers EWR assessment team

No.	Position	Name	Organisation
1	EWR task team leader	Dr Karl Reinecke	Southern Waters ER&C
2	DRIFT DSS team leader	Dr Alison Joubert	Southern Waters ER&C
3	Hydrological modelling	Gerald Howard	Pvt
4	Hydraulic modelling	Dr Andrew Birkhead	Streamflow solutions
5	Water quality	Nico Rossouw	Private
6	Geomorphology	Dr Bennie van der Waal	Private
7	Riparian vegetation	James Mackenzie	Private
8	Aquatic invertebrates	Colleen Todd	Private
9	Fish	Dr Mathew Ross	Enviross
10	Socio-economics lead	Dr Jane Turpie	Anchor Environmental
11	Socio-economics	Gwyn Letley	Anchor Environmental
12	EWR assessment advisor	Prof Cate Brown	Southern Waters ER&C
13	Scenario development	Toriso Tlou	Myra Consulting